Anil Kumar Singh · Jagdish Chander Dagar
Ayyanadar Arunachalam · Gopichandran R
Kirit Nanubhai Shelat *Editors*

Climate Change Modelling, Planning and Policy for Agriculture

Springer

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ISBN 978-81-322-2156-2 ISBN 978-81-322-2157-9 (eBook)
DOI 10.1007/978-81-322-2157-9

Library of Congress Control Number: 2015934694

Springer New Delhi Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer (India) Pvt. Ltd. is part of Springer Science+Business Media (www.springer.com)

Preface

As one of the world's largest agrarian economies, agriculture sector in India accounts for about 14 % of the GDP and over 10 % of country's exports. Agriculture remains the core sector, providing employment to over 50 % of the work force, food security as well as inclusive growth and development of the Indian economy. Development and infusion of appropriate technologies have enabled annual production of over 250 mt of foodgrains and 248 mt of horticultural produce. India is among 15 leading exporters of agricultural products.

A major challenge at this stage, however, is to ensure nutritional security for over a billion people, tackle widespread hunger and child malnutrition. Related issues as the growing impacts of climate change on agriculture, biodiversity losses, erosion of natural resources base, competing demands, abiotic stresses, emerging pests and diseases, losses in harvest and post-harvest interventions compound the context. Youth from rural areas are moving away from agriculture. This enhances the vulnerability of 'stress agriculture' calling for changes in multiple dimensions of inputs, infrastructure, policy, governance and regulation, with science as the starting point.

In order to discuss the above stated and related issues pertaining to climate change impact on agriculture per se, the Indian Council of Agricultural Research and the National Council for Climate Change, Sustainable Development and Public Leadership joined hands to organize the International Conference on Climate Change, Sustainable Agriculture and Public Leadership in New Delhi on 7–9 February 2012. Over 400 national and international experts from different disciplines participated and deliberated on the pros and cons of climate change and the best options to mitigate and/or adapt in response to the challenges that emerge duly integrating agroforestry, livestock and fisheries along with agriculture.

In this synthesis volume, we have attempted to compile 22 research papers with analytical and policy planning perspectives. These insights along with the others fed into the 'New Delhi Charter 2012'. These insights are important given the fact that the country is implementing the National Mission on

Sustainable Agriculture under the Prime Minister's National Action Plan on Climate Change and that the country is committed to secure food security as well.

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Prologue

The objective of the present volume is to highlight some salient work reported in India at the international conference organized by the Indian Council for Agricultural Research and the National Council for Climate Change, Sustainable Development and Public Leadership. While a large number of papers on several themes were presented at the conference, the present initiative is to focus on papers related to modeling of parameters relevant for interpretation of climate change impacts on crops. Such related aspects as sustainability conjectures and an overarching framework of policies to promote climate resilient agriculture are also included in the collection of papers.

It is well known that the impacts of climate change are tangible and hence there can be no debate about the need for appropriate adaptation measures, on a priority basis. However, it is equally important to recognize the fact that adaptation measures actually represent a dynamic synthesis of interventions pertaining to multiple systems. These are particularly of water, soil characteristics, genotypic and phenotypic variations and their expressions, age-correlated biochemical changes aligned with planting schedules and favorable weather/climate conditions. Nutrients, occurrence and distribution of associated vegetation including crop mixes also influence productivity. The overarching aspect of farming practice wields significant influence on the outcome and hence it is important to be clear about the particular focus of the investigations being carried out and reported in a suitable manner.

It is essential to recognize that scientific research in agriculture in India has always produced valuable results of direct relevance to her people. Importantly, preparedness to tackle disasters due to inclement weather system has prominently featured on the agenda. The recent focus on climate change and impacts has provided the necessary impetus to reorganize the framework of investigation to capture the specifics of such impacts. In this context, the importance of micro-climate variations too viz-a-viz the larger scales of impacts cannot be overemphasized. It will also be useful to help characterize natural variations versus artificially induced variations, helping us understand the complexities of individual and synergistic impacts too. Obviously, the limits and limitations of models could determine the spread and depth of the outcomes of investigations. Empirical evidences to reinforce assumptions have also to be documented with utmost care, guided by an understanding of the limits of tolerance, limiting factors, and the precautionary principle especially in the public policy interface.

The National Mission on Sustainable Agriculture has created the context to consolidate existing and emerging insights from India to set the roadmap for value added investigations for the future. Research infrastructure in India is also being embellished to rise up to the challenges. The present volume is, therefore, a useful compendium of insights at a time when these initiatives are emerging and are set to grow substantially very soon. Some of the most important questions that have designed the guiding principles for the present volume are:

1. What are the recent interpretations of the dynamics of crop productivity across several states of India? This is relevant because the soil structures, agricultural practices, and crop mixes are distinctly different across the country, further modulated by location specific agricultural practices, including alternative systems.
2. What are the sets of assumptions and models used by scientists, and is it possible to capture some initial and emerging insights especially in the Indian context? While it might be a bit too early to ask for significantly greater depth in investigation, the nature of findings reported could become useful inspiration for the way forward.
3. What is the nature of policy interventions proposed on the basis of comparable initiatives from other parts of the world, so that agriculture is mainstreamed as an integrated adaptation and mitigation option to tackle challenges posed by climate change?

