e-Book

Strategies for Climate Risk Management and Resilient Farming

ICAR-Central Research Institute for Dryland Agriculture (CRIDA)
Ministry of Agriculture and Farmers' Welfare, Government of India
Santoshnagar, Hyderabad - 500 059

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Strategies for climate risk management and resilient farming

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Strategies for Climate Risk Management and Resilient Farming

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MESSAGE

Director General, MANAGE

According to Global Climate Risk Index 2020, India is the 5th most climate risk country in the world. India succumbs to all kinds of climatic risks that range from floods, cyclones, droughts, heatwaves, cold waves, hailstorms, etc. Climatic risks impact agricultural production adversely as well as their latent effects significantly disrupt the input and output value chain in agriculture, thus causing severe loss to the farmers. Research reports that the yield of crops has been reduced where there is no adoption of climate risks management and strategies to facilitate in adaptation and mitigation of risks.

According to World Bank, Agricultural Risk Management (ARM) is ideally placed to support stakeholders in building resilience to the increased risks of climate change in short and medium-term. To adapt agriculture to climatic risks and enable farmers to make agriculture resilient to climate change, considerable strategies were adopted by central and state governments, ICAR institutes, agricultural management institutes, State Agricultural Universities (SAUs), private sector, NGOs, CSOs, etc. Most of the strategies are offered to farmers in terms of programmes, technology, institutions, extension and capacity building, community development etc.

Risk management strategies can enable farmers to adapt to climate change and manage future risks. The risks management strategies may further facilitate farmers to plan, prepare for anticipated risks, recover from, and adapt to present climatic risks with the adoption of climate resilient technologies and practices. In this context, the present collaborative training on "Strategies for Climate Risk Management and Resilient Farming" from September 20 to 24, 2021 conducted jointly by Central Research Institute for Dryland Agriculture (CRIDA) and MANAGE is well appreciated.

Further, I sincerely extend my heartfelt thanks to the entire team of the Training Programme and appreciate the scientists and experts for their contributions to the preparation of the e-book. Further, the chapters on weather insurance, agrometeorology services, infrastructure facilities, carbon sequestration, social interventions, new technologies, etc, will enable the extension functionaries to understand the broad spectrum of climate risks management and provide extension services to farmers.

Also, I congratulate Dr K.Nagasree, Course Director and Principal Scientist (Agricultural Extension), CRIDA, Hyderabad for her efforts to organise a timely training programme and appreciate Dr N Balasubramani, Director, Centre for Climate Change and Adaptation (CCA), MANAGE for extending necessary cooperation for organizing the training programme and facilitated in the preparation of e-Book as part of the training programme.

Date: 28.01.2022

(P Chandra Shekara)
Director General, MANAGE

FOREWORD

Central Research Institute for Dryland Agriculture (CRIDA) is the premier National Research Institute under the Indian Council of Agricultural Research (ICAR) established in 1985 with a mandate to carry out basic and applied research in rainfed farming. ICAR-CRIDA is working closely with various stakeholders (farmers, line department officials, SAUs, other ICAR institutes, different ministries, etc) for attaining climate resilient agriculture pan India through technology demonstrations which aims at climate preparedness, management of extreme events, enhancing resilience at farm household level through proven technologies.

Increasing climatic variability and climate change pose new challenges to Indian agriculture in terms of increased frequency of droughts, floods, cyclones, extreme temperatures, etc. The institute which is currently implementing the ICAR flagship programme, National Initiative on Climate Resilient Agriculture (NICRA), is playing an important role at national level in evolving adaptation and mitigation strategies in agriculture and allied sectors and also taking up their demonstrations initially in more than 150 villages representing key climate vulnerabilities and presently expanding to nearly 400 villages. Efforts are being made for scaling up best practices technologies and the experiences would be shared with the practitioners who are implementing programmes on climate smart agriculture

Keeping this in view the training programme has been proposed to sensitize different officials involved in research, extension and training in agriculture and allied sectors for enhancing their knowledge on risk management and resilient farming techniques in changing climate scenario.

This e-book contains important topics on themes like climate resilient agriculture concepts and initiatives, resource Management, climate Risk management and social interventions towards climate resilient farming. Lectures delivered by the interdisciplinary group of experts from agriculture and allied subjects are captured in this book. Hope wide circulation of this book will help a large number of readers to enrich their knowledge on strategies for climate risk management and resilient farming.

September, 2021.

Dr. Vinod Kumar Singh
Director, ICAR-CRIDA

Training programme Schedule
20-24, September, 2021

DAY-1 20th Sep, 2021	**Introduction and Overview**	
DAY-1 20th Sep, 2021	Introduction and Overview	
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Session-IV	Infrastructure and facilities requirements for climate change studies	M Vanaja
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Session-II	Climate smart agriculture through rain water management technologies	K Sreenivasa Reddy
Session-III	Climate change mitigation through soil carbon sequestration	K Srinivas
Session-IV	Soil Management strategies for sustainable rainfed crop production in the context of climate change	K SammiReddy
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PREFACE

This e-book is an outcome of collaborative online training program on **"Strategies for climate risk management and resilient farming"**. This book is intended to educate extension workers, students, research scholars, academicians and other stakeholders related to agriculture. There is dire need to compile recent advances in climate risk management and resilient farming in changing climatic scenario. Bringing views of experts for different stakeholders of agriculture through this training programme suffice opportunities for updation of knowledge and also facilitates cross-learnings among trainees.

The content of this e publication has been designed in such a way, so that it can provide updated information towards capacity building in proposed area. Attempt has been made to cover topics about advances in climate risk management and resilient farming. Topics like concepts and initiatives on climate resilient agriculture, NICRA, resource management which includes weather insurance based climatic risk management in rainfed crops, climate smart agriculture through rain water management, climate change mitigation through soil carbon sequestration, soil management strategies have been included. Under climate risk management theme real time contingency plans, management of horticultural crops under changing climatic scenario, adapting small holder livestock livelihood production systems to climate change etc. have been included. Lectures on social interventions included risk and vulnerability assessment for adaptation planning, Social interventions and institutions for community action towards climate resilience, farmers' perceptions, attitudes and adaptations towards climate change in India and extension strategies for promotion of climate resilient farming. The valuable suggestions for future improvements are always welcome.

September, 2021 **Editors & Organizing team.**

Climate Resilient Agriculture Concepts and Initiatives in India: Overview

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According to worldwide population figures, India's population will reach 1.38 billion in 2020, accounting for 17.7% of the world's population. Since independence, the country's population has expanded 3.35 times, and by 2027, it will have surpassed China as the world's most populous country. With 80 percent of farmers being smallholders (0.5 ha) from a variety of socioeconomic backgrounds, monsoon-dependent rainfed agriculture (58 percent), about 30 percent of the population undernourished, migration from rural to urban areas, child malnutrition, and other issues, Indian agriculture has become more vulnerable to climate change or variability.For around 58 percent of India's population, agriculture is the primary source of income. Reduced food grain yield, loss of vegetable and fruit harvests, fodder scarcity, shortage of drinking water for animals throughout the summer, forced animal migration, and severe losses in the poultry and fishing industries have all been reported, posing a threat to the rural poor's lives. As a result, increasing agricultural productivity is vital for maintaining food and nutritional security for all, particularly resource-poor, small, and marginal farmers who will be the most affected. Long-term climate change could have serious effects for the poor's livelihood security if adaptation is not planned.Other natural resource-based sectors are also important for the country's economic development. Field crops, horticulture, livestock, fisheries, and poultry are all strongly associated with various United Nations Sustainable Development Goals (SDGs), including zero hunger, nutrition, and climate action, among others.

Climate change is happening and it is evidenced by rise in globally averaged combined land and ocean surface temperature show a warming of 0.85°C over the period 1880 to 2012. The number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale. Frequency of heat waves has increased in large parts of Europe, Asia and Australia. Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass and there are reports of retreating Glaciers. The frequency of extreme events in India has also increased in recent decades. Kumar et al. (1994) reported that the warming trend over India was 0.57°C per 100 years and is expected to increase 1.4°C to 5.8°C by 2010 over the globe (Intergovernmental Panel on Climate Change (IPCC), Sathaye et al. (2006)). In addition to the abnormal inter-annual, seasonal and intra-seasonal variations in the climate indices, the extreme weather events such as floods, droughts, heat and cold waves are known to create adverse effects in widely separated areas of Asia (Karl et al., 1995, World Health Organization Report, 2007). Recently, India has faced extreme rainfall events that resulted in a large damage to infrastructure and affectedlives of millions. The Bengaluru (in Southern India) floods in July 2016, caused by heavy rainfall, disrupted lives and halted transportation (The Hindu, 19 July 2016). The November–December 2015 South India flood (Tamil Nadu and Andhra Pradesh) affected 4 million people with economic damages of about $3 billion (USD) (Kotteswaran, 2015). Moreover, the 2005 flood in Mumbai caused approximately 1094 lives (Bohra et al., 2006).

Climate change, especially its influence in the form of extreme weather events, is one of the most serious threats to a country's food security. The expected temperature changes of 1-2.5 degrees Celsius by 2030 is likely to have a significant impact on crop output. High temperatures can decrease crop life, induce photosynthesis to vary, increase crop respiration rates, and influence insect populations. Cultivation methods are largely dependent on climate conditions. By the mid-twentieth century, South Asian countries are expected to have had a 30% decline in crop output on average. In India, for example, a 1.5°C increase in temperature and a 2 mm reduction in precipitation can reduce rice yield by 3 to 15%. (Ahluwalia and Malhotra, 2006). Increased metabolic heat production breeds are more susceptible to heat stress, whereas low milk-producing animals are less susceptible (Dash et al., 2016). Apart from crops, fisheries sector, poultry sector may also be affected. In nut shell, all the agriculture and agriculture related sector will have its impact due to change in climate.

Climate resilient agriculture (CRA) refers to the use of adaptation and resilient methods in agriculture to improve the system's ability to respond to diverse climate-related disturbances by preventing harm and ensuring rapid recovery. Droughts, floods, heat/cold waves, unpredictable rainfall patterns, insect outbreaks, and other climate-related risks are examples of such disruptions. Resilience refers to a system's ability to bounce back, and it entails careful and improved management of natural resources, such as land, water, soil, and genetic resources, by using best practices.Climate resilient agriculture has been taken up by the Indian government to ensure farm output and household incomes remain stable, as well as resilience through livelihood diversification in the face of extreme weather events such as droughts and flood.

The three major initiative is to: (1) sustainably increase agricultural productivity and incomes in order to meet national food security and development goals, (2) build resilience and the capacity of agricultural and food systems to adapt to climate change, and (3) seek opportunities to mitigate emissions of greenhouse gases (GHGs) and increase carbon sequestration.With these issues in mind, the Government of India's Ministry of Agriculture and Farmers Welfare, as well as the Indian Council of Agricultural Research (ICAR), have developed a number of proactive initiatives at the village level.

National programmes for climate change adaptation

The National Mission of Sustainable Agriculture was launched in 2010 as part of the National Action Plan on Climate Change (NAPCC) to promote sensible resource management. It was one of eight missions under the NAPCC.

The Pradhan MantriKrishiSinchayeeYojana (PMKSY) was created in 2015 to solve water resource challenges and provide a long-term solution that promotes Per Drop More Crop by promoting micro/drip irrigation for optimal water conservation.

In collaboration with the Indian Council of Agricultural Research and state governments, the Paramparagat Krishi VikasYojana mission was implemented to extensively utilise adaption of climate-smart practices and technology.

Green India Mission was started by the Government of India in 2014 under the auspices of the NAPCC with the primary goal of protecting, restoring, and increasing India's declining forest cover, thereby reducing the negative consequences of climate change.

To maintain soil health, the Government of India has created the Soil Health Card scheme, which aims to analyse cluster soil samples and advise farmers on their land fertility condition. In addition, Neem-Coated Urea was created to reduce the overuse of urea fertilisers, protecting soil health and providing plant nitrogen. Programmes such as the National Project on Organic Farming and the National Agroforestry Policy were implemented in 2004 and 2014, respectively, to incentivize farmers with increased financial benefits and ecosystem conservation. These policies attempt to provide plant nutrients in the form of organic amendments, boost soil carbon stock, and protect soil from erosion.

National Initiative on Climate Resilient Agriculture (NICRA)

To meet the challenges of sustaining domestic food production in the face of changing climate and to generate information on adaptation and mitigation in agriculture, the Indian Council of Agricultural Research (ICAR) launched a flagship network project '*National Initiative on Climate Resilient Agriculture*' (NICRA) during 2011, presently renamed as National Innovations in Climate Resilient Agriculture. NICRA is by far the largest farmer-participation outreach programme ever attempted in the subject of climate change adaptation anywhere on the planet. The research organization is in charge of programme planning, coordination, monitoring, and capacity building at the country level (ICAR-Central Research Institute for Dryland Agriculture). KrishiVigyan Kendra (KVK; Farm Science Centre) under the Division of Agricultural Extension of the Indian Council of Agricultural Research (ICAR), All India Coordinated Research Project for Dryland Agriculture (AICRPDA) centres, and Transfer of Technology divisions of various ICAR Institutions across the country are responsible in implementing the project at village level through farmers' participatory approach.

The major objectives of the project are: to enhance the resilience of Indian agriculture to climatic variability and climate change through strategic research on adaptation and mitigation; to validate and demonstrate climate resilient technologies on farmer's fields; to strengthen the capacity of scientists and other stakeholders in climate resilient agriculture and to draw policy guidelines for wider scale adoption of resilience-enhancing technologies and options. The project is being implemented through 3 major components viz. Strategic research through network and sponsored/competitive grants mode, Technology demonstration & dissemination and Capacity building.

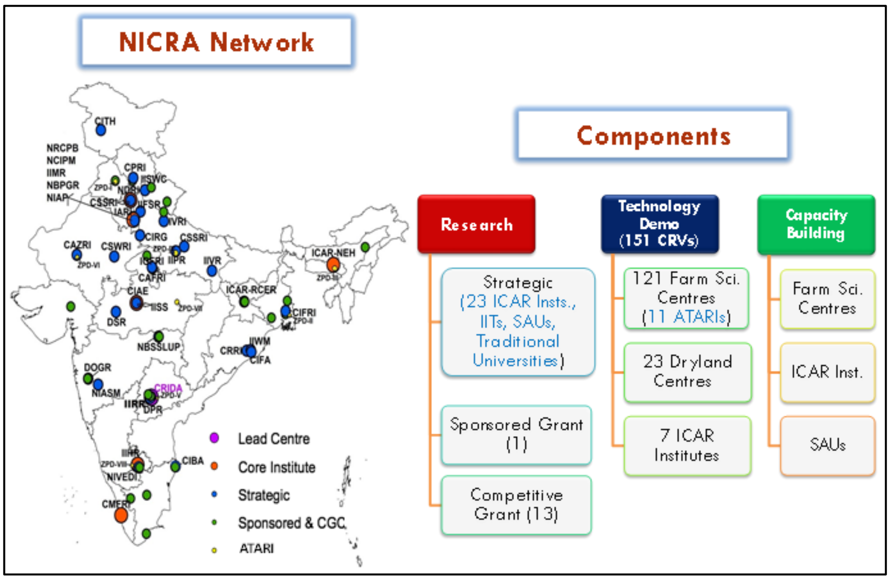

Fig 1: NICRA network

Technology demonstration component (TDC)

The TDC is a participatory programme of NICRA involving farmers to demonstrate site-specific technology interventions on farmers' fields for coping with climate variability in climatically vulnerable districts, to generate awareness and build capacity of farmers and other stakeholders on climate resilient agriculture and to evolve innovative institutional mechanisms at village level that enable the communities to respond to climate stresses in a continuous manner beyond the project period also. The objective of **Technology demonstration component (TDC) are as follows.**

- To **demonstrate site specific technology** interventions on farmers' fields for coping with **climate variability** in vulnerable districts.
- To generate **awareness and build capacity of farmers** and other stakeholders on climate resilient agriculture
- To evolve **innovative institutional mechanisms** at village level that enable the communities to respond to climate stresses

Under TDC-NICRA, from 2011-2017 171 villages were covered but now since 2018 onwards around 448 villages come under its ambit. The Krishi Vigyan Kendra (Farm Science Centres) located in the district is implementing the programme in 121 districts, the Centers of All India Coordinated Research Project on Dryland Agriculture (AICRPDA) implementing the programme in 23 districts and the ICAR Institutes involved in the implementing in 7 districts. Eleven Agricultural Technology Application Research Institutes (ATARIs) of ICAR are involved in coordinating the project in their respective zones.

Area of operation	Earlier (2011-17)	Now (2018 onwards)
Villages	171	446
Area (ha)	102702	235874
Households (No.)	86355	213421

Fig 2. Coverage by TDC NICRA

Module I: Natural resources: This module consists of interventions related to *in-situ* moisture conservation, biomass mulching, residue incorporation instead of burning, brown and green manuring, water harvesting and recycling for supplemental irrigation, improved drainage in flood prone areas, conservation tillage where appropriate, artificial ground water recharge and water saving irrigation methods.

Module II: Crop Production: This module consists of introducing drought/temperature tolerant varieties, advancement of planting dates of *Rabi* crops in areas with terminal heat stress, water saving paddy cultivation methods (SRI, aerobic, direct seeding), frost management in horticulture through fumigation, community nurseries in multiple dates for delayed monsoon, farm machinery custom hiring centers for timely completion of farm operations, location specific intercropping systems with high sustainable yield index.

Module III: Livestock and Fisheries: Use of community lands for fodder production during droughts/floods, augmentation of fodder production through improved planting material, improved fodder/feed storage methods, fodder enrichment, prophylaxis, improved shelters for reducing heat stress in livestock, management of fish ponds/tanks during water scarcity and excess water and promotion of livestock as such as a climate change adaptation strategy.

Module IV: Institutional Interventions: This module consists of village level institutional interventions to guide the implementation, continuation of interventions and for their long-lasting impact. Village Climate Risk Management Committee (VCRMC) was conceptualized and established as supporting systems for taking up technological interventions at grassroot level and as a nodal point for organization of climate resilient villages. The activities of other institutional structures like community seed bank, fodder bank, custom hiring center (CHC) for farm machinery etc. were also established and are coordinated by VCRMCs. CHCs were established in all the NICRA villages to meet farm machinery needs of the local farming communities and to support various natural resources management (NRM) interventions and various agricultural operations.Seed banks were established to provide quality seed of climatically resilient varieties to famers in the NICRA villages.

Climate resilient animal husbandry concepts and initiatives: an overview

Climate change is posing a challenge not only to crops but also to livestock. The climatic change would result in lesser availability of fodder for the animals, lowered/ unavailability of pure water, increase in parasitic diseases due to mosquitoes, flies, and lice decreased fertility, and reduced productivity. In such a scenario, the native breeds would be more adaptive to the rising temperature than the crossbredanimals. Intending to promote climate adaptive farming and animal husbandry, the Indian government is running National Innovations on Climate Resilient Agriculture (NICRA). Under the project, many national institutes are engaged in scientific research and demonstration of climate resilient technologies to the farmers' field through KVKs underthe NICRA-TDC component.

As global warming is evident across India, the conservation of indigenous breeds that are hardy and better suited to withstand high temperatures must be promoted. But, due to the indiscriminate cross-breeding in India, these valuable indigenous breeds are now downgraded in numbers.Each region of India has native breeds with distinct characteristics, suited to local conditions. To sustain rural livelihoods, it is critical to identify livestock breeds that are climate resilient, select the elite among them and propagate through selective breeding.

Challenges associated with changing climate on livestock production system

The livestock production system is expected to be exposed to many challenges due to climate change in India. Direct effects are a result of a change in air temperature, humidity, radiation, wind speed, weather extremes, and other climate factors, which influence animal performance such as growth, milk production, wool production, and reproduction. Climate change can also affect the quantity and quality of feedstuffs such as pasture, forage, and grain, and the severity and distribution of livestock diseases and parasites. Indian livestock productivity has been severely affected by vector-borne livestock diseases which are known to be climate-sensitive. The direct effects of climate change could also be felt in terms of the increased spread of existing vector-borne diseases and parasites, accompanied by the emergence of new diseases. The impacts of climate change also depend on the rainfall which generally affects crop and grassland productivity, ultimately affecting livestock net income.

Livestock production and its economic efficiency depend on the quantity and quality of feed and water that animals need to survive, produce and reproduce. About 10% of cropland is used for producing animal feed and other agricultural land provides crop residues used for feeding livestock. The future of livestock production systems depends on the continued productivity of these various feed-producing areas – all of which are potentially affected by climate change. The influence of the climate on the distribution of plant variety and type is complex. The effects of climatic interaction with soil characteristics and its direct effect on plants influence the distribution of the various other biological components of the agroecosystem – pests, diseases, herbivorous animals, pollinators, soil microorganisms, etc. – all of which in turn influence plant communities. All these processes have the potential to influence directly or indirectly the growth of the forages on which livestock feed. Pressure on feed resources and other constraints to traditional livestock-keeping livelihoods have promoted the spread of agro-pastoralism (i.e. livelihoods that involve some crop production in addition to livestock keeping) at the expense of pastoralism. In production systems where animals are fed on concentrates, rising grain prices (maybe driven by climate change) increase the pressure to use animals that efficiently convert grains into meat, eggs, or milk. Thus, within such systems, climate change may lead to greater use of specific species which is less vulnerable, and a greater focus on the breeds that are the best converters of concentrate feed under high external input conditions. Increases in the price of grain may also contribute to the further concentration of production in the hands of large-scale producers.

The geographical and seasonal distributions of many infectious diseases, particularly vector-borne, as well as those of many parasites and pests of various kinds are affected by climate. Pathogens, vectors, and intermediate and final hosts can all be affected both directly by the climate (e.g., temperature and humidity) and by the effects of climate on other aspects of their habitats (e.g., vegetation). If the climate changes, hosts and pathogens may be brought together in new locations and contexts, bringing new threats to animal (and in some cases human) health and new challenges for livestock management. Climate is characterized not merely by averages, but also by short-term fluctuations, seasonal oscillations, sudden discontinuities, and long-term variations, all of which can influence disease distribution and impacts. The rapid spread of pathogens, or even small spatial or seasonal changes in disease distribution, whether driven by climate change or not, may expose livestock populations to new disease challenges. Disease-related threats can be both acute or chronic and can be caused by the direct effects of disease or indirectly by the measures used to control the disease.

Initiatives taken by CRIDA for creating climate resilience in animal husbandry sector in India

Under the NICRA technology demonstration component, demonstration of proven technologies wascarried out to enhance the adaptive capacity and enable the farmers to cope with ongoing climatic variability. Location-specific technologies which are developed by the basic and strategic research component of NICRA can impart resilience against climatic vulnerability are also being demonstrated all over India. TDC is being implemented in 121 climatically vulnerable districts of the country through Krishi Vigyan Kendras (KVKs) spread across the country. Under the livestock module demonstrations on fodder production, especially under drought/flood situations, improved shelter for reducing heat stress in livestock, silage-making methods for storage of green fodder and feeding during the dry season, breed selection, and integrated farming system models in diverse agroecosystems are being taken up. These interventions helped farmers to reduce the yield losses and enhanced their adaptive capacity against climatic variability.

Few of the other initiatives were also taken at CRIDA, like promoting fodder cafeteria, contingency plans, promotion of improved fodder, backyard poultry, indigenous sheep breeds and group formation under FFP, training, and promotion of fodder and backyard poultry under SCSP/TSP and organic fodder production and sheep production which will help the farmers to achieve the resilience for the livestock sector.

Linkages & partnerships under NICRA

NICRA has led to other initiatives in the area of climate resilient agriculture. It has linkages with Maharashtra- Project on Climate Resilient Agriculture (PoCRA) for about 5000 villages in 15 districts of Maharashtra(POCRA Rs 4500 Crores, 5000 VillagesMOU), Odissa (State Funds MOU), Telangana(NABARD), Assam (5 Districts), MP(Adaptation Fund), Mizoram (State Funds) and Andhra Pradesh (IFAD).

Conclusion

Since its inception, interventions under NICRA aims at enhancing the resilience of Indian agriculture towards climate change. The interventions have proved to be beneficial for the famers at the field level. Agromet advisories, contingency planning, natural resource management measures like farmer ponds and drought resistant varieties etc have been widely adopted by the farmers across the country. NICRA has contributed immensely towards the bettering the livelihood of farming communities in India.

References

1. Ahluwalia V K and Malhotra Sumita (2006), Environmental Science, Anne Books India, New Delhi
2. Bohra, A. K., Basu, S., Rajagopal, E. N., Iyengar, G. R., Gupta, M. D., Ashrit, R., &Athiyaman, B. (2006). Heavy rainfall episode over Mumbai on 26 July 2005: Assessment of NWP guidance. *Current Science*, 1188-1194.
3. Dash S, Chakravarty AK, Singh A, Upadhyay A, Singh M, Yousuf S. Effect of heat stress on reproductive performances of dairy cattle and buffaloes: A review. Vet World. 2016;9(3):235-244. doi:10.14202/vetworld.2016.235-244
4. Karl, T. R., Knight, R. W., & Plummer, N. (1995). Trends in high-frequency climate variability in the twentieth century. *Nature*, *377*(6546), 217-220.
5. Kotteswaran, C. S. (2015). Tamil Nadu: Chennai floods cause a loss of Rs 50,000-cr. *Deccan Chronicle*, *6*.
6. Sathaye, J., Shukla, P. R., &Ravindranath, N. H. (2006). Climate change, sustainable development and India: Global and national concerns. *Current science*, 314-325.
7. World Health Organization report on Climate Change and Human health in Asia Pacific: From evidence to action, Report of the Regional Workshop, Bali, Indonesia, 10- 12 December 2007.

National Innovations in Climate Resilient Agriculture (NICRA):
A Flagship Project of ICAR Addressing Climate Change in Agriculture

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Introduction

Climate change has become an important area of concern for India to ensure food and nutritional security for growing population. The year 2019 was the seventh warmest year on record since 1901 with annual mean surface air temperature +0.36°C above the 1981-2010 period average. 11 out of 15 warmest years were recorded during the recent past fifteen years (2005-2019). As per latest Sixth Assessment Report of IPCC the global surface temperatures will continue to increase until at least the mid-century under all emissions scenario. The global warming of 1.5°C and 2.0°C will be exceeded during the 21st century unless the predictions in the carbon dioxide and other GHG emissions occur in the coming years.

The climate change is manifested in terms of rising temperature, more variable rainfall patterns, rise in sea level, increased frequency of extreme climatic events such as drought, floods, cyclones, heat wave, etc. Though climate change is a global phenomenon, the impacts are more inequitable in the sense that developing countries will be more affected. India, being a developing country, with a large population depending on agriculture will be more affected by climate change. Climate change affects agriculture directly through crop yields and indirectly by influencing water availability and changes in pest and pathogen incidence.

With this background, Indian Council for Agricultural Research launched a flagship network project 'National Innovations in Climate Resilient Agriculture' (NICRA) during 2011. NICRA is the unique project which brings all sectors of agriculture viz., crops, horticulture, livestock, fisheries, natural resource management (NRM) and extension scientists on one platform.

Objectives

- To undertake strategic and applied research on climate change adaptation and mitigation
- To validate, demonstrate and assess the impact of climate resilient technologies on farmers' fields
- To strengthen the capacity of scientists, farmers and other stakeholders on climate resilient agriculture

Mission

Enhancing the resilience of Indian Agriculture to climate variability and climate change through both application of improved technologies and new policies

Vision

To develop and promote climate resilient technologies in agriculture which will address vulnerable areas of the country and the outputs of the project will help the districts and regions prone to extreme weather conditions like droughts, floods, frost, heat waves, etc. to cope with such extremes

Climate Change Research Infrastructure

Under this project about 41 Institutes of ICAR are conducting research under Strategic Research Component covering various theme areas viz., development of multiple stress tolerant crop genotypes, natural resource management, quantification of greenhouse gas emissions in agriculture and the develop technologies for their reduction, climate resilient horticulture, marine, brackish and inland fisheries, heat tolerant livestock, mitigation and adaptation to changing climate in small ruminants and poultry. Sate of the art infrastructure required or climate change research such as high through-put phenotyping platforms, free air temperature elevation (FATE), carbon dioxide and temperature gradient tunnels (CTGC), high performance computers, automatic weather stations, growth chambers, rainout shelters, animal calorimeter, shipping vessel, flux towers and satellite data receiving station were established in the research institutes across the country under NICRA project.

Climate Resilient Crop Varieties

NICRA aims to evolve crop varieties tolerant to climatic stresses like floods, droughts, frost, inundation due to cyclones and heat waves Large number of germplasms screened for drought, heat, salinity, submergence tolerance etc. in different field and horticultural crops, for identifying donors for stress tolerance. Number of advance breeding materials was generated and evaluated at multi-locations for developing new cultivars. Germplasm lines of rice and wheat tolerant to drought and heat stress have been collected from different climatic hot-spot regions of India. So far a total of 184 rice accessions were collected. Evaluation of wheat germplasm for drought tolerance with 1485 accessions was conducted to identify drought tolerance lines based on 22 morpho-physiological traits. Based on the drought susceptible index a reference set will be developed for allele mining using micro satellite markers. Marker assisted back cross breeding was carried out using molecular markers link to the QTL governing drought tolerance into Pusa Basmati-1. rice varieties. Two rice genotypes for submergence tolerance was registered with National Bureau of Plant Genetic Resources (NBPGR), New Delhi. One salinity tolerant variety is in final year of All India Coordinated Research Project trials. Three superior heat tolerant hybrids were developed. Four drought tolerant rice varieties were released for Tripura. Two extra-early (50-55 days) green gram varieties were identified for summer cultivation (IPM 409-4, IPM 205-7) and one multiple stress tolerance redgramwild accession (*C. scarabaeoides*). A large number of soybean genotypes were evaluated for drought. Lines JS 97-52, EC 538828, EC 456548 and EC 602288 identified as relatively tolerant. These lines have been crossed among each other and with lines with superior agronomic background and are in F_{2-3} generations. Five heat tolerant and 12 drought tolerant genotypes in tomato. Number of mapping population in rice, wheat, maize were developed for identifying QTL for various abiotic stresses in these crops for utilization in maker assisted selection (MAS) breeding.

