CLIMATE CHANGE AND AGRICULTURE

CAUSES, IMPACTS AND INTERVENTIONS

Editors

GSLHV Prasada Rao | VUM Rao | DVS Rao

Climate Change and Agriculture

About the Editors

Dr. GSLHV Prasada Rao, had his B.Sc (Physics), M.Sc (Meteorology) and Ph.D (Agroclimatology) from Andhra University, Waltair. He commenced his service in Ground Water Department, Govt. of Rajasthan as Junior Hydrometeorologist in January 1980 and later joined as Assistant Professor (Agricultural Meteorology) in Kerala Agricultural University in December 1980. He served as Professor & Head, Department of Agricultural Meteorology, Associate Dean, College of Horticulture, Associate Director of Research and Special Officer, Academy of Climate Change Education and Research, Comptroller and Coordinator (Finance), Kerala Agricultural University before his superannuation from KAU service on 29-07-2012. Later, he took up assignment as Consultant Professor, Centre for Animal Adaptation to Environment and Climate Change Studies, Kerala Veterinary and Animal Sciences University from 01-04-2013 to 30-09-2016. Had short term assignment as International Agrometeorologist in a World Bank aided Project on Climate Resilience, MoALM&C, Govt. of Nepal in 2018.

Instrumental in establishment of “Academy of Climate Change Education and Research (ACCER)” in Kerala Agricultural University and launched unique and innovate dual degree program in Climate Change Adaptation (B.Sc.–M.Sc. dual degree program of five year duration) after plus two. It is the first of its kind in India. It is a multi-disciplinary and multi-institutional program. Instrumental in establishment of “Centre for Animal Adaptation to Environment and Climate Change Studies (CAADECCS)” in Kerala Veterinary and Animal Sciences University and launched unique and innovative Ph.D. program in “Climate Change and Animal Agriculture” during the Academic year 2015-16 in addition to Two P.G. Diploma Courses (one year duration) in Climate Services for Veterinary Students and for general science stream students.

He possesses 38 years of experience in teaching, research and extension in Agricultural Meteorology, Climate Change and Climate Change Risk Management in Agriculture. Many publications are to his credit. He is currently involved in farming and editing/writing books.

Dr. V. Uma Maheswara Rao (VUM Rao) had his post-graduation from the Department of Meteorology and Oceanography, Andhra University, Waltair. He obtained his Ph.D in Agricultural Meteorology in 1981and had a Post Doctoral Research Fellowship during 1982-83. He joined in CCS HAU service as Assistant Climatologist/Assistant Professor in 1983 and served the Department of Agricultural Meteorology in various capacities. He was the Professor and Head in CCS HAU before he joined as Principal Scientist in ICAR System and retired as Project Coordinator (AICRP on Agricultural Meteorology), Central Research Institute for Dryland Agriculture (CRIDA), Indian Council of Agricultural Research in 2016. The **prestigious Choudary Devi Lal ICAR** best AICRPAM award was obtained under his dynamic leadership as the Project Co-ordinator (Agricultural Meteorology) in 2014. He had 35 years of experience in the field of Agricultural Meteorology as researcher, scientist and teacher. He is Life Member in six scientific societies viz., “Indian Meteorological Society, The Arid Zone Research Association of India, Indian Society of Remote Sensing, Association of Agrometeorologists, International Society for Agrometeorology and The Indian Society of Dryland Agriculture. He is a Fellow of Association of Agro-meteorologists. He served as President and Vice-President of Association of Agrometeorologists. He is a reviewer for various international and national research journals, expert in several selection committees, member in Board of Studies of several universities, paper setter and external examiner and one of the renowned resource personnel in Agricultural Meteorology. Many students were trained under him with postgraduate degrees, spread across the country and settled in various positions in the field of Agricultural Meteorology. He has more than 200 publications including popular articles. He visited abroad on many occasions in his official capacity.

Dr. D.V. Subba Rao obtained B.Sc(Ag) in 1980 and M.Sc.(Ag) in Agricultural Economics in 1982 from ANGRAU. He was an ICSSR Doctoral Fellow at Institute of Economic Growth during 1988-93. He obtained Ph.D. from the Department of Economics, Delhi School of Economics, University of Delhi in 1995 under the supervision of Professor Kanchan Chopra and Professor V.N. Pandit. He has been awarded with Jawaharlal Nehru Award, ICAR, Professor Chablani Memorial Prize, University of Delhi and Vetiver Network Award of World Bank for his research contributions. He joined as research assistant in 1983 in the same university and is working for more than three decades in various capacities. At present, he is holding the NABARD Chair Professor at Agricultural College, Bapatla, ANGRAU, Andhra Pradesh. Earlier, he worked as Professor & University Head in the Department of Agricultural Economics, and Hon Director, Cost of Cultivation Scheme at College of Agriculture, Rajendranagar, Hyderabad. Further, he has worked as an Economist on projects pertaining to natural resource accounting for a year and half at Institute of

Economic Growth, Delhi during 1996-97on deputation. Subsequently, he worked as Asst. Professor, Associate Professor, and Professor at College of Agriculture, Rajendranagar, Hyderabad. He guided 20 M. Sc (Ag) and 6 PhD students in different areas such as agro forestry, minor forest products, infrastructure, water management, tank and well irrigation, institutional aspects of irrigation, potential for horticultural products, trade competitiveness of oil seeds, profitability and plant protection, land policy, women empowerment etc. in India and abroad. He attended several conferences and seminars and organized conferences on agribusiness, climate change and smart farming. He has been life member of the Indian Society of Agricultural Economics, the Indian Econometric Society and Agricultural Economics Research Association. Dr. D.V. Subba Rao has published several articles on natural resource and environmental economics.