The present volume is an attempt to present developments, indicative at best, from India in response to the questions raised above.

The conference also took note of some interesting segments of information reported from India and other parts of the world, centered on the aspects stated. These include the following:

- Dev 2011 (Dev MS 2011. Climate Change, Rural Livelihood and Agriculture "Focus on Food Security" in Asia-Pacific region. WP-2011-014; IGIDR) highlighted vulnerabilities associated with agriculture with special reference to livelihoods. The roles of such parameters as exposure, sensitivity and adaptive capacities have been discussed. A wide range of adaptation options and supportive policies have also been presented.
- The Food and Agriculture Organization in its report of the roundtable on organic agriculture and climate change (FAO 2011. Organic Agriculture and Climate Change Mitigation. A report of the roundtable on organic agriculture and climate change. December 2011, Rome, Italy) highlighted the dynamics of soil carbon sequestration of organic crops and importantly gaps in data for assessing mitigation potential of organic agriculture. Lifecycle assessments and related methodological challenges are also stated. This sets the context for understanding emerging trends in interpretation and their relationship with such market mechanisms as carbon credits to quantify mitigation and adaptation benefits.
- The CGIAR Research Programme on Climate Change, Agriculture and Food Security (CCAFS) in March 2012 presented its final report on sustainable agriculture and climate change (CCAFS 2012. Achieving

Food Security in the Face of Climate Change. Final report from the Commission on Sustainable Agriculture on Climate Change 63P) focused on the need for location-specific interventions duly recognizing the wide variety of options for adaptation and such preventive practices as emission reduction through suitably designed agricultural practices. The need to understand current capacities to meet technical challenges and hence the design and implementation of appropriate capacity building programmes has also been emphasized.

- The Meridian Institute (2011 Agriculture and Climate Change: A Scoping Report ISBN:978-0-615-49585-9; 116P) indicated that the options for early action on climate smart agriculture have to be shaped only by the specific circumstances and capacities within countries determined by the periodicity of productivity deficit, further modulated by food price volatility. It is therefore essential to establish and validate evidences for countries to design their respective portfolios of mitigation and adaptation options.
- Smith et al 2007 as part of the fourth assessment report of the IPCC present an excellent overview of the assessment of mitigation technologies, practices, options, potential costs with respect to sustainability and links with policies that will foster responses. (Smith P, D Martino, Z CAI, D Gwary, H Janzen, P Kumar, B McCarl, S Ogle, F O'Mara, C Rice, D Scholes and O. Sirotenko 2007: Agriculture. In Climate Change 2007: Mitigation. Contribution of Working Group-III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (B Metz, O R Davidson, P R Bosch, R Dev, L A Meyer (eds). Cambridge University Press, UK and New York)).
- The report of the Working Group-I of the IPCC in the form of the summary for policy makers (IPCC, 2007: Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, m. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY (USA)) provides a comprehensive overview of the scenarios considered for interpreting the dynamics of the phenomenon and its impacts.
- The US Department of Agriculture (Malcolm S, Marshall E, Aillery M, Heisey P, Livingston M, and Day-Rubenstein K, Agricultural Adaptation to a Changing Climate. Economic and Environmental implications vary by US region. ERR-137, USDA, Economic Research Service July 2012) indicates the region specific economic and environmental mitigation options for adaptation to climate change. The influence of crop rotations, tillage and other land use practices are also highlighted.
- The GEF and UNEP (Clemants, R., J. Haggar, A. Quezada, and J. Tomes (2011) Technologies for Climate Change Adaptation – Agriculture Sector. X. Zhu (Ed.). UNEP Rise Centre, Roskilde, 2011) discussed technologies for climate change adaptation in agriculture with a special emphasis on vulnerability assessments and criteria to prioritize related technologies. Some of the important sectors addressed by them include

water use and management, soil, crop, livestock management and sustainable farming systems.

- The IFPRI (Fofana I. 2011. Simulating the impact of Climate Change and Adaptation Strategies on Farm Productivity and Income – A Bio-economic Analysis. IFPRI discussion paper 01095, June 2011) presents an interesting case of assessing variations in land productivity as a function of temperature and precipitation patterns, with implications for farm income.
- The IFAD (2011. Climate – Smart Small Holder Agriculture: What's Different) argues for increasing access to an efficient use of water especially for the small holders followed by institutional capacities for adaptation.

These essentially represent some predominant strands of thinking and interventions. India too is witnessing several of these in various stages of development. The chapters presented reflect this emerging status. The present volume, therefore, showcases these strands with the fond hope that they will stimulate further thinking and enable appropriate action. The scale of action and its timeliness is equally important. The sources of information presented below are of the references cited in this prologue and of some others in addition to them. The objective of the listing (compiled on 09-02-2013) is also to further help readers access information cited.