Management of Natural Resource

Under NICRA, emphasis has been placed on the development of technologies, which can reduce the greenhouse gas emissions without compromising on yield. As part of this initiative, various ICAR institutes such as Indian Agricultural Research Institute (IARI), New Delhi, Indian Institute of Farming Systems Research (IIFSR), Modipuram, Indian Institute Soil Science (IISS), Bhopal, Central Arid Zone Research Institute (CAZRI), Jodhpur, ICAR Research Complex for NEH Region (ICAR-NEH), Umiam are working on various themes related to the GHG emissions Mitigation strategies by reducing carbon foot prints through conservation agriculture in rainfed regions, carbon foot print from various practices like decomposition of crop residues, application of synthetic N fertilizers, field operations and input production indicated that there is a scope to reduce carbon foot prints by reducing one tillage operation with harvesting at 10 cm height with minimal impact on the crop yields. Long-term conservation horticultural practices in mango orchards improved the quality of soils through enhancing the organic carbon fraction and biological status, especially near the surface. Soil aggregates and water stability improved under conservation treatments. Cover crop, Mucuna, could conserve maximum moisture and reported higher Glomalin content in soil indicating the improvement in soil aggregation. Assessment of biochar on productivity, nutrient use efficiency and C sequestration potential of maize based cropping system in North-Eastern Hill region indicated a higher soil microbial biomass carbon (SMBC), dehydrogenase enzyme activity (DHA) and soil organic carbon (SOC) with application of biochar @ 5.0 t/ha along with 75% RDF + 4 t/ha FYM, while exchangeable aluminium and exchangeable acidity were reduced.

GHG inventory for different cropping systems and production systems. Quantified GHG emissions from Conservation Agriculture (15 to 20% reduction)and resource conservation technologies (Biochar, zero tillage, reduced tillage, mulching etc.). Quantified C Sequestration in different agroforestry systems (16-22 t C ha^{-1}). The proven resilient practices are being integrated in the development programs such as the Crop diversification in traditionally paddy growing regions as part of the National Food Security Mission (NFSM) wherein 1.02 lakh ha is being diversified from paddy to other less water consuming crops in the country during the year 2015-2016. Similarly, the paddy systems of cultivation such as System of rice cultivation, direct seeded rice are being promoted by the development programs as part of the NFSM where in 1.63 lakh ha area was brought under these improved methods of paddy cultivation in the country during the year 2015-2016. Such kind of efforts would contribute to reduction of GHG emissions in the country.

Climate Resilient Horticulture

Climate change impacts several horticultural crops in the country. Flooding for 24 hours severely affects tomato during flowering stage. Onion during blub stage is highly sensitive to flooding, whereas warmer temperatures shorten the duration of onion bulb development leading to lower yields. Similarly, soil warming adversely affects several cucurbits. Reduction in chilling temperature in the recent years in Himachal Pradesh drastically affected apple production, and the farmers are shifting from apple to kiwi, pomegranate and other vegetables. More importantly, temperature and carbon dioxide are likely to alter the biology and forging behaviour of pollinators that play key role in several horticulture crops. Under NICRA project research has been initiated at 5 ICAR Institutes viz., Indian Institute of Horticultural Research (IIHR), Bengaluru, Indian Institute of Vegetable Research (IIVR), Varanasi, Central Potato Research Institute (CPRI), Shimla, Central Institute of Temperate Horticulture (CITH), Srinagar and Directorate of Onion and Garlic Research (DOGR), Pune. High throughput screening of germplasm using plant Phenomics, Temperature Gradient Chambers, FATE Facility, Root imaging system, Environmental Chamber, TIR Facility, Photosynthetic System and Rainout shelter enabled to characterizes large number of germplasm lines and identify suitable donors for breeding against drought, heat stress and flooding in tomato, brinjal and onion. The technique for inter-specific grafting of tomato over brinjal has been standardized and large-scale demonstrations have been taken up to withstand drought and flooding in tomato. Environmentally safe protocol was developed for synchronizing flowering in mango, which is induced due to changing climate. A microbial inoculation with osmo tolerant bacterial strains has been developed to improve yield under limited moisture stress in tomato. Several resource conservation technologies viz., mulching, zero tillage, reduced tillage, biochar etc. have been demonstrated in climatically vulnerable districts across the country through Krishi Vigyan Kendras (KVKs). Large-scale adoption of this climate resilient technologies enables to adopt the changes associated with global warming and also keep pace with increasing demand for horticulture products in the country in the years to come.

Climate Resilient Livestock Management

Under NICRA project climate change research facilities for livestock viz., CO_2 Environmental Chambers, Thermal Imaging System, Animal Calorimeter, Custom Designed Animal Shed etc. have been established at ICAR-National Dairy Research Institute (NDRI), Karnal and ICAR-Indian Veterinary Research Institute (IVRI), Izatnagar. Biochemical, morphological and physiological characterization of indigenous cattle breeds were carried out and compared with exotic breeds. The traits identified in indigenous breed viz., heat shock proteins, air coat colour, wooly hair etc. that impart tolerance to heat stress could be used in future animal breeding programs to develop breeds that can withstand high temperature. Different feed supplements have been identified and tested successfully to withstand heat stress in cattle. Studies on prilled feeding in cattle showed that they help lowering stress levels and methane emission.Custom designed shelters system and feed supplementation with chromium propionate, mineral supplements (Cu, Mg, Ca and Zn) both in feed and fodder significantly improved the ability to withstand heat stress. At ICAR-North Eastern Hill Region, Umiam, the local birds of Mizoramare predominantly black in colour, small size, crown appearance on head, light pink comb with black, poorly develop wattle, small ear lobe, shank is brown to black and elongated. The average annual egg production of local birds is 45-55 eggs. Local birds are more tolerant to common diseases of poultry. Innovative deep litter pig housing model was developed that offers the advantages of better micro-environment both summer and winter, better physiological adaptation, protecting animal welfare and behaviour, faster growth rate of piglets and higher performance and productivity and low incidences of diseases/ conditions. The performance of Vanaraja poultry under backyard farming at different altitude under diversified agro-climatic condition was evaluated. Vanaraja birds have high tolerance to incidence of diseases and showed wide adaptability under different altitude. Many of these climate resilient technologies viz., feed supplement, shelter management, improved breeds, silage making, de-warming etc. have been demonstrated in the farmer's field through KVKs in the 121 climatically vulnerable districts across the country. Up-scaling of these technologies through respective State Governments would enable the livestock farmers in the country cope with vagaries associated with climate change.

Climate Resilient Fisheries Technologies

Under NICRA project climate change research facilities for Fisheries viz., Research Vessel, Green House Gases analyzer Agilent 7890A GC Customized, Fish Biology Lab, CHNS/O analyzer, Automatic Weather Station installed etc. have been established at ICAR- Central Marine Fisheries Research Institute (CMFRI), Kochi, ICAR- Central Inland Fisheries Research Institute (CIFRI), Barrackpore, ICAR- Central Institute of Brackish water Aquaculture (CIBA), Chennai and ICAR- Central Institute of Freshwater Aquaculture (CIFA), Bhubaneswar. Relationship of temperature and spawning in marine and freshwater fisheries sector is being elucidated so that fish catch in different regions can be predicted by temperature monitoring. A shift in the spawning season of oil sardine was observed off the Chennai coast from January-March season to June-July. Optimum temperature for highest hatching percentage was determined in Cobia. A closed poly house technology was standardized for enhancing the hatching rate of common carp during winter season. An e-Atlas of freshwater inland capture fisheries was prepared which helps in contingency planning during aberrant weather. For the first time a greenhouse gas emission measurement system was standardized for brackish water aquaculture ponds. Cost effective adaptation strategies like aeration and addition of immuno-stimulant in the high energy floating feed helped freshwater fish to cope with salinity stress as a result of seawater inundation in Sundarban islands. Relationship was established between increase in Surface Sea Temperature (SST) and catch and spawning in major marine fish species. Simulation modeling was used to understand the climate change and impacts at regional/national level.

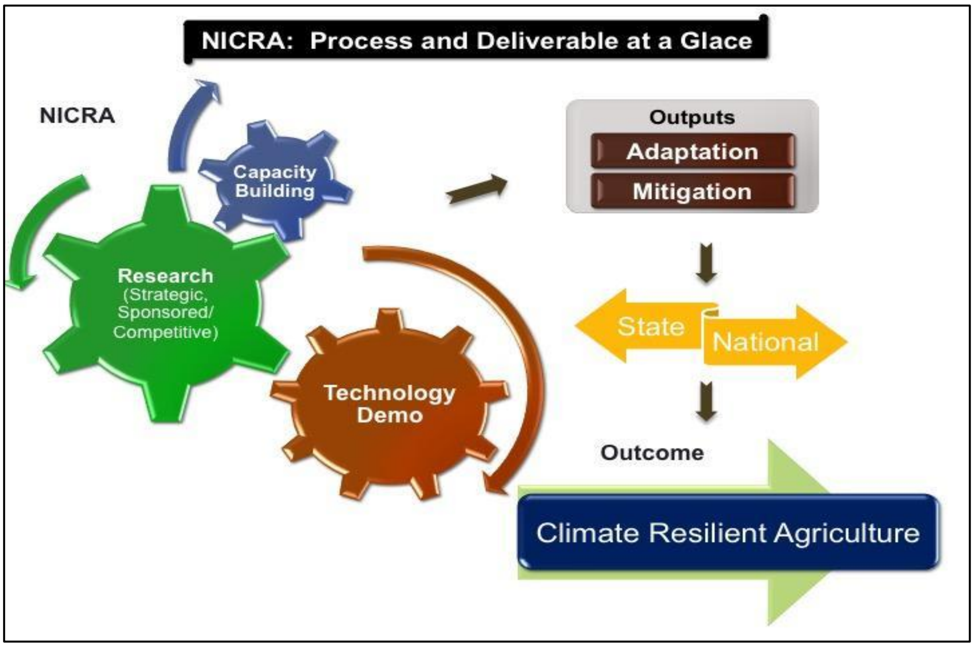
Policy Support

Vulnerability assessment map prepared under NICRA is being used by different Ministries and several NGOs/CBOs.

- NICRA is also contributing to National missions like NMSA, Water mission, Green fund and INDC
- Outcome of NICRA project supported some of the policy issues in Sates of Maharashtra (BBF Technology), Million farm ponds in the Sates of Andhra Pradesh and Telangana, ground water recharge initiatives (Southern states), drought proofing in Odisha, NABARD action plans, NICRA model village expansion in Assam etc.
- Contingency planning workshops organized every year in different States helps in preparedness to face weather aberrations.

Conclusions

A large network platform related to climate change research has been created in the country. The system-wide impacts and responses to climate change need to be understood better and more comprehensively. Crop improvement for multiple stresses takes several years of research and multi location testing. Efforts made under this project, in some cases resulted in development of varieties/hybrids ready for large-scale cultivation. Research, essentially long term in nature, should continue further to achieve the intended outputs and outcomes. In fact, the technologies found to be performing well are getting fed into programs such as NMSA. There is still need to develop variety of adaptation options for different sub-sectors within agriculture, for different regions and for farmers with varying resource endowments. Such an effort is to be accompanied by identification of factors that help adopt technologies on a wider scale. Over all, NICRA project is contributing towards developing adaptation and mitigation strategies in the country and enabling to make Indian agriculture more resilient to climate change. Government of India has committed for the reduction of emission intensity of GDP by 32-35% by 2030 from 2005 levels, and the outputs of NICRA project contributing to several national project reports i.e., Intended Nationally Determined Contribution (INDC), Biennial Update Report (BUR), Nationally Appropriate Mitigation Action (NAMAs), National Mission on Sustainable Agriculture (NMSA) and several other Missions under National Action Plan on Climate Change.



To sum up, the activities initiated under NICRA would continue and expand in scope and content, and enable to develop multi location multi sector mitigation and adaptation strategies so that we combat major challenge posed due to climate change in Agriculture.

References

IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press.In Press.

MoEFCC, 2021. India: Third Biennial Updated Report, United Nations Framework Convention on Climate Change. Ministry of Environment, Forest and Climate Change, Govt. of India

Prabhakar M, 2019. Climate Smart Agriculture: Policies and Practices for Adaptation and Mitigation to Climate Change in India. In: Climate Smart Agriculture: Strategies to Respond Climate Change in South Asia, edts: Shrestha RB., &Bokhtiar SM., SAARC Agriculture Centre, Dhaka, Bangladesh, pp. 62-78.

Doable Climate Resilient Technologies

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Climate Change is one of the greatest threats to humanity, and agriculture is one of the sectors that is witnessing the negative effects of Climate Change. The Intergovernmental Panel on Climate Change has reiterated that human induced global warming is happening quickly and is affecting many aspects of life including food, water, energy and livelihood security. The combined land and ocean temperature has increased at an average rate of 0.07°C (0.13°F) per decade since 1880; the average rate of increase since 1981 is significantly higher (0.18°C / 0.32°F) and warming from pre- industrial levels to 2006–2015 decade is 0.87°C. The industrial activities have raised atmospheric carbon dioxide levels from 280 parts per million to 414 parts per million in the last 150 years (IPCC, 2018). However, the impacts of climate change, which include increasing temperatures, shifting precipitation patterns, more severe and frequent extreme weather events and the loss of ecosystem services and biodiversity will threaten the agricultural production and food systems, especially in developing countries, in the years to come.

Climate resilient technologies contributes towards minimizing the impact of variable climate during the stress years and contributes to higher productivity and farm incomes during the normal years. Climate resilient technologies can stabilise agricultural production in a sustainable manner.Some of the important and doable climate resilient technologies are listed and discussed below:

1) Resilient technologies and their impact on crop productivity in drought prone regions of India

Rainfed areas are frequently drought-prone. On an average, India's rainfed regions suffer from drought every three years. Often the effects drought lasts for three to six years and affects availability of water for people, livestock and crop and fodder production. Droughts has direct and negative impacts on agricultural production.

(i) Climate resilient technologies for regions receivinglow to medium rainfall regions

The low rainfall regions suffer from a number of biophysical and socio-economic constraints which affect productivity of crops and livestock. These include low and uneven rainfall, dry spells, droughts, land degradation and poor productivity, low level of input use and technology adoption, inadequate fodder availability and low productive livestock. The impact can be minimized with the adoption of suitable improved technologies in right time and place.

a) Natural resource management (NRM) technologies

Natural resource management technologies such as in-situ water management and water harvesting technologies play a major role in low rainfall regions to enhance the crop and livestock productivity. NRM technologies provides favorable conditions to improve crop and livestock production by conserving moisture and making it available for longer days and also making water available for supplemental irrigation during dry spells or moisture stress condition. In-situ water management technologies such as farm bunding, ridges and furrows, broad bed furrows, trench cum bunding and compartmental bunds has been assessed for various situations and production systems.

In-situ water management practices for crop yield improvement

In-situ moisture conservation approaches conserves soil and water by reducing runoff, enables greater infiltration in to soil by increasing infiltration time, increase soil moisture, reduce soil evaporation and increase root system development. These methods collectrain waterwhere it falls, and make available water to overcome the stress during crop period contributing to higher yields. Several land treatments for *in-situ*rainwater conservation are developed for various rainfall regimes. They are location and crop specificandbased on slope, soil depth, rainfall intensity, nature of crop, spacing, etc.

Table 1. Impact of *in-situ* water management practices for low to medium rainfall regions

Technology	Study area	Rainfall (mm)	Crop	Yield improvement (%) over the farmers' practice
Trench cum bund	Tumkuru, ChikkaballapurDavangere,	696	Groundnut, Finger millet, Maize	Up to 50
Ridges and furrows	Amravati, Jalna, Tikamgarh	921 to 1032	Soybean	25 to 35
Farm bunding	Namakkal, Palamu	640 to 1085	Groundnut Paddy	20 to 22
Compartmental bunding	Belagavi Pune	572 468	Rabi sorghum	25 to 87
Land levelling	Jhunhjunu, Aurangabad	460 to 838	wheat	22 to 31

(**Source:**Chary*et al*., 2018)

b) **Water harvesting structures for sustainable crop production during adverse climatic condition**

Rainwater harvesting through farm ponds and supplemental irrigation in the rainfed regions is one of the most important proactive measures for drought proofing and enhancing productivity. Rain water harvesting and efficient utilization is the most effective technology for crop production especially in low and uneven rainfall regions. Rainwater harvesting and efficient use of harvested water offers opportunity to farmers to give lifesaving or critical irrigation to crops during moisture stress situation. Harvested water also to help to grow second and sometimes third crop depending on the availability of water and it helps in enhancing cropping intensification. The water harvesting structures like farm pond, check dam, percolation tanks, groundwater recharge structures significantly increase the groundwater level in places receiving rainfall in low to medium rainfall regions of various agro-ecological regions.

Table 2. Impact of waterharvesting structures and their efficient use as a supplemental irrigation to enhance the groundwater level and crop yield in low to medium rainfall regions

Structure	Study area	Rainfall (mm)	Crop	Yield improvement (%) over the farmers' practice
Farm pond	Davangere,Datia Chitrakoot	644 to 815	Finger millet, Wheat	11 to 19
Community pond	Namakkal Aurangabad Khammam	644 to 1125	Cotton, Rabi onion, Paddy	11 to 20
Check dam	Kalaburagi, Jehanabad	665 to 1074	Cotton, Paddy	Up to 14
Sand bag check dam	Pune, Guna, Datia	468 to 1120	Pearl millet, onion, Soybean, wheat,	25 to 63
Recharging of wells with silt trap	Jhunhjunu	460	Green gram, Wheat	Up to 25
Micro irrigation (Drip and sprinkler)	Amravati	921	Soybean, chickpea	35 to 56

(**Source:**Chary*et al.,* 2018)

c) Short duration drought escaping varieties for minimizing drought stress on crop production

Short duration drought escaping varieties can serve as one of the important strategy to ensure food security in drought prone areas (Dar *et al.,* 2020).In Shekta village of Aurangabad district of Maharashtra, short duration varieties of soybean (MAUS-158) and pigeon pea (BDN-711) during the year 2018performed better which has produced additional yield of 29 and 33%, respectively compared to local varieties. Short duration drought escaping varieties of green gram (Phule Vaibhav) and pearl millet (ICTP-8203) performed better during prolonged dry spells and obtained yield advantage of 72 and 65% respectively more compared to local check in JalgaonKadepathar village of Pune district Maharashtra during 2018. Similarly, adoption of short duration drought escaping varieties of finger millet (ML-365) in Tumkuru, cluster bean (RGC-1066) and cow pea ((RC-19) in Jhunhjunu, pigeon pea (LRG-52) in Kurnool and black gram (VBN-8) in Namakkal performed better by minimizing the impact of moisture stress and obtained additional yield by 40, 15, 20, 52 and 37% respectively compared to local cultivars.

Table 3. Performance of short duration drought escaping varieties on crop yields in low to medium rainfall regions of the country

Crops	Varieties	Study area	Yield improvement (%) over the farmers' practice
Pigeon pea	BRG-2, PRG-176, JKM-189, TS-3R, BDN-711	Tumkuru, Nalgonda,Chitrakoot, Kalaburagi, Pune	20 to 70
Finger millet	ML-365	Davangere,Tumkuru, Chikkaballapur	Up to 53
Foxtail millet	DHFT-109-3	Belagavi	Up to 33
Black gram	Shekhar-02, PU-1,	Hamirpur, Datia	50 to 70
Rice	Sahbhagidhan, Abhishek, SabourArdhjal	Chatra, Jehanabad, Aurangabad	11 to 22
Groundnut	Dharani, Kadiri-6	Anantapur, Jhansi	10 to 42
Sorghum	M,35-1, GS-23, (NJ-2446), Phule- Revati	Belagavi, Kalaburagi, Kurnool, Pune	21 to 45
Chickpea	BGD-103, RVG-202	Kalaburagi, Datia	22 to 37
Mustard	NRCHB-101	Datia	Up to 24

(**Source:**Chary*et al*., 2018)

d) Livestock technologies for low to medium rainfall regions

In low to medium rainfall regions livestock plays an important role in sustaining livelihood of poor farmers, because of inherent risk involved in the crop production due to uncertainty of rainfall and occurrence of recurrent droughts. Drought stress leads to inadequate availability and poor quality of feed and fodder, the major problems facing smallholder farmers.This can be minimized by cultivating improved short and medium duration fodder cultivars of several crops that can withstand up to 2-3 weeks of stress to drought in rainfed areas. These include: sorghum (M P Chari, Red Chari, MFSH-4, COFS-29/31, sudan grass, MFSH-4), maize (African tall), oat (JHO-99-2/822, Kent), lucern (Anand-2), bajra (APBN-1, CO-4, Phule Jaywant, FMH-3, Chari, AVKB-19)and berseem (BL-10, Mascabi, Varadan, JB-5, BB-3/2, UPB-10). These cultivars can be sown immediately after the rains under rainfed conditions in arable lands during *kharif* season and are ready for cutting by 50-60 days. Cultivars of *rabi* crops like Berseem (BL-10) and Lucerne (Anand-2) can be grown with the available moisture during winter. Perennial fodders like Hybrid Napier(NB-21, IGFRI-6, DHN-10, Jaywant), Super Napier, Perennial fodder (DHN-6 and Dhaman) and

Yashvant grass can also be cultivated under limited irrigated conditions and improved fodder production system like silage, hay, Azolla, Urea molasses mineral blocks, dry fodder enrichment and other concentrate feeds can be used for minimizing the impact of drought during lean season. The improved green fodder production in NICRA villages of Tumkuru, Kalaburagi, Davangere, Belagavi, Namakkal, Anantapur, Kurnool, Aurangabad, Ahmednagar, Pune, Bharatpur, Jodhpur, Jhunjhunu, Bahraich, Chitrakoot, Gonda, Hamirpur, Jhansi, Chatra, Jehanabad, Buxar, Saran, Aurangabad, Gumla, Datia, Tikamgarh, Guna, Amravati, Nalgonda and Khammam districts contributed to the improvement in milk yield up to10 to 15% compared to without green fodder feeding during lean season. Feeding of green fodder crop maize (AT), cowpea, oat (Kent), berseem and hybrid Napier (BNH-10) increased the milk production by 23% and use of concentrate feeding was reduced by 27% in Odisha (Singh *et al.,* 2018).

ii) Climate resilient technologies for regions receivinghigh rainfall

Heavy rainfall during the rainy season often cause crop damage in several parts of the country, particularly in Odisha, West Bengal and parts of western and Southern states.In high rainfall regions, the strategy is to conserve as much rainwater as possible and to harvest the surplus water for lifesaving irrigation. Wherever possible efforts are to be made for sustainable intensification and for enhancing the cropping intensity, and to maximize returns from the harvested water. Apart from enhancing the availability of water by various methods, the approach is to increase the water-use efficiency by arresting losses associated with utilization of water and to maximize returns from every drop of harvested water.

Resilient practices like crop residue mulching, plastic mulching, Jalkunds, desilting of drainage channels, protected cultivation with low-cost poly house, drought and flood tolerant varieties and improved livestock intervention have potentiality to increase crop yield against the adverse climatic conditions in high rainfall regions.Two supplemental irrigation from Jalkund during vegetative and flowering stage in cabbage increased the productivity by 73% in high rainfall region of Kyrdem village of RiBhoi district of Meghalaya. Drought tolerant variety of rice (Gitesh) performed with 30% more crop yield compared to local variety during the moisture stress condition in Dhansiripar village of Dimapur district, Nagaland. Similarly, drought tolerant varieties of paddy (Bhalum – III, CAU-R3, Gomoti, CAU-R1, etc.) increased the paddy yield up to 60% compared to local variety in high rainfall regions of North-East states. Low cost poly house technology helped to grow high value vegetable crops in spite of stress condition and obtained higher yield up to 600 q/ha in tomato and 40 q/ha in coriander with additional return to the farmers compared to farmers' practice. The improved piggery system helped in minimizing the mortality rate and get additional meat compared to local breed. The improved low-cost elevated shelter for livestock helped to reduce mortality rate by 15 to 20% and offers better return from livestock.

2) Resilient technologies and their impact on crop productivity in flood and cyclone prone regions of India

Several districts in the country are prone to floods from inundation due to rise in water level in rivers, cyclones and due to high intense rains. Several districts in the Brahmaputra and Ganga River basins in the Indo-Gangetic- Brahmaputra plains in North and Northeast India are frequently and severely impacted by floods. Some of the districts in the north-west region of west flowing rivers such as Narmada and Tapti, Central India and the Decan region with major east flowing rivers like Mahanadi, Krishna and Cauvery and the districts of east coastal and west coastal plains are frequently impacted by flood. Flash floods leading to complete submergence of rice plants is one of the major constraints for rice production in rainfed lowlands of South and South-East Asia (Septiningsih*et al.,* 2009).

In India rainfed lowland areas of Assam, Odisha, West Bengal and parts of coastal Andhra Pradesh, Maharashtra, Tamil Nadu, and seasonal floods in Bihar seriously affects crop establishment leading to severe yield losses. Rice varieties Swarna-sub1, MTU-1010, MTU-1001 and MTU-1140 are high yielding with good grain quality apart from possessing submergence tolerance and perform better under flood situation. Flood tolerant rice variety of Swarna-Sub1, Ranjit Sub-1, Bahadur sub-1, etc. had a clear yield advantage over Swarna when fields were submerged for seven to fourteen days. For each additional day of flooding, planting Swarna-Sub1 increased yields by approximately 64 kg/ha, and led to a 10.5 percent increase in total rice yield compared to farmers' practice. For floods lasting ten days, the averted yield loss was 628 kg per hectare, representing a 45 percent yield advantage over Swarna (Janvry*et al.,* 2013). Study was conducted by Reddy et al., 2014 in flood prone areas of Andhra Pradesh with flood tolerant varieties of paddy (PLA-1100), Indra (MTU-1061) and RGL-2537 in Srikakulam district and MTU-1121 and MTU-7029 in West Godavari district, registered 25 to 60% higher yield over respective farmers practice.

Table 4. Impact of climate resilient technologies in cyclone and flood prone regions

Technologies	Study area	Impact
Land shaping	South 24 Parganas, West Bengal	Increase of net income by 119% in paddy-vegetable fish combination
Paddy straw mulch in bitter gourd	South 24 Parganas, West Bengal	Yield up to 352 q/ha and Net return by Rs. 324000 per ha
Submergence tolerance paddy (Swarna Sub-1)	Coochbehar, West Bengal	Yield increased by 45% more compared to local variety
Flood tolerant rice (Bina-11)	Ganjam, Odisha	Yield up to 53 q/ha
Raising seedling in low cost poly house	Ganjam, Odisha	Mortality of seedling reduced by 40% Net return up to Rs. 15500 per unit
Flood tolerant paddy (MTU-1140)	West Godavari, Andhra Pradesh	Yield up to 76.5 q/ha and net return up to Rs. 65438 per ha
Integrated farming system (Paddy cum fish culture)	West Godavari, Andhra Pradesh	Net return up to Rs. 163750 per ha, whereas from farmers practice was Rs. 100000 per ha
Flood prone paddy (Pooja and RGL 2537)	Srikakulam, Andhra Pradesh	Yield up to 51.5 q/ha
Improved low cost shelter for backyard poultry	Alappuzha, Kerala	Reduced mortality by 40% compared to earlier shelter

(**Source:**Chary*et al.*, 2018)

3) Resilient technologies for frequently high temperature stress prone regions of India

Heat wave is a period of abnormally high temperatures, more than the normal maximum temperature that occurs mostly during the winter/summer season in the North-Western parts of India. Heat waves typically occur between March and June and cause permanent damage to plant growth and development. Heat stress or high temperature during crop growing period restricts wheat production and productivity, particularly at germination and grain filling stage (Monu Kumar *et al.,* 2013). The optimum temperature required for growth and development of wheat is in the range 18-24ºC and even short periods (5-6 days) of exposure of wheat crops to temperatures of 28-32ºC may result up to 20 percent decrease in yield (Rane *et al.,* 2007). Varieties suitable for advanced planting and early maturity can escape heat stress in wheat in Eastern Gangetic Plains and western regions of India. Heat stress tolerant varieties of wheat (Raj-4120, Raj-4037, HI-1544, Raj-4238) chickpea (JG-130), pigeon pea (NA-1) recorded higher yields of 26 -51% compared to local wheat variety Lok-1, etc. Heat tolerant varieties of wheat (Raj 4238 and HI 1544) performed with higher yields in Udaipur, India (Malav*et al.,* 2020). In Jhabua district in Madhya Pradesh, heat tolerant varieties of wheat (HI-1544) and chickpea (JG-130) recorded higher yields of 26 and 28% over the traditional varieties, respectively.

Table 5. Impact of climate resilient technologies in high temperature regions

Crop	Variety	Study area	Yield improvement (%) over the farmers' practice
Mothbean	CZM-2 and RMO-435	Jodhpur, Rajasthan	Up to 70
Chickpea	JG-14 and JG-130	Raipur, Guna	35 to 4/8
Wheat	JW-3211, Raj-4083, Raj-4037, Raj-4238	Balaghat, Barmer, Bharatpur, Jhunhjunu	18 to 28

(**Source**: Chary*et al*., 2018)

References

Chary, G.R, Prasad, J.V.N.S., Osman, M., Ramana, D.B.V., Nagasree, K., Rejani, R., Subbarao, A.V.M., Srinivas, I., Rama Rao, C.A., Prabhakar, M., Bhaskar, S., Singh, A.K. and Alagusundaram, K. (Editors). 2019. Technology Demonstrations: Enabling communities to cope with climate variability and to enhance adaptive capacity and resilience. National Innovations in Climate Resilient Agriculture (NICRA) Project, ICAR-Central Research Institute for Dryland Agriculture, Hyderabad, Research Highlights: 121 pp.

Dar, M.H., Waza, S.A., Shukla, S., Zaidi, N.W., Nayak, S., Hossain, M., Kumar, A., Ismail, A.M. and Singh, U.S. 2020. Drought tolerant rice for ensuring food security in Eastern India. *Sustainability*, **12**(6): 2214.

IPCC, 2018: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press.

Janvry, A.D., Sadoulet, E., Emerick, K. and Raitzer, D. 2013. Reducing farmers' risk through flood-tolerant rice in India.https://www.povertyactionlab.org/evaluation/reducing- farmers-risk-through-flood-tolerant-rice-india

Malav, A. K., Vyas, M.M., Choudhary, J., Meghawal, D.R., and Bangarwa, S.K. 2020. Assessment the heterosis and combining ability for grain yield components and heat tolerance traits in bread wheat. Int. J. Curr. Microbiol. App. Sci, 11: 1372-1397.