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Foreword

Global warming is real and happening now, and India is not an exception, though there might be some spatial differences in warming across the country. An increasing body of scientific evidence, as brought out by the Intergovernmental Panel on Climate Change (IPCC) assessment reports and special reports, conclusively establishes that the major cause of global warming is the unabated increase in greenhouse gas (e.g., carbon dioxide, methane, etc.) concentrations in the atmosphere way beyond their natural levels. It is also abundantly clear that global warming and the consequent climate change are almost entirely due to the uncontrolled human activities such as burning of fossil fuels, deforestation, land use and land cover changes, intensive exploitation of natural resources, unsustainable agricultural practices, etc. The rapid scientific and technological advances over the past couple of centuries fed the industrial revolution and all-round development, but at an enormous cost to the entire human society and ecosystem. Rise in surface air temperature is widespread over the globe and is greater at higher northern latitudes. Land regions have warmed faster than the oceans. The latest Annual Statement of the Status of the Climate issued by the World Meteorological Organization (WMO) reports that the long-term warming trend has continued in 2018, with the average global temperature set to be the fourth highest on record. As many as 20 of the warmest ever-recorded years happened to be in the past 22 years, with the top four in the past four years, according to the statement. Other tell-tale signs of climate change, including sea level rise, ocean heat and acidification and sea-ice and glacier melt continue, whilst extreme weather left a trail of devastation on all continents, according to the WMO Statement. The HudHud cyclone over Visakhapatnam Coast in October 2014, Chennai floods in 2015, Kerala floods in August 2018 and the Titli cyclone over Orissa and North Andhra Pradesh Coast in October 2018, the

Gaja Cyclone over Tamil Nadu Coast in mid November and the Phethai Cyclone in mid December 2018 devastated the crops and infrastructure to a large extent in respective regions. In contrast, the Indian foodgrains production was adversely affected due to consecutive droughts during monsoon season in 2014 and 2015 since agricultural production is mainly dependent on monsoonal rains in India. Similarly, the occurrence of cold and heat waves in northern states of the country causes recurring damage to crops. Untimely snowfall over western Himalayan region in early November 2018 severely damaged apple production. The ill effects of climate change in the form of frequent occurrence of floods, droughts, cold and heat waves are clearly evident on various agricultural production systems, thereby posing a serious threat to food security.

Climate change is considered to be the biggest challenge confronting the global society, both to prevent future changes and to adapt to changes that are already happening and are imminent. To mitigate the climate change effects on agricultural production and productivity a range of adaptive strategies need to be considered. Changing cropping calendars and pattern will be the immediate best available option with available crop varieties to mitigate the climate change impact. The options like introducing new cropping sequences, late or early maturing crop varieties depending on the available growing season, conserving soil moisture through appropriate tillage practices and efficient water harvesting techniques are also important. Developing heat and drought tolerant crop varieties by utilizing genetic resources that may be better adapted to new climatic and atmospheric conditions should be the long-term strategy. Genetic manipulation may also help to exploit the beneficial effects of increased carbon dioxide on crop growth and water use. One of the promising approaches would be gene pyramiding to enhance the adaptation capacity of plants to climatic change inputs. There is thus an urgent need to address the climate change and variability issues holistically through improving the natural resource base, diversifying cropping systems, adapting farming systems approach, strengthening of extension system and institutional support. Latest improvements in biotechnology and information technologies need to be used for better agricultural planning and weather/climate based management to enhance the agricultural productivity of the country.

Successful adaptation to climate change requires long-term investments in strategic research and new policy initiatives that mainstream climate change adaptation into development planning. As a first step, we need to document all the indigenous practices adopted by rainfed farmers 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 agro-ecological 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. In 2010, the Indian Council of Agricultural Research (ICAR) 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 nascent stage in India but based on knowledge already generated, some options for adaptation to climate variability induced effects like droughts, high temperatures, floods and sea water inundation can be suggested. These strategies fall into two broad categories viz., (i) crop based and (ii) resource management based.

Several experts have identified research areas that would reduce uncertainty and improve knowledge to face the consequences of climate change and provide improved planning. These include, but not limited to:

- Precision weather-forewarning at farm level
- Quantitative assessment of specific crop responses at different crop stages to enhanced levels of greenhouse gases, precipitation and UV-B radiation
- Breeding agricultural crops for tolerance to extreme temperatures, floods, salinity and droughts
- Innovative agroclimatic resource mapping to avoid potentially inappropriate land-use choices
- The impacts of elevated carbon dioxide levels on plant and soil-water balances
- Improved crop simulation models as tools for both research and crop management.