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About the Editors

Anil Kumar Singh is currently the Vice-Chancellor of the Rajmata Vijayaraje Scindia Krishi VishwaVidyalaya, Gwalior. Earlier he was the Deputy Director General (NRM) in ICAR—2007–2012; Acting Director, IARI-2005–2006; Project Director, Water Technology Centre-1999–2007. Dr. Singh joined the Agricultural Research Service in 1976 and grew up to Principal Scientist until 1999. His areas of research interest have been soil-water-nutrient-plant-atmosphere interactions, crop growth simulation, irrigation water management, and integrated watershed management. Dr. Singh has been known as a DAAD Fellow at University of Hohenheim, Germany, and has served in International Rice Research Institute between 1993 and 1995.

Jagdish Chander Dagar has been well recognized for his research in the area of agroforestry, both nationally and internationally. He is presently working as Scientist Emeritus in Central Soil Salinity Research Institute, Karnal; previously Dr. Dagar was the Assistant Director General (Agronomy/Agroforestry) at the headquarters of ICAR (2010–2012). His research interest has been in the areas of biosaline agriculture, agroforestry, rehabilitation of degraded lands, management of natural resources, bio-drainage, climate change, and sustainable agriculture and policy. He has written several books and has published more than 200 research papers of high repute in international and national level journals.

A. Arunachalam is a trained ecologist from the North-Eastern Hill University, Shillong, and has grown professionally through strong pursuit in natural resource management ecological research that is evident from his 150 research papers, 5 synthesis volumes, 100 book chapters and 25 popular articles. He started his service as a Lecturer/Assistant Professor in Forestry, North Eastern Regional Institute of Science and Technology (Arunachal Pradesh) and currently he is working as a Principal Scientist in the headquarters of Indian Council of Agricultural Research, Krishi Bhawan, New Delhi. His areas of research have been: restoration ecology and environmental management; ecosystems; forest ecology and management; agriculture and soil nutrient management; and conservation biology.

R. Gopichandran serves as the Director of Vigyan Prasar, an autonomous institution of the Department of Science and Technology, Government of India. His two doctoral degrees are in the areas of microbial ecology and chemical ecology. He holds a degree in law. A significant part of his career that has spanned nearly 25 years till now was spent on chemicals management for ozone layer protection. His insights on substitution, phase out and integrated management of ozone depletion and climate protection including inclusive mitigation and adaptation approaches were derived through strong working links with the Compliance Assistance Programme of the OzonAction programme, United Nations Environment Programme, at the regional levels. This was predominantly as part of his output at the Centre for Environment Education, Ahmedabad, and the Gujarat Energy Research and Management Institute, Gandhinagar.

Kirit Nanubhai Shelat was a public administrator for the Government of Gujarat, India. He is currently associated with NGOs and Trusts. Dr. Kirit Nanubhai Shelat is Ph.D. in Public Administration. He recently retired from the Indian Administrative Service. He started his career in public administration by joining the Gujarat Administrative Service in the year 1967. During his career of 40 years, he has worked at the grass-root level and had his hand in the formulation and implementation of policies for agricultural, rural and industrial development. He has worked as

Commissioner of Rural Development, Industries Commissioner, Commissioner for Employment and Training, Commissioner for disabled persons and Secretary Energy Department. He has also worked as Chairman of State Level Public undertakings like Gujarat Agro Industries Corporation and Land Development Corporation. He also worked in Afghanistan as Land Settlement Advisor to Government of Afghanistan. He has designed and implemented large-scale projects for poor families, farmers, and micro-entrepreneurs. He developed guidelines for micro-level planning with focus on individual poor family and village development plan. He was responsible for “cluster development approach” for small industries and “step up project” for rural micro-level entrepreneurs. He developed micro-level production plan module for individual farmer and has his hand in restructuring the Gujarat agriculture sector. He introduced new extension approach of meeting with farmers at their door step prior to monsoon by team led by agriculture scientist. He introduced scientific agriculture based on soil health moisture analysis giving a soil health card to every farmer of Gujarat. This effort went in a long way in developing sustainable agriculture in Gujarat.

Climate Change Adaptation and Mitigation Strategies in Rainfed Agriculture

B. Venkateswarlu and Anil Kumar Singh

Abstract

Climate change impacts on agriculture have been dealt at several national and international fora wherein it has always been indicated as a vulnerable ecosystem to climate change and reports do indicate that these ecosystems to contribute to the growing CO_2 level in the atmosphere, whilst a few studies do establish negative impact on the productivity of a few crops and also positive impact on crop movement along altitudinal gradient. With projected increase in water requirements, sustaining production in the rainfed areas is a challenge and in a country like India where a major junk of agricultural practices are monsoon-dependent, and has a strong socio-cultural and socio-economic bondages with farms and farming communities. Within the paradox of climate resilience in agriculture, opportunities for adaptation and mitigation strategies have been discussed in this paper with specific reference to rainfed agriculture.