Monu, K., Sharma, R. K., Kumar, P., Singh, G. P., Sharma, J. B. and Rahul, G. 2013. Evaluation of bread wheat (Triticumaestivum L.) genotypes for terminal heat tolerance under different environments. Indian J. Genet. 73: 446-449.

Septiningsih, E.M., Pamplona, A.M., Sanchez, D.L., Neeraja, C.N., Vergara, G.V., Heuer, S., Ismail, A.M. and Mackill, D.J. 2009. Development of submergence-tolerant rice cultivars: The Sub1 locus and beyond. *Annals of Botany*, **103**: 151–160.Singh, V.K.,

Sinha, A.K., Tiwari, M.K., Singh, S.K., Singh, V. and Singh, P.K. 2018.Effect of green fodder feeding on CB milking animals in Odisha. International Journal of Research, 5(4): 1636-163.

Infrastructure and Facilities Requirements for Climate Change Studies

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The increased pace of change in climatic conditions is the concern for sustaining the future agricultural productivity as the productivity of agriculture is strongly linked with weather. Increased GHGs in the atmosphere, enhanced temperatureand erratic rainfall are the major issues of the predicted future climate change conditions in sustaining the productivity of agricultural crops. Many assessment studies clearly indicated thatthe productivity of major agricultural crops is going to be drastically affected negatively in the future especially in tropical areas. To meet the increased food demand for growing population from dwindling cultivated areas as well as to address changing food habits,the strategies need to be worked out with better conservation of natural resources along with development of tolerant crop varieties is the need of the hour.

To address the issues envisaged for impact of climate change on Indian agriculture sector, a network project on 'National Innovations in Climate Resilient Agriculture (NICRA)' was launched by ICAR in 2011. One of the main objectives of this program is to enhance resilience of Indian agriculture to climate change through basic and strategic research in areas of natural resource management, crops, pests and disease dynamics, livestock, fisheries, and energy efficiency.To conduct research and/or generate data for climate change research, state of art infrastructure facilitiesis vital to capture the changes, quantify the impacts and develop the strategies to cope up with predicted changes.

The infrastructure and facilities are categorized based on the sector they are addressing such as i). Crop based infrastructure are a) Plant Phenomics Facility, b) Free-air Temperature Elevation (FATE) facility, c) Carbon dioxide and Temperature Gradient Chamber (CTGC) facility, d) Open Top Chamber (OTC) facility, e) Rainout Shelter facility. The sophisticated and sensitive instruments such as a) Root image analyzer, b) Photosynthesis and Chlorophyll Florescence system. ii). NRM based infrastructure are a)Eddy Covariance System, b) Biochar making system. iii). Animal based infrastructure such as Thermal imaging System, iv). Fisheries based infrastructure such asResearch Vessel with modern navigational and oceanographic equipment, v). Network of automatic weather stations and Satellite data reception system.

The Plant Phenomics facility will improve our understanding and ability to dissect the genetics of quantitative traits. The phenotype is the result from the complex interrelation between genes and the environment. The gap between the knowledge about genes and phenotypes is particularly large in analyses of plant-environment interactions that are urgently needed for research and application to sustainable and resource-efficient crop production in the context of climate change and varying agricultural production conditions. Quantitative information on genotype-environment relations is the key to address these major challenges. This quantitative information needs to be obtained in a certain throughput with hundreds and more of plants using minimal invasive or non-invasive technologies which are integrated into screening protocols. These systems are with a variety of imaging methodologies to collect data for quantitative studies of complex traits related to the growth, yield and adaptation to biotic or abiotic stress such as disease, insects, drought and salinity. These imaging techniques include visible imaging, imaging spectroscopy such as multispectral and hyperspectral remote sensing, thermal infrared imaging, fluorescence imaging.

The mean annual temperature over India is projected to increase 1.7-2.0°C by 2030s, 2.5-3.0°C by 2050s and 4.0-5.0°C by 2080s as compared to baseline period of 1960-90.The Free Air Temperature Enrichment (FATE) system is a research facility with elevated temperature conditions over ambient and intended to conduct controlled experiments with other manipulative parameters such as CO_2 enrichment and moisture deficit stress on intact ecosystems under naturalenvironmental conditions. The facility creates an artificially induced high temperature through arrays of infrared heaters under open field conditions with uniformity of the thermal radiation and canopy temperature across the plot. This facility enables to conduct realistic experiments to understand how plants and ecosystems will respond to increasing CO_2 concentration of Earth's atmosphere and associated predictions of global warming.

Carbon dioxide and Temperature Gradient Chamber (CTGC) facilitydesigned for measuring the impacts of elevated CO_2 and gradient of temperature on the performance of crops.The elevated CO_2 condition along with temperature gradient will facilitate to assess the combined effects.Increase in temperature and elevated CO_2 influence crop growth significantly and in turn affect the insect herbivores both directly and indirectly.Higher growing season temperatures can significantly impact agricultural productivity. In areas where temperatures are already close to the physiological maxima for crops, higher temperatures may be more immediately detrimental, increasing the heat stress on crops and water loss by evaporation.

Open top chambers (OTCs) are widely used to study the effects of elevated CO_2 and other atmospheric gases on vegetation. They are plastic enclosures, with an open top, constructed of an aluminium frame covered by panels of polyvinyl chloride plastic film.OTCs are relatively inexpensive to construct and maintain.

Water is vital to plant growth, so varying precipitation patterns have a significant impact on agriculture. As over 80 per cent of total agriculture is rain-fed, projections of future precipitation change often influence the magnitude and direction of climate impacts on crop production.Quantifying the impacts of inter-annual variation of productivity and precipitation is pre-requisite in clarifying the potential impacts of a range of climate variability/change scenarios on ecosystems.Manipulative experiments are an alternative way to explore this by using field established rainout shelters which facilitate water exclusion to reduce natural precipitation. Rainout shelters are designed to protect a certain area of land against receiving precipitations so that an experimentally controlled drought stress can be imposed on that area. This provides to generate information on the water availability and ecological processes under present climatic conditions and to predict the responses to future climatic scenarios.

The root system is of critical importance for the survival, development, and performance of plants, as it is the major component for anchorage, acquisition of water and nutrients, as well as for carbon storage. The ability of plant roots to extract water and nutrients from the soil, when such resources are altered depends on its interaction with the soil through their altered physical, chemical and biological properties. Hence precise measurements of root system architecture traits are an important requirement for plant phenotyping.The root image analysis systemis faster, more accurate and less prone to human error. This system is useful to study morphology, topology, architecture, and colour analyses and is made of a computer program and image acquisition components.

Photosynthesis systems are electronic scientific instruments designed for non-destructive measurement of photosynthetic rates in the field.The effect of light, CO_2, humidity, temperature, chemical, or biological factors on leaf gas exchange can be measured within short time.This equipment is used for studying response of photosynthesis in plants to external factors such as temperature, CO_2, water, PAR, andnitrogen levels. Applications include screening of germplasm, quantification of photosynthetic rate and water use efficiency, response to several biotic and abiotic stresses.

The eddy covariance technique is a widely used, accurate, and direct method for quantifying exchanges of carbon dioxide, water vapour, methane, various other gases, and energy between the surface of the earth and the atmosphere. Eddy covariance provides an accurate way to measure surface-atmosphere fluxes of energy and trace gas fluxes over a variety of ecosystems. These measurements are useful to understand the ecosystem function, to estimate terrestrial carbon budgets, to test ecosystem and land surface models, and to predict ecosystem responses to changes in mean and extreme climate conditions.

Biochar is recalcitrant organic carbon compound, generated when biomass is heated at high temperatures under low oxygen concentrations. Application of Biochar to soils considered as a means of mitigating climate change by sequestering C in the soil, which also expected to improve the properties of soil. Biochar produced from the crop residue such as rice husk, rice straw, perennial trees, crop stalks, saw dust etc. avoid burning them and polluting environment there by mitigate the global warming.There is potential for biochar to enhance soil function for agricultural productivity and thus offset the opportunity cost associated with its residual energy value.

Thermal imaging system is adopted in livestock to understand the stress susceptibility or health state of animals. Fast and cost-effective measuring methods are needed to improve cattle management particularly in the fields of health and fertility diagnostics.As the skin temperature of animal is influenced by the intensity of blood circulation, gravidity of cattle might be visible in thermal images.

The Research Vessel with modern navigational and oceanographic equipment like echo sounder, sonar, GPS, VHF radio and CTD to assess and measure in-situ environmental parameters, primary and secondary productivity, plastic pollution, current direction and pattern along with trawl fishing operations.

Indian agriculture is dependent on monsoon and variation in rainfall pattern, change in temperatures in recent past are causing considerable impact on agriculture productivity. The observations of surface meteorological parameters are important in understanding the spatio-temporal variations in weather and climate.100 automatic weather stations (AWS) were installed across the country to have continuous real time weather data over the Indian sub-continent, representing various climatic vulnerabilities.

The data reception system provides direct data downlink from an ERS satellite and register the target data stream during a communication session. System provides real time coarse resolution satellite images from direct broadcast systems. This enables to generate district level information for monitoring crop environmental condition and crop health condition to support stakeholders' decision making. Also used for monitoring active fires due to crop residue burning.

These infrastructure and facilities enable to generate very precise and accurate information which is prerequisite for the accurate prediction of the climate change impacts and to prepare the strategies to cope with it.

Higher growing season temperatures can significantly impact agricultural productivity. In areas where temperatures are already close to the physiological maxima for crops, such as seasonally arid and tropical regions, higher temperatures may be more immediately detrimental, increasing the heat stress on crops and water loss by evaporation. A 2°C local warming in the mid-latitudes could increase wheat production by nearly 10 per cent. Different crops show different sensitivities to warming.

Water is vital to plant growth, so varying precipitation patterns have a significant impact on agriculture. As over 80 per cent of total agriculture is rain-fed, projections of future precipitation changes often influence the magnitude and direction of climate impacts on crop production (Olesen & Bindi, 2002; Tubiello *et al*., 2002; Reilly *et al*., 2003).

Soil Management Strategies for Sustainable Rainfed Crop Production in the Context of Climate Change

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Nearly 52% of the net sown area in India is rainfedwhere farming depends solely on rainfall and harvested rain water even without groundwater. About 40% of the nation's food grains are produced in rainfed areas which also support two-thirds of the livestock population. Significant area (more than 70%) of pulses and oilseeds is cultivated under rainfed situations. More than 90% of nutritious cereals (sorghum, pearl millet and finger millet) is cultivated in rainfed areas. Major fiber crop i.e., cotton is cultivated in rainfed conditions to an extent of 66%. About 51% of rice is cultivated under upland conditions. Rainfed agriculture production systems in the country are characterized by diversity and heterogeneity. Lack of irrigation facilities, improper distribution of rainfall, high intensity rainfall in short time, inadequate groundwater, frequent droughts, prolonged dry spells, reduced number of rainy days, 84% small and marginal farmers, shallow soil depth and poor water holding capacity, sub-surface hardpan, surface crusting and micronutrient deficiencies are major crop production constraints in rainfed agriculture. Although the average per hectare productivity levels have increased from 0.6 tonnes in the eighties to 1.2 tonnes at present, large gaps still remain in several crops and regions between yields obtained at research stations and in farmers' fields. Rainfed areas are more vulnerable to climate change due to several constraints as compared to irrigated areas.

1. Climate Change and Indian Agriculture

The rising temperature due to increasing greenhouse gas concentrations in the atmosphere are the main drivers of climate change and variability. In India, the emissions from agriculture sector amounted to 16% of the gross emissions in 2014 (BUR, 2018). The agriculture sector emitted 417.22 Gg CO_2e of which 74% was methane and 26% was nitrous oxide. Among the agriculture sectors, enteric fermentation contributed maximum emissions of 54%, while Soil management, rice cultivation, manure management and crop residue burning contributed 19%, 18%, 8% and 2% of total emissions from agriculture, respectively. Therefore, efficient soil management strategies play an important role on reducing greenhouse gas emissions.

Clear indications of change in climate are being noticed in the country. Last three decades saw a sharp rise in all India mean annual temperature. Analysis of data for the period 1901-2005 by IMD suggests that annual mean temperature for the country as a whole has risen to 0.51°C over the period. It may be mentioned that annual mean temperature has been consistently above normal (normal based on period, 1961-1990) since 1993. This warming is primarily due to rise in maximum temperature across the country, over a larger part of the data set. However, since 1990, minimum temperature is steadily rising and rate of rise is slightly more than that of maximum temperature.

The number of cold days and nights has decreased and the number of warm days and nights has increased globally. Frequency of heat waves has increased in large parts of Europe, Asia and Australia.Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass.In India significant increase in mean maximum temperature is observed in many states in the last 60 years. The climate change and its variability in the country led to occurrence of one or other sudden extreme weather events in almost every year in one or other part of the country during the last 18 years (Fig 1). If we observe the occurrence of el-nino drought years during the last 140 years from1870 to 2010, the frequency of El-nino drought is on the rise. During the period from 1870 to 1939, the country experienced only 10 drought years but during the second part of 70 years from 1940-2010, 15 drought years have been observed.

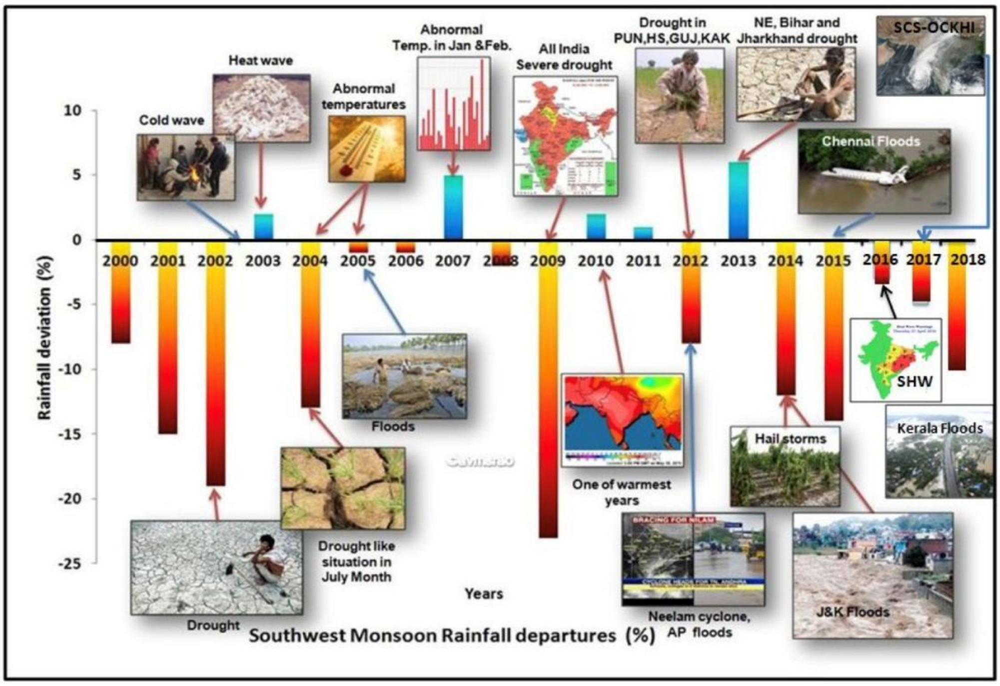

Fig. 1. Occurrence of extreme weather events in India during the last 18 years

(Source: Prabhakar, 2019)

2. Impact of Climate Change on Crop Productivity

Studies on impacts of climate change on agricultural crop yields predicted that irrigated rice yields are likely to be reduced by 4% in 2020, 7% in 2050 and by 10% in 2080 scenarios. On the other hand, rainfed rice yields in India are likely to be reduced by 6% in 2020 scenario, but in 2050 and 2080 scenarios they are projected to decrease only marginally (<2.5%). Climate change is projected to reduce the timely sown irrigated wheat yields by about 6% in 2020 scenario from existing levels. When late and very late sown wheat also were taken into consideration, the impacts are projected to be about 18% in 2020, 23% in 2050 and 25% in 2080 scenarios. *Kharif* groundnut yields are projected to increase by 4-7% in 2020 and 2050 scenarios where as in 2080 scenario the yield is likely to decline by 5%.Future climates are likely to benefit Chickpea by an average increase in productivity ranging from 23 to 54%. However, a large spatial variability for magnitude of change in the productivity is projected. Climate change may likely to benefit potato in Punjab, Haryana and western and Central UP by 3.46 to 7.11% increase in production in A1b2030 scenario, but in West Bengal and southern plateau region, potato production may likely to decline by 4-16% by 2030.

High temperature and its interaction with elevated CO_2 (eCO_2) significantly affected physiological, biochemical, biomass and yield parameters of groundnut genotypes grown on Alfisolsin Free Air Temperature Elevation (FATE) plots (Vanaja *et al*., 2019). There was significant variability between the selected groundnut genotypes for their performance including seed yield under eT and $eT+eCO_2$ conditions. The superior performance for seed yield of groundnut genotype K-9 at high temperature of >40°C, while responsiveness to elevated CO_2 even at high temperature were due to their ability to maintain better pod and seed number as well as improved test weight indicating their role under these conditions. The eCO_2 significantly improved the total biomass pod number and pod weight of the selected groundnut genotypes even at high temperature. Among the four groundnut genotypes, the better performance of K-9 under high temperature was attributed to its capacity to accumulate significantly higher concentrations of osmotic solutes especially proline and total soluble sugars, which led to better RWC and increased cell membrane stability. This indicated that the presence of eCO_2 ameliorated the negative impacts of elevated temperature of >40°C on this C3 leguminous oil seed crop.

3. Climate Resilient Agriculture

Climate resilient agriculture (CRA) is an integrative approach to address the interlinked challenges of food security and climate change, that explicitly aims for three objectives: (1) sustainably increasing agricultural productivity, to support equitable increases in farm incomes, food security and human development; (2) adapting and building resilience of agricultural and food security systems to climate change at multiple levels, and (3) reducing greenhouse gas emissions from agriculture (including crops, livestock and fisheries) to the extent possible. The climate resilient agriculture, encompassing adaptation and mitigation strategies and the effective use of biodiversity at all levels - genes, species and ecosystems is thus an essential pre-requisite for sustainable development in the face of changing climate. CRA reduces poverty and hunger in the face of climate change, improving the resources it depends on for future generation. CRA wants to transform the current systems, and has a wider perspective than increased production only. It supports food production systems at local, regional and global level that are socially, economically and environmentally sustainable. Improved water storage through *in-situ* moisture conservation and stored runoff are basics for bringing resilience to drought or moisture stress conditions often encountered by the dryland crops. Other strategies for bringing resilience are through soil management, resilient intercropping systems, drought tolerant short duration cultivars, suitable farm implements for small holdings, fodder systems, integrated farming systems etc.

4. Impact of Climate Change on Soil Health

Soil health indicators are a composite set of measurable physical, chemical and biological attributes which relate to functional soil processes and can be used to evaluate soil health status, as affected by management and climate change drivers. Defining soil health in relation to climate change should consider the impacts of a range of predicted global change drivers such as rising atmosphere carbon dioxide levels (eCO_2), elevated temperature (eT), altered rainfall, and atmospheric N deposition on soil chemical, physical and biological functions (French et al., 2009). eCO_2 , eT, atmospheric N deposition and changes in total and seasonal distribution of rainfall and extreme events such as droughts and floods will impact soil biological processes, C and N cycling, and consequently on soil structure and erosion events, nutrient availability and plant decreases, and hence on ecosystem functionality and agricultural productivity. Major soil properties which may indicate the status of soil health in relation to climate change impacts are given in Table 1.Global climate change variables of soil moisture, CO_2 and soil temperature causes leaching of nitrates, sulphates, Ca and Mg and volatilization loss of N and soil salinization. Climate change variables such as heavy rainfall and drought affect soil erosion and thereby causes loss of soil nutrients and soil organic C. Drought, increasing temperature, higher relative humidity, and eCO_2 will adversely affect the transpiration-driven mass flow of nitrates, sulphates, Ca and Mg and thereby plant uptake, root growth and architecture. Drought and high temperature may also reduce the N fixation by legumes particularly under field conditions and N cycling. Weather aberrations such as excess rainfall, cyclones, heavy rainfall cause flooding and higher soil redox potential due to anaerobic condition which results in reduction of Mn and Fe.

Table 1. Soil health and relation to processes and functions under projected climate change scenarios.

Soil health indicator	Soil processes affected	Landscape Scale
Soil Physical indicators		
Soil structure	Aggregate stability, organic matter turnover	Aggregation, surface seal, indication of water and chemical retention and transportation
Porosity	Air capacity, available water capacity, relative water capacity	Soil crusting, reduced seed germination, aeration, water entry
Infiltration	Soil water availability and movement	Potential for leaching, productivity, erosion
Bulk density	Soil structural condition, compaction	Volumetric basis for soil reporting
Soil depth and rooting	Available water capacity, Sub soil salinity	Productivity potential, uncertain

		weather trends can be discerned over longer periods
Soil-plant available water and distribution	Field capacity, permanent wilting point, macropore flow, texture	Water and chemical retention and transportation, yield
Soil protective cover	Soil water and nutrient movement, soil stabilization, C and N fixation	Soil physical movement, organic matter input and movement
Soil Chemical Indicators		
pH	Biological and chemical activity thresholds	Soil scidification, salinization, electrical conductivity, soil structural stability
EC	Plant and microbial activity thresholds,	Leachable salts, soil structural decline
Plant available N, P, and K	Plant available nutrients and potential for loss	Capacity for crop growth and yield environmental hazard (e.g. algal bloom)
SOM (light fraction, macro-organic matter, mineralizable N and P)	Plant residue decomposition, organic matter storage and quality macroaggregate formation, metabolic activity of organisms, Inorganic N flux from mineralisation and immobilization	Loss of soil organic matter, soil aggregate formation, Total organic C, soil respiration rate, nutrient supply, microbial activity, nutrient supply
Soil Biological Indicators		
Soil total C and N	C and N mass and balance	Soil structure, nutrient supply
Soil respiration	Microbial activity	Microbial activity
Microbial biomass C and N	Microbial activity	Soil structure, nutrient supply, pesticide degradation
Microbial diversity	Substrate use efficiency	Substrate quality
Enzyme activity	Nutrient cycling and availability, Labile carbon	Biochemical activity, nutrient supply
		Source: Allen *et al*. (2011)

4.1. Effect of Temperature on soil organic carbon

At the global and regional scales, temperature and precipitationare dominant factors affecting soil organic carbon storage, and the soil organic carbon increases with increasing precipitation and decreasing temperature. There is a close relationship between air temperature and soil temperature and a general increase in air temperature will inevitably lead to an increase in soil temperature. Warmer soil temperature will accelerate soil processes, rapid decomposition of organic matter, increased microbiological activity, quicker nutrients release, increase nitrification rate and generally accentuate chemical weathering of minerals. Temperature affect the soil carbon by influencing (i) Soil Carbon pools, (ii) Carbon mineralization, and (iii) C Sequestration. The temperature and rainfall in some parts of the country will continue to remain a potential threat for C sequestration in tropical soils of the Indian subcontinent. Interpretation of soil analysis data from soils of different dryland centres of India showed a significant negative relationship between the minimum, mean and maximum temperature with the organic C stocks. The modeling studies using the soil organic carbon data from long term experiment at BCKVV, Barrackpore indicated that the integrated nutrient management (100%NPK+FYM) predicted to maintain the higher soil organic C at different RCPs of 2.6, 4.5, 6.0 and 8.5 scenarios as compared to control and 100% NPK.

4.2. Increased temperature impacts on soil fertility

Climate change may cause in high intensity rainfall in the short time which causes waterlogged condition in soils without proper drainage. Soils become hypoxic and produce phytotoxic organic solutes impair the root growth and function. Soil submergence increase the concentration of acetic, propionic, and butyric acids in soil solution in anaerobic conditions. N losses due to denitrification were predicted to increase in the future climate scenarios.

The increased temperature due to climate change may also increase the volatilization losses from soil. The increase in temperature from 15 to 45°C increased cumulative ammonia losses from 3.3 to 19.6 mg/kg soil (Kumar et al., 2000). On the other hand, the reduction in soil moisture due to drought conditions decrease enzyme activity in soils. Sardas and Penuelas (2005) found that the activities of soil enzymes such as urease, protease and beta glucosidase decreased by 54, 40 and 59%, respectively due to reduction in soil moisture by 21% under drought conditions. It shows that the close link between drought and slow nutrient turn-over in soil, which decreases nutrient supply to plants.

Phosphorus uptake by wheat grown on Inceptisol increased with eCO_2 and decreased with eT and with overall increase of 17.4% under eCO_2+eT signifying higher P requirements by plants due to climate change. There was 17% decline in PUE of wheat under eCO_2+eT (Kumar et al., 2011).

4.3 Impact of increased CO_2 concentration

Rao *et al* (2016) studied the effect of elevated CO_2(eCO_2) on available N and P status in Alfisol soil after 4 years of intensive cropping in open top chambers. The available N status in soil decreased from 165 kg/ha with 370 ppm CO_2 to 155 and 150 kg/ha with 550 and 700 ppm CO_2 concentration, respectively. Similarly the available P content decreased from 52 kg/ha with 370 ppm CO_2 to 40 kg/ha with 550 ppm CO_2 and 30 kg/ha with 700 ppm.

Tobert *et al*. (2004)studied the effect of N fixation by legume crops and found that the N fixed increased from 163 kg/ha with ambient CO_2 concentration (357 ppm) to 198 kg/ha with elevated CO_2 of 750 ppm due to increase in nodule size, nodule number and nitrogenase activity. The review of literature (Hungate *et al*. 2004; Groenigen et al. 2006) pertinent to effect of elevated CO_2 concentration showed that the N fixation by legume crops increased with increase in CO_2 concentration under controlled laboratory conditions. But this positive effect of eCO_2on N fixation by legumes was not consistent under filed conditions which may be due to deficiency of other plant nutrients such as P, Mo, etc inhibited N fixation under eCO_2.

5. Soil Management Strategies for Climate Resilient Agriculture

Direct drivers of climate change and variability are greenhouse gases (GHGs) emissions, temperature, land use and land use change, land and other natural resource management practices. Indirect drivers include demographic pressure, socio-economic conditions, infrastructure etc which cause overexploitation of natural resources. Soils are the reservoirs of active C and play an important role in the global C cycle. Soil can be either a source or sink for atmospheric CO_2 depending upon land use and the management of vegetation.

Soil management approaches to mitigate climate change are by a) reducing emissions of greenhouse gases (GHGs). Reducing rate of application of N to different crops reduces N_2O emissions through increasing N use efficiency and b) by sequestering CO_2 from the atmosphere in the soil. Carbon sequestration not only helps in reducing CO_2 and CH_4 emissions but also improves soil quality and soil moisture holding capacity.

5.1. Conservation Agriculture in Rainfed Systems

Conservation agriculture (CA) is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment" (FAO 2007). The first key principle in

CA (Conservation Agriculture) is practicing minimum soil disturbance which is essential to maintaining minerals within the soil, stopping erosion, and preventing water loss from occurring within the soil. The second key principle in CA is much like the first in dealing with protecting the soil. The principle of managing the top soil to create a permanent organic soil cover can allow for growth of organisms within the soil structure. The third principle is the practicing diverse crop rotations or crop interactions. Crop rotation can be used best as a disease control against other preferred crops. This process will not allow pests such as insects and weeds to be set into a rotation with specific crops. Rotational crops will act as a natural insecticide and herbicide against specific crops. Not allowing insects or weeds to establish a pattern will help to eliminate problems with yield reduction and infestations within fields (FAO 2007).

The minimization of soil disturbance through conservation tillage, use of cover crops and the application of crop residues on the soil surface result in increased restorative activity in the soil leading to the accumulation of soil organic matter (SOM). Long-term (2005-2012) experiment conducted with sorghum-cowpea on Alfisol revealed that the minimum tillage and surface application of sorghum residue @ 6 t/ha and 4 t/ha recorded 21% and 16% higher sorghum grain yields, respectively over control (No residue) whereas the corresponding increase in the cowpea yield was 50% and 60%, respectively (Sharma et al., 2017). Application of residues with minimum tillage had a significant effect on soil C fractions. The amount of very labile fraction of C was significantly higher (3.96 g/kg) with the application of sorghum stover 6t/ha in the 0-5 cm soil layer. Similar trends were observed in case of labile and less labile organic C fractions. Lability Index (LI) increased with increase in the amount of residue applied. Smaller size soil aggregates (0.053 mm) contained significantly higher amount of SOC compared to the large sized fractions (2mm) In 0.053 mm sized aggregate fractions, the SOC content was found significantly higher (5.34 g/kg) with the application of sorghum stover @ 6 t/ha and recorded an increase of 19% higher over no residue control. Under rainfedcastor – pigeonpea sequence in Alfisols, conventional tillage (CT) recorded 24% higher yields over zero tillage (ZT), but CT and reduced tillage (RT) were on par with each other.However, the yield gap between the tillage treatments is narrowing down over 5 years. ZT and RT recorded 26 and 11% lower indirect GHG emissions over CT, respectively. Castor grown on pigeonpea residue recorded 20% higher GHG emissions over pigeonpea grown on castor residue (Pratibha *et al*.,2016).Selection of the environment friendly farm implement for performing ZT and RT is also very important. Investigations on direct GHG emissions from soils after field operations with different implements and indirect GHG emissions from the consumption of fuel revealed that the Cultivator, Mould Board Plough and Rotovator recorded higher soil based GHG emissions. NT and animal drawn implements recorded lower soil based GHG emissions. Fuel consumption based CO_2 emissions for preparatory cultivation and sowing were found to be 92, 81, 60, 60 and 40 percent lower in bullock drawn plough, bullock drawn harrow, tractor drawn cultivator, disc harrow, rotovator, respectively as compared to mould board plough followed by disc harrow (Pratibha et al., 2019). The ZT or RT with retention of crop residue on surface in different production systems not only produce similar or higher crop yields but also enhances long-term hydrological properties of soils and reduce GHG emissions as compared to conventional tillage systems.