This publication revolves around interventions to minimize crop losses due to global warming and climate change, organized in 32 chapters collectively spanning more than 560 pages. The contributions emerged from research findings in different parts of the country in the ICAR and the State Agricultural Universities, which I consider to be a commendable compilation. I am sure this publication will be of immense use to researchers, teachers, students as well as farmers.

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Preamble

Global warming is real. Rise in temperature is likely to be around **2**°C by the end of this century with regional uncertainties in rainfall. It is a threat to the society linked sectors viz., agriculture, water resources, forestry, biodiversity (both land and ocean), infrastructure and health. The adverse impact of climate change is already noticed across the world in the above society linked sectors due to weather related disasters in the form of cyclones, floods, droughts, cold and heat waves and sea level rise. The monsoon aberrations have become more frequent over **India on which rainfed Agriculture is dependant. The years 2014 and 2015 were recorded as monsoon drought years and the monsoon 2018 also ended with nine percent deficit rainfall against the long term Average. The recent years 2015, 2016 and 2017 were recorded as warmest years after 2009 and 2010 in India.** Decline in rainfall and increase in temperature are observed in the last 50-60 years across the **Country and reports indicate that the semiarid belt is increasing.** Melting of glaciers and snow from the Himalayas due to global warming is a serious threat to the seasonal water availability **across the northern states of India.** The global hydrological and energy cycles are likely to be adversely affected and thus the change in whole climate system.

This Publication deals with climate change impacts and interventions in agriculture across various regions of the Country based on the research findings emanated from ICAR institutes and State Agricultural Universities as global warming and climate change is a threat to food security. I understand that more than 60 authors are involved with 32 Chapters, containing about 560 pages focussing on mitigation and adaptation strategies in agriculture against ill effects of climate change across India. Researchers indicate that crop yields are likely to decline with increase in atmospheric CO_2 and temperature in ensuing decades and crop losses can be minimized through technologies generated in crop management, crop improvement and crop protection practices. Farmers concern to minimize crop losses against weather extremes rather than climate change as the impacts of climate change (increase in atmospheric CO_2 and temperature) on crops at the field level is not clear if water is not a constraint. The publication includes vulnerability assessment, adaptation strategies, crop choices/combinations in different climate scenarios and preparedness to face the exigencies of climate change and emphasis is given on interventions. There is an urgent need to intensify research and development to generate technologies and location specific farm practices which can minimise the impact of climate change.

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Preface

Weather and climate play an important role in crop distribution and production. While climate determines the adaptability of a particular crop in a region, weather determines the yield attributes of the crop. Over a period of years, changes have occurred in climate of the earth's atmospheric system mostly due to human interventions in the form of emission of large quantities of greenhouse gases (GHGs). The present level of carbon dioxide concentration in the atmosphere has crossed 400ppm level. As a result of the dumping of GHGs (CO_2, Methane, Nitrous Oxide and CFCs) the earth's atmospheric system is getting warmer at an alarming rate, which lead to a state called global warming. It is now a topic of concern to the society. The global mean atmospheric temperature has risen by 0.8°C since 1901and it is likely to be between 1.5 and 2°C by the end of 2100 A.D. This situation leads to changes in earth's climate system viz., Atmosphere, Hydrosphere, Lithosphere, Cryosphere and Biosphere. Its ill effects are evident in different society linked sectors viz., water, health, agriculture, forestry, biodiversity and infrastructure. Unprecedented floods in Kerala during August, floods in some pockets across southern states viz.,Tamil Nadu, Karnataka and Andhra Pradesh during monsoon season, cyclone Titli in October that hit Orissa and Andhra Coast (Srikakulam District), snowfall in early November in 'apple bowl' of Kashmir. Cyclone Gaja across the T.N. Coast in November and Phethai in mid-December across the Andhra Coast during 2018 led to huge damage to infrastructure including crops of the respective regions. Extreme weather events such as floods and droughts, heavy rainfall, avalanche, landslides, heat and cold waves, cyclonic storms, thunder storms, hail storms, sand storms and cloud bursts are not uncommon and likely to be frequent in ensuing decades under projected climate change scenario. The impact of drought on Indian foodgrains production is much more predominant when compared to that of flood/heavy rainfall during monsoon since large areas of cultivable land experiences drought situation if monsoon breaks or fails. Deficit monsoon during 1965, 1966, 1972, 1984, 1987, 1997, 2002, 2004, 2009, 2012, 2014 and 2015 led to drought and adversely affected the kharif foodgrains production. The unexpected rains that lashed during February, March and April, 2015 across large part of northern and central India led to extensive crop damage. March and April are the months when the rabi crop is harvested. But the heavy rainfall accompanied by strong winds dashed the hopes of many farmers. Rain induced by western disturbances usually occurs during the winter and the late precipitation close to the rabi harvest has caused widespread crop damage. Thousands of acres of wheat across the States such as Rajasthan, Madhya Pradesh, Uttar Pradesh, Gujarat and Maharashtra were destroyed. Potato crop had been damaged in U.P. In Maharashtra, the onion crop has also been hit hard, both by the rain as well as hailstorms. The unseasonal rain accompanied by high speed winds and hailstorms badly affected quantity and quality of pulses. Marathwada, Vidarbha, Northern Maharashtra and parts of Western Maharashtra were the worst affected by the unprecedented hailstorms and unseasonal rainfall. Rabi crops like wheat, harbhara, cotton, jowar, summer onion are lost, horticultural crops like Papaya, sweet lime, grapes are battered and orchards which took years to grow are ridden to the ground. The unseasonal rains also adversely affected the yield of the king of fruits this season, with many mango trees in Maharashtra being uprooted due to strong winds accompanying rain. It also affected vegetable prices as cauliflower, tomato and coriander produce suffered in a State like Maharashtra. The vegetable baskets of Junnar, Ambegaon and Khed in Maharshtra were some of the worst affected areas. Even fruits like grapes grown in parts of Maharashtra were damaged. The conditions in Gujarat were also similar; the yield of spices like jeera and coriander suffered due to unusual rains. The destruction in standing crops had resulted in vegetable prices rising in North Indian cities. Landslides and snowfall led to the closure of the Jammu & Kashmir highway leaving thousands of people stranded. Such events occur and reoccur every year somewhere or other across the World. Therefore, it is important to understand the impact of climate variability or climate change on crop production and suitable interventions are need of the hour as a proactive measure to sustain agriculture/food security in the event of global warming and climate change. Hence, an attempt has been made to compile the work done by the authors on climate change impacts and interventions across the country and published in an abridged form for the benefit of farmers and to sustain Agriculture against malevolent effects of global warming and climate change.