Keywords

Climatic change adaption • Mitigation • Rainfed agriculture • Carbon sequestration • Conservation agriculture • Biochar

Introduction

Climate change impacts on agriculture are being witnessed all over the world. However, countries like India are more vulnerable in view of the high population depending on agriculture and excessive pressure on natural resources. The warming trend in India over the past 100 years (1901–2007) was observed to be 0.51 °C with accelerated warming of 0.21 °C for every 10 years since 1970 (Krishna Kumar 2009). The projected impacts are likely to further aggravate yield fluctuations of many crops with implications for food security and prices. Cereal productivity is projected to decrease by 10–40 % by 2100 and greater loss is expected in *rabi*. There are already evidences of negative impacts on yield of wheat and paddy in parts of India due to increased temperature, increasing

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A.K. Singh et al. (eds.), *Climate Change Modelling, Planning and Policy for Agriculture*,
DOI 10.1007/978-81-322-2157-9_1,

water stress, and reduction in number of rainy days. Modeling studies project a significant decrease in cereal production by the end of this century (Mujumdar 2008). Climate change impacts are likely to vary in different parts of the country. Parts of western Rajasthan, Southern Gujarat, Madhya Pradesh, Maharashtra, Northern Karnataka, Northern Andhra Pradesh, and Southern Bihar are likely to be more vulnerable in terms of extreme events (Mall et al. 2006). For every 1° increase in temperature, yields of wheat, soybean, mustard, groundnut, and potato are expected to decline by 3–7 % (Agarwal 2009a). Similarly, rice yields may decline by 6 % for every 1° increase in temperature (Saseendran et al. 2000). Water requirement of crops is also likely to go up with projected warming, and extreme events are likely to increase.

Greater Vulnerability of Rainfed Agriculture

While climate change impacts agriculture sector in general, rainfed agriculture is likely to be more vulnerable in view of its high dependency on monsoon, the likelihood of increased extreme weather events due to aberrant behavior of south west monsoon. Nearly 85 m ha of India's 141 m ha net sown area is rainfed. Rainfed farming area falls mainly in arid, semiarid, and dry subhumid zones. About 74 % of annual rainfall occurs during southwest monsoon (June to September). This rainfall exhibits high coefficient of variation particularly in arid and dry semiarid regions. Skewed distribution has now become more common with reduction in number of rainy days. Aberrations in southwest monsoon which include delay in onset, long dry spells, and early withdrawal, all of which affect the crops, strongly influence productivity levels (Lal 2001). These aberrations are likely to further increase in the future. The risk of crop failure and poor yields always influence farmers' decision on investing on new technologies and level of input use (Pandey et al. 2000). Numerous technological (e.g., cropping patterns, crop diversification, and shifts to drought-/salt-resistant varieties) and socioeconomic (e.g., ownership of assets, access to services, and infrastructural support) factors will enhance or constrain the current capacity of rainfed farmers to cope with climate change.

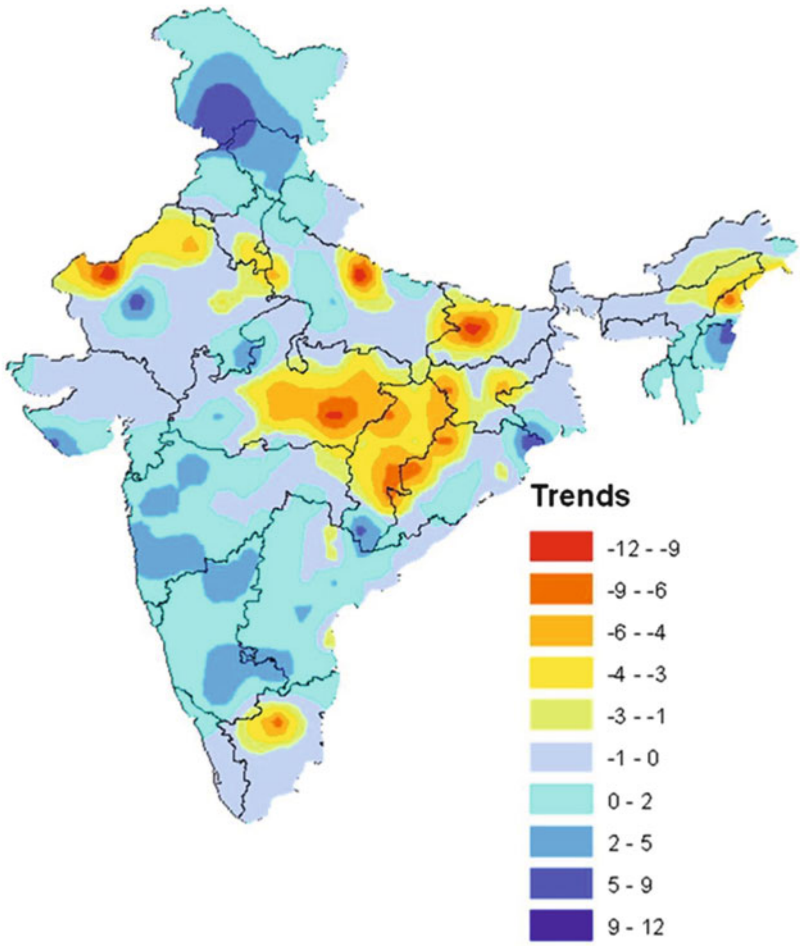
Trends in Key Weather Parameters and Crop Impacts