5.2. Integrated Nutrient Management for Carbon Sequestration in Rainfed Crops

Long-term experiments on different rainfed production systems at various centres of All India Co-Ordinated Research Project on Dryland Agriculture (AICRPDA) showed that the integarated use of inorganic fertilizers and organic manures/green manures enhanced the carbon sequestration in different soils. With INM, the C input into soils varied from 1.9 t/ha/year from pearlmillet - clusterbean-castor sequence at S. K. Nagar, Gujarat (Entisol) to 7 t/ha/year from soybean-safflower sequence at Indore, M. P. (Vertisol). The C sequestration rate varied from 0.32 t/ha/year with upland rice-lentil sequence on Inceptisol to 0.89 t/ha/year with winter sorghum at Solapur on Vertisol. The Best Integrated Nutrient Management Practices those produced higher crop yields under rainfed conditions and sequestered more C in soil have been identified for different rainfed soils and presented in Table 2.

Table 2. Carbon sequestration in different rainfed production systems

Location	Production system	Duration (Yrs)	Soil type	Best management practice	C input (t/ha/yr)	C sequestration rate (t/ha/yr)
Anantapur	Groundnut	20	Alfisol	50 % RDF + 4 t/ha ground nut shells	**3.5**	**0.57**
Bangalore	Groundnut-Fingermillet	13	Alfisol	10 t/ha FYM+ 100 % RDF	**3.0**	**0.71**
Bangalore	Fingermillet	17	Alfisol	10 Mg/ha FYM + 100 % RDF	**3.1**	**0.82**
Solapur	Winter sorghum	22	Vertisol	25 kg N/ha CRT + 25 kg N *Leucaena*loppings	**3.4**	**0.89**
S.K. Nagar	Pearlmillet-clusterbean-castor	18	Entisol	50 % RDN + 50 % RDN FYM	**1.9**	**0.42**
Indore	Soybean-Safflower	15	Vertisol	6 Mg FYM ha-1 + N20P13	**7.0**	**1.26**
Varanasi	Upland rice-lentil	21	Inceptisol	100 % organic	**5.6**	**0.32**

5.3. Biochar Impacts on Crop Yields and Soil C Sequestration

Biochar obtained by slow pyrolysis from biomass waste with the primary goal of soil improvement (Lehmann et al. 2006) is highly porous, fine grained, carbon dominant product,rich in paramagnetic centres having both organic and inorganic nature, with large surface area possessing oxygen functional groups and aromatic surfaces. Biochar has the potential to counter change because the inherent fixed carbon in raw biomass that would otherwise degrade to greenhouse gases is sequestered in soil for years. Lehmann *et al*. (2006) estimated a potential global C-sequestration of 0.16 Gt/year can be achieved from biochar production from agricultural and forestry wastes. Biochar will reduce emission of non-CO_2 greenhouse gases by soil that could be due to inhibition of either stage of nitrification and/or inhibition of denitrification, or promotion of the reduction of N_2O; increases CH_4 uptake by soil and long-term C sequestration in soil. The estimated biochar production potential from different crop and woody residues in India is 162 and 32.7 M t/year and combined C sequestration potential of this available biochar incorporation in soil is 95 Mt/year (Venkatesh et al., 2018). Nine years of experimentation on the residual influence of different biochars in rainfedAlfisols under maize revealed that the application of biochar prepared from maize stalks was proved better than biochar prepared from castor, cotton and pigeon pea stalks in influencing the soil available N and P and maize yield. Maize (DHM 117) grain yield varied from 0.26-3.14 t/ha under maize stalk biochar; 0.34-2.72 t/ha under castor stalk biochar; 0.33-2.97 t/ha under cotton stalk biochar and 0.49-2.32 t/ha under pigeonpea stalk biochar across the combination of organic and inorganic fertilizers with different dosage rates (Venkatesh *et al*., 2018). In another experiment with pigeonpea in Alfisol, application of 3 to 6 t/ha pigeonpea biochar every year or alternate years produced higher pigeanpea seed yield as compared to cotton and castor biochars. Castor biochar application had no significant effect on pigeonpea seed yield. Application of 3 to 6 t/ha cotton biochar or pigeon pea biochar at alternate years produced higher yield as compared to every year application in initial four years. But application of biochars every year maintained higher organic C content in soils as compared to alternate year application. As expected, application 6 t/ha biochar increased the organic C content in Alfisol significantly over the 3 t/ha application, irrespective of source of biochar(Venkatesh *et al.,* 2018).

5.4. C Sequestration through Bio-fuel Crops

Total carbon sequestered by 8 year old *Jatropha curcas* in Alfisol was 151.84 t/ha and the percent contribution of above and below ground dry biomass to the total biomass (305.19 t/ha) was in the order of 77.22 and 22.78 %, respectively. Studies on role of bio-fuel crops in rural energy supply and GHG mitigation revealed that the above and belowground biomass accumulated by 8-year-old *pongamia* was 20.91 and 18.63 t/ha, respectively. The share of total carbon by above ground parts and below ground parts of the tree was 55.15% and 44.85%, respectively and the total carbon sequestered by 8 year old *Pongamia* trees was 17.06 t/ha. Quantification of biomass and C stock showed that total above and below ground biomass of *Simaroubaglauca* was 45.54 t/ha and biomass C was 18.89 t/ha and total above and below ground biomass of *Azadirachtaindica* was 45.29 t/ha and biomass C was 18.11 t/ha Measurement of GHG emissions (CO_2, CH_4 and N_2O) in plantations of *Jatropha curcas, Pongamiapinnata and Simaroubaglauca* showed that emissions were higher in rainy season compared to winter season. Initial results indicated that among the three biofuel species, *jatropha* had the highest values for CO_2-Cemissions followed by *pongamia, simarouba*, neem and *tectona*.Whereas, N_2O emissions from soils were higher under pongamia followed by jatropha, *simarouba,* neem and t*ectona*(Table 3) (Rajeshwar Rao *et al*., 2018**)**.Agro-forestry trees which have low gestation period, high C sequestration potential, low GHGs emissions from soils and higher productivity should be selected for agro-forestry on marginal lands of dry areas.

Table 3. Greenhouse gas (GHG) emissions from Alfisol soil under bio-fuel crops

Plantation	CO_2-C flux (t/ha/year)	CH_4-C flux (t/ha/year)	N_2O flux (t/ha/year)
Jatropha	7.72	0.023	0.017
Pongamia	7.63	0.008	0.019
Simarouba	6.96	0.061	0.014
Neem	5.51	0.010	0.009
Tectonagranidis	4.39	0.010	0.004
			Source: Rajeshwar Rao *et al.* (2018)

5.5. Organic Farming

Organic farming aims to self-sufficient in nitrogen. Mixed organic farms practice highly efficient recycling of manures from livestock and of crop residues by composting. Leguminous crops deliver additional nitrogen in sufficient quantities particularly on livestock less organic farms. Emissions of nitrous oxide are directly linked to the concentration of easily available mineral nitrogen in soils. High emission rates are detected directly after fertilization and are highly variable. Denitrification is additionally enhanced in compacted soils. According to IPCC, 1.5% of nitrogen fertilizer applied is emitted as nitrous oxide. In organic farming, the ban of mineral nitrogen and the reduced livestock units per hectare considerably reduce the concentration of easily available mineral nitrogen in soils and thus N_2O emissions. Furthermore, these factors add to lower emissions of nitrous oxide: (i) Diversified crop rotations with green manure improve soil structure and diminish emissions of nitrousoxide, (ii) Soils managed organically are more aerated and have significantly lower mobile nitrogen concentrations. Both factors reduce emissions of nitrousoxides. (iii) Organic land management may help to stop soil erosion and convert carbon losses into gains, particularly due to: (i) the use of green and animalmanure, (ii) soil fertility-conserving crop rotations with intercropping and covercropping, and (iii) compostingtechniques. Results of field experiment conducted on Alfisol soil revealed that the seed yield of sunflower was 14% and 7% higher in the plots under INM than that under inorganic and organic management. However plots under organic management gave marginally higher seed yield of greengram and pigeonpea. Plots under organic management recorded significantly higher soil organic C (Sammi Reddy *et al*., (2019). Organic management treatments produced significantly lower N_2O emissions under all the three crops as compared to INM and inorganic nutrient management. But contrarily CO_2 emissions were higher under organic management followed by integrated nutrient management and inorganic nutrient management (Sammi Reddy *et al*., 2019).

5.6. Assessing GHGs in Rainfed Crops

Among different rainfed crops, CO_2 emissions were higher from leuceana agro-forestry system (51.9 mg CO^2-C/m^2/hour) Maximum amount of N_2O fluxes were observed after fertilizer application. Relatively higher emissions in sorghum, redgram and leucaena in comparison to cenchrus could be due to the interculral operations being taken up in these systems to control weeds, Interculture results in physical disturbance of the surface soil resulting in the release of CO_2 trapped in the soil air space and also due to the biological oxidation of soil. Nitrous oxide fluxes were observed from all rainfed crops. The magnitude of N_2O fluxes during the season varied from 14-68 µg/m^2/hour. Relatively highest N_2O emissions were observed in Redgram (32 µg/m^2/hour) whereas lowest were observed in castor. The N_2O fluxes in agricultural soils depends on fertilizer application during the current year and the N applied to previous crops, the biological N fixation by legumes and the atmospheric N deposition. In addition to this, plant residues also provide substrate for nitrification and denitrification, leading to N_2O production. Relatively higher N_2O emissions from redgram and leucaena might be due to the leguminous nature of these two crops and also higher ability to produce large quantities of residues which have relatively higher N content.

5.7. Efficient N Management for Enhancing its Use Efficiency

The three most important agricultural greenhouse gases (GHGs) are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Nitrous oxide is 310 times more potent than carbon dioxide and is a very important GHG emitted from field crops. For example, 61% of GHG emissions from corn production are from N_2O and production of nitrogen (N) fertilizer (Wightman et al. 2015). Nitrous oxide is a gas produced naturally by soil microbes. Much more N_2O is produced when there is abundant nitrogen in the soil, such as after application of manure or synthetic nitrogen fertilizer. Improving nitrogen fertilizer management is one of the most effective GHG reduction strategies that farmers can adopt. The opportunities for reducing the GHGs emissions from fertilizer and manure are, (i) Use the 4 Rs of fertilizer management to reduce N_2O emissions. (ii) Reduce the use of synthetic nitrogen fertilizer to reduce GHG emissions. (iii) Use appropriate manure management practices to reduce GHG emissions. (iv) Use appropriate crop rotations to reduce N_2O emissions. (v) Use cover crops to reduce N_2O emissions and (vi) Develop and use a comprehensive nutrient management plan.

Applying nitrogen fertilizer from the Right source at the Right rate, Right time, and Right place increases crop yield and profitability, while also greatly reducing GHG emissions. These 4 Rs should be used all together in a comprehensive plan appropriate for the cropping system, and accounting for all sources of nitrogen input to crop fields.

5.8. Roots and Carbon Sequestration in Soils

Root system perform several vital functions that are essential to growth and development of plants such as anchorage and support, absorption and conduction, storage, synthesis, sensing and signaling etc. In addtion to these functions, roots also play a crucial role in the storage and turnover of carbon in the terrestrial ecosystem. The investigations conducted with rainfed crops on Alfisol soils showed that the biomass of roots of different crops was much lower than the respective shoot biomass at late flowering stage. The roots expressed as the % of total biomass varied from 12.1 in horsegram to 28.6 in maize. Residue N and lignin contents exert the greatest control over the decomposition process. Residue N concentration, C/N and lignin/N ratios were important parameters that determine the decomposability due to the influence of N availability on microbial metabolism (Parton *et al*., 2007).The lignin/N ratio which integrates the two important characteristics governing plant residue decomposition, has been found to be better indicator of chemical recalcitrance than lignin content alone and used extensively to distinguish plant residue that are difficult to degrade due to high lignin/N ratio. Studies on mineralization of roots and shoots of the above crops showed that the percent C mineralized in 120 days was 37.5% in roots and 50.2% in shoots due to wider C/N and lignin/N ratios in roots.

These results suggest that roots which have higher lignin/N and C/N ratios than shoots decompose moreslowly and thus may contribute proportionately more to the formation of stable organic matter in soil

(Srinivas *et al*., 2017). Any strategy that increases the quantity of C allocated below ground C, will result in greater C sequestration in soils. Since potential for C sequestration in deeper soil layers is large, crop varieties that have deeper root system should be selected. Therefore, crop varieties with greater root biomass, rooting depth, and recalcitrant constituents can be selected for cultivation to achieve the higher C sequestration in soil to mitigate the climate change.

5.9. Mitigation Potential of Climate Resilient Practices in Reducing GHGs and Enhancing C Balance

In addition to soil management practices, **c**limate resilient agriculture also consists of preparedness measures such as documentation of aberrant weather conditions, weather based agro-advisory, awareness about the impacts of weather, etc. In case of water, resilient practices consists of aquifer recharge, ground water recharge, in-situ-moisture conservation, farm ponds, efficient application system, etc. The climate resilient villages (CRVs) envisages implementing these resilient practices at a scale to cover the entire village in a saturation mode depending on the resources of the farmers with one or several interventions for imparting resilience to the production systems.

. A number of climate resilient practices are being demonstrated in climate resilient villages (CRVs) (initiated during 2010-11) with an objective to enhance the adaptive capacity to the growing climate risks. Some of these practices are being accepted by the farming community and are being scaled up not only in the village but also across the villages.A number of these practices besides enhancing the adaptive capacity also contributes to the mitigation.Quantifying the mitigation potential at village level is important in view of the necessity to reduce the emissions from the agriculture sector.The study area is located in East India, and 16 climate vulnerable villages were selected from Bihar, Jharkhand, West Bengal and Andaman and Nicobar Island of East India**.** These districts were selected under the NICRA project based on the climatic vulnerability data of past 30 years. Eastern India, mainly Bihar, Jharkhand, West Bengal and Andaman and Nicobar Islands are subjected to droughts, floods, cyclones. These regions predominantly follow rice based cropping systems and vegetables.

GHG emissions from annuals, perennials, irrigated rice, fields with inputs use (fertilizers), different land use, afforestation /deforestation and livestock were calculated using the EX-ante Appraisal Carbon-balance tool (Ex-ACT) (http://www.fao.org/tc/exact/ex-act-home/en/). Ex-ACT consists of a set of linked Microsoft Excel sheets in which basic data on land use and management practices is to be inserted as it is an excel based model. It is a C balance calculator developed by FAO for ex-ante measurements of the impact of agriculture and forestry development projects on GHG emissions. Tier 1 approach was used to calculate C balance in tonnes of CO_2 equivalent (t CO_2eq) for 20 years.

Exact model predictions in the 16 study villages showed that there was lot of scope to enhance the sink capacity in East India by adopting improved management practices. The overall C balance was found to be negative in all the study villages suggesting a sink except in Sadanandpur village, Bihar, Chopanadih, Dulsulma&Murma and Gunia villages of Jharkhand, Bhongeri village of West Bengal and Portmount&Badmashpur village of Andaman & Nicobar Islands. When studied individually, the major source of emission in all the study villages was livestock, while the major source of sink in all the study villages were annuals, perennials and afforestation (Table 4) (Sammi Reddy *et al*., 2020). The emissions (source) as well as sink was observed due to irrigated rice, forest & non-forest land use change and fertilizer use in some of the study villages. The overall C balance in all the study villages was found negative suggesting sink. When the C balance from all the components (annuals, perennials, irrigated rice, fertilizer/inputs, livestock land use change) are combined, the overall C balance suggests that the sink potential was higher than emissions.

Vetter *et al* (2017) reported that livestock and rice production are the main sources of GHG emissions in Indian agriculture.

Table 4. Module-wise C balance in climate vulnerable villages of Eastern India

Village		C balance (t CO_2-eq)						
	Annuals	Perennials	Irrigated rice	Forest land use change	Non-forest land use change	Livestock	Fertilizer use	Overall C balance(t CO_2 eq)
V_1	-25936	-2789	-776	--	44815	11145	10429	36888
V_2	-26974	-139	-1989	-22.4	-2031	3380	-905	-28680
V_3	-1613	--	115	-3044.8	-434	2678	-221	-50335
V_4	-6625	--	-3444	-174	3973	1284	737	-4249
V_5	-1538	-227	-8341	-2.7	828	7730	-1178	-104309
V_6	-109961	-6798	-7824	-692.4	54018	2827	-11224	-79654
V_7	-90628	-6798	-7824	-692.4	19275	3365	-14877	-98179
V_8	-4003	-523	--	--	3380	2888	-576	1166
V_9	-3800	-523	154	16.5	2415	9172	2589	10024
V_{10}	-4448	-1569	-104	-42.9	-7097	2340	1974	-8947
V_{11}	-1775	-687	946	-12.2	-937	4906	2304	-8516
V_{12}	-10714	-5667	-1407	199	7976	1581	3742	-4290
V_{13}	-16317	-480	525	-12.9	2189	1623	3549	-8924
V_{14}	-5686	-4131	--	--	2787	2171	2129	-2730
V_{15}	-7957	-906	-7818	35.0	15044	2551	2520	3469
V_{16}	-1073	-1064	1054	112.2	357	1372	723	1481

Note:- V_1-Sadanandpur; V_2-Kukurha; V_3-Manjhil; V_4-Harigaon; V_5-Sakrorha; V_6-Affaur; V_7-Darihara; V_8-Chopanadih; V_9-Dulsulma&Murma; V_{10}-Lowkeshra; V_{11}-Gunia; V_{12}-Mardanpur; V_{13}-Khagribari; V_{14}-Brozolala tota; V_{15}-Bhongeri; V_{16}-Portmount &Badmashpahar.

V_1-V_7 -villages of Bihar, V_8-V_{12}- villages of Jharkhand; V_{13}-V_{15}- villages of West Bengal; V_{16}- village of Andaman and Nicobar Island

Source: Sammi Reddy *et al*. (2020)

6. Conclusions

Climate Resilient Agriculture (CRA) is the agriculture system that reduces poverty and hunger in the face of climate change, and improving the resources it depends on for future generations. Four pillars of CRA are the enhancing productivity, climate change mitigation, adaptation and enhancing livelihoods. Direct drivers of climate change are greenhouse gas emissions and the resulted increased in atmospheric temperature and erratic distribution of rainfall. Several studies earlier revealed that the climate change and variability adversely affect the crop production due to weather aberrations such as drought, prolonged dry spells, late onset of monsoons, unseasonal rainfall, excess rainfall etc. Rainfed areas are more vulnerable to climate change and variability. In agriculture, after enteric fermentation, soil management, manure management and crop residue burning are the major contributors to the GHG emissions.

Therefore efficient soil management practices which reduce GHGs emissions, increase N use efficiency, enhance short and long term quality of soils and crop productivity are major climate resilient practices in rainfed agriculture. Several studies revealed that there is ample scope of enhancing the SOC stocks in rainfed soils by adopting climate resilient agriculture practices such as conservation agriculture, integrated nutrient management, agro-forestry, enhanced root production, etc. Increasing SOC can improve soil health and additionally reduce GHG emissions. Thus the intensification of SOC has gained major attention in terms of climate change. Promotion of reduced tillage or minimum tillage with disc harrow in rainfedAlfisols of semiarid regions for reducing energy consumption and mitigation of GHG emissions is very essential.Climate resilient agriculture also consist of preparedness measures such as documentation of aberrant weather conditions, weather based agro-advisory, etc. In case of water, resilient practices consists of aquifer recharge, ground water recharge, in-situ-moisture conservation, farm ponds, efficient application system, etc. The climate resilient villages (CRVs) consists of implementing these resilient practices at a scale to cover the entire village in a saturation mode for imparting resilience to the production systems. Implementation of these practices in 16 CRVs of eastern India for the last 8 years proved that the village system acted as the sink for C rather than source of GHG emissions. Ultimately the economics and policy driven incentives can make farmers to effectively adopt the climate resilient practices that help to meet the national intended targets to reduce the GHG emissions and improve soil health.

7. References

Allen, D. K., Singh, B. P. and Dalal, R. C. (2011) Soil health indicators under climate change: A review of current knowledge. In: Soil Health and Climate Change: Soil Biology (Editor: Singh B. P.), Springer - Verlag, Berlin. pp. 1-29.French, S., Levy-Bosch, D.

BUR (2018) Second Biennial Report to the United Nations Framework Convention on Climate Change, Ministry of Environment, Forest and Climate Change, Government of India. pp. 1-228.

FAO (2007) Conservation Agriculture, Agriculture and Consumer Protection Department, Food and Agriculture Organization, United Nations, http://www.fao.org/ag/ca/.

French, S. Levy-Booth, D., Samarajeewa, A., Shannon, K. E., Smith, J. and Trevors, J.T. (2009) Elevated temperatures and carbon dioxide concentrations: effects on selected microbial activities in temperate agricultural soils. World J MicrobiolBiotechnol 25:1887–1900.

Groenigen, K. J., Six, J., Hungate, B. A., Graaff, M. A. de., Breemen, N Van, and Kessel, Ch.Van (2006) Element interactions limit soil carbon storage. Proceedings of the National Academy of Sciences of the United States of America 103 (17): 6571-6574.

Hungate, B. A., Stiling, P. D., Dijkstra,P., Johnson, D. W., Ketterer, M. E., Hymus, G. J., Hinkle, C. R. and Drake, B. G. (2004) CO_2 Elicits Long-Term Decline in Nitrogen Fixation. Science 304:1291.

Kumar, U., Jain, M.C., Pathak, H., Kumar, S. and Majumdar, D. (2000) Nitrous oxide emissions from different fertilizers and its mitigation by nitrification inhibitors in irrigated rice. Biol. Fertil. Soils 32:474–478.

Lehmann, J.,Gaunt, J. and Rondon, M. (2006) Biochar sequestration in terrestrial ecosystems: A review. Mitigation Adaptation strategies Global change 11(2): 395-419.

Parton, W., Silver, W. L., Burke, I. C., Grassens, L., Harmon, M. E., Currie, W. S., King, J. Y., Adair, E. C., Brandt, L. A., Hart, S. C., and Fash, B. (2007) Global scale similarities in nitrogen release patterns during long-term decomposition. Science 315: 361-364.

Prabhakar, M. (2019) Personal communication.National Innovations in Climate Resilient Agriculture (NICRA), ICAR-Central Research Institute for Dryland Agriculture, Hyderabad.

Pratibha, G., Srinivas, I., Rao, K. V., Raju, B. M. K., Shanker, K. Arun, AnamikaJha, Uday Kumar, M., Srinivasa Rao, K. and Sammi Reddy, K. (2019) Identification of Environment Friendly Tillage Implement as a Strategy for Energy Efficiency and Mitigation of Climate Change in Semiarid Rainfed Agro Ecosystems. Journal of Cleaner Production 214(2019): 524-535.DOI: https://doi.org/10.1016/j.jclepro.2018.12.251.

Pratibha, G., Srinivas, I., Rao, K. V., Shanker, K. Arun, Raju, B. M. K., Deepak K. Choudhary, Srinivasa Rao, K., Srinivasa Rao, M. and Maheswari, M. (2016) Net global warming potential and greenhouse gas intensity of conventional and conservation agriculture system in rainfedsemi arid tropics of India. Atmospheric Environment 145: 239-250.

Rajeshwar Rao, G., Prabhakar, M., Venkatesh, G., Srinivas, I. and Sammi Reddy, K. (Editors) (2018) Agroforestry Opportunities for Enhancing Resilience to Climate Change in Rainfed Areas.National Innovations in Climate Resilient Agriculture. ICAR - Central Research Institute for Dryland Agriculture. Pp. 1-224.

Rao, Ch. S., Kundu, S., Shanker, A. K., Naik, R. P., Vanaja, M., Venkanna, K., Shankar, G. R. M., and Rao, V. U. M. (2016) Continuous cropping under elevated CO2: Differential effects on C4 and C3 crops, soil properties and carbon dynamics in semi-arid Alfisols. Agriculture, Ecosystems and Environment 218: 73-86.

Sammi Reddy, K., Prabhakar, M., Sharma, K. L., Rama Rao, C. A., Vanaja, M., Srinivasa Rao, M., Gopinath, K. A., Sarkar, B., Ramana, D. B. V., Subba Rao, A. V. M., SharathChandran, M. A., Pankaj, P. K., Prasad, J. V. N. S., Bhaskar, S. and Alagusundaram, K. (2019) Research Highlights (2016-18). National Innovations in Climate Resilient Agriculture (NICRA), ICAR – Central Research Institute for Dryland Agriculture, Hyderabad.P. 128.

Sammi Reddy, K., Rao, Ch. S., GirijaVeni, V., Prasad, J. V. N. S., Sharma, K. L., Sumanta,K., Chandrasekhar, Ch., Jha, R. K., Choudhary, S. K., Deokaran, Mishra, N., Shobha Rani, Singh, V. K., Das, L. K., Ekka, A. B., Sanjay Kumar, RanjayKumar,S., Biswas, S., Gangopadhyay, P. K., NilenduJyoti, M., Ram Nagesh, Rahman, F. H., Anjani Kumar, Singh, S. S., and Singh, A. K. (2020) Mitigation strategies to enhance carbon sink potential in climate vulnerable districts of Eastern India. Climate and Development, https://doi.org/10.1080/17565529.2020.1780190.

Sardans, J., Penuelas, J. 2005. Drought decreases soil enzyme activity in a mediterraneanquercus ilex l. Forest. Soil Biology and Biochemistry 37: 455-461.

Sharma, K. L., Srinivasarao, Ch., Suma Chandrika, D., Munna Lal, Indoria, A. K. , Thakur, P. K., Srinivas, K., Sammi Reddy, K. and Usha Rani, K. (2017) Effect of Graded Levels of Surface Crop Residue Application Under Minimum Tillage on Carbon Pools and Carbon Lability Index in Sorghum (Sorghum bicolor (L.) Moench)-Cowpea (Vignaunguiculata) System in RainfedAlfisols, Communications in Soil Science and Plant Analysis, 48 (21):2506-2513.

Srinivas, K., Maruthi, V., Ramana, D. B. V., Vimala, B., Nataraja, K. C., Sharma, K. L., Srinivas Rao, M., Maheshwari, M.., Prabhakar, M. and Sammi Reddy, K. (2017) Roots of rainfed crops: biomass, composition and carbon mineralization. Research Bulletin 01/2017. ICAR – Central Research Institute for Dryland Agriculture, Hyderabad, India. Pp. 1-68.

Tobert, H.A., Prior, S.A., Rogers, H.H. and Runion, G.B. (2004) Elevated atmospheric CO2 effects on N fertilization in grain sorghum and soybean. Field Crops Res. 88 : 57-67.

Vanaja, M., Sathish, P., Jyothi Lakshmi, N., Vijayakumar, G., Vagheera, P., Mohan, C. H., Yadav, S. K., Sarkar, B., Maheshwari, M. and Sammi Reddy, K. (2019) Elevated CO_2 ameliorate the negative effects of high temperature on groundnut (Arachis hypogea) – Studies under free-air temperature elevation. Journal of Agrometreology 21(4): 411-419.

Venkatesh, G., Gopinath, K. A., Sammi Reddy, K.,Sanjeeva Reddy, B., Prasad, J V N S., Rajeshwar Rao, G., Pratibha, G., Srinivasarao, Ch., Ravindra Chary, G., Prabhakar, M., VishaKumari, V., Arun Kumar Shankar, and Venkteswarlu, B. (2018) Biochar production and its use in rainfed agriculture: Experiences from CRIDA. CRIDA-NICRA Research Bulletin 02/2018. National Innovations in Climate Resilient Agriculture, Central Research Institute for Dryland Agriculture, Hyderabad.Pp.1-50.

Vetter, S.H., Sapkota, T.B., Hillier, J., et al., 2017. Greenhouse gas emissions from agricultural food production to supply Indian diets: implications for climate change mitigation. Agric. Ecosyst. Environ. 237, pp. 234-241.

Wightman, J. L., J. M. Duxbury, and P. B. Woodbury. 2015. Land Quality and Management Practices Strongly Affect Greenhouse Gas Emissions of Bioenergy Feedstocks. BioEnergy Research 8:1681-1690.

Climate Smart Agriculture through Rainwater Management Technologies

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Rain water is the primary constraint defining the semi-arid tropics (SAT) and is a limiting resource for sustainable agriculture in the SAT. If not managed properly, it affects crop productivity significantly and causes land degradation through runoff and associated soil loss. Out of 140.30 m ha net cropped area in India, nearly 83.90 m ha is the net rain-fed area and the remaining 56.40 m ha is the irrigated area. The SAT is characterized by high water demand with a mean annual temperature greater than 18 °C where rainfall exceeds evapotranspiration for only 2 to 4.5 months in the dry and 4.5 to 7 months in the wet-dry semi-arid tropics (Troll, 1965).The coefficient of variation for the annual rainfall ranges between 20 and 30 per cent in these dry regions. Along with the erratic rainfall, increasing population, rising demand of water for non-agricultural uses is proportionally reducing the water availability for agriculture, which is the lifeline for rural poor. Thus efficient management of rainwater through water harvesting and efficient water use technologies is the solution for increasing productivity, reducing poverty, and maintaining the natural resource base in the SAT.

The average annual rainfall in India is about 1170 mm. Most rain falls in the monsoon season (June-September), necessitating the creation of large storages for maximum utilisation of the surface run-off. Within any given year, it is possible to have both situations of drought and floods in the same region. Regional variations are also extreme, ranging from a low value of 100 mm in Western Rajasthan to over 11,000 mm in Meghalaya in North-Eastern India. Possible changes in rainfall patterns in the coming decade, global warming and climate change could affect India's water resources.

The peninsular India consists of four agri based important states namely Andhra Pradesh, Tamil Nadu, Karnataka and Kerala representing the different topograpy and climate. Andhra Pradesh receives its rainfall both from South-West (SW) and North-East (NE) monsoons. There is a wide variation of the rainfall between the different districts of the State. The six north coastal districts and three north telangana districts receive more than 1,000 mm per annum, while a scanty rainfall below 700 mm is registered in Kurnool, Anantapur and Kadapa Districts. The lowest is recorded in Anantapur District (568 mm), while Vizianagaram District has the highest rainfall (1,159 mm) on an average.