In introductory chapter, greenhouse effect, global warming, status of atmospheric carbon dioxide in the atmosphere and its impact on rising temperature, aerosols and their impacts on global cooling, dual effect of clouds on global warming or cooling, ozone depletion and UV radiation and climate change awareness in society linked sectors viz., water, agriculture, forestry, biodiversity and health are discussed. The need to implement crop weather insurance as a part of climate risk management is also pointed out. Global warming and its impact on food price along with climate change awareness programmes are also included. The need for conducting climate change awareness programmes on the impact of climate change is focused. Chapter two is on Rainfall Variability in India. The arid and semi-arid areas are expanding whereas the moist subhumid, humid and perhumid areas are shrinking. The semi-arid area, which occupies the large and central portion of the country, is expanding significantly. The overall effect is that the country is experiencing dry climate in the recent period with a westward shifting of rainfall. A declining tendency in monsoon rainfall can be seen from 1965 onwards and a sharp declining trend from 1995. This is essentially due to weakening of the Tibetan Anticyclone associated with cooling of the upper troposphere (600–150 hPa) over the Himalayan region and surrounding atmosphere. The recent sharp increasing trend in the surface air temperature over India is due to a declining trend in rainfall during winter and summer monsoon seasons. Climate change and food security is included in chapter 3. Zonal differences in warming across the Country are highlighted. Impact of drought on Indian food grains production, climate change impacts on Indian food grains production, climate variability and food price are discussed in detail with facts and figures in chapter 3.

Climate Change: Extreme Events, Causes and Effects on Agriculture and Farmers Economy is included in chapter four. There is a need to intensify research to develop cultivars and develop management practices which can withstand the impact of climate change. The experiences under technology demonstration component of NICRA shows that technologies developed by the National Agricultural Research System can minimize the losses under variable climates and found to stabilize the productivity and incomes. These resilient practices need to be scaled up as part of the developmental programs for large scale adoption of resilient practices and to impart resilience to the agriculture production in the country. Chapter 5 includes climate risk management in smallholder farming systems in the Semiarid Tropics. Climate risk management requires holistic solutions derived from cross-disciplinary and participatory, user-oriented research – this implies that the multiple institutions/agencies present in India are required to better integrate their efforts for the benefit of smallholder farmers. State-wise climate change, impacts and interventions in Agriculture is focused in various chapters commencing from chapter 6 to chapter 23. The States include Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, Maharastra, Gujarat, Haryana, Punjab, Himachal Pradesh, Jammu and Kashmir, Assam, Bihar, Jharkhand, Chhatisgarh and Orissa. The crops include field and horticultural crops that are grown across the Country. This publication highlights more on interventions to mitigate ill effects of climate change in Agriculture. In chapter 24, climate change impacts on soil microflora and fauna are included since soil health is very important for better crop productivity and more so, in a changed climate scenario. Chapter 25 focuses on importance of monitoring weather parameters in crop insurance schemes. Weather insurance is the only one which will help to a little extent when the farmers lose everything from their farm land during weather disasters. Agroadvisory services based on medium range forecasting play an important role in mitigating the ill effects of climate variability/change, therefore its relevance is included in chapters 26 and 27. Role of satellites and remote sensing in impacts of climate change monitoring is incorporated in chapters 28 and 29. NABARD's initiatives and interventions in climate change are highlighted inchapter 30. Chapter 31 high lights on sorghum while wheet in chapter 32 in relation to climate change issues. Altogether, the publication contains more than 500 pages with Tables, Figures, Illustrations and Plates.