Rainfall is the key variable influencing crop productivity in rainfed farming. Intermittent and prolonged droughts are a major cause of yield reduction in most crops. Long-term data for India indicates that rainfed areas witness 3–4 drought years in every 10-year period. Of these, 2–3 are moderate and one may be of severe intensity. However, so far no definite trend is seen on the frequency of droughts as a result of climate change. For any R&D and policy initiatives, it is important to know the spatial distribution of drought events in the country.

A long-term analysis of rainfall trends in India (1901–2004) using Mann Kendall test of significance by AICRPAM, CRIDA indicates significant increase in rainfall trends in West Bengal, Central India, coastal regions, southwestern Andhra Pradesh, and central Tamil Nadu. A significant decreasing trend was observed with respect to the central part of Jammu Kashmir, Northern MP, central and western part of UP, and northern and central part of Chattisgarh (Fig. 1). Analysis of number of rainy days based on the IMD grid data from 1957 to 2007 showed declining trends in Chattisgarh, Madhya Pradesh, and Jammu Kashmir. In Chattisgarh and eastern Madhya Pradesh, both rainfall and number of rainy days are declining. This is a cause for concern as this is a rainfed rice production system that supports a large tribal population with poor coping abilities.

Temperature is another important variable influencing crop production particularly during *rabi* season. A general warming trend has been predicted for India. It is however important to know the temporal and spatial distribution of the trend. An analysis carried out by AICPRAM, CRIDA using maximum and minimum

Fig. 1 Rainfall trends over India from 1901 to 2004 (*Source*: NPCC Annual Report, CRIDA 2009–2010)



temperature data for 47 stations across India (DARE 2009) showed 9 of 12 locations in south zone with an increasing trend for maximum temperature, whereas the north, only 20 % locations showed increasing trend (Fig. 2). With respect to minimum temperature, most of the stations in India are showing an increasing trend. This is a cause of concern for agriculture as increased night temperatures accelerate respiration, hasten crop maturity, and reduce yields. The increasing trend is more evident in central and eastern zones where rainfall is also showing a declining trend. This is an area of concern and requires high attention for adaptation research.

Besides hastening crop maturity and reducing crop yields, increased temperatures will also increase the crop water requirement. A study carried out by CRIDA (unpublished) on the major crop-growing districts in the country for four crops, viz., groundnut, mustard, wheat, and maize, indicated a 3 % increase in crop water requirement by 2020 and 7 % by 2050 across all the crops/locations. The climate scenarios for 2020 and 2050 were obtained from HadCM3 model outputs using 1960–1990 as base line weather data (Table 1).

Adaptation and Mitigation Strategies

Successful adaptation to climate change requires long-term investments in strategic research and new policy initiatives that mainstream climate change adaptation into development planning.