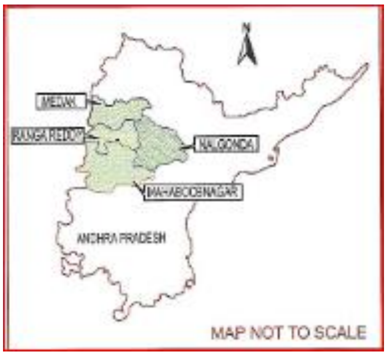
The average annual rainfall of Tamil Nadu is 912mm. Tamil Nadu occupies 4% of India's geographical area while it has only 3% of the water resources at all India level. The occurrence and distribution of rainfall in the Karnataka is highly erratic. The annual normal rainfall is 1138 mm received over 55 rainy days. It varies from as low as 569 mm in the east to as high as 4029 mm in the west. About 2/3rd of the geographical area of the state receives less than 750 mm of rainfall. Even assured rainfall areas of the state experience scarcity of water in some years.Kerala gets on an average of 307 cm rainfall, the bulk of which (70%) is received during the South-West monsoon which sets in by June and extends upto September. The state also get rains from the North-East monsoons during October to December.The state experience severe summer from January to May when the rainfall is minimum. The two monsoons have a direct bearing on the ground water potential of the state which also follows the same seasonal trends.

In-situ Rain water management practices in Peninsular India

Conservation furrows:

Castor is an important non-edible oilseed crops grown by the rainfed farmers in Alfisols of southern Telangana . The productivity of this crop in the region is very low due to shallow soils and frequent dry spells.

The dry spells occur at early (0-45 DAS), mid (45-90 DAS) and terminal (90-120 DAS) growth stages of the crop and reduce potential yields considerably. This involves management of drought through a package of practices covering (i) sowing of drought tolerant cultivars of castor like Jyothi, Kranti during June 15th to July 7th week across the slope (ii) formation of conservation furrows for every 2 rows planted at 90 cm apart (iii) operation of blade harrow in between castor rows during early growth stage of the crop and iv) additional nitrogen application 10 kg N/ ha after the relief of the dry spells either at early (up to 45 DAS) or mid (45-90 DAS) growth stages of the crop



Conservation furrows for drought mitigation

Nitrogen application after the relief of dry spell

The adoption of drought management practices as a package gives 35-50% higher yields of castor over farmers practice with a B:C ratio of 1.8. The technology is prevalent in the districts of Mahaboobnagar, Ranga Reddy, Nalgonda and parts of Medak districts in Telangana region.

Compartmental bunding for moisture conservation

In northern dry zone of Karnataka, *kharif* cropping is not possible due to workability and tillage related constraints in medium to deep black soils. Further, infiltration rate is low resulting in more runoff. It involves making square compartments on the field to retain rainwater and arrest soil erosion. After receipt of early rains in June and July, land is harrowed to remove germinating weeds. Then compartmental bunds (0.15 m height) are formed using bullock drawn bund former. The size of the bunds varies from 3 m x 3 m to 4.5 m x 4.5 m depending on the slope. The cost of compartmental bunding is Rs.150/ha. These bunds are retained till the sowing of *rabi* crops, which are sown with seed cum ferti drill during second fortnight of September to first fortnight of October. Compartmental bunds provide more opportunity time for water to infiltrate into the soil and help in conserving soil moisture.

Gravel and sand mulching in sodic soils for moisture conservation

Sodic medium and deep black soils exist on an extent of 2.5 lakh ha in Koppal and Gadag districts in northern Karnataka. The infiltration rate is low and most of the rainwater is lost as runoff in these soils. However, traditionally, some farmers in this region apply locally available gravel and sand mixture as mulch and successfully produce better crops and get more income. The technology involves sand application during summer to sodic vertisols. Before application of sand, perennial weeds like *Cynodon dactylon, Cyperus rotundus* etc., are removed. FYM @ 5 t/ha is applied followed by deep ploughing. After bringing the soil to fine tilth, nearly 275-300 tractor loads/ha of gravel and sand mixture is uniformly applied and spread manually using spades to ensure uniform thickness of 10 to 15 cm on soil surface. The cost of application of gravel sand is Rs.77500/ha (Rs.2500 for labour cost spreading + Rs.75, 000/- for transportation @Rs. 250/tractor loads).

Cover cropping for in-situ moisture conservation in black soils

Farmers keep land fallow during *kharif* in medium to deep black soils of northern dry zone of Karnataka and cultivate sorghum, sunflower and chickpea during rabi. This results in splash erosion and high runoff in *kharif*, which leads to loss of topsoil, decline in soil fertility and crop yields over time.

In order to reduce runoff and splash erosion, cover cropping with quick growing species have been used. These crops include sunhemp, greengram, cucumber, ridge gourd in kharif. These species quickly cover the ground surface in 45 days and reduce run off, conserve rainwater in-situ. Legume cover crops improve soil fertility by adding nitrogen and benefitting succeeding crops when incorporated at harvest or during vegetative stage as in case of sunhemp (at 45 days).

Ridge furrow and Broad Bed furrow systems for moisture conservation

In South Tamilnadu region, where the black cotton soils are predominant, were tried with land configuration systems like ridge furrow and broad bed furrow systems. The spacing of furrows was 45 cm and 1.2 m width broad bed was found suitable in black soils. When the systems are grown with sorghum, the BBF gave the maximum yields followed by ridge furrow and flatbed systems. These systems improved the rainwater use efficiency as well as controls the erosion within the field and provides efficient drainage to the crop for proper growth and yield. The above technology is very useful to the farmers of the rainfed black soils for improving the productivity and profitability.

Farm Pond Technology in Peninsular India as Ex-situ runoff water harvesting from farm fields

Andhra Pradesh, CRIDA has optimized the size of farm ponds and catchment command ratios for different runoff co-efficients. 500 m^3 capacity farm pond of size 17x17 x 3 m and 750 m^3 with size 20 x 20 x 3 m have been suggested to implement in medium to high rainfall regions. The minimum catchment required for such farm ponds varies from 2 to 10 ha depending upon the slope, crops and other multiple uses of water. However, there is a scope for increasing the capacity of the farm ponds in high rainfall regions when planned with cropping system and fish culture. Oil seed crops (ground nut, sunflower, sesamum, soybean, castor and cotton), pulses(redgram, chick pea,blackgram, green gram) and cereals(sorghum,maize) are popularly grown in rainfed areas of AP like Anantapur, mahaboobnagar, Adilabad, Medak, Nizamabad, Kurnool, Prakasam, Chittor and YSR kadapa districts. In addition to the above crops, vegetables can also be planned under farm ponds. Lining of farm ponds is required in red soils regions to arrest seepage and black soils have good potential for water harvesting. The cost of the excavation is estimated to be Rs. 25-30/m^3 of storage. The lining cost of the film(500 micron HDPE/300gsm silpulin) is Rs 80-100/ m^2. Supplemental irrigation at critical stages of flowering and pod filling with 50 mm water has improved the yield of groundnut by 65% over the rainfed.

After the establishment he cultivated groundnut in half acre of land. The water stored in the farm pond was sufficient to irrigate and sustain the crop and he was able to harvest 14 bags of ground nut worth of Rs. 15400 (Rs. 1100 per bag). The net income after deducting all the input and cultivation expenses was Rs. 9400.

Conclusions

The paper deals with different in situ and ex situ rain water harvesting technologies adopted in different regions of peninsular India. Farm pond technology would serve the purpose of climate resilience in rainfed agriculture and found more profitable in black soil regions. The technology will help the farmers to reap multiple benefits from the localised storage of water like fish farming, growing vegetables apart from their traditional crops ensuring both water and food security in the rainfed regions.

Climate change mitigation through soil carbon sequestration

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Climate change

Climate change is a change in the statistical properties of the climate system that persists for several decades - usually at least 30 years. These statistical properties include averages, variability and extremes. Fluctuations over shorterperiods, such as El Niño, do not represent climate change. Climate change may be due to natural processes, such as changes in the Sun's radiation, volcanoes or internal variability in the climate system, or due to human influences such as changes in the composition of the atmosphere or land use.However, the term climate change is sometimes used to refer specifically to climate change caused by human activity, as opposed to changes in climate that may have resulted as part of Earth's natural processes. In this sense, especially in the context of environmental policy, the term climate change has become synonymous with anthropogenicglobal warming. In the academia, global warming refers to surface temperature increases while climate change includes global warming and everything else that global warming causes.

Global warming can be attributed to elevated levels of greenhouse gases in the atmosphere resulting from anthropogenic emissions emanating from burning of fossil fuels, deforestation and land use changes, biomass burning, draining of wetlands, and inappropriate agricultural practices. Among the greenhouse gases emitted from human activities, CO_2 is the most important human-emitted greenhouse gas in the atmosphere. The concentration of CO_2 in the atmosphere has increased from the pre-industrial (before 1750) level of about 280 ppmv (IPCC, 2007) to 414ppmv at present (www.CO2.earth).

Climate change mitigation

Climate change mitigation consists of actions to limit global warming and its related effects. Theseinclude actions that reduce human emissions of greenhouse gases (GHGs) as well as actions that reduce their concentration in the atmosphere.Climate change mitigation is one of the ways to respond to climate change, besides adaptation. Mitigation can mean using new technologies and renewable energies, making older equipment more energy efficient, or changing management practices or consumer behaviour. Protecting natural carbon sinks like forests and oceans,or creating new sinks through silviculture or green agriculture are also elements of mitigation. Sequestering carbon in soil is one of the options for mitigating climate change.

Soil C sequestration

The process of transfer and secure storage of atmospheric CO_2 into other long-lived C pools that would otherwise be emitted or remain in the atmosphere is called carbon sequestration (Lal, 2008). Carbon is found in all living organisms and is the major building block for life on Earth. Carbonexists in many forms, predominately as plant biomass, soil organic matter, and as the gas carbondioxide (CO_2) in the atmosphere, and dissolved in seawater. Soil is a large reservoir of carbon, with about 60% organic carbon in the form of soil organic matter (SOM), and the remaining inorganic carbon in the form of inorganic compounds (e.g., limestone, or $CaCO_3$). It is estimated that SOM stores about twice as much carbon as the atmosphere, and about three times as much as forests and other vegetation. Soil carbon sequestrationis the removal of CO_2 from the atmosphere through plant photosynthesis, and storage as long-lived, stable forms of soil organic matter that is not rapidly decomposed. Changes in soil organic carbon levels can have significant effects on atmospheric CO_2 levels. Each 1% increase in average soil organic carbon content could reduce atmospheric CO_2 by up to 2%.

Through the process of photosynthesis,plants assimilate carbon and return someof it to the atmosphere through respiration.The carbon that remains as plant tissue isthen consumed by animals or added to thesoil as litter when plants die anddecompose.

The primary way that carbonis stored in the soil is as soil organicmatter (SOM). SOM is a complex mixtureof carbon compounds, consisting ofdecomposing plant and animal tissue,microbes (protozoa, nematodes, fungi, andbacteria), and carbon associated with soil minerals. Carbon can remain stored in soilsfor millennia, or be quickly released backinto the atmosphere. Climatic conditions,natural vegetation, soil texture, anddrainage all affect the amount and lengthof time carbon is stored.In agricultural systems, the amount and length of time carbon is stored is determined predominately byhow the soil resource is managed. A variety of agricultural practices can enhance carbon storage in soils.

Transferring atmospheric C to relatively long-lived soil organic matter pools not only reduces atmospheric CO_2 levels, but also enhances the productive capacity of the soil, which in turn enables greater C fixation and transfer, resulting in an atmospheric C negative (desirable) feedback loop. The fact that most soils under managed ecosystems contain a lower SOC pool than their counterparts under natural ecosystems owing to the depletion of the SOC pool in cultivated soils makes SOC sequestration possible and achievable. In general, cultivated soils normally contain 50–75% of the original SOC pool (Lal, 2008). The potential for C sequestration in soil organic matter in the world's soils is estimated to be 0.6–1.2 Pg C yr^{-1} for up to 50 years, suggesting a sink capacity of 30-60 Pg C (Lal, 2004). The build-up of each Mg of soil organic matter removes 3.667 tons of CO_2 from the atmosphere. Increase in the SOC pool also has numerous ancillary benefits affecting local, regional and global processes. Principal benefits of SOC sequestration to soil and ecosystem are: (i) improvement in soil structure, (ii) reduction in soil erosion, (iii) decrease in non-point source pollution, (iv) increase in plant-available water capacity (v) increase in storage of plant nutrients, (vi) denaturing of pollutants, (vii) improvement in soil quality, (viii) increase in crop productivity and food security, (ix) moderation of climate, and (x) increase in aesthetic and economic value of the soil (Lal, 2008). Environmental benefits of SOC sequestration include (i) reduction in sediment load in streams and rivers, (ii) filtration of agricultural chemical pollutants, (iii) serving as reactors for biodegradation of contaminants, and (iv) buffering the emissions of GHGs from soil to the atmosphere. (Lal, 2004)

Management practices for soil carbon sequestration

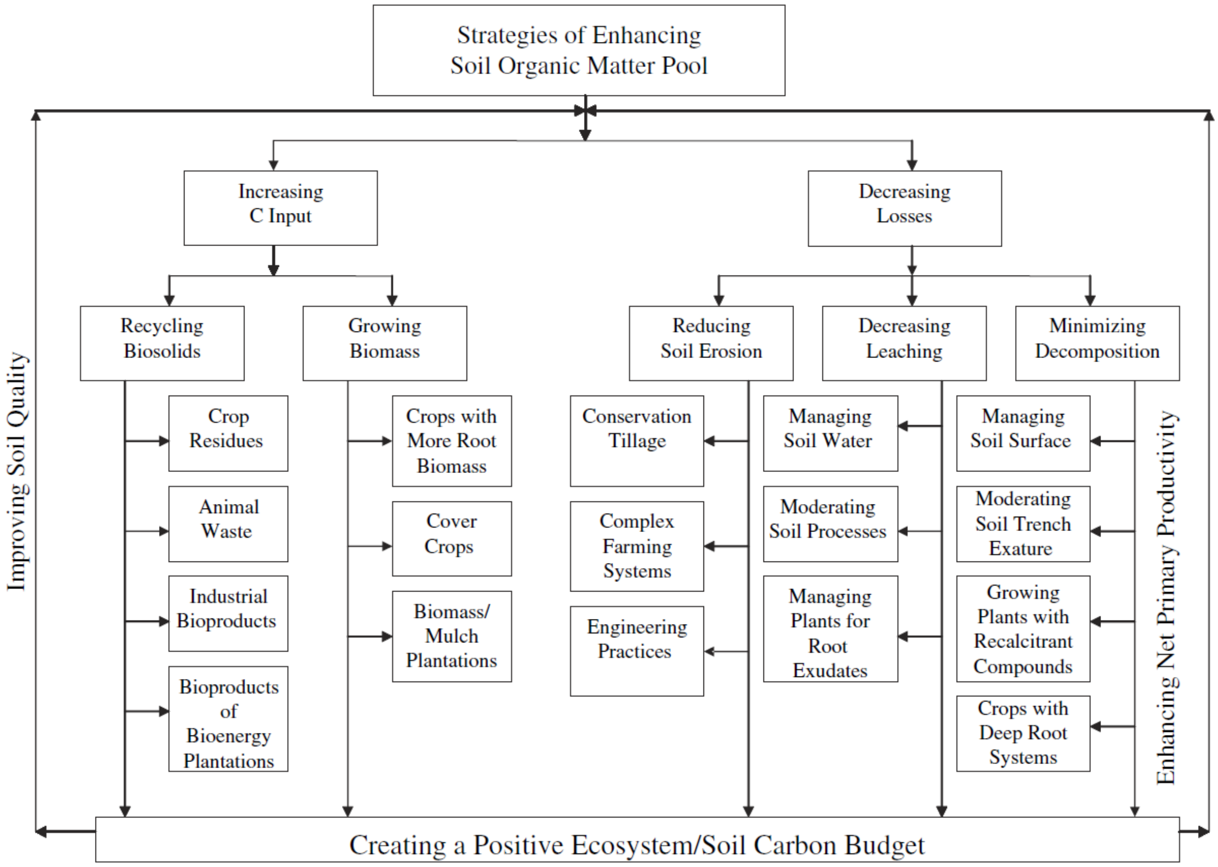
A wide range of the agricultural practices exist for sequestering organic carbon in agricultural soils. Some conventional and improved practices for sequestering carbon in soils are shown in (Table 1). Appropriate practices differ for different soil, crop, and climate conditions. A site-specific approach should be used to select the most appropriate practice to meet local needs by considering all inputs and benefits/costs associated with each input. A life-cycle analysis that considers inputs and associated environmental and economic benefits needs to be applied. For example, no-till or minimum-till has been identified as one of the best practices to sequester soil organic carbon. However, it may require use of herbicides, which have both environmental and economic implications.

Table 1. Conventional and corresponding improved practices for sequestering carbon in soils

Conventional practice	**Carbon sequestering practice**
Biomass burning	Residue use as soil cover
Tillage and clean cultivation	Reduced tillage, surface residue
Fallow	Cover cropping
Monoculture	Diversified cropping system – crop rotation/intercropping/mixed cropping
Low input/subsistence farming	Judicious use of inputs
Intensive chemical fertilizer use	Integrated nutrient management
Intensive cropping	Integrated farming system with crops, trees, livestock

Surface flood irrigation	Subsurface/drip/sprinkler irrigation
Cultivation of marginal soils	Conservation reserves/Plantations for restoring degraded lands

Increases in soil organic carbon can be achieved by 1. arresting losses from soil and 2. increasing inputs to soil. The strategies for enhancing SOM Lal (2009) are shown in the flowchart below.



Losses of organic C from soil

Burning of natural vegetation and crop residues

The burning of maize, rice and other crop residues in the field is a common practice. Residues are usually burnt to render the soil bare and to help control insects or diseases or to make field preparation easier in the following season or just for disposing them off. Burning destroys the litter layer and so diminishes the amount of organic matter returned to the soil. The organisms that inhabit the surface soil and litter layer are also eliminated. For future decomposition to take place, energy has to be invested first in rebuilding the microbial community before plant nutrients can be released. Similarly, fallow lands and bush are burned before cultivation. This loss of nutrients, organic matter and soil biological activity has severe long-term consequences.

Tillage

Tillage is one of the major practices that reduces the organic matter level in the soil. Each time the soil is tilled, it is aerated. As the decomposition of organic matter and the liberation of C are aerobic processes, the oxygen stimulates or speeds up the action of soil microbes, which feed on organic matter. The decomposition is faster, resulting in the formation of less stable humus and an increased liberation of CO_2 to the atmosphere, and thus a reduction in organic matter.

In terms of short-term organic matter loss, the more a soil is tilled, the more the organic matter is broken down (Table 1). There are also longer-term losses, attributed to repeated, annual cultivation. Cropping systems that return little residue to the soil accelerate this decline. Many modern cropping systems combine frequent tillage with small amounts of residue, with resultant reductions in the organic matter content of many soils.

Table 1. Tillage induced flush of decomposition of SOM

Type of tillage	SOM lost in 19 days (kg/ha)
Moldboarld plough + disc harrow twice	4300
Moldboarld plough	2230
Disc harrow	1840
Chisel plough	1720
Direct seeding	860

Source: Glanz (1995)

Organic matter production and conservation is affected dramatically by conventional tillage, which not only decreases soil organic matter but also increases the potential for erosion by wind and water. The impact occurs in many ways:

- Ploughing leaves no residues on the soil surface to lessen the impact of rain.
- Ploughing reduces the quantity of food sources for earthworms and disturbs their burrows and living space, hence populations of certain species decrease drastically. Moreover, reduction of earthworm numbers reduces their impact, through burrowing, in increasing porosity and aeration (particularly continuous macropores) and lowers their ability to bury and incorporate plant residues, which facilitates rapid decomposition of organic matter.
- Tillage by repeated hoeing or disking smoothes the surface and destroys natural soil aggregates and channels that connect the surface with the subsoil, leaving the soil susceptible to erosion. Old root channels and earthworm holes are eliminated, as are the cracks between natural aggregates. The large pores, the ones destroyed by conventional tillage practices, are necessary to conduct water into the soil during rainfall.
- The development of a plough pan or hoe pan, a layer of compacted soil resulting from smearing action at the bottom of the plough or hoe, may retard both root penetration and water infiltration.
- Ploughing or disking under dry conditions exacerbates the pulverization of the soil, causing the soil surface to crust more easily, leading to greater water runoff and erosion. This is exacerbated by reduced soil surface roughness, which leaves few depressions for temporary storage of water during intense storms.
- Increased runoff during rainstorms may also increase the possibility of drought stress later in the season, because water that runs off the field does not infiltrate into the soil to remain available to plants.

Fallowing

Fallowing leads to the loss of SOM as there are no additions of organic matter, but removal by microbial respiration continues. Research results indicate that during fallow the rate of soil organic carbon decomposition is approximately 2 to 2.5 times faster than in a crop year. Thus, to maintain soil organic carbon level, if the fallow frequency is once every two years, the organic carbon input must be 1.5 times higher than in a system with no fallow.

Losses of soil carbon can be reduced by avoiding residue burning and fallowing and adopting zero, reduced or modified tillage.

Increasing organic C in soil
Increase in organic C in soil can be achieved by the following means:

- Increased crop biomass including root biomass
- Cover crops/green manure crops
- Crop rotation
- Perennial forage crops
- Zero or reduced tillage
- Agroforestry

Increased crop biomass production

Carbon fixation by photosynthesis is the primary process through which organic matter is created. Significant increases in crop biomass per unit land area can be achieved by changing/modifyingthe cropping systems.

Crop rotations/Intercropping/Mixed cropping

- Growing a sequence of crops in regularly recurring succession or a combination or mixture of crops on the same area of land mimics the diversity of natural ecosystems more closely than intensive monocropping. Varying the type of crops grown can increase the level of soil organic matter. However, effectiveness of crop rotations depends on the type of crops and crop rotation times. Crop diversity generally results in higher yield. Further, crop diversity Contributes to a more diverse microbial community. Large, deep rooted plants are best for increasing SOC.

Cover crops

Growing cover crops is one of the best practices for improving organic matter levels. The benefits of growing cover crops are:

- They prevent erosion by anchoring soil and lessening the impact of raindrops.
- They add plant material to the soil for organic matter replenishment.
- Some cover crop species bind excess nutrients in the soil and prevent leaching.
- Some, especially leguminous species, e.g. hairy vetch, fix N in the soil for future use.
- Most provide habitat for beneficial insects and other organisms.
- They moderate soil temperatures and, hence, protect soil organisms.

A range of crops can be used as vegetative cover, e.g. grasses, legumes. All have the potential to provide great benefit to the soil. However, some crops emphasize certain benefits; a useful consideration when planning a rotation scheme. It is important to start the first years with (cover) crops that cover the surface with a large amount of residues that decompose slowly (because of the high C:N ratio). Grasses and cereals are most appropriate for this stage, also because of their intensive rooting system, which improves the soil structure rapidly. In the following years, when soil health has begun to improve, legumes can be incorporated in the rotation. Leguminous crops enrich the soil with N and their residues decompose rapidly because of their low C:N ratio. Later, when the system is stabilized, it is possible to include cover crops with an economic function, e.g. livestock fodder. The selection of cover crops should depend on the presence of high levels of lignin and phenolic compounds. These give the residues a higher resistance to decomposition and thus result in soil protection for a longer period and the production of more stable humus.

Crop management

The choice of crops/cropping systems is determined by markets and farmer preferences, so within a given cropping system, higher biomass can be obtained by water, nutrient and pest management.

Water management - Increased water availability for plants: water harvesting and irrigation

In dry conditions, water may be provided through irrigation or water harvesting. The increased water availability enhances biomass production, soil biological activity and plant residues and roots that provide organic matter. The concept of water harvesting includes various technologies for runoff management and utilization. It involves capture of runoff (in some cases through treating the upstream capture area), and its concentration on a runon area for use by a specific crop (annual or perennial) in order to enhance crop growth and yields, or its collection and storage for supplementary irrigation. This aids stabilization of crop production by enhancing soil moisture availability or allowing irrigation during a dry period within the rainy season or by extending crop production into the dry season.

Nutrient management - Balanced fertilization

The application of adequate nutrients through integrated nutrient management ensures greater crop production, greater root growth and greater availability of biomass for recycling. Long term experiments consistently show improvement in soil organic matter with application of recommended doses of nutrients through integrated nutrient management. Fertilizers are needed in those cases where nutrients in the soil are lacking and cannot produce healthy crops and sufficient biomass. Unbalanced fertilization, for example mainly with N, may result in more weed competition, higher pest incidence and loss of quality of the product. Unbalanced fertilization eventually leads to unhealthy plants. Therefore, fertilizers should be applied in sufficient quantities and in balanced proportions. The efficiency of fertilizer use will be high where the organic matter content of the soil is also high. In very poor or depleted soils, crops use fertilizer applications inefficiently. When soil organic matter levels are restored, fertilizer can help maintain the store of nutrients in the soil by increasing crop yields and, consequently, the amount of residues returned to the soil.

Integrated pest management

As with balanced fertilization, proper pest and disease management results in healthy crops. Healthy crops produce optimal biomass, which is necessary for organic matter production in the soil. Diversified cropping and mixed crop-livestock systems enhance biological control of pests and diseases through species interactions. Through integrated production and pest management farmers learn how to maintain a healthy environment for their crops. They learn to examine their crops regularly to observe ratios of pests to natural enemies (beneficial predators) and cases of damage, and on that basis to make decisions as to whether it is necessary to use natural treatments (using local products such as neem or tobacco) or chemical treatments and the required applications.

Addition of organic biosolids such as crop residues, animal manuresand composts, and biochar

Crop residues

In systems where crop residues are managed well, they:

- Add soil organic matter, which improves the quality of the seedbed and increases the water infiltration and retention capacity of the soil, buffers the pH and facilitates the availability of nutrients
- Sequester C in the soil
- Provide nutrients for soil biological activity and plant uptake
- Capture the rainfall on the surface and thus increase infiltration and the soil moisture content
- Provide a cover to protect the soil from being eroded
- Reduce evaporation and avoid desiccation from the soil surface

Animal manures and composts

Any application of animal manure, slurry or other carbon-rich wastes improves the organic matter content of the soil. In some cases, it is better to allow a period of decomposition before application to the field. Any addition of carbon-rich compounds immobilizes available N in the soil temporarily, as micro-organisms need both C and N for their growth and development. Animal manure is usually rich in N, so N immobilization is minimal. Where straw makes up part of the manure, a decomposition period avoids N immobilization in the field.

Composting is a technology for recycling organic materials to achieve enhanced agricultural production. Biological and chemical processes accelerate the rate of decomposition and transform organic materials into a more stable humus form for application to the soil. Composting proceeds under controlled conditions in compost heaps and pits. Compost is very similar in composition to soil organic matter. It breaks down slowly in the soil and is very good at improving the physical condition of the soil (whereas manure and sludge may break down fairly quickly, releasing a flush of nutrients for plant growth). It has ameliorative effects on soil fertility and physical, chemical and biological soil properties. Well-made compost contains all the nutrients needed by plants. It can be used to maintain and improve soil fertility as well as to regenerate degraded soil.

The return of manure and recycled organic materials to the soil is considered the practice with greatest potential to increase SOC levels. Its ability to improve soil carbon levels depends on the amendments' quality – mature composted products are best. The conversion efficiencies of manure are almost twice that of plant residues. In other words, for constant rates of addition, net soil organic carbon accumulation from manure is nearly twice of that from plant residue additions. It is a fact that soil microbial residues are more resistant to decomposition than plant residues. It is postulated that the slower decomposition of manure in soils results from the fact that manure consists of largely partially decomposed products. Similarly, products of aerobic composting and anaerobic digestion are also expected to have higher efficiencies for increasing soil organic carbon content than plant materials.

Generally, decline in SOM in soils is attributed mainly to tillage and removal of above ground biomass. If the above ground biomass is used in animal production and manure is returned to the soil, what is the implication for long-term soil organic carbon sequestration? Approximately one half of the carbon in the animal feed is present in the manure. Since manure is nearly twice as efficient in storing organic carbon in soils, if manure is returned to the soil, it will be as effective in maintaining soil organic carbon level as in a natural system in which most of the plant biomass is returned to the soil.

Biochar

Biochar is a microbially resistant carbon substance which is produced by heating organic wastes such as crop residues or wood chips in the absence of oxygen by a process called pyrolysis. Ordinary biomass fuels are carbon neutral; the carbon captured in the biomass by photosynthesis is eventually returned to the atmosphere through natural processes like decomposition. Sustainable biochar systems can be carbon negative by transforming the carbon in biomass into stable carbon structures in biochar which can remain sequestered in soils for hundreds and even thousands of years. The result is a net reduction of CO_2 in the atmosphere

Role of plant roots in soil C sequestration

Roots represent direct inputs of carbon into the soil system, and as such have the potential to make major contributions to SOM stocks. In addition to the spatial location within the mineral soil, roots generally decay slower than aboveground residue (Silver and Miya 2001; Rasse*et al.,* 2005) due to litter quality as well as environmental factors (Crow *et al.,* 2009; Kogel-Knabner 2002). Many studies suggest that the relative contribution of plant roots to soil organic C stocks is larger than that of plant shoots. Root biomass has considerable value for SOC storage because of the significant amount of C contained in these residues and the fact that they are less easily mineralized, thus more likely to become chemically or physically stabilized in deeper soil layers (Bolinder*et al.* 1999). Mycorrhizal fungi also play a significant role in sequestering carbon in soil.

The scope for sequestering atmospheric C in soil by managing plant roots and root associated fungi is substantial. Any strategy that increases the quantity of C allocated belowground, enhances the recalcitrance of belowground inputs, or retards the decomposition of belowground C, will result in greater C sequestration in soil. In agroecosystems, such strategies include crop improvement through breeding or biotechnology, choice of cultivars, crops and cropping systems (intensive cropping, intercropping, mixed cropping, rotational cropping, alley cropping with tree components, etc.), and soil and crop management practices. Since potential for C sequestration in deeper soil layers is large, crop cultivars that express deeper and denser rooting characteristics will present greater opportunities for C sequestration. There is considerable scope for increasing the depth of roots by appropriate breeding strategies (Kell, 2011). Subsoil C sequestration may be achieved by higher inputs of fairly stable organic matter to deeper soil horizons. This can be achieved directly by selecting plants/cultivars with deeper and thicker root systems that are high in chemically recalcitrant compounds like suberin. Furthermore, recalcitrant compounds could be a target for plant breeding/biotechnology to promote C sequestration (Lorenz and Lal, 2005). Breeding crops that could cover present cropland areas but that had roots a metre deeper in the soil could double the amount of carbon captured from the environment (Kell, 2011). Agricultural practices that promote root colonization by AM fungi (choice of crops and varieties and crop rotations, avoiding planting of non-mycorrhizal crops such as crucifers, avoiding fallowing and tillage, refraining from fungicide use, avoiding tillage, organic agriculture, etc.) will promote C sequestration in soil.