Successful adaptation to climate variability/change requires long-term investments in strategic research and new policy initiatives. As a first step, we need to document all the indigenous practices that farmers follow with 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 agro-ecological 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. 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 nascent stage in India but based on knowledge already generated, some options for adaptation to climate variability induced effects like droughts, high temperatures, floods and sea water inundation can be suggested. Like NICRA at ICAR level, SICRA (State Initiative on Climate Resilient Agriculture) should be given top priority in all the States to generate technologies to minimize crop losses during the occurrence of weather extremes such as floods, droughts, cold and heat waves for sustenance of rural livelihoods.

This publication revolves around interventions to minimize crop losses due to global warming and climate change across the Country. In that respect, the contributions emerged based on research findings from different parts of the Country in the ICAR and SAUs system are noteworthy, unique and innovative. we are sure this publication will be of immense use to researchers, teachers, students and farmers and read with zeal and enthusiasm.

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D.V. Subba Rao

Contents

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Climate Risk Management in Smallholder Farming Systems in the Semiarid Tropics

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Climate risk management in the semi-arid tropics (SAT) is one of the major challenges to achieving food security and development in India and large parts of sub-Saharan Africa and also in the case of Australia. Climate-induced production risk associated with the current season-to-season variability of rainfall is a major barrier in making rainfed agriculture sustainable and viable farm business. Since season outcomes are uncertain, even with the best climate information, farmers have limited flexibility in applying management with confidence. In fact in risky environments, farmers most often respond by adapting a risk averse strategy and are reluctant to invest in even risk reducing measures (Leathers and Quiggin 1991). In the SAT agro-ecologies, there are a limited range of enterprise or crop options to consider which may be further restricted by cultural traditions, food preferences or market opportunities.While there are fundamental differences between large scale commercial farms in Australia compared to the predominantly smallholder resource poor farms found in India, when it comes to climate risk management in the SAT, there are many commonalities. The purpose of this paper is therefore to (i) establish a framework for managing climate variability and transforming farming systems to be more resilient and sustainable for future climates; and (ii) provide some case study examples from climate risk management in low rainfall cropping system in Australia and consider how they may be applied in smallholder systems of the SAT.

In the smallholder farming systems of the semi-arid, the majority of rural livelihoods are based on the production of cereals under rainfed mixed crop-livestock systems. Under these systems, yield gap between potential and achieved productivity is large, water and nutrient use efficiencies are generally low and land degradation is widespread and severe. There are many commentaries as to why the productivity gains achieved in other more favourable agro-ecologies have not positively impacted on agricultural production in the drylands. While most conclude that lack of government support, infrastructure, poor management and governance of natural resources, i.e. the enabling environment, are the major barriers, we argue that the effects of climate variation which act as a powerful disincentive to investment across all scales should not be overlooked as a major contributing factor. This paper argues that research, development and extension efforts in the drylands pay inadequate attention to climate risk encompassing both present variability and future climate changes. The effect of extreme climatic events such as severe and long term droughts, high intensity rainfall events and heat waves leading to crop loss and land degradation are significant disincentives to investment by small holders. Non availability of customized climate information, a lack of the 'enabling environment'and the lack of knowledge on how to respond to climate information with confidence are the real constraints to the further sustainable development of semiarid smallholder farmers. While there are a number of possible solutions to manage climate risk in small holder farming systems, we explore if some successful examples of climate risk management from low rainfall commercial cereal systems in Australia can provide insights that are applicable to smallholder farms in India to manage climate risk.

5.1 Climate now and in the future

Climate in the SAT in India is driven primarily by the summer southwest monsoons (June to Sept) and the winter northeast monsoons (Nov-Feb) which contribute to the vast majority of rainfall. The El Nino Southern Oscillation (ENSO) phenomenon influences inter-annual variability in climate with strong correlations found with rainfall in these monsoon periods (Krishna Kumar *et al*. 1999, Geethalakshmi *et al.*, 2009).In SAT regions, in addition to inherent climate variability, climate change is likely tobe harsher with frequent extreme events (droughts, floods), increasing temperatures and shifting rainfall patterns.Analysis by Singh *et al.* (2014) suggests increasing variability inrainfall in the sub-continent with significant increases in the frequency of dry spells and intensity of wet spells.

5.2 Planning for now and the future- a framework

To remain profitable and food secure, farmers must cope effectively with current variability in climate as a first step to adjust their farming systems to cope better with future climate. For near term and current decision making, this can be termed 'tactical' where a flexible risk management strategy is adopted that uses multiple information sources to make decisions(Table 1). This may include pre-season enterprise planning guided by seasonal climate forecasts, a set of criteria or 'triggers' for sowing and variety selection and a range of in-season responses to the prevailing weather, market signals or other factors. The longer term perspective, where a farming system is redesigned or adjusted to be more resilient to the current and future climate patterns, can be termed 'strategic' planning (Table 5.1). Farm design should consider what mix of enterprises, crop types, and farming systems are most resilient to current and future climate also considering market and cultural factors. This requires significant analytical efforts to understand historical and projected climate, model based scenario analysis, co-design of farming systems that are more resilient to extreme events and reduce the damage of such events on the natural resource base. In some landscapes and environments, this may suggest transformational changes in landscape design. In both strategic and tactical planning, climate information that is based on both historical observations and current forecasts or projectionsare used as an underpinning tool. Such approaches are not deterministic and must be interpreted and communicated as probabilistic.