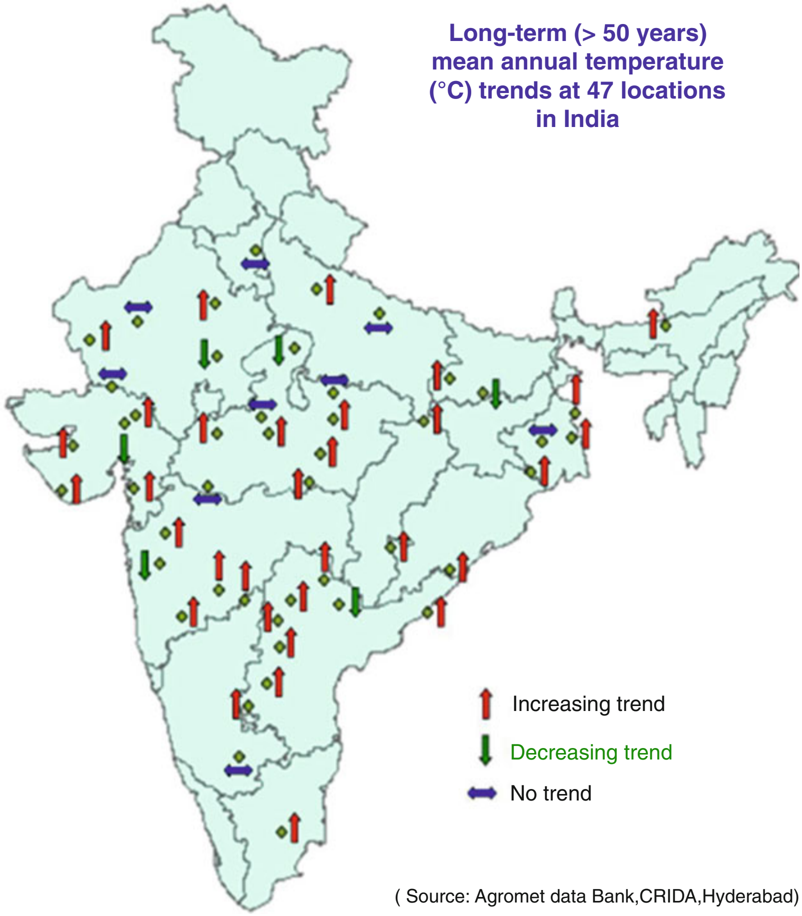


Fig. 2 Trends in mean temperature over different parts of India

As a first step, we need to document all the indigenous practices farmers have been following over time for coping with climate change. Secondly, we need to quantify the adaptation and mitigation potential of the existing best bet practices for different crop and livestock production systems in different agroecological regions of the country. Thirdly, a long-term strategic research planning is required to evolve new tools and techniques including crop varieties and management practices that help in adaptation.

Initiative of the ICAR

The Indian Council of Agricultural Research (ICAR) has initiated a Network Project on Climate Change (NPCC) in the X Five-Year Plan with 15 centers. This has been expanded in the XI Plan covering 23 centers. The initial results of the project through crop modeling have helped to understand the impacts of changes in rainfall and temperature regimes on important crops and livestock (Agarwal 2009b). Currently, the focus is on evolving cost-effective adaptation strategies. More recently during 2010, ICAR has launched the National Initiative on Climate Resilient Agriculture (NICRA) as a comprehensive project covering strategic research, technology demonstration, and capacity building. Targeted research on adaptation and mitigation is at a nascent stage in India However, some options for adaptation to climate variability can be suggested based on the knowledge already generated. These can be with respect to such induced effects as droughts, high temperatures,

Table 1 Estimated crop water requirement (mm) of four crops in major growing districts of the country under climate change scenario

				% change over 1990 in	
District (state)	1990	2020	2050	2020	2050
Groundnut					
Tiruvannamalai (TN)	506.0	515.2	544.0	1.8	7.5
Rajkot (Gujarat)	559.3	562.3	582.2	0.5	4.1
Junagadh (Gujarat)	522.6	528.5	550.2	1.1	5.3
Belgaum (Karnataka)	354.9	366.3	386.0	3.2	8.7
Anantapur (AP)	517.6	567.1	650.3	9.6	25.6
Bangalore (Karnataka)	490.9	510.9	559.3	4.1	13.9
Mustard					
Agra (UP)	276.4	284.0	295.5	2.7	6.9
Bharatpur (Raj)	276.2	283.8	295.1	2.8	6.8
Hisar (Haryana)	357.0	369.6	380.8	3.5	6.7
Nadia (WB)	483.2	491.5	508.8	1.7	5.3
Morena (MP)	263.4	269.0	282.5	2.1	7.2
Wheat					
Sirsa (Haryana)	281.8	293.1	301.4	4.0	7.0
Ahmedabad (Gujarat)	523.0	536.8	551.0	2.6	5.4
Ahemedanagar (Mah)	485.8	496.1	509.5	2.1	4.9
Ganganagar (Raj)	278.9	290.3	298.2	4.1	6.9
Hardoi (UP)	475.0	488.2	502.2	2.8	5.7
Kangra (HP)	367.7	380.7	391.2	3.5	6.4
Vidisha (MP)	437.1	446.9	460.4	2.3	5.3
Sangrur (Punjab)	391.1	405.4	416.3	3.7	6.4
Maize					
Udaipur (Raj)	388.8	392.4	400.9	0.9	3.1
Karimnagar (AP)	424.7	433.4	440.0	2.0	3.6
Jhabua (MP)	424.5	430.6	441.9	1.4	4.1
Begusarai (Bihar)	370.0	374.7	388.9	1.3	5.1
Bahraich (UP)	407.4	412.1	426.5	1.1	4.7
Godhra (Gujarat)	426.3	432.3	444.0	1.4	4.2
Khargaon (MP)	354.3	365.0	381.0	3.0	7.6
Aurangabad (Mah)	413.4	423.1	435.7	2.3	5.4

floods, and sea water inundation. These could be crop-based and/or resource management-based strategies.