References

Bolinder M A, Angers D A, Giroux M and Laverdiere M R 1999. Estimating C inputs retained as soil organic matter from corn (*Zea mays* L.). Plant and Soil, 215:85–91.

Crow, S.E., Lajtha, K., Filley, T.R., Swanston, C.W., Bowden, R.D. and Caldwell, B.A. 2009. Sources of plant-derived carbon and stability of organic matter in soil: Implications for global change. Global Change Biology, 15: 2003-2019.

Glanz, J. 1995. Saving our soil: solutions for sustaining earth's vital resource.Johnson Books, Boulder, USA.P. 182.

IPCC. 2007. Climate Change 2007: The Physical Science Basis. Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, U.K., and New York, U.S.A..

Kell, D.B. 2011. Breeding crop plants with deep roots: their role in sustainable carbon, nutrient and water sequestration. Annals of Botany,108: 407–418.

Kogel-Knabner, I. 2002.The macromolecular organic composition of plant and microbial residues as inputs to soil organic matter. Soil Biology and Biochemistry, 34: 139-162.

Lal, R. 2004. Soil carbon sequestration to mitigate climate change. Geoderma, 123: 1–22.

Lal, R. 2008. Carbon sequestration. Philosohical Transactions of the Royal Society B, 363, 815–830.

Lal, R. 2009. Challenges and opportunities in soil organic matter research. European Journal of Soil Science, 60, 158-169.

Lorenz, K. and Lal, R. 2005. The depth distribution of soil organic carbon in relation to land use and management and the potential of carbon sequestration in subsoil horizons. Advances in Agronomy, 88: 35-66.

Rasse, D.P., Rumpel, C. and Dignac, M-F., 2005. Is soil carbon mostly root carbon? Mechanisms for a specific stabilization. Plant and Soil, 269: 341–356.

Silver, W.L., and Miya, R.K. 2001. Global patterns in root decomposition: comparisons of climate and litter quality effects. Oecologia, 129: 407-419.

Resource conservation technologies for farmers adoption in Rainfed areas

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The crop productivity depend on natural resources of a region which includes land (over 55 percent of non forest land), water (about 80 percent of total fresh water), soil, biodiversity (forests, pastures, and wildlife) and climate. These natural resources are national treasure since they are critical to agricultural production. The crop production activities not only are influenced by the resources but have major impacts on the quality and availability of these resources for example, they may cause downstream pollution and soil erosion. In recent years, increase in agricultural productivity is at the expense of the natural resource base on which farming systems depend. Hence, It is necessary to encouragethe farmers to adopt more sustainable methods of farming that will have long-term benefits in natural resource conservation, minimum environment impact and development of sustainable livelihoods.

India has the largest irrigated area in the world, but still has 53% of its cropped area under rainfed conditions These rainfed areas contributes substantially to the coarse cereals (87%), pulses (90%), and oilseeds (80%) production and meets the requirement of 40 and 60% of human population and livestock population, respectively in India. In India rainfed areas are distributed throughout the country in all the states. The important states which have rainfed regions are M.P, Maharashtra, Jharkhand, Odisa, Chattishgarh, Karnataka, T.N, U.P, Rajasthan and Andhra Pradesh. The major rainfed crops are Groundnut, Redgram, Maize, Ragi, Bajra, Castor and cotton etc.

Problems of Crop productivity

Improved crop and soil management practices has been successful in increasing the crop productivity by 5% and 1% per annum in irrigated and rainfed regions respectively and this improved productivity helped in achieving food security but this is albeit at a low level of satisfaction since the gains were due to massive exploitation of natural resources which led to resource degradation. Moreover the productivity of the rainfed crops is only 1-2 t/ha as against its potential of 4 t/ha. The causes for wild yield gap potential rainfed agriculture are multifarious of them the most significant are moisture stress due to aberrant weather which include low and erratic rainfall, late onset of monsoons, early cessation, drought, prolonged dry spells for 2 to 3 weeks in critical growth stages of the crops, land degradation, poor economic condition often much behind the risk bearing capacity of the farmers which led to poor adoption of modern technology. The second most important cause for low yields is resource degradation. The most pronounced resource degradation is land degradation . It is estimated that 70% of partially productive drylands are threatened by different forms of degradation, impacting the well being and future of 40% of the Indian population. The land degradation is due to water and wind erosion due to sloppy lands (1 to 10% and low infiltration capacity of the soil), faulty agriculture practices like deforestation, imbalance fertilizer use, soil mining, soil salinization, depletion of soil organic matter, and weeds etc. which varies from, the problem is further aggravated by high intense rains and faulty agricultural practices. The erosion not only causes runoff but results in loss of top layer of fertile soils along with the nutrients,

Over the past 100 years, the temperature has increased by 0.5^0 in atmosphere and in future, by 2080, the estimated raise in temperature is from 3.5^0C – 5.5^0C. According to an estimate, every 1^0C increase in temperature decreases the crop yield by 3-7% and further for every 10 years, drought will occur in 3 to 4 years. Further the aberrant weather conditions like uncertainty of rainfall untimely rains, floods and droughts are becoming more frequent. The impact of these environmental changes on rainfed crops is likely to be higher. Therefore the reversal of land and water degradation especially in rainfed regions is most crucial for sustainable agricultural production.

The experiments conducted by AICRPDA and CRIDA identified several resource conservation technologies (RCT). Tobridge large gaps between actual and attainable yields in rainfed agriculture. The important RCT technologies include *ex situ* and *in-situ* water conservation, adoption of appropriate land use based cropping systems, balance nutrient application/site specific nutrient management, organic nutrient management.These technologies aims at improving the productivity, biodiversity conservation, reduce land degradation,improve rain water use efficiency, furthermore these technologies in a way help in adaptation and mitigation of the effects of global climate change.

Resource conservation technologies for sustainable crop productivity and Resource conservation in Rainfed regions

Rainwater conservation

In India the present rate of water use and increase in use indicates that agriculture may not receive the present share of water in future hence rain water would be the main source for agriculture therefore increase in rain water use efficiency is the need of the hour. The amount and distribution of rainfall is not uniform in all the places and is erratic. The deficient and uncertain rainfall causes dry spells whereas high intensity rains would cause excessive soil loss through erosion. Hence even humid areas with 2000 mm of annual rainfall suffer soil moisture stress, and sometimes face drinking water scarcity, since the event is in such a short time that it causes high intense surface runoff, and evaporation from open soil surfaces which leads to moisture stress during critical stages. By contrast, in the arid zone, crop water needs often exceed total rainfall, causing absolute water scarcity. Hence appropriate location specific efficient *in-situ* and *ex situ* rainwater conservation techniques and land management techniques are desired in both high and low rainfall situations to achieve the desired crop production and improve rain water use efficiency. The increase in yield and water productivity varied between 12 to 20 percent and 35% respectively which could reduce additional crop water consumption from 80% to 20% by adopting soil and water conservation measures but these are at times not convincing enough to farmers. *Ex-situ* conservation of rainwater is conservation of the excess runoff for safe disposal through grassed waterways to the farm ponds/tanks/dams for its storage and recycling to the agricultural lands. This is usually recommended in areas with >750mm rainfall and are usually made at lower areas of the fields. The participatory research program illustrated the harvesting of the run-off enable farmers to improve the productivity by providing supplemental irrigation, diversify the crops and expand cropping season and increase cropping intensity. As per an estimate single supplemental irrigation of 100 mm depth in a rain-fed area of 27.5 m ha, through harvested water and an additional annual production enhancement of food grains of the order of about 9.3 mt could be achieved. The size of farm pond depends on rainfall and slope of the land. The infiltration of harvested water is high in red and sandy soils, but less in black soils. Hence farm pond is a better option for black soils as compared to alfisols as the infiltration is low. However, to reduce the infiltration, the ponds are lined with cement, concrete and bricks. But this is very expensive and labour intensive. Hence clay application is a cheaper option but durability is very low. In recent times plastic sheet lining is recommended. The advantages with plastic lining are it reduces the input costs and weeds. Experiments have shown that irrigating crop at critical stages improves crop yields upto 10%.

The main disadvantages of the farm ponds are farmers loose some area and are expensive. Moreover, in rainfed regions, majority of the farmers are small and marginal with low land holdings. Hence farmers neither can afford to loose land nor spend without government support and subsidies.

The other method of exsitu conservation is percolation tanks. In this method trenches are formed around the field to collect the runoff water from the field. The depth and width should be similar throughout the field. Normally these are in square/rectangular shape. The trenches can be used as live bunds. On the trenches, thorny shrubs and perennial species like teak, Aloe vera, Henna, Glyricidia, Subabul, etc. can be grown. These trenches not only reduce soil erosion but also enriches ground water table.

In situ moisture conservationis another option of moisture conservation it is comparatively easier to be adopted by farmers than ex-situ rainwater conservation. This in-situ rainwater conservation in rainfed areas is a way to bridge gap between potential productivity of available crop varieties and existing crop yields by improving soil moisture content. The quality of surface flow improves considerably by reducing the silting of water harvesting structure and prolonging their life. In-situ rainwater conservation includes deep tillage, land configuration methods like broad bed, conservation furrows, contour farming, graded border strips which can be made with low cost and energy efficient implements are some of the efficient methods which hold great promise. However, the in situ conservation methods adopted are based on rainfall and soil type (Table 1) and Land capability classification.

Contour cultivation is practiced is recommended for a slope of 4-10%. This reduces the velocity of runoff by 10% which in turn reduces the soil erosion and improves yield. Whereas Contour furrows are most suitable on fairly light soils with gentle slopes of about 0.5-3%. These are less effective on heavier, more clayey soils.and usually recommended for areas with annual rainfall of about 350-700mm.

Conservation Furrows after every two crop rows across the slope is recommended for rainfed crops. Several studies proved that dead furrows conserve the water and increases yield. The participatory trials conducted under NATP by CRIDA have shown 20, 30 and 11% increase in yield of sunflower, castor groundnut, respectively. These furrows are usually made with bullock drawn plough at 30-40 DAS. The main disadvantage of this method is if a *dry spell* occurs between 30-40 DAS, formation of conservation furrows are delayed and sometimes it may not be possible to make the conservation furrow. The other disadvantage is the initial rainfall received till 30-40 DAS is not conserved and results in higher runoff during early stages of crop growth since canopy growth is less in the initial crop growth stages.Furthermore, the furrows are usually made with country plough so the furrows made with furrow are shallow. Hence the development of technologies to overcome this constraint a new method viz., paired row planting and conservation furrow in the pair was developed at CRIDA. In this method the recommended row spacing of the crop is reduced and the plant population is maintained. For example in pigeonpea the recommended spacing of 90cm between rows is reduced to 60cm both the rows together are known as paired rows. The next pair of rows will be spaced at 120 cm The interspace between two pairs can be utilized for sowing intercrops like horsegram, Muccina etc., and the conservation furrow is made between two crop rows (60 cm). For efficient planting and formation of conservation furrows an implement was designed and developed at CRIDA with which sowing of crop, formation of conservation furrows and fertilizer application can be done simultaneously. A furrow of 60cm width and 20-30cm depth can be made with this implement A furrow of this dimension can store 250 m^3 water and reduce the runoff by 1/6th. The implement can be used to sow all the crops, since it can be adjusted according to spacing of the crop. The studies at CRIDA has shown that this method reduces the soil and water loss to a tune of 50% and increases the yield by 30-40%. Besides conserving the water, and increasing the yields it increases the profitability as it saves the labour and input cost also.

The other *in -situ* conservation methods recommended apart from conservation furrow are ridges and furrows which is usually practiced in cereals like Maize, Jowar, Bajra, etc. Whereas, Broad bed and Furrow method is adopted in the regions with a slope on a grade of 0.2 to 0.4% in black soils, having rainfall of 700-1500mm. This method is more suitable for narrow spaced row crops. Even though plant population is lost due to the furrow, the yields are compensated due to better in situ rainwater conservation. In black soils this system acts both as disposal system during high intensity rains and as a conservation measure during low rainfall situation in vertisols and alfisols. This method reduces the runoff velocity by 40% and increases the infiltration rate which inturn increases the soil moisture by 24-30%. This leads to Increase in crop yield and net returns by 27 and 26.1% in soybean.

Deep tillage and Conservation agriculture

The main objective of summer or deep ploughing either every year or once in three years is done to increase infiltration of water and reduce runoff by breaking subsurface hard layers beneath the soil surface and surface crust depending upon the soil type. Besides the deep tillage frequent harrowing and secondary tillage practices helps in land smoothening to avoid local depressions, which create soil mulch. Experiments have shown increase in sorghum yield by deep tillage with plough followed by chiselling. Moreover, the beneficial effects of off season tillage are much pronounced during the low rainfall as compared to mild drought year (31% increases in yield) and near to the normal rainfall year (24% increase in yield). Deep tillage, repeated tillage and inter cultivation operations even though increased the crop yield but has negative effects like loss of organic matter, soil structure, nutrient losses through erosion and results in physical, chemical and biological degradation of soil. Hence the concept of minimum tillage was introduced. In its extreme form, minimum tillage includes zero tillage, and/or no-till subsystems where the crops are planted by direct seed drilling without opening any furrows or pits. Initial trials conducted on reduced tillage at CRIDA have shown that only reduced tillage without residues reduced the yields considerably. Moreover, it was observed that rainfall and soil type have a strong influence on the performance of reduced tillage. Studies conducted by AICRPDA at various locations has shown that in arid regions (<500 mm rainfall), low tillage was on par with conventional tillage since weed control is manageable in aridisols. Whereas, in semi arid (500-1000 mm) region conventional tillage was superior to low tillage + interculture in vertisols. The low tillage has not worked well due to poor infiltration (as soils are easily self-sealing). Furthermore the technique is labour intensive. Hence, the concepts of strip tillage, stubble tillage and conservation agriculture has emerged as alternative strategies.

Conservation agriculture (CA) CA is an important environment friendly strategy with 3 principles viz. reduction in tillage, leaving the crop residues on soil surface and crop rotation to sustain agricultural production and addresses the resource degradation by arresting and reversing the downward spiral of resource degradation and efficient use of natural resources. The studies conducted in rainfed regions with various cropping systems at CRIDA has shown that the CA records lower yields in the initial years but may overtake conventional tillage subsequently. The added advantage of CA is reduction of soil erosion, improved organic carbon and soil fertility due to addition of crop residues and crop rotation.

But the key to success of CA is retention of crop residues on the soil and the weed control. The major constraints to adopt CA in rainfed regions is availability of crop residues as the livestock compete for fodder, termite infestation to the residues in rainfed regions is more, weed control and seeding of crops in zero tillage. Studies at CRIDA has shown that the crop residues can be increased by managing harvesting height of the crop, growing of cover crops between widely spaced crops, cultivation of second crop like horse gram after harvest of short duration crop. The crops like pigeon pea, castor can be harvested up to 30 cm ht whereas ceral crops like maize and jowar should be harvested at 60cm ht since the fodder quality and nutrients are better in maize and jowar in the top portions of the crop. So harvesting at 60cm has dual advantage. The harvested above portion is used as fodder and the lower part can be used as crop residues to the soil.It was observed that termite infestation will be more on the crop residues present on the soil surface than the anchored crop residues.

The biological conservation measures like vegetative barriers as live bunds have drawn greater attention in recent years because of their long life, low cost, low maintenance and some time farmers get some additional income. This is usually adopted in the areas having a slope of 0.4-0.8%. Vegetative barriers include rows of perennial grasses, hedges, wind brakes and shelter belts etc. on contours. The ideal characteristics of the species to be used are they should be bushy non grazable and have some economic value like fuel, fodder, etc. Species like vettiver, lemon grass, palmarosa, stylo, agave, aloe vera, cenchrus grass and glyricidia can be used. The major precaution to be adopted is the roots of the barriers should not compete with the main crop. The additional advantage of the species like glyricidia is the leaves contain 2.4:0.1:1.8 (NPK) besides this they also contain Ca, Mg and micro nutrients. Hence, leaves can be used as green leaf manuring and also act as mulching material. The experimental evidences has shown that a glyciridia line of 700m width 0.5m depth which gives 3 cuttings year can supply 30-45 kg N/ha/year. Studies in rainfed regions have shown that vetiver grass can reduce 18% of runoff and 78% of soil loss..

Another biological measure is mulching. Mulching is usually practiced in low rainfall areas proned to drought and weed infestation. This method reduces evaporation,weed growth runoff and prevents crust formation. The optimal proportion of mulch as soil cover is around 30 to 70%. Any locally available material like crop residues, tree leaves can be used. The anchored residues not only reduce the evaporation but also reduce soil erosion through wind and water by binding the soil particles. The availability of the materials is a constraint hence plastic sheet as mulch is recommended for high value crops. The thickness of the plastic film depends on type and age of the crop. For example, in groundnut 7 microns thickness *ie.,* 28 gauge is required. Whereas, for short duration crops, 20 microns thickness sheet is used. The advantages of plastic sheet mulching is evaporation from soil can be reduced by 40-70%. Usually white colour sheet in summer and black colour sheet in winter is recommended. Experiments has shown yield increase upto 80% in alfisols. Whereas, in vertisols 45% increase in maize yield was observed in addition to reduction of runoff by 25 mm. But the farmers prefer to use the plastic mulch for high value crops like orchards abut not for annual crops due to its high cost. The biological materials in addition to increase in yields and reduction in soil loss it also increases soil organic carbon soil structure and texture. The leaves of the trees of hedge rows in alley cropping, crop residues such as maize and sorghum stalks can be left on the ground after harvesting. Large pieces of crop residues should be cut into smaller pieces before application.

Table 1: Water (moisture) conservation practices based on rainfall

Rainfall			
<500mm	500-750mm	750-1000mm	>1000mm
Insitu conservation in between rows Contour cultivation Dead furrows Field bunds Tie bunds Mulching Ploughing across the slope Summer deep ploughing	Contour cultivation Live bunds Field bunds In situ conservation in between rows Tie bunds Mulching Summer deep ploughing Dead furrows Vertical mulching in black soils.	Vertical mulching in black soils. Contour cultivation Dead furrows Live bunds Minimum tillage Graded bunds Cultivation of crops across the slope.	Live bunds Field bunds Graded bunds Vertical mulching in black soils.

Besides the biological, agronomic and engineering measures application of the soil amendments like tank silt in red and sandy shallow soils to improve water holding capacity and sand application to black soils help not only to improve soil texture and structure but reduces the erosion and conserves soil moisture, add nutrient and improve the organic carbon content of the soil. The added advantage of tank silt application is desilting of tanks and improves the storage capacity of tanks. The quantity of tank silt to be applied to soil depends on clay content of soil and can be applied once in every three years. The major precaution to be taken is to avoid high P^H tank silt.

Studies by CRIDA at Hyderabad, Bangalore and Anantapur revealed that more than 80 % farmers follow in-situ conservation measures like sowing across the slope, opening of dead furrows and key line cultivation. But adoption rate of many mechanical soil conservation practices like contour bunds, graded bunds, grassing of waterways and construction of farm ponds without the government support was very poor. This low adoption rate of the soil and water conservation technologies is due to many technical and socio-economic constraints like most technologies involve labour, high cost and returns are not sufficiently high to persuade farmers to adopt these in a significant manner.

Soil Health

Apart from decreasing the soil erosion minimising soil degradation or ameliorating the degraded soil through judicious and scientific management of soil resources through increase in the the organic carbon content of the soil by the use of improved management practices such as minimum soil disturbance through practices such as land use based on capability, crop diversification, efficient residue management, INM, weed control, conservation agriculture, agroforestry are some of the ways which can improve the soil fertility and and efficient rain water use efficiency.

Land use based capability

In a country like India endowed with diverse climate, edaphic, biota and socioeconomic settings on one side and challenged by unabated competing demands for food production, In this context land use

Rain fall (mm)							
Land Capability class		**100**	**250**	**500**	**750**	**1000**	**1250**
	II	**Animal based farming systems**		**Oilseeds & pulses**		**Diversified land uses**	
	III					**(Sequence cropping/High value perennials)**	
	IV	**Tree farming**		**Millet based systems**		**Cereal /legume inter crop**	
	V	**Silvi-pastoral**					**Horti-pastoral**
	VI	**(includes trees and bushes yielding fodder, fuel,dyes,oils,medicines,insecticides…)**					
	VII	**Tree farming**					
	VIII	**Wild life/recreation**					
		100	**250**	**500**	**750**	**1000**	**1250**
Rain fall (mm)							

based on capability is an important factor of production particularly in stressed rainfed agro-ecosystem. Land use planning is the sectoral allocation of land to optimize the postulated objectives under the existing environmental and societal opportunities and constraints. Based on the capability, land is divided into 8 classes. Among them, first 4 classes are suitable for arable crop production. Whereas, class V to VIII are suitable for forestry, grassesand wild animals. Selection and cultivation of crop based on soil type, its capability with effective resource conservation strategies plays a major role in increasing the crop yields.

Fig. Land capability classification

Crops and cropping System

The crop productivity is very low in rainfed regions mainly due to selection of non-suitable crop or growing crop varieties of low genetic potential crops. Hence selection of crops and varieties are very important for resource conservation and higher productivity. The major criteria adopted for selection of a crop is soil, climate and rainfall. In rainfed regions crop based planning on determination of length of growing period (LGP) i.e., moisture availability of a given soil type, is a better index than total rainfall. Selection of a suitable crops and varieties capable of maturing within actual rainfall periods will not only help in enhancing productivity of a crop but also increases the cropping intensity. Besides the suitable crop, variety also play an important role in improving the crop yields. The crop yields can be improved by 15-20% through crop diversification with drought tolerant crops. Farmers participatory studies in Mahaboobnagar district with different oil seeds has revealed that KBSH-1 performed well in shallow soils. Whereas,performance of MSH-17 was better in deeper soils. Similarly, DCH-32 in castor has recorded 18.2% higher yields than Kranthi.

Besides improving the productivity levels of rainfed crops, efforts are needed to increase the cropping intensity in dry land areas in view of shrinking land resources. Cropping intensities of these areas can be increased by intercropping and multi cropping (sequential) by way of more efficient utilization of resources The cropping intensity depends on the length of growing season which in turn depends on rainfall pattern and the soil moisture storage capacity of the soil (Table 2).

Table 2: Selection of crop based on rainfall and type of soil in drylands

Rainfall (mm)	Soils	Crop Period (weeks)	Cropping System
350-600	Red soils, Shallow black soils	20	Single crop
600-700	Red and black soils	20-30	Inter crops
750-900	Very deep black soils, red soils	30	Two crops
>900	Deep black soils, red soils	>30	Two crops

In intercropping systems, the growth factors water, nutrients, and solar radiation can often be used more efficiently. The intercropping systems helps in reducing the weed and pest pressure which leads to reduction of herbicides and pesticides use which in turn reduces the productioncost, increase the productivity and environmental benefits. The intercropping system has a strong potential to counteract resource degradation by improving soil quality, controlling erosion, and reducing nutrient leaching. Furthermore, intercropping acts as insurance against crop failure and market fluctuations especially for the farmers practicing low-input (high labour) and also meets food preference and/or cultural demands. Despite its potential benefits, intercropping is not preferred over mono crop farming due to several constraints. The most important one is it is labour intensive as suitable mechanization, is not available lack of proper management practices like nutrient management practices, weed management practices are not available. Adoption rate can be improved through the development of new agronomic practices, improved nutrient management, including the mechanization. The row-intercropping systems can be transformed to paired row cropping, strip-intercropping system, to suit the existing machinery.

Experiments at CRIDA has shown that paired row intercropping (60-120-60 cm) in pigeonpea /castor increased the yields and reduced the erosion by 20 and 10% respectively in pigeonpea and castor based inter cropping systems. Machinery has been developed for this system. Adoption of double cropping in the areas receiving rainfall >750mm in black soils with soil moisture storage of 200 mm m^{-1} is also another way to improve the cropping intensity. Usually in black soils the rainy season is kept fallow due to high moisture condition if a short duration pulse crop is sown pests, diseases and weed problems can be minimized rather than leaving it fallow.

Table 3. Traditional and Alternate Efficient crops in Different Dryland Regions of India

S. no	Region	Traditional crop	Alternate efficient crop
1.	Deccan Rabi season	Cotton, wheat	safflower
2.	Malwa Plateau	wheat	Safflower, Chick pea
3.	Uplands of Bihar Plateau and Orissa	Rice	Ragi, Blackgram, Groundnut
4.	South-easy Rajasthan	Maize	Sorghum
5.	North Madhya Pradesh	Maize	Soybean
6.	Eastern UP	Kalitur	Chick pea
7.	Sierozems of North-west India	Wheat	Mustard, Taramira (*Eruca sativa*

Fertilizer Management:

Soils of rainfed regions in India are not only thirsty but also hungry. The soil erosion has resulted in shallow depth and nutrient deficiencies, particularly N, P, K and some micronutrients. Moreover the farmers do not apply fertilizers to rainfed crops since the crop failure is a common phenomenon due to aberrant weather conditions and farmers also have a belief that the chance of crop failure increases with fertilizer application but recent findings have shown that the use of fertilizer is not only helpful in providing nutrients to crop but also helps in efficient use of profile soil moisture and improve the yields. This implies that interaction of water and nutrients is very important and hence it is essential to combine insitu water management practices with fertilizer application to enhance the water and nutrient use efficiency. Furthermore, the nutrient availability and nutrient use efficiency is also very low in these regions due to limited moisture availability. The NUE varies between 15-50% for major nutrients and 2-5% for micrronutrients like Cu, Fe, Zn and Mn. Little attention was given to issues of maintaining and improving hydrological and biological soil properties which are critical for functioning of essential processes that impart good soil health. It was proved in various studies that fertilizer application increases the yield by 50% in rainfed regions and remaining 50% depends on other management practices. Hence to improve the productivity of crops and sustainability in rainfed regions it is necessary to increase nutrient use efficiency through a span of technologies like balanced nutrient application, application of organic fertilizers, chemical fertilizers , SSNM, and integrated nutrient management.

The fertilizer use efficiency can be improved by 4 RS (right fertilizer, right quantity, right method and right type). In many areas the imbalanced fertilization is the root cause of poor crop yields and poor soil fertility status. Hence immediate attention to correct the imbalances in nutrient consumptions to prevent further deterioration of soil quality and to break the yield barriers is essential.

Organic nutrient management is a production system which avoids or largely excludes the use of synthetically compounded fertilizers, so organic nutrient management systems rely on animal manures like farmyard manure, insitu biomass generation through different methods like intercropping/bund cropping of green manure crops, crop residues, cover cropping recycling of farm and household waste, recalcitrant biomass through use of microbial cultures or earthworms and use of bio-fertilizers at regional and local levels, Crop rotations with pulses and leguminous crops, multiple cropping which enriches soil fertility should be encouraged instead of monocropping, If organic nutrient management is given the priority on its merits, it has the potential to transform agriculture and helps in natural resource conservation by improving the soil fertility, soil structure, water retention biological activity and sustainable agriculture. Recycling of crop residues to soil is also an important organic nutrient management strategy for improving soil organic carbon content but there are many socioeconomic constraints. The major constraint is competing demand for fodder, fuel wood and for which often there are no substitutes.

Apart from this, proper machinery to sow the crop in residues is not available hence the farmers prefer to burn the crop residues even though they are available rather than recycling. Besides the loss of macro and micro nutrients due to burning of crop residues, methane and nirous oxide emissions were also recorded. In view of the constraints involved in availability of residues in rainfed arid and semi-arid regions, several alternative strategies were developed at CRIDA. Some of them were growing of cover crops, green leaf manuring, alley cropping systems where the leaves of the trees are added as mulch, Growing of legume crops like horsegram and cowpea in the widely spaced crops and in between tree rows. The other option is brown manuring in this crops like Daincha, Horsegram, etc. are grown in between the rows of the main crop, at flowering of these crops, herbicides like 2,4-D is sprayed or the plants are cut close to the ground and left on the soil. The main advantage of this method is these crops provide additional nitrogen to the soil besides providing soil cover. This brown manuring can be done beneath the trees also. The experiment conducted at CRIDA has proved that, growing of Daincha, or sunhemp in amla and tamrind tree basins and applied to the basins after 40 days has improved soil moisture and nitrogen status of the soil.The added advantage of this system is insitu residue generation (both above ground and below ground) residues are added without additional cost and moreover farmers these intercrops reduces runoff, soil erosion and improve physical and chemical properties of the soil. These crops can be taken up at the same time as sowing the main crop, or after the main crop has been established, to avoid competition or can be grown in rainy season in black soils. The main advantage of these options are biomass generation can be integrated along with crop production. But these systems are not usually adopted by the farmers since they are labour intensive.

Summary

For every one tone of food grain production, 1000 tonnes of water is required. In the present context, additional water allocation from irrigation source is not possible So, every drop of water should be used precious. Hence the concepts of rainwater use efficiency to the center stage of water resources management in rainfed areas.Besides this the land also is degraded and productive capacity of soils is decreasing The amount of agricultural land going out of production each year due to soil erosion is about 20 million hectares, and approximately 40 percent of the world's cropland is now degraded hence natural resource conservation is the basic thing for sustainable agricultural production, the natural resources should be conserved effectively to meet the needs of the future generations. So for the conservation of soil and water in drylands, we need to fully *expand the speed and scope of watershed development programs,* harness the potential of surplus runoff at farm level and supplemental irrigation by strengthening traditional water harvesting structures, promoting farm ponds and other such measures along with these,

Invest on and incentivize groundwater sharing and usage for supplemental and support irrigation for kharif crops, Promote agronomic innovations that can reduce costs and usage of water and other inputs, while increasing productivity (eg vegetative barriers, mulching practices, intercropping, improved water management in rice cultivation etc.).

Specific objectives for sustainable natural resource management (NRM) include improving agroecosystem productivity, conserving biodiversity, reducing land degradation, improving water management, ensuring the sustainability of forests, managing the sustainability of wildlife and fisheries, and mitigating the effects of global climate change. Hence revolution of Natural Resource Conservation is the only solution for the problems of drylands.