Table 5.1: A framework for planning for resilience to impacts of current and future climate

Strategic	Tactical (pre- and in-season responsive management)
Historical and future climate analyses	[a]Climate forecasting (long, medium and short term)
Modelled scenario analysis: e.g. farming systems modelling, climate change prediction.	Pre-season enterprise planning including the contingency planning
Co-design of the farm system for resilience (extreme events/ food security) and market opportunities (commercialization)	Decision making triggers for sowing and other operations
Infrastructure and institutions to enhance adaptive capacity (irrigation, NRM, markets, enhanced logistics).	In-season responses to prevailing weather

[a]*Note:* Short-term refers to a lead time 2-3 day forecast which is useful for tactical or operational purposes, medium range forecasts are 7-10 days, potentially for tactical and long term may mean extended range (10-30 days) /seasonal climate forecasts for 1-3 months in advance

5.3 The enabling environment

Rainfed agriculture plays a crucial role in India's food security by contributing about 45% of the total food grain production and around 90% of coarse cereals and pulses production (Sharma, 2011). However, rainfed agriculture faces multiple challenges like low cropping intensity, low productivity, uncertainty in output, high cost of cultivation, poor adoption of modern technology, lack of institutional credit and inadequate public investment with significant social impacts such as high incidence of rural poverty (Singh *et al.*, 2010). Policy and infrastructure development: To increase the productivity of rainfed crops and improve the profitability of rainfed farmers, the Indian government initiated a number of targetedprogrammes such as the Integrated Scheme of Oilseeds, Pulses, Oil Palm and Maize (ISOPAM), and increased minimum support price (MSP) for pulses to incentivize the farmers to increase the area under pulses to attain self-sufficiency in pulses. It also constituted a National Rainfed Area Authority (NRAA) as an advisory body for policy and programme formulation withrainfed crops of pulses and coarse cereals as major components of its agenda. These initiatives have been underpinned by the National Food Security Mission (NSFM). To realize the full potential of rainfed agriculture, higher strategic research investments to develop biotic (pests and diseases) and abiotic (weather and soil fatigue) stress-tolerant cultivars, short-duration varieties, incremental increases and arrangements to get MSP forrainfed crops (coarse cereals, pulses and oilseeds) on par with wheat and rice, sustainable seed systems to increase seed replacement rate (SRR), warehouse facilities and scientific storage methods that reduce post-harvest losses and information and communications technology (ICT) innovations to provide real time information to improve farmers decision will be required.

5.3.1 Development programs and investments

There is growing evidence on the importance of water management and investments in rainfed agriculture to reduce the risk and to face the impacts of changing climate (Reddy and Chiranjeevi 2016; Kerr *et al* 2002, Kumar *et al* 2016). To increase water use efficiency and to realize "*per drop more crop*", water conservation technologies and water saving irrigation methods should be promoted in the rainfed regions by providing customized information, low cost institutional credit and investment subsides to increase the adoption of these technologies. To realize the potential of R&D investment in rainfed agriculture, there is need of enabling policy environments that promote sustainable seed systems to increase seed replacement rate (SSR);sustains infrastructure initiatives such as modern weather and pest proof.The incentives to promote ICT innovations to provide information for real time farm decision are critical where traditional extension services are being over stretched. To enable farmers and agricultural industries to adapt to current and future climates, investment by government and the private sector will be required. In general, in the SAT regions adequate investment in infrastructure (roads, storage and marketing facilities,) and human capacity have not been made compared with more favorable agro-ecologies. Such investments are fundamental to creating agribusiness opportunitiesthrough adoption of next generation and emerging technologies.

5.3.2 Transformative technologies

The use of digital technologies is an exciting opportunity for enabling the communication of real time and context specific information to stakeholders. In Australia, for example, precision agriculture has been enabled by technology and has led to transformational change incrop management. Technology is being applied by actors in various ways. For example, in the delivery of information from various sources (downscaled market, weather, farming system, and soil) as locally specific advisories direct to farmers on smart phones or tablets; in the application of risk management intelligence on markets or weather in the banking, or insurance sectors; in business intelligence through harnessing information to a dashboard to monitor project outputs. Case study #2 provides a model for how this was successfully achieved in a commercial setting in Australia.