Crop-Based Strategies

Crop-based approaches include:

- Growing crops and varieties that fit into the changed rainfall and seasons
- Development of varieties:
  - With changed duration that can over winter the transient effects of change
  - For heat stress, drought, and submergence tolerance
- Evolving varieties which respond positively in terms of growth and yield under high CO_2

In addition to the above, varieties with high fertilizer and radiation use efficiency and novel crops/varieties that can tolerate coastal salinity and sea water inundation are needed. Inter-cropping is a time tested practice to cope with climate variability and climate change. If a crop fails due to floods or droughts, the alternative crop could give some minimum assured returns for livelihood security. Germplasm of wild relatives and local land races could provide valuable sources of climate-ready traits. We need to revisit the germplasm collected so far to examine tolerance for heat and cold stresses and consider them even if they have been relegated earlier due to low yield considerations. A detailed account of crop-based approaches is beyond the scope of this paper. Susheel Kumar (2006) provides a succinct account of breeding objectives under the climate change context in India.

Strategies Based on Resource Conservation and Management

There are several options in soil, water, and nutrient management technologies that contribute to both adaptation and mitigation. Much of the research done in rainfed agriculture in India relates to conservation of soil and rain water and drought proofing which is an ideal strategy for adaptation to climate change (Venkateswarlu et al. 2009). Important technologies include in situ moisture conservation, rainwater harvesting and recycling, efficient use of irrigation water, conservation agriculture, energy efficiency in agriculture, and use of poor quality water. Watershed management is now considered an accepted strategy for the development of rainfed agriculture. Watershed approach has many elements which help both adaptation and mitigation. For example, soil and water conservation works, farm ponds, check dams, etc., moderate runoff and minimize floods during high intensity rainfall. The plantation of multipurpose trees in degraded lands helps in carbon sequestration. The crop and soil management practices can be tailored for both adaptation and mitigation at the landscape level. Some of the most important adaptation and mitigation approaches with high potential are described below:

Rainwater conservation and harvesting interventions are based on in situ and ex situ conservation of rainwater for recycling to rainfed crops. The arresting of soil loss contributes to reduced carbon losses. Lal (2004) estimates that if water and wind erosion are arrested, it can contribute to 3–4.6 Tg year^{-1} of carbon in India. Increased groundwater utilization and pumping water from deep tube wells is the largest contributor to GHG emissions in agriculture. If surface storage of rainwater in dugout ponds is encouraged and low lift pumps are used to lift that water for supplemental irrigation, it can reduce dependence on ground water. Sharma et al. (2010) estimated that about 28 m ha of rainfed area in eastern and central states has the maximum potential to generate runoff of 114 billion cubic meters which can be used to provide one supplemental irrigation in about 25 m ha of rainfed area. For storing such quantum of rainwater, about 50 million farm ponds are required. This is one of the most important strategies to control runoff and soil loss and contribute to climate change mitigation. Conjunctive use of surface and ground water is an important strategy to mitigate climate change. Innovative approaches in groundwater sharing can also help equitable distribution of water and reduce energy use in pumping.

Soil Carbon Sequestration

Soil carbon sequestration is yet another strategy towards mitigation of climate change. Although tropical regions have limitation of sequestering carbon in soil due to high temperatures, adoption of appropriate management practices helps in sequestering reasonable quantities of carbon in some cropping systems particularly in high rainfall regions. The potential of cropping systems can be optimized through soil carbon sequestration and sequestration into vegetation. Tree-based systems can sequester substantial quantities of carbon into biomass in a short period.

The total potential of soil C sequestration in India is 39–49 Tg year^{-1} (Lal 2004). This is inclusive of the potential of the restoration of degraded soils and ecosystems, estimated at 7–10 TgC year^{-1} (Table 2). The potential of adoption of recommended package of practices on agricultural soils is 6–7 Tg year^{-1}. This is in addition to the potential of soil inorganic carbon sequestration estimated at 21.8–25.6 TgC year^{-1}. Long-term manurial trials conducted in arid

Table 2 Soil organic carbon sequestration potential through restoration of degraded soils (Source: Lal, 2004)

Degradation process	Area (Mha)	SOC sequestration rate (kg/ha/y)	Total SOC sequestration potential (Tg C/y)
Water erosion	32.8	80–120	2.62–3.94
Wind erosion	10.8	40–60	0.43–0.65
Soil fertility decline	29.4	120–150	3.53–4.41
Waterlogging	3.1	40–60	0.12–0.19
Salinization	4.1	120–150	0.49–0.62
Lowering of water table	0.2	40–60	0.01–0.012
Total			7.20–9.82

regions of Andhra Pradesh (at Anantapur) under rainfed conditions indicate that the rate of carbon sequestration in groundnut production system varied from 0.08 to 0.45 t ha^{-1} $year^{-1}$ with different nutrient management systems (Srinivasarao et al. 2009). Under semiarid conditions in alfisol region of Karnataka, the rate of carbon sequestration was 0.04–0.38 t ha^{-1} $year^{-1}$ in finger millet system under diverse management practices. Under rabi sorghum production system in vertisol region of Maharashtra (semiarid), the sequestration rate ranged from 0.1 to 0.29 t ha^{-1} $year^{-1}$ with different integrated management options. In soybean production system in black soils of Madhya Pradesh (semiarid), the potential rate of carbon sequestration is up to 0.33 t ha^{-1} $year^{-1}$ in top 20 cm soil depth.