The technology of crop production and resource conservation in dry land areas have been generated to a great extent. But is important now to view it in socio-economic context of the farmers. Once these resource conservation technologies are adopted by the farmers, the contribution of dry land areas to the total production can be sizably improved thereby the living standards of the farmers of these areas can be improved. Hence the technology developed should be easily adopted and moreover these technologies can be implemented with appropriate trainings, demonstration, action learning exercise in various aspects like in situ rainwater conservation etc so that these technologies can be easily popularized and further the ill effects of resource degradation of natural resources like soil, water and environment and importance resource conservation to increase the yields should be explained clearly to the farmers. Moreover, several indigenous technical knowledge (ITKs) relating to in situ rainwater conservation measures are in practice, befitting the agro-ecological settings. These ITKs can be converted to medium technical knowledge (MTK) by addressing the researchable and extension issues. Besides this farmer may be supported for 5 years in the form of incentives for practicing several resource conservation practices like agronomic measures, crop patterns, and application of organic matter eg.Leaving crop residues on soil surface, adopting No-Till/reduced tillage options etc that enhance soil productivity. Support may be in the form of additional labor costs and seed material, Investment on regeneration of biomass within and nearer to the agriculture areas to reduce costs of harvesting and transport.

Climate change adaptation and mitigation potential of organic farming

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Introduction

Climate change is one of the potential threats to sustainable development of agriculture coupled with food security. Climate change and variability are a considerable threat to agricultural communities, particularly in India. This threat includes the likely increase of temperature, extreme weather conditions, increased water stress and drought, and desertification. Crop growth, development, water use and yield under normal conditions are largely determined by weather during the growing season. Seasonal variations in weather events may pose risks to traditional methods of crop production either due to water constraints or surplus of water and erosion. In this regard, soil stability will become crucial to store water in the soil profile, to resist extreme weather events and minimize soil erosion. These changes will bring new challenges to farmers. Farmers need tools to help them adapt to these new conditions. Organic farming is one such option which is reported to have both climate change mitigation and adaptation potential particularly in rainfed agriculture.

Potential of organic farming to mitigate climate change

There is considerable world-wide support at present in advocating organic agriculture for mitigating climate change (IFOAM, 2008;Sqalli and Adamkiewicz, 2018). The potential of organic agriculture in mitigating climate change depends on its ability to reduce emissions of GHGs (nitrous oxide, carbon dioxide and methane), increase soil carbon sequestration, and enhance effects of organic farming practices which favour the above two processes (Goh, 2011).

Reduction of GHG emissions

The global warming potential of conventional agriculture is strongly affected by the use of synthetic nitrogen fertilizers and by high nitrogen concentrations in soils. However, organic farming systems avoid the use of synthetic fertilizers, and rely on practices such as green manuring, crop rotation with legumes, efficient recycling of residues and the use of organic manures. In addition, these systems avoid the use of synthetic pesticides and rely on practices such as crop rotations, use of bio-pesticides and increase beneficial insects for pest management. These restrictions on fossil-fuel based fertilizer and pesticide inputs can significantly reduce the overall GHG footprint of organic systems in comparison to conventional production systems (Sreejith and Sherief, 2011).

N_2O emissions are the most important source of agricultural emissions accounting forabout 38% of agricultural GHG emissions (Smith *et al*., 2007). N_2Oemissions are directly linked to the concentration of available mineral N (ammonium and nitrate) in soils arising from the nitrification and denitrification of available soil and added fertilizer N (Firestone and Davidson, 1989). Organic farming involves cover and intercrops which extract plant available Nunused by the preceding crop and keep it to the system reducing the level of reactive N in the top soil. High emissions rates are detected directly after mineral fertilizer additions and are very variable (Bouwman, 1995).

In organic systems, the N input to soils, and hence the potential N_2Oemissions, are reduced. The share of reactive N that is emitted as N_2O depends on a broad range of soil and weather conditions and management practices, which could partly foil the positive effect of lower N levels in top soil (Scialabba and Muller-Lindenlauf, 2010). In a study by Petersen *et al*.(2005), lower emission rates for organic compared to conventional farming were found for five European countries. One study found no significant differences between mineral and organic fertilization (Dambreville*et al*.,2007). Tuomisto*et al*. (2012), report about 30%lower median N_2Oemissions per area in organic systemsthan in conventional farming systems.

On the other hand, comparisons between soils receiving manure versus mineral fertilizers found higher N_2O emissions after manure application compared to mineral fertilizer applications, but not for all soil types. The higher N_2Oemissions after incorporation of manure and plant residues are explained by the high oxygen consumption for decomposition of the organic matter (Flessa and Beese, 2000). As there is high uncertainty in N_2O emission factors, further research is needed.

The reduction or avoidance of CH_4 emissions is of special importance in global warming from the agricultural sector because two thirds of global CH_4 emissions are of anthropogenic origin, mainly from enteric ruminant fermentation in animals (FAO, 2006) and in paddy rice production (Smith and Conan, 2004). In general, the CH_4 emissions from ruminants and rice production are not significantly different between organic and conventional agriculture. Differences are due largely to the extent and intensity of various farming practices and their improvement used within different forms of agriculture.

Although research on CH_4 emissions in organic and conventional paddy rice production is still in its infancy (Goh, 2011),employing better rice production techniques such as using low CH_4-emitting varieties,composted manures with low C/N ratio, adjusting the timing of organic residue additions and using mid-season drainage or avoiding continuous flooding have been shown to reduce CH_4 emissions (Smith and Conan, 2004). The storage and treatment of manure can have a very significant effect on GHG emissions. In organic farming systems, cropping depends on nutrient supply from livestock and the combination of cropping and livestock provides an efficient means of mitigating GHG emissions especially CH_4 (Goh, 2011). Efficient and direct recycling of manure and slurry is the best option to reduce GHG emissions as this practice avoids long-distance transport (Niggli, 2007).

CH_4 and N_2O from manure account for about 7% of the agricultural GHG emissions. CH_4 emissions predominantly occur in liquid manure systems, while N_2O emissions are higher in solid manure systems and on pastures (Smith *et al*., 2007). There is a very high variance for both gaseous emissions, depending on composition, coverage, temperature and moisture of the manure.

CO_2emissions are reported to be around 40-60 per cent lower in organic farming systems than conventional systems, largely because they don't use synthetic nitrogen fertilizers which require large amounts of energy in their production and are associated with emissions of the powerful GHG N_2O (Sayre, 2003).

Soil carbon sequestration

Soil carbon sequestration is an important strategy and is a win-win option of producing more food per unit area besides mitigation of climate change (Lal, 2004). Although soils of the tropical regions have low carbon sequestration rate because of high temperatures, adoption of appropriate management practices can lead to higher rates particularly in high rainfall regions (Srinivasarao*et al*., 2012). Soil carbon sequestration at a global scale is considered the mechanism responsible for the greatest mitigation potential within the agricultural sector, with an estimated 90% contribution to the potential of what is technically feasible (Smith *et al*., 2008). However, global soil carbon stocks of agricultural land have decreased historically and continue to decline (Lal, 2004). Thus, improved agronomic practices that could lead to reduced carbon losses or even increased soil carbon storage are highly desired.

Soil carbon sequestration is enhanced through agricultural management practices (such as increased application of organic manures, use of intercrops and green manures, higher shares of perennial grasslands and trees or hedges, etc.), which promote greater soil organic matter (and thus soil organic carbon) content and improve soil structure (Muller, 2009). Though organic matter application and the planting of legume crops are key features of organic farming, crop rotation as commonly practiced on organic farms can also increase soil organic carbon stocks by about 0.8 tCO_2–eq/ha/year, compared to monoculture practices. There is strong scientific evidence that organic farming generally results in higher soil carbon levels in cultivated soils compared to chemical fertilizer based agriculture. Very rough estimates for the global mitigation potential of organic agriculture amount to 3.5-4.8 Gt CO_2 from carbon sequestration (around 55-80 per cent of total global greenhouse gas emissions from agriculture) and a reduction of N_2O by two-thirds (Niggli*et al*., 2008). The potential of carbon sequestration rate by organic farming for European agricultural soils has been estimated at 0–0.5 t C/ha/year (Freibauer*et al*., 2004).In the USA, a field trial showed a fivefold higher carbon sequestration in the organic system (1218 kg C/ha/year) in comparison with conventional management (Pimentel *et al*. 2005). Leifeld and Fuhrer (2010) found in their review an average annual increase of the soil organic carbon (SOC) concentration in organic systems by 2.2%, whereas in conventional systems, SOC did not change significantly.Gattinger*et al*. (2012), based on meta-analysis of 74 studies, reported significant differences and higher values for organically farmed soils of 0.18±0.06 per cent points (mean±95% confidence interval) for SOC concentrations, 3.50±1.08 Mg C/ha for stocks, and 0.45±0.21 Mg C/ha/year for sequestration rates compared with nonorganic management. All these studies prove that organic agricultural systems have an inherent potential toboth reduce GHG emissions and to enhance carbonsequestration in the soil (Table 1.3).

Table 1.3 Mitigation potential of organic agriculture

Source of GHG	**Share of total GHG emissions (%)**	**Impacts of optimized organic management**	**Remarks**
Direct emissions from agriculture	10-12		
N_2O from soils	4.2	Reduction	Higher nitrogen use efficiency
$CH_4$from enteric fermentation	3.5	Opposed effect	Reduced by lower replacement rate and multi-use breeds
Biomass burning	1.3	Reduction	Burning avoided according to organic standards
Paddy rice	1.2	Opposed effect	Increased by organic amendments but lowered by drainage and aquatic weeds
Manure handling	0.8	Equal	Reduced methane emissions but no effect on N_2O emissions
Carbon sequestration			
Arable lands	-	Enhanced	Increased soil organic matter
Grasslands	-	Enhanced	Increased soil organic matter

Source: Adapted from Scialabba and Muller-Lindenlauf (2010)

Organic agriculture as an adaptation strategy

Adaptation in agriculture is not new. Historically, farmers have developed several methods to adapt to changing climate including aberrant weather. However, the adaptation needs to occur at a much faster rate due to impending climate change. The Intergovernmental Panel on Climate Change (IPPC) defines adaptation to climate change as ‘adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2001). Long-term crop yield stability and the ability to buffer yields through climatic adversity are critical factors in agriculture's ability to support society in the future (Lotter *et al*., 2003). Several researchers have reported that organic farming systems perform superior than their conventional counterparts during climate extremes including drought and excessive rainfall.

Organic agriculture systems have a strong potential for building resilient food systems in the face of uncertainties, through farm diversification and building soil fertility with organic matter (Scialabba and Muller-Lindenlauf, 2010). Several mechanisms may increase drought tolerance of organic cropping systems. Soil organic matter has positive effects on the water-capturing capacity of the soil. Numerous studies have shown soil organic carbon to be higher in organically managed systems (Gopinath *et al*.,2008and 2011). As a result, organically managed soils have high water holding capacity (Liebig and Doran 1999; Wells *et al*., 2000). It was found that water capture in organic plots was twice as high as in conventional plots during torrential rains reducing soil erosion (Lotter *et al*., 2003). Similarly, Pimentel *et al*. (2005) reported that the amount of water percolating through the top 36 cm was 15-20% greater in the organic systems of the Rodale farming systems trial compared to conventional systems. The organic soils held 816,000 litres/ha in the upper 15 cm of soil. This water reservoir was likely the reason for higher yields of corn and soybean in dry years. In India, most of the organic cotton farmers stated that the capacity of their soils to absorb and retain water was increased after conversion to organic management (Eyhorn*et al*.,2009). Many farmers also said that they need less rounds of irrigation and the crops can sustain longer periods of drought. In Central America, farmers using organic and sustainable methods reported substantially lower economic losses, and 90% of the neighbours of the study farms indicated a desire to adopt their neighbours' methods after observing the environmental stress tolerance of the organic/sustainable farms (Holt-Gimenez, 2002). In the 21-year Rodale Farming Systems Trial, the organic crop systems performed significantly better in 4 out of 5 years of moderate drought. In the severe drought year of 1999, three out of the four crop comparisons resulted in significantly better yields in the organic systems than the conventional (Lotter *et al*., 2003).

Furthermore, plant water uptake and ability to withstand drought are significantly improved by mycorrhizal associations (Syliva and Williams, 1992). Mycorrhizae have been shown to be more abundant in the roots of crops from organically managed systems relative to those of conventionally managed crops (Eason *et al*., 1999; Mader*et al*., 2000). This suggests both a physicochemical and biological basis for the increased drought tolerance of organic cropping systems (Lotter *et al*., 2003).

The mitigation of runoff, erosion and crop losses as a result of rainfall excess is also improved in organically managed systems (Lotter *et al*., 2003). Organic management of soils leads to improved soil stability and resistance to water erosion compared to conventionally managed soils, due to higher soil C content and improved soil aggregation (Reganold, 1995; Clark *et al*.,1998; Liebig and Doran, 1999), permeability (Reganold*et al*., 2001) and lower bulk density as well as higher resistance to wind erosion. Lockeretz*et al*. (1981) reported one-third less erosion from Midwest organic farms than from comparable conventionally managed farms. Many studies have reported that organically managed crops have out-yielded conventionally managed crops under flood conditions, due to higher levels of water-stable aggregates in organic soils and associated reduced soil compaction after tillage (Denison, 1996; Lotter *et al*., 2003). Hence, organic crop management techniques will be a valuable resource in view of climatic variability, providing soil and crop characteristics that can better buffer environmental extremes.

Summary

Organic agricultural systems have an inherent potential to both mitigate climate change through reduced GHG emissions and higher carbon sequestration in the soil, and adapt to climate change. Farming practices such as organic agriculture that preserve soil fertility and maintain or even increase organic matter in soils are in a good position to maintain productivity in the event of drought, irregular rainfall events with floods, and rising temperatures. Soils in organic agriculture capture and store more water than soils of conventional cultivation. Therefore, organic agriculture is one of the adaptation strategies that can be targeted at improving the livelihoods of rural populations that are especially vulnerable to the adverse effects of climate change and variability.

REFERENCES

Bouwman AF. 1995. Uncertainties in the global source distribution of nitrous oxide. Journal of Geophysical Research*,* 100:2785-2800.

Clark MS, Ferris H,Klonsky K, Lanini WT, vanBruggen AHC and Zalom FG. 1998. Agronomic, economic,and environmental comparison of pest management in conventionaland alternative tomato and corn systems in northernCalifornia. Agriculture Ecosystems and Environment, 68(1-2):51-71.

DambrevilleCh, MorvanTh and German JC. 2007. N_2O emission in maize crops fertilized with pig slurry, matured pig manure or ammonia nitrate in Brittany. Agriculture, Ecosystems and Environment,123:201-210.

Denison RF. 1996. Organic matters. The LTRAS century, 4(March):Long Term Research on Agricultural Systems(LTRAS). College of Agricultural and EnvironmentalSciences, University of California Davis.

Eason WR, Scullion J and Scott EP. 1999. Soil parameters and plant responses associated witharbuscular mycorrhizasfrom contrasting grassland management regimes. AgricultureEcosystems and Environment, 73(3):245-255.

Eyhorn F, Mader P and Ramakrishnan M. 2009. The impact of organic cotton farming on the livelihoods of smallholders: Evidence from the MaikaalbioRe project in central India. Organic Farming Newsletter 5(1): 19-21.

FAO. 2006. Livestock's Long Shadow-Environmental Issues and Options, Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

Firestone MK and Davidson. 1989. Microbial basis of NO and N_2O production and consumptionin soil. In:*Exchange of Trace Gases Between Terrestrial Ecosystems and the Atmosphere* (MOAndreaeand DS Schimel, Eds.), Wiley, New York, U.S.A.pp 2-21.

Flessa H and Beese F. 2000. Laboratory estimates of trace gas emissions following surface application and injection of cattle slurry. Journal of Environmental Quality, 29:262-268.

Freibauer, A., Rounsevell, M.D.A., Smith, P., and Verhagen,J. 2004. Carbon sequestration in the agricultural soils ofEurope. Geoderma, 122:1-23.

GattingerA, Muller A, HaeniM, Skinner C, FliessbachA, BuchmannN, MäderP,StolzeM, Smith P, ScialabbaN El-Hage and NiggliU. 2012. Enhanced top soil carbon stocks under organic farming. PANS, 109(44): 18226-18231.

Goh KM. 2011. Greater mitigation of climate change by organic than conventional agriculture: A review. Biological Agriculture & Horticulture, 27(2): 205-229.

Gopinath KA, SupradipSaha and Mina BL. 2011. Effects of organic amendments on productivity and profitability of bell pepper-french bean-garden pea system and on soil properties during transition to organic production. Communications in Soil Science and Plant Analysis, 42(21): 2572-2585.

Gopinath KA, SupradipSaha, Mina BL, Kundu S, HaritPande and Gupta HS. 2008. Influence of organic amendments on growth, yield and quality of wheat and on soil properties during transition to organic production. Nutrient Cycling in Agroecosystems, 82: 51-60.

Holt-Gimenez E. 2002. Measuring farmers' agroecologicalresistance after Hurricane Mitch in Nicaragua: a case study inparticipatory, sustainable land management impact monitoring.Agriculture Ecosystems and Environment, 93: 87-105.

IFOAM. 2008. FAO Workshop on Organic Agriculture and Climate Change. Workshop at the 6th IFOAM Organic World Congress, Modena, Italy, June 18, 2008.

IPCC. 2001. Climate change 2001 synthesis report: a summary for policymakers. Wembley, UK, Intergovernmental Panel on Climate Change.Available at www.ipcc.ch/pub/un/syreng/spm.pdf.

Lal R. 2004. Soil carbon sequestration impacts on global climate change and foodsecurity. Science, 304:1623-1627.

Leifeld J and Fuhrer J. 2010. Organic farming and soil carbon sequestration: What do wereally know about the benefits? Ambio, 39: 585-599.

Liebig MA and Doran JW. 1999. Impact of organic productionpractices on soil quality indicators. Journal of EnvironmentalQuality, 28(5):1601-1609.

Lockeretz W, Shearer G and Kohl DH. 1981. Organic farmingin the corn belt. Science 211:540-546.

Lotter D, Seidel R and Liebhardt W. 2003.The performanceof organic and conventional cropping systems in anextreme climate year. American Journal of AlternativeAgriculture, 18:146-154.

Mader P, Edenhofer S, Boller T, Wiemken A and Niggli U.2000. Arbuscular mycorrhizae in a long-term field trialcomparing low-input (organic, biological) and high-input(conventional) farming systems in a crop rotation. Biologyand Fertility of Soils, 31(2):150-156.

Muller A, Bautze L, Meier M and Gattinger A. 2016.Organic Farming, climate change mitigation and beyond.IFOAM EU. Available:www.ifoameu.org/sites/default /.../ifoameu_dvocacy_climate_change_report_72p.

Muller A. 2009. Benefits of organic agriculture as a climate change adaptation and mitigation strategy for developing countries. EfD Discussion Paper 09, 19 p.

Niggli U, Fliessbach A, HepperlyP and ScialabbaN. 2008. Low greenhouse gas agriculture: Mitigation and adaptation potential of sustainable farming systems, Rome: FAO.

Niggli U. 2007.*Organic Farming and Climate Change.*Available at www.intracen.org/ Organics/documents/Organic_Farming_and_Ciimate_Change.pdf.

Petersen SO, Regina K,Pollinger A, Rigler E, Valli L,Yamulki S, Esala M, Fabbri C,Syviisalo, E andVinther FP. 2005. Nitrous oxide emissions from organic and conventionalcrop rotations in five European countries. Agriculture, Ecosystems and Environment, 112: 200-206.

Pimentel D, Hepperly P, Hanson J, Douds D and Seidel R. 2005.Environmental, energetic and economic comparison of organic and conventional farming systems. Bioscience, 55: 573-582.

Reganold JP, GloverJD, AndrewsPK and HinmanHR.2001.Sustainability of three apple production systems. Nature, 410(6831):926-930.

Reganold JP. 1995. Soil quality and profitability of biodynamicand conventional farming systems: A review. American Journalof Alternative Agriculture, 10(1): 36-46.

Sayre L. 2003.*Organic farming combats global warming – big time*, Rodale Institute,http://www.rodaleinstitute.org/ob_31.

Scialabba NE and Muller-Lindenlauf M. 2010. Organic agriculture and climate change. Renewable Agriculture and Food Systems, 25(2): 158-169.

Smith KA and Conan F. 2004. Impacts of land management on fluxes of trace greenhousegases. Soil Use and Management, 20: 255-263.

Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B,Ogle S, O'Mara F, Rice C, Scholes B, Sirotenko O, Howden M,McAllister T, Pan G, Romanenkov V, Schneider U, Towprayoon S,Wattenbach M and Smith J. 2008. Greenhouse gas mitigation in agriculture.Philosophical Transactions of the Royal Society of London. Series B, Biological sciences, 363: 789-813.

Smith P, Martino D, CaiZ, Gwary D, Janzen H, Kumar P,McCarl B, Ogle S, O'Mara F, Rice C, Scholes B andSirotenko O.2007. Agriculture. In:*Climate Change 2007: Mitigation* (B Metz, OR Davidson, PR Bosch, R Dave and LA Meyer, Eds.), Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.pp 497-450.

Sqalli J and Adamkiewicz G. 2018. Organic farming and greenhouse gas emissions: A longitudinal U.S. state-level study. Journal of Cleaner Production 192: 30-42.

SreejithA and Sherief AK. 2011.*The wanted change against climate change: assessing the role of organic farming as an adaptation strategy.In*:*Climate Change Adaptation Strategies in Agriculture and Allied Sectors* (GSLHV Prasad Rao, Ed.), Scientific Publishers, New Delhi, India. pp. 193-200.

SrinivasaraoCh, Venkateswarlu B, Lal R, Singh AK, Vittal KPR, Kundu S,Singh SR and Singh SP. 2012. Long-term effects of soil fertility management on carbonsequestration in a rice-lentil cropping system of the Indo-Gangetic plains. Soil Science Society of America Journal, 76(1): 168-178.

Syliva DM and Williams SE. 1992.Vesicular-arbuscularmycorrhizae and environmental stress. In:*Mycorrhizae in Sustainable Agriculture* (GJ Bethenfalvay andRG Linderman,Eds.), Proceedings of a symposium, 31 October 1991. AmericanSociety of Agronomy, Crop Science Society of America, andSoil Science Society of America, Madison Wisconsin, pp 101-124.

Tuomisto HL, Hodge ID, Riordan P and Macdonald DW. 2012. Does organic farming reduce environmental impacts? – A meta-analysis of European research. Journal of Environmental Management 112: 309-320.

Wells AT, ChanKY and CornishPS. 2000. Comparison ofconventional and alternative vegetable farming systems on theproperties of a yellow earth in New South Wales. AgricultureEcosystems and Environment, 80(1-2):47-60.

Management of horticultural cropsunder changing climatic scenario

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Introduction

Climate can be defined as a long-term average of weather conditions (typically 30 years). Climate change is defined as a change in the climate that lasts for decades or more and is caused by either natural or human-caused factors (IPCC, 2007). Temperature rises, changes in rainfall patterns, sea level rise, salt-water intrusion, floods and droughts, etc are all examples (Bates et al., 2008; Shetty et al., 2013; Pathak et al., 2012). CO2 levels in the atmosphere have risen dramatically from 280 parts per million to 370 parts per million, and are expected to double in the twenty-first century (IPCC, 2007). The Indian climate has witnessed considerable changes, with yearly temperatures increasing by 0.56°C on average during the last 100 years (Rao et al., 2009; IMD, 2010). The main issue and responsibility of the scientific community is to provide food security for India's population in the face of changing climate circumstances. Climate change and its variability are creating enormous problems to agriculture, especially annual and perennial horticultural crops, in terms of performance. Short growing periods are anticipated to cause a reduction in fruit and vegetable production, which will have a detrimental influence on growth and development, particularly due to terminal heat stress and reduced water availability. Rainfed agriculture will be harmed mostly as a result of rainfall variability and a decrease in the number of wet days (Venkateswarlu and Shanker 2012). Climate change and unpredictability have created more uncertainties and dangers, putting additional limits on horticulture production systems. Climate change may lead to an increase in the price of fruits and vegetables. The challenges ahead are sustainability and competitiveness, as well as achieving targeted production to meet increasing demands in an environment of reducing land, water, and the threat of climate change, which usually requires climate smart horticulture interventions which are highly location specific and knowledge-intensive for improving production in the challenged environment (Malhotra and Srivastava 2014, Malhotra 2015).

We require extensive information on physiological reactions of the crops, effects on growth and development, quality, and production to estimate the implications of climate change on horticulture crops. In order to prepare the horticulture sector to handle the impending difficulties of climate change, the many impacts must be tackled in a deliberate and methodical manner. Increased respiration, altered photosynthesis, and partitioning of photosynthates to economic components would all result from a change in temperature. It could also change phenology, reduce crop duration, flowering and fruiting days, and hasten fruit maturity, ripening, and senescence. Individual crop temperature sensitivity is determined by intrinsic tolerance and growing behaviours. Due to their longer flowering periods, indeterminate crops are less susceptible to heat stress than determinate crops. The increase in temperature may not be uniformly distributed between day and night, or between seasons (Srinivas Rao et al. 2010). Even moderate warming in tropical places may result in disproportionate yield declines. Crop yields in high latitudes may benefit from a minor increase in temperature. Temperatures in developing countries, which are primarily located in lower latitudes, are already approaching or exceeding thresholds, and further warming would reduce rather than boost production.

The Indian Council of Agricultural Research (ICAR) has been working on climate-resilient methods in food grains and horticultural crops since 2011, as part of the National Innovations on Climate Resilient Agriculture (NICRA) network initiative. Other organisations, such as the Consultative Group on International Agricultural Research (CGIAR), have begun a programme on Climate Change, Agriculture, and Food Security (CCAFS), which promotes adaptable resilient technology in a number of countries, including India. Several climate-smart technologies have been developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Despite facing climate change issues, India is the world's second largest producer of vegetables and fruits, behind China, and supports 17 percent of the population with a land share of 2.4 percent. We are still dealing with the situation of food security.

According to the UN study Right to Food, approximately 1 billion people go to bed hungry, and children are malnourished. Given these realities, the focus of this chapter is on production issues in vegetables and fruits, as well as approaches to alleviate them using climate-resilient technologies.

Climate resilient technologies for horticultural crops (Vegetables)

1.1 Selection of location specific crop and cultivar

Cowpea, drumstick, brinjal, cluster bean, okra, dolichos bean, limabean, and chilli are all ideal for rain-fed vegetable growing. Vegetable crops, particularly legumes, are most suited for contingency crop planning in the case of a monsoon delay. Selection of cultivars with a strong root system and the ability to recover quickly after being stressed.

1.2 Production of seedlings using improved method

Under shade net cover, use Portray grown seedlings with coco peat instead of soil. For disease-free seedlings in the nursery, bio fertilisers or bio-pesticides can be utilised. These seedlings will establish rapidly, have a less damaged root system during transplantation, and will withstand biotic and abiotic challenges better, particularly water stress.

Portray grown seedlings

1.3 Crop residues to enhance soil organic matter

Continuous efforts must be made to improve the condition of soil organic carbon, soil structure, and water holding capacity by incorporating plant leftovers in soil and applying farm yard manure. Crop residues and farmyard manure incorporation enhances soil organic matter status, soil structure, and soil moisture storage capacity. By using an alley cropping system, incorporating green manure crops into the soil, crop rotation, and agroforestry, we can boost the organic matter in the oil. Vegetable crops require adequate organic matter in the soil for rapid growth because they are short-lived crops.

1.4 Foliar application micro nutrients

The use of K and Ca at the right time under water stress and drought is critical for improved growth and production in vegetable crops. The nutrients will be promptly absorbed in the plants as a result of foliar spray, which will aid in the crop's general development.

1.5 Water Resource Conservation

1.5.1 Micro irrigation

Drip irrigation is superior to traditional irrigation in vegetables because it improves the quality of the food and saves water by 30–50% depending on the crop season. It also allows you to irrigate a larger area with the same amount of water. Drip irrigation also aids in fertiliser efficiency, weed control, and personnel savings. Drip irrigation makes optimal use of water because the water drops only fall in the root zone. Drip irrigation has its own range of benefits, including faster plant growth and development and increased yields in fruit crops. With paired row planting, which is done by using one drip lateral in two crop rows, drip irrigation is easily utilised in chilli, brinjal, cauliflower, and okra.

The benefits of drip irrigation include significant water savings, increased growth, development, and yields of fruits and vegetables, weed control, and labour savings. Fruit crops, as well as all vegetable crops, even closely spaced crops like onions and beans, can benefit from drip irrigation. Water savings range from 30 to 50 percent, depending on the crop and season. For vegetable crops, inline drip laterals with emitting points spaced 30 cm apart and emitting at a rate of 2 LPH are commonly used. Paired row planting is utilised in crops like chilli, brinjal, cauliflower, and okra, and one drip lateral is used for two crop rows.

Drip irrigation

1.5.2 Sprinkler irrigation system

Micro sprinkler irrigation systems are less expensive to install than drip irrigation systems, and they can be utilised in practically all fruit and vegetable crops depending on water availability and soil structure. It aids in the reduction of microclimate temperature and the increase of humidity in the summer, which aids in aggressive development and increased production. Water can be saved by 20–30% when micro sprinklers are used.

1.5.3 Water saving method under limited water resources

The alternate furrow irrigation method is becoming increasingly common. This strategy can be easily used in many crops such as capsicum, tomato, okra, and cauliflower by irrigating alternate-furrows, which saves 35–40% of water.

1.5.4 Moisture conservation and soil conservation techniques

Tillage, mulching, zero tillage, contour cultivation, contour trip cropping, multi-cropping systems, and other soil moisture conservation measures include tillage, mulching, zero tillage, contour cultivation, contour trip cropping, and multi-cropping systems. Contour bench terracing, bunding, graded bunding, vertical mulching, and other mechanical methods for soil and moisture conservation can be used in arid terrain. Another method for preventing runoff is to collect rainwater and recycle it. Rainwater collection can be done in locations with 500-800 mm of rainfall. In farm ponds, 10-50 percent of runoff water can be collected and used for life-saving irrigation in diverse crops during periods of water scarcity.

1.5.5 Mulching in Vegetable Production

This approach involves covering the soil with plant leftovers or plastic sheets, which aids in water conservation and weed control. Mulching is utilized in all fruit and vegetable crops, and it is done with both crop waste and organic materials. Plastic mulches have recently become popular due to their benefits in moisture conservation, weed control, and soil structure maintenance. A 30-micron thick polyethylene with a width of 1 to 2 m is utilised in vegetable crops. The mulching sheets are laid in a raised bed method.

Plastic mulching in vegetable crops

1.6 Wind breaks, hedges and inter cropping

To counteract strong winds and undesirable effects such as dry spells and high temperatures, tall growing trees should be planted along the field's edge. During the summer, vegetable crops can be produced as an inter crop in orchards.