5.3.3 Responsive farming using decision triggers: Case study 1

In Australian low rainfall cropping regions (growing season rainfall < 300 mm) face major challenges associated with high yield variability and its effect on profitability, with production risk historically much more important than price risk. To combat variability in cropping yields, farm businesses adopt a range of practices such as diversification (mainly involving livestock) to provide more reliable cash flow during difficult seasons. The use of responsive farming systems allows flexibility in crop area and in crop type between years, and is an important component of risk management. In the absence of reliable seasonal climate outlooks, other indicators are sought to provide robust trigger points to adjust decisions about crop type and area. It is widely accepted that seasons which allow earlier seeding times with higher initial plant available water (PAW) usually results in enhanced yield outcomes. Scenario analyses using crop models (APSIM) and historical weather data compute the probability of favorable outcomes under different starting conditions of plant available water and seeding opportunity. This approach offered a means to make more informed decision making around cropping intentions and to determine appropriate trigger points at the individual farmer level.For example, even a site with a mean rainfall of about 220mm / year (Port Germein, South Australia) is responsive to the storage of out of season soil water with relatively high simulated fallow efficiencies (average of 24%).The effects of different ranges of PAW and seeding opportunity on the probability of different yield outcomes (divided into terciles) show that the interaction of plant available water at seeding and seeding opportunity is a strong indicator of final crop yield (Fig. 5.1). The combination of low PAW and late seeding rarely produces a favourable outcome with most yields in the lower tercile. At the other extreme, poor crop yields (in the lowertercile, (bottom 33% of the yields) are rare when PAW at seeding is categorised as high.Decisions around modifying sowing intentions to limit exposure in poor seasons and capitalize on better years rely on reliable indicators to "trigger" appropriate changes to the farm programs. While farmers have lamented the lack of more reliable seasonal outlooks(1-3 monthly rainfall forecasts)to provide such information, usingmultipleand integrated information sources will enable more robust decision making.

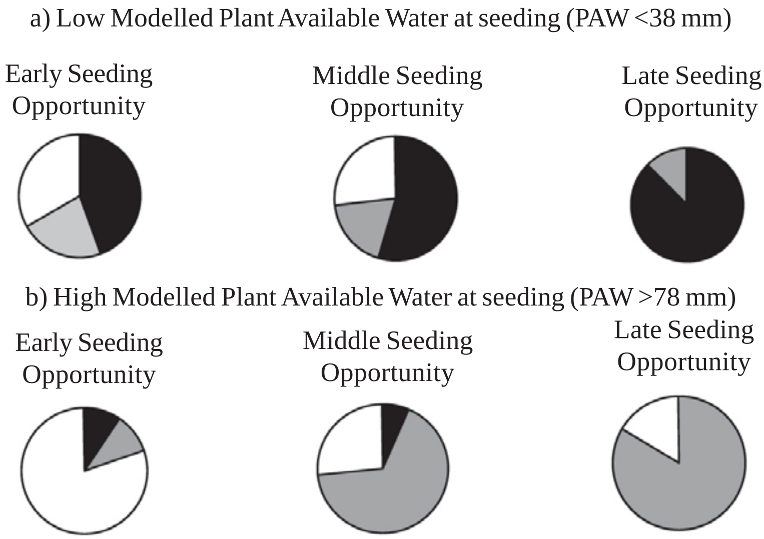

Fig. 5.1: Effect of variations in PAW and seeding opportunity on percentage of modelled yields in upper tercile (white), middle tercile (grey) and lower tercile (black)

5.3.4 In-season prediction of crop performance and benchmarking: Case study 2

Yield potential has long been used in Australian cropping systems to benchmark crop performance at a field level against a water limited potential yield target. Onewidely used method in the southern Australian wheat belt was devised by French and Schultz (1984) based on a boundary function derived from a large field data set. Predicted wheat grain yield is the result of in-season rainfall minus a fixed evaporation of 110 mm, which is multiplied by a transpiration efficiency factor of 20 kg/mm/ha. While this empirically based method was simple, a linear rainfall-yield relationship cannot address yield differences caused by soil variability, in season rainfall deficit at critical times. Since about 2005, the prediction of crop performance with crop models which simulate important process and interactions have been widely applied by researchers to analyse the seasonal-spatial dynamic nature of crop productivity (Hoffmann *et al*., 2015; Whitbread *et al*., 2015; Sadras and Angus 2006; Sadras and Rodriguez

2010).According to McCown *et al*. (2006) however, the effectiveness of decision support systems in influencing farmer behaviour has been disappointing. A program led by CSIRO in Australia explored whether researchers and advisors could benefit from simulation and decision support aid to risk management (Hochman *et al*. 2009). This led to the development of a highly successful commercial on-line (http://www.yieldprophet.com.au/) system where farmers and their consultants could enter site specific details about their soil, crop and location and generate reports which predicted crop growth and possible season finishes using local weather information and driven by the APSIM model (Fig. 5.2.) A range of other 'system' information (frost and heat risk, crop stage dates, soil water and mineral N status) is also reported to further inform decision making.

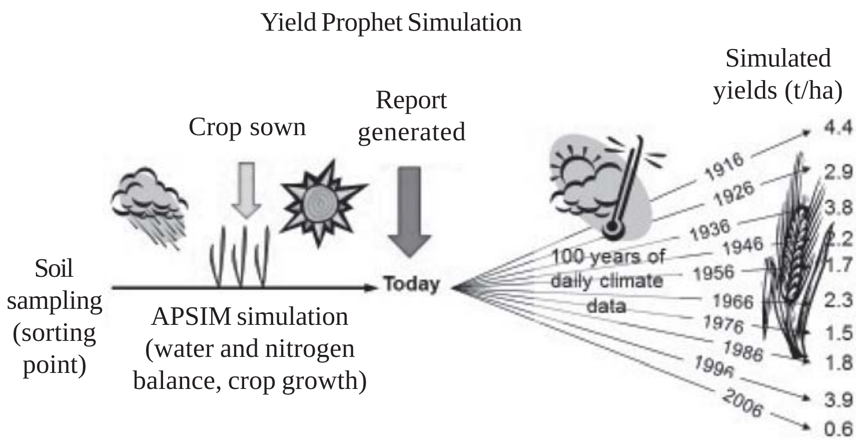

Fig. 5.2: A pictorial display of a Yield Prophet report generated at a point in the growing season with APSIM then simulating yield outcomes using historical weather data from a local station