Site-Specific Nutrient Management

Integrated Nutrient Management and Site-Specific Nutrient Management (SSNM) is another approach with potential to mitigate effects of climate change. Demonstrated benefits of these technologies are increased rice yields and thereby increased CO_2 net assimilation and 30–40 % increase in nitrogen use efficiency. This offers important prospect for decreasing GHG emissions linked with N fertilizer use in rice systems. It is critical to note here that higher CO_2 concentrations in the future will result in temperature stress for many rice production systems, but will also offer a chance to obtain higher yield levels in environments where temperatures are not reaching critical levels. This effect can only be tapped under integrated and site directed nutrient supply, particularly N. Phosphorus (P) deficiency, for example, not only decreases yields but also triggers high root exudation and increases CH_4 emissions. Judicious fertilizer application, a principal component of SSNM approach, thus has twofold benefit, i.e., reducing greenhouse gas emissions, simultaneously improving yields under high CO_2 levels. The application of a urease inhibitor, hydroquinone (HQ), and a nitrification inhibitor, dicyandiamide (DCD), together with urea also is an effective technology for reducing N_2O and CH_4 from paddy fields. Very little information is available on the potential of SSNM in reducing GHG emissions in rainfed crops.

Conservation Agriculture (CA)

In irrigated areas, zero tillage (ZT) in particular has effectively reduced the demand for water in rice-wheat cropping system of Indo-Gangetic plains and is now considered a viable option to combat climate change. ZT has some mitigation effect in terms of enhancing soil carbon, reducing energy requirement, and improving water and nutrient use efficiency, but its actual potential has to be quantified from long-term experiments. The scope of CA in rainfed agriculture has been reviewed by Singh and Venkateswarlu (2009). While reduced tillage is possible in few production systems in high rainfall regions in eastern and northern India, non-availability of crop residue for surface application is a major constraint, particularly in peninsular and western India where it is mainly used as fodder.

Biomass Energy and Waste Recycling

A large amount of energy is used in cultivation and processing of such crops as sugarcane, food grains, vegetables, and fruits, which can be recovered by utilizing residues for energy production. This can be a major strategy in climate change mitigation by avoiding burning of fossil fuels and recycling crop residues. The integration of biomass-fuelled gasifiers and coal-fired energy generation would be advantageous in terms of improved flexibility in response to fluctuations in biomass availability with lower investment costs. Waste-to-energy plants offer twin benefits of environmentally sound waste management and disposal, as well as the generation of clean energy.

Livestock production has been an integral part of agriculture in India. Livestock provides an excellent recycling arrangement for most of the crop residue. Most by-products of cereals, pulses, and oilseeds are useful as feed and fodder for livestock, while that of cotton, maize, pigeon pea, castor and sunflower, and sugarcane are used as low-calorie fuel or burnt to ashes or left in the open to decompose over time. Ideally such residue is incorporated into soil to enhance physical properties of the soil and its water holding capacity. Lack of proper chipping and soil incorporation equipment is one of the major reasons for the colossal wastage of agricultural biomass in India. Increased cost of labor and transport is another reason for lack of interest in utilizing the biomass. This is an area where little or no effort has gone in despite availability of opportunities for reasons such as aggregation, transport, and investment in residue processing facilities.

Many technologies as briquetting, anaerobic digestion vermin-composting, biochar, etc., exist, but they have not been commercially exploited. This area is gradually receiving attention now as a means to producing clean energy by substituting forest biomass for domestic needs. Modest investments in decentralized facilities for anaerobic digestion of agricultural residue through vermin-composting and biogas generation can meet the needs of energy-deficit rural areas and simultaneously contribute to climate change mitigation.

Biomass-Based Biogas Production

There is renewed interest in the use of anaerobic digestion processes for efficient management and conversion of cattle dung and other agro-industrial wastes (livestock, paper and pulp, brewery, and distillery) into clean renewable energy and organic fertilizer source. The biogas captured could not only mitigate the potential local and global pollution but could either be combusted for electricity generation using combined heat and power generator in large to medium enterprises or used for cooking and lighting for small households. A 2 m^3 digester can generate up to 4.93 t CO_2e year-1 of certified emission reduction (CER). Animal wastes are generally used as feedstock in biogas plants. But the availability of these substrates is one of the major problems hindering the successful operation of biogas digesters. Khandelwal (1990) reported that the availability of cattle waste could support only 12–30 million family-size biogas plants against the requirement of 100 million plants. A significant portion of 70–88 million biogas plants can be run with fresh/dry biomass residues. Of the available 1,150 billion tons of biomass, a fifth would be sufficient to meet this demand.

Biochar

When biomass is exposed to moderate temperatures, between about 400 and 500 °C (a kind of low-temperature pyrolysis), under complete or partial exclusion of oxygen, it goes through exothermic processes and releases many gases in addition to heat along with biochar (Czernik and Bridgewater 2004). Pyrolysis produces