5.3.5 Climate forecasting: Case study 3

Climate forecasting has long been an important component of climate risk management in Australian agriculture. According to Hayman (2007), while 30-50% of farmers use seasonal climate forecasts when making farm management decisions, most farmers and advisers are quick to point out that they place less weight on the information than they would like to if the forecast was more reliable. Increasing the skill of forecasting using dynamic climate modelling is the focus of much current research (Franzke *et al*., 2015).Following Meinke and Stone (2005) some speciûc Australian examples of the use of forecasting in decision-making include:

1. Cotton growers in Queensland scheduling the timing of their cotton harvests based on the expected passing of the next Madden Julian Oscillation (MJO);
2. Farmers in northeastern Australia who use ENSO-based information to tailor their rotations and crop management based on local conditions at the time and rainfall probabilities for the coming months;
3. Sugar growers and millers in north Queensland who use targeted climate forecasts in management decisions involving harvest strategies, planting decisions, and mill throughput operations;
4. Bulk handling and marketing agencies, which require accurate regional commodity forecasts to assist them in storage and transport logistics and export sales well before harvest;
5. Government agencies, which require objective assessments of the effect and severity of climate variability on production;

5.4 Relevance to smallholder systems in SAT

The case studies highlight the potential benefits from informed decision making that is built on the scientific rationality and local knowledge and needs. Pilot studies in many developing countries have clearly established that similar or even greater benefits are also possible under smallholder faming systems (Hansen *et al*., 2011). However, several obstacles prevent smallholder farmers from benefiting from such information. Important among them are poor access to information especially in a user friendly format, location specificity, timeliness and reliability or credibility of the information. Recent developments in ICT have opened up new opportunities to develop and deliver data and information that is location specific in real time to decision makers. However, access to information alone is not sufficient. The capacity of end users (smallholder farmers and their support agents) to understand and utilize the information is equally important. We believe that by developing appropriate information systems and by strengthening the capacity of the farmers, significant benefits can be harnessed from the experiences and successes of large scale commercial farmers in the developed world.

Summary

This paper has presented a short review of current climate risk management strategies and enabling environments in commercial dryland cereal systems in Australia and explored how these may provide insights for managing climate risk on to smallholders farming systems in semi-arid India. Three case studies have shown (i) how the analysis of historical weather records combined with systems information and a well validated crop-soil model provides powerful indication of a season outcome at the start of the season; (ii) a commercially available web based system based on the APSIM model providing farmers and their consultants with in-season predictive reports; and (iii) examples of the use of climate forecasts by agricultural industries in decision making and a range of scales. In India, enhancing climate risk assessment and management will occur through a combination of approaches, many of which are already underway to varying degrees. Of highest priority will include enhancing the use of public seasonal climate services which are location and system specific and which may be increasingly delivered through private sector led ICT delivery with support from public and other actors. An important aspect in the context of resource poor farmers, will be equity i.e. making sure access to information and inputs are socially inclusive particularly in poorer SAT regions. The building of capacity in multiple stakeholders as a pre-requisite for effective climate risk management in semiarid regions, especially around information translation to action i.e. access to inputs (seeds, fertiliser, labour etc) to apply to take advantage of the climate information. Meinke *et al*. (2006) concluded that climate risk management requires holistic solutions derived from cross-disciplinary and participatory, user-oriented research – this implies that the multiple institutions/ agencies present in India are required to better integrate their efforts for the benefit of smallholder farmers.

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CLIMATE CHANGE AND AGRICULTURE

This book deals with climate change causes, impacts and interventions in Agriculture across various regions of the Country based on the research findings emanated from ICAR institutes and State Agricultural Universities as Global warming and climate change is a threat to food security. Impacts of weather extremes viz., droughts, floods, heat wave and cold waves pose immediate threat to Agriculture because of their frequent occurrence due to global warming and climate change rather than the climate change threat directly to crops. More than 60 authors are involved with 32 Chapters to focus on mitigation and adaptation strategies in Agriculture against ill effects of climate change/variability. Research investigations indicate that crop yields are likely to decline with increase in atmospheric CO_2 and temperature in ensuing decades and crop losses can be minimized through technologies generated in crop management, crop improvement and crop protection practices. Farmers concern to minimize crop losses against weather extremes rather than climate change as the impacts of climate change (increase in atmospheric CO_2 and temperature) on crops at the field level is not clear if soil moisture is not a constraint. The publication includes vulnerability assessment, adaptation strategies, crop choices/combinations in different climate scenarios and preparedness to face the exigencies of climate change and emphasis is given on interventions. Of course, there is need to intensify research to generate technologies/location specific farm strategies which can withstand the impact of climate change as a long term strategy and farmers are the best to cope up with suitable strategies against global warming and climate change/climate variability. It is very complex and complicated at the farm level to sustain rural livelihoods against climate change.

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