1.7 Protected cultivation of vegetables

In peri-urban locations where the climate is not as favourable all year as it is in open fields, vegetable cultivation can be done in a protected environment. Biological and abiotic restrictions will be avoided under protected culture. Green homes, plastic or net houses, tunnels, poly houses, and other similar structures are commonly used as material protection structures. A simple construction such as a rain-shelter wrapped with polyethylene sheet aids in crop production by preventing heavy rainfall. Heavy rainfall and difficult-to-control fungal foliar diseases have harmed production in vegetable crops such as tomato, onion, and melons, which are also difficult to manage resulting from poor soil aeration, poor drainage, and blossom drop in crops. The better solutions for dealing with summer heat waves are net houses and shade nets. It aids in the reduction of high temperatures, the creation of a microclimate, and the improvement of humidity. Tomato, French bean, and capsicum production can be increased by employing a shade net or a net house.

1.8 Management of leaf miner and mites during high temperature stress

In the case of beans, spraying neem soap 4 grammes per litre or triazophos at a rate of 1.5 ml per litre of water can be used to control leaf miners, and Abanectin 0.5 ml/l can be used to manage mites and control Aphids. Leaf minor and mites can also be controlled using neem soap (1.0 percent) or kernel extract (4.00 percent).

2. Climate resilient technologies for horticultural crops (Orchards)

2.1 Abiotic stress tolerance varieties

Drought tolerant cultivars to be included in the cropping system are Pomogrante (Ruby hybrid), Annona (Arka Sahan hybrid), and Fig selection (Deanna and Excel). Dogris (Vitis champine) is a promising cultivar for crop development and yield, as well as being ideal for seeded and seedless grapes, as well as being drought tolerant and able to withstand saline soil.

2.2 Water management in orchard

Water application in the root zone area is critical for appropriate growth and higher yields. It also helps to preserve water by allowing for timely irrigation and water quantity. Drip irrigation or micro spray can be used instead of the traditional form of irrigation using channels for more effective and efficient water consumption.

Farm pond for supplemental irrigation in orchard crops

2.3 High-density planting in orchards

In lighter soils, a row spacing of 10 metres and a line spacing of 5 metres is ideal for accommodating more trees and achieving higher yields, and this is now attainable due to recent high-density planting technology. In heavy clay soils, row spacing may be 10 m. and line spacing may be 8 m., subject to the selection of less vigorous types in the case of mango.

2.4 Agri-horti-silviculture and canopy management

Cultivation of legume-based pastures and leguminous crops is excellent for orchards because it allows them to use more nutrients or avoid using fertilizers totally, lowering cultivation costs and allowing farmers to earn more money from the same area. Tree canopy management aids in the harvesting of high-quality fruits.

Horti-pastoral System (Grass + Custard apple)

2.5 Soil organic matter

Organic matter in the form of animal manures, wood chips mulches, deep roots ground coverings, and leguminous pastures is used in orchards to assist maintain healthy soil structure and drainage. Water holding capacity, root health, nutrient cycling, and organic carbon levels are all improved.

2.6 Integrated pests and disease management

Crop rotation in orchard crops between rows, planting of resistant plant kinds, and the use of pest-free root stock are all examples of appropriate planting strategies. These solutions are extremely beneficial in terms of cost savings and reduced risk to human health and the environment.

Conclusions

The horticulture production system has been challenged by the ever-increasing worldwide population. Because there is limited space for expansion, it is necessary to investigate strategies to boost the yield of these crops through various approaches. Climate change has added to the strain on crops by increasing numerous biotic and abiotic stresses, causing crop production systems to suffer even more. We need to implement specific climate resilient technology and techniques to combat new insect pests, diseases, and previously unknown pressures, as well as enhance productivity to feed the world's population without losing product quality. To achieve the best yields in changing climates, a holistic climate resilient technologies strategy combining traditional and modern approaches, such as climate resilient crops, water conservation strategies, and bio molecules for the management of new pests, must be used.

References:

1. Bates, B., Kundzewicz, Z.W., Wu, S. and Palutikof, J. 2008. *Climate Change and Water: IPCC Technical Paper VI*. United Nations Environment Programme. World MeteorologicalOrganization, Geneva, pp. 210.
2. IMD, Annual Climate Summary. 2010. India Meteorological Department, Pune (MH). Government of India, Ministry of Earth Sciences, p. 27.
3. IPCC. 2007. The physical science basis. In Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), *Contribution of Working Group I to the Fourth Assessment Report of the IPCC*. Cambridge University Press, Cambridge, UK, p. 996.
4. IPCC Summary for Policymakers Climate Change 2014. Impacts, Adaptation, and Vulnerability. Part A: *Global and Sectoral Aspects* (eds Field, C. B. et al.) (Cambridge Univ. Press, 2014).
5. Malhotra S.K. and Srivastava A.K. Climate smart horticulture for addressing food, nutritional security and climate challenges. (In) Shodh Chintan- Scientific articles, by Srivastava A.K et al. ASM Foundation, – New Delhi, 2014.– P. 83–97.
6. Malhotra S.K. Mission approach for development of protected cultivation. New Age Protected Cultivation – 1(1). 2015.– P. 29–32.
7. Pathak, H., Aggarwal, P.K. and Singh, S.D. 2012. *Climate Change Impact, Adaptationand Mitigation in Agriculture: Methodology for Assessment and Applications.* Indian Agricultural Research Institute, New Delhi, India.
8. Rao, G.G.S.N., Rao, A.V.M.S. and Rao, V.U.M. 2009. *Trends in Rainfall and Temperaturein Rainfed India in Previous Century. Global Climate Change and Indian Agriculture Case Studies from ICAR Network Project.* ICAR Publication, New Delhi, India, pp. 71–73.
9. Shetty, P.K., Ayyappan, S. and Swaminathan, M.S. 2013. *Climate Change and Sustainable Food Security*. National Institute of Advanced Studies, Bangalore and Indian Council of Agricultural Research, New Delhi, India. ISBN: 978-81-87663-76-8.
10. Srinivasa Rao, N K Laxman R H and Bhatt R M. 2010. Impact of climate change on vegetable crops. (In) *Challenges of Climate Change in Indian Horticulture*, pp 113–23. Singh H P, Singh J P and Lal S S (Eds.). Westville Pub. House, New Delhi.
11. Venkateswarlu B. and Shanker A.K. Dryland agriculture: bringing resilience to crop production under changing climate. (In) Crop Stress and its Management: Perspectives and Strategies. Springer, Netherlands, 2012.– P. 19–44.

Adapting Smallholder Livestock Livelihood Production Systems to Climate Change

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Introduction:

In tropical countries like India, climate change has been, and continues to be the most important cause of instability in small holder livestock production systems and the dependent livelihoods. Climatic related risks like extreme weather events (heat stress/cold stress), drought, floods etc., are expected to rise sharply in near future as global average surface temperature is predicted to increase 1.8 to 4.0° C by 2100. These changes would destabilize the small holder livelihood production systems through crop failures, fodder scarcity, low livestock production and increased incidence of endemic animal diseases. Along with crops and tree plantations, livestock also contribute to human food supply. It converts low-value crop residues and by-products, inedible or unpalatable for human, into milk, meat, and eggs and directly contributes to nutritional security. Nearly two-thirds of farm households are associated with livestock production as a resilient mechanism to the crop production and 80% of them are small landholders (≤2 ha). Besides contributing over one-fourth to the agricultural GDP, livestock provides employment to 18 million people in principal or subsidiary status in India.

At present, resource depletion and climate change in small holder livelihood production systems driving the farmers gradually towards more resilient livestock integrated farming systems. Climate change would also impact severely the economic viability and production of these integrated production systems. Drought and high ambient temperatures in particular, affects production of milk, meat and egg, reproduction, health of animals and condition of pastures. Changes in pasture and crop biomass availability and quality affect animal production through changes in daily or seasonal feed supplies. Further, growing population in the country require more food, feed and fuel and creates additional pressure on agro-ecosystemsand may increase potential for higher incomes from farming.To mitigate the adverse effects of extreme weather events and cope with changing climate, much precised resilient basket of options suitable to local conditions and resources are needed. Hence, one should be critical in recommending resilient production systems in view of much diversified and heterogeneous group of farmers and the resources accessible to them in these systems. This will help in sustaining the productivity and profitability to the farmers even in the era of climate change.

Impact of climate change on livestock production systems:

Dry matter intake decreases especially in high yielding milch cattle and buffaloes exposed to heat stress. In addition, there can also be a decrease in the efficiency of nutrient utilization and increased loss of sodium and potassium electrolytes. Sudden changes in temperature, either a rise in T max (>4°C above normal) during summer i.e. heat wave or a fall in T min (<3°C than normal) during winter i.e. cold wave cause a decline in milk yield of crossbred cattle and buffaloes. The estimated annual loss due to heat stress at the all-India level is 1.8 million tonnes, that is, nearly 2 percent of the total milk production in the country. Global warming is likely to lead to a loss of 1.6 million tonnes in milk production by 2020 and 15 million tons by 2050 from current level in business as usual scenario (Upadhyay *et al*., 2007). The decline in yield varies from 10-30% in first lactation and 5-20% in second and third lactation (Srivastava, A.K., 2010). Northern India is likely to experience more negative impact of climate change on milk production of both cattle and buffaloes due to higher variation in day and night temperatures. The decline in milk production will be higher in crossbreds (0.63%) followed by buffalo (0.5%) and indigenous cattle (0.4%). A rise of 2-6 °C due to global warming (time slices 2040-2069 and 2070-2099) projected to negatively impact growth, puberty and maturity of crossbreds and buffaloes (Naresh *et al*., 2012). Heat stress induced by climate change has also been reported to decrease reproductive performance in dairy animals. Time to attain puberty of crossbreds and buffaloes will increase by one to two weeks due to their higher sensitivity to temperature than indigenous cattle. The main effects include decrease in the length and intensity of the oestrus period, decreased fertility rate, decreased growth, size and development of ovarian follicles, increased risk of early embryonic deaths and decreased foetal growth and calf size.

Decrease in weight gain and alterations in reproductive behaviour were also observed in small ruminants. Lack of prior conditioning to weather events most often results in catastrophic losses in the domestic livestock industry. Further, intensive livestock and poultry production systems rely heavily on food grains as their principal feed type will be the most affected. Since climate changes will have the potential to affect the crop production it will put pressure on livestock industry as a whole.

Besides the direct effects of climate change on animal production, there are profound indirect effects as well, which include climatic influences on quantity and quality of feed and fodder resources such as pastures, forages, grain and crop residues and the severity and distribution of livestock diseases and parasites. Climate change will have a substantial effect on global water availability in also. Not only this will affect livestock drinking water sources, but it will also have a bearing on livestock feed production systems and pasture yield. Rising temperatures increase lignification of plant tissues and thus reduce the digestibility and the rates of degradation of plant species. Areas which receive relatively low rainfall are expected much reduction in herbage yields especially in dry seasons. Incessant rains during 2010 monsoon in India have indicated increased incidence of epidemics of blue tongue disease outbreak in costal districts of Tamilnadu, Karnataka, Andhra Pradesh due to heavy breeding of the vector *Culicoides*sps (Venkateswarlu*et al*., 2011). Temperature and humidity variations could have a significant effect on helminth infections also. Thus, in general, climate change-related aberrations will have adverse impacts on animal health and production systems.

Adaptation and mitigation strategies for optimum production from animal production systems:

Adaptation helps in reducing vulnerability of animals and ecosystems to climatic changes, and mitigation reduces the magnitude of climate change impact in the long term. Livestock keepers, especially resource poor farmers have a key role to play in promoting and sustaining a low-carbon rural path through good management practices. It is important to remember that the capacity of local communities to adapt to climate change and mitigate its impacts will also depend on their socio-economic and environmental conditions, and on the resources available and extent of accessibility for the resources.

Adaptation strategies: Adaptation strategies augment tolerance of livestock production systems and enhances ability to survive, grow and reproduce in conditions of deprived nutrition, high incidence of parasites and diseases under extreme weather events. There is no one-size-fits-all solution for adaptation, measures need to be tailored to specific contexts, such as different species of animals, production level, ecological and socioeconomic patterns, and to geographical location and traditional practices. The foremost adaptation strategy that help in reducing the vulnerability of small holder livestock production systems include enhancing feed and fodder base both at household and community level. This can be achieved by intensive irrigated fodder production systems with high yielding perennial (hybrid Napier varieties like CO-3, CO-4, APBN-1 etc.,) and multicut fodders varieties (MP Chari, SSG etc.,), intensive fodder production systems by growing two or more annual fodder crops as sole crops in mixed strands of legume (Stylo or cow pea or hedge Lucerne etc) and cereal fodder crops like sorghum, ragi in rainy season followed by berseem or Lucerne etc., in rabi season, short duration fodder production from tank beds with sorghum and maize fodder, sowing *Stylohamata* and *Cenchrusciliaris* in the inter spaces between the tree rows in orchards or plantations as hortipastoral and silvopastoral integrated fodder production systems, fodder production systems through alley cropping, perennial non-conventional fodder production systems with deep rooted top feed fodder trees and bushes such as *Prosopis cineraria, Hardwickiabinata, Albizia* species, *Zizyphusnumularia, Colospermum mopane, Leucaena leucocephala, Azadirachtaindica, Ailanthus excelsa, Acacia nilotica* etc., use of unconventional resourcesform food industries like palm press fibre, fruit pulp waste, vegetable waste, brewers' grain waste and all the cakes after expelling oil as feed. Further, fodder production at homesteads through Azolla, hydroponic Fodder Production with barley, oats, lucerne and rye grass, year-round forage production with suitable perennial and annual forages like growing annual leguminous fodders like cowpea or horse gram etc inter-planted withperennial fodders like Co-3, CO-4, APBN-1 varieties of hybrid Napier in kharif and intercropping of the grasses with berseem, Lucerne, etc., during rabi season would also increases resilience of livestock production systems through continuous supply of nutritious fodder.

Substantial fodder can be produced through prior contingency planning. During early season drought, **s**hort to medium durationcultivated fodder crops like sorghum (Pusa Chari Hybrid-106 (HC-106), CSH 14, CSH 23 (SPH-1290), CSV 17 etc) or Bajra (CO 8, TNSC 1, APFB 2, Avika Bajra Chari (AVKB 19)etc.,) or Maize (African tall, APFM 8 etc.,) which are ready for cutting in 50-60 days and can be sown immediately after rains in arable lands during kharif season results in optimum fodder production. If a normal rain takes place in later part of the year, rabi crops like Berseem (Wardan, UPB 110, etc varieties), Lucerne (CO-1, LLC 3, RL 88, etc.) can be grown as second crop with the available moisture during winter. In waste lands fodder varieties like BundelAnjan 3, CO1 (Neela Kalu Kattai), *Stylosanthesscabra,* etc. can be sown for fodder production. In case of mid-season drought, suitable fodder crops of short to long duration may be sown in kharif under rainfed conditions. Mid-season drought affects the growth of the fodder crop. Once rains are received in later part of the season the crop revives and immediate fertilization help in speedy recovery. If sufficient moisture is available, rabi crops like Berseem (Wardan, UPB 110, etc. varieties), Lucerne (CO 1, LLC 3, RL 88, etc.) can be grown during winter. In waste lands fodder varieties like BundelAnjan 3, CO-1 (Neela Kalu Kattai), Stylosanthesscabra etc., can be sown for fodder production. As late season drought affects seed setting, normal short duration fodder crops may be sown. Avoid multicut fodder varieties under rainfed conditions. All the available fodder must be harvested before drying out to preserve nutritive quality. Depending on availability of moisture, rabi fodder crops especially low water requiring varieties of lucerne may be planted. In wastelands, grasses like *Cenchrusciliaris, C. setigerus, Chloris gayana, Panicum maximum, Desmanthusvirgatus, Stylosanthesscabra* can be taken up to increase forage production. In areas that receive north east monsoon rains, multi-cut fodder varieties of sorghum (CO 27, Pant Chari-5 (UPFS- 32), COFS- 29 or pearl millet (Co-8) or maize (African tall) are recommended. In areas that receive summer rains, fodder crops like cowpea and maize are best suited.

The second most important in building the resilience of small holder livelihood production systems is development and promotion of integrated farming systems. Integrated farming system besides generating higher productivity, it also produces sufficient food, fruits, vegetables etc., to the farm families. Several IFS models like (A) Conventional cropping; (B) crop + poultry (20) + goat (4); (C) crop + poultry (20) + goat (4) + dairy (1); (D) crop + poultry (20) + goat (4) + sheep (6); and (E) crop + poultry (20) + goat (4) + sheep (6) + dairy (1) were studied. Among the models examined, model (E) recorded a maximum net income of Rs 52794/ha, with maximum employment generation (389 man days/ha/year) (Solaiappan*et al*., 2007). Integrated farming system comprising enterprises viz. field and horticultural crops, poultry, fishery (0.20 ha) and apiary (5 bee hive boxes) in 0.6 ha area in Chintapalli of high altitude tribal zone of Andhra Pradesh recorded a net income of Rs.29,102 and B:C ratio of 1.83 with productivity of 14.40 (t ha-1) and 464 man days/ha/year over arable cropping returns (Rs.14500/ha) and B:C ratio (1.47) with less productivity (7.50 t ha-1) (Sekhar *et al*., 2014). Integration of field crops (Rice) + poultry + fish + horticultural crop (banana) resulted in highest system productivity (14.90 t ha- 1) in terms of rice grain equivalent yields. Further, integration of different farm components i.e., crops + horticultural crops (fruits & vegetables) and livestock along with vermi-composting as value addition practice has been found to have maximum gross and net returns with maximum net returns of Rs. 42,610 (51.7%) from livestock, including vermin-compost (AICRP-IFS,2013). Inclusion of 10-20 synthetic poultry breeds like Giriraja/Vanaraja/Gramapriya/Rajasree etc., at backyard with available food grain wastes/ grain byproducts (broken rice/rice bran etc.) from the cropping system will also provide additional income through sale of eggs and chicken. All these types of systems are suitable for the scarce rainfall zone where the rainfall is 500-750 mm.

Crop-livestock integrated systems are recommended for the areas having some irrigation facilities and or receiving above 1000mm rain fall with high yielding graded Murrah buffaloes and crossbred cows and crops. These areas generally produce surplus crop residues besides allocation of some cultivated land for fodder crops and purchase of feed supplements. In these systems inclusion of 10-20 synthetic poultry breeds like Giriraja/Vanaraja/Gramapriya/Rajasree etc., at backyard will further boost the income of the farmers. Crop- livestock- poultry - fishery integrated farming system are mostly suitable for high rainfall areas, where paddy is cultivated both in *Kharif* and *Rabi* seasons. Cows and or buffaloes are maintained at backyard with crop residues and supplements. Fish is reared in farm ponds and poultry is maintained in cages over the pond with grain and bran supplementation. The droppings of poultry serve as feed for the fish in the pond.

Silvo-pastoral systems are efficient integrated land use management systems of agricultural crops, tree fodder species and or livestock simultaneously on the same unit of land which results in an increase of overall production. Inter spaces between fodder trees species (*Leucaena leucocephala*) are utilized for cultivation of grasses and grass legume mixtures (*Cenchrusciliaris* and *Stylosantheshamata*or*scabra*), which provides a two tier grazing under in situThis type of systems provide Rs.25000-30000 income per ha (Ramana, *et al*., 2000) and helps in reclamation of soil in waste lands and are more suitable for rearing small ruminants (10-12 animals/ha) in degraded waste lands under dryland conditions in Scarce rainfall zone. Horti-pastoral systems, the inter tree spaces in the mango/lemon/sweet orange orchards are utilized for cultivation of grasses and grass legume mixtures (*Cenchrusciliaris* and *Stylosantheshamata*or*scabra*) along with one side boundary plantation of fodder trees species (*Leucaena leucocephala*). Cultivated fodder and weeds serve as feed for the animals. Integration of lambs provide Rs.4000-5000 additional income per ha through sale of animals, control weeds by grazing/browsing and also improve soil fertility through faeces and urine (Ramana, 2008 and Ramana *et al*., 2011)

Further, modifications in feeding, breeding and shelter management for different species of livestock would enhance resilience of small holder livestock-basedlivelihood production systems. This includes, (i) modifying grazing practices (rotational grazing and or restricted grazing); (ii) introducing especially during lean period, such as stall-fed systems through cut and carry fodder production; (iii) better feeding management through conventional and unconventional feed resources (iv) providing proper shelter and adequate wholesome water throughout the year (v) identification and promotion of local high productive resilient breeds that have adapted to local climatic stress and feed sources; (vi) improvement of local animals through cross-breeding with heat and disease tolerant breeds and (vii) synchronization of oestrus based on the availability of feed resources and favourable climatic conditions, (viii) supplementation of micro minerals and vitamins especially during lean season, (ix) Eradication, containment and surveillance of endemic animal diseases

Strategies for efficient utilization of available crop residues: In order to meet the nutrient requirement of huge livestock population in India, it is essential to improve the fodder quality of cereal and legume food crops through crop improvement programs. The resulting new varieties would provide good yields of both human food, livestock feed and mulching material. One should make greater use of crop residues as animal feeds, which will make better use of water resources by spreading the "cost" of the water used for growing crops across the grain and animal feed components. The excess and unpalatable crop residues like castor stalks and cotton stalks should be used as mulching material. Farmers should more effectively harness manure for crop production by adopting the technology of storing and distributing manure to avoid the loss of nutrients and biomass. Inter row spaces or waste lands should be sown with legume cover crops like velvet bean and at the end of the season pods may be used as feed material and leaf can be used as mulching material.

Modifications in managemental practices: This includes feeding, breeding and shelter management for different species of livestock.Changes in livestock management practices could include: (i) mixed crop livestock farming systems, diversification, intensification and/or integration of fodder production (silvopastoral systems) and/or orchards (hortipastoral systems), alley cropping; (ii) changing land use and irrigation; (iii) conservation of CPRs; (iv) modifying grazing practices (rotational grazing and or restricted grazing); (v) introducing especially during lean period, such as stall-fed systems through cut and carry fodder production; (vi) better feeding management through conventional and unconventional feed resources (vii) providing proper shelter and adequate wholesome water throughout the year (viii) identification and promotion of local breeds that have adapted to local climatic stress and feed sources; (ix) improvement of local animals through cross-breeding with heat and disease tolerant breeds and (x) synchronization of oestrus based on the availability of feed resources and favourable climatic conditions, (xi) supplementation of micro minerals and vitamins especially during lean season.

Further, use of sprinkler and or rain gun irrigation systems for fodder production, cleaning of animals with recycled water, high yielding and low water required multi-cut fodder varieties, improving CPRs productivity through re-sowing and weeding etc., would increase livestock water productivity.

Eradication, containment and surveillance of diseases: Diseases results in i) reducing the livestock population through death or culling; ii) reducing productivity of livestock; iii) creating market shocks when demand falls and supply contracts in response; and iv) disrupting international trade in livestock products. They decrease the productivity of animals by causing death or reducing the efficiency with which they convert feed into meat, milk and eggs. Hence, participatory disease surveillance, early forewarning, traceability and emergency systems would help in containment of disease epidemics. Ring vaccination (5km radius) and restriction of animal movement prevents spreading of contagious diseases in rural areas in the event of any outbreak.

***Technology development*:** Working towards a better understanding of the impacts of climate change on livestock production systems, developing tolerant breeds, fodder varieties and specific vaccines, improving animal health and enhancing water and soil management would support adaptation measures in the long term.

***Institutional and policy support*:** Introducing subsidies for fodder production, establishment of complete feed mills, insurance of animals, income diversification practices and establishing livestock early warning systems and other forecasting and crisis-preparedness systems could strengthen adaptation efforts.

Capacity building of stake holders:It is essential to improve the capacity of livestock producers and herders to understand and deal with climate change impacts in the long run. Capacity building training programmes on agroecology specific technologies and practices for the production and conservation of fodder and also better health management practices improves the supply of animal feed, reduces malnutrition and mortality in livestock.

Conclusions:

Enhancing the fodder supply, integrated production systems, value addition, information and knowledge sharing through agro and animal advisories, crop cum livestock insurance, conservation and promotion of highly productive native breeds, contingent fodder-animal planning, mitigation of GHG emissions, scaling-up of proven resilient production systems to spread the adaptation options and innovations to a wider community with capacity building of small holders along with good policies would certainly build the resilience of small holder livestock based livelihood production systems in India.

References:

Naresh Kumar, S., Anil Kumar Singh, Aggarwal, P.K., Rao, V.U.M. and Venkateswarlu, B. (2012). Climate Change and Indian Agriculture: Impact, Adaptation and Vulnerability – Salient Achievements from ICAR Network Project, IARI Publication, p. 32.

Ramana, D.B.V. (2008). Silvopastoral and hortipastoral models for small ruminant production. In: Alternate land use systems for resource conservation, emerging market needs and mitigation of climate change in rainfed regions, 16th January-5h February 2009, CRIDA, Hyderabad, 239-249pp.

Ramana, D.B.V., Rai, P., Solanki, K.R and Singh, U.P. (2000).Comparative performance of lambs and kids under silvopastoralsystem.In: Proc. III Biennial ANA conference, Hissar.

Ramana, D.B.V., Reddy, N. N and Rao, G. R. (2011). Hortipastoral systems for ram lamb production in rain fed areas. Annals of Biological Research, 2011, 2 (4) : 150-158.

Robertson, T.D, Ribeiro, S.A., Zodrow, S. and Breman, J.V. (1994). Assessment of Strategic Livestock Feed Supplementation as an Opportunity for Generating Income for Small-Scale Dairy Producers and Reducing Methane Emissions in Bangladesh, Appropriate Technology International, USA.

Sekhar, D, K. Tejeswara Rao, N andVenugopala Rao (2014). Studies on Integrated Farming Systems For Tribal Areas of Eastern Ghats In Andhra Pradesh. *Indian Journal of Applied Research* 4(10)14-15.

Solaiappan, U., Subramanian, V andMaruthi Sankar, G.R. (2007). Selection of suitable integrated farming system model for rainfed semi-arid verticinceptisols in Tamil Nadu. *Indian Journal of Agronomy* 52 (3): 194-197.

Srivastava A.K. (2010). Climate Change Impacts on Livestock and Dairy Sector: Issues and Strategies. In: National Symposium on Climate Change and Rainfed Agriculture, February 18-20, 2010, Indian Society of Dryland Agriculture, Central Research Institute for Dryland Agriculture, Hyderabad, India. Pp 127-135.

Upadhyay R.C., Ashok Kumar, Ashutosh, S.V. Singh and Avtar Singh (2007).Impact of climate change on milk production of crossbred cows. 4 th Congress of Federation of Indian Physiological Societies (FIPS), January 11-13, 2007, DIPAS, DRDO, Delhi.

Venkateswarlu, B., Singh, A.K., Prasad, Y.G., Ravindhra Chary, G., Srinivasa Rao, Ch., Rao, K.V., Ramana, D.B.V., Rao, V.U.M. (2011). District level Contingency Plans for Weather Aberrations in India. Central Research Institute for Dryland Agriculture, Natural Resource Management Division, ICAR, Hyderabad, India. 136p.

Managing livestock production systems to climate variability for enhanced productivity

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Livestock rearing is one of the major occupations in rural India and it is making significant contribution to the country's GDP. The animal husbandry sector has a good growth potential. Livestock rearing in India provides manure, draught power for agriculture and local transportation and forms important source of food and cash income to millions of households spread across various parts of the country.

Amongst the other variables, temperature as an important meteorological variable is greatly imposing impacts on livestock in terms of heat stress directly. However, moisture stress and drought affect the fodder as well as grain yields on which livestock production system is dependant. Thus, present chapter has been made to sensitize the stakeholders about how climate variability is affecting livestock and how to maintain productivity under these circumstances.

Climate change and livestock management

Most of the resource poor farmers (small and marginal) keep few cattle, goats, sheep and chickens in almost all parts of India. Only some of the progressive farmers who has the resources keep a bigger herd of animals. The livestock are usually fed on crop residues or are allowed to graze nearby which expose them to trace element deficiency as well as broader deficiency known as Hollow Gut Syndrome. Even if the crop fails, the animals can graze on it or animals graze on the harvested fields also. Livestock provide manure for the fields, either by grazing on the stubble after the harvest, or through composting. Special fodder crops are meagrely cultivated due to higher opportunity cost of lands under urbanization scenario. The only viable option, therefore, is to revitalize the degrading common fodder and pasture resources in the country and improve their productivity. Small livestock are a source of ready cash and a safeguard in times of distress to the farmers.

Vast tracts of arid and semi-arid lands are unsuitable for crop production but support livestock, especially small ruminants (sheep and goats). Livestock is not only a vital source of protein but also constitutes an important sector of the economy which makes use of land that would otherwise be unproductive, providing livelihoods to millions of people around the world. In arid and semi-arid regions where crop failures and draught are frequent dependency on livestock increases. Most people depend on the sale of livestock products like milk, meat and hide and livestock itself for their livelihood. Livestock is the main source of food and people different species that cope well with harsh dry environment. The most common and well adapted and acclimatized livestock in these regions are breeds of sheep, goats, camels and cows as per the necessity and purpose to rear these animals.

Climate change may affect the prevalence of parasites and diseases that affect livestock. The change in pattern of onset of monsoon, duration of monsoon, building up of humidity for longer duration, etc could allow some parasites and pathogens to survive more easily. In areas with increased rainfall, moisture-reliant pathogens could thrive. Increases in CO_2 may increase the productivity of pastures but may also decrease their quality in terms of protein and fibre.

Heat waves, which are projected to increase under climate change, directly impacts the livestock productivity and efficiency. Apart from this, drought reduces the amount of quality forage available to grazing livestock. Some areas could experience longer, more intense droughts, resulting from higher summer temperatures and reduced precipitation.For animals that rely on grain, changes in crop production due to drought could also become a problem.

Impact of high/ low temperature on livestock

Under heat stress, immediately physiological response followed by behavioural responses of livestock are manifested. Heat stress is one of the most important stressors along with extended periods of high ambient temperature and humidity. In India, livestock begins to suffer from mild heat stress when thermal heat index (THI) reaches higher than 72, moderate heat stress occurs at 80 and severe stress is observed after it reaches 90. These stresses reduce feed intake and animal productivity in terms of milk yield, body weight and reproductive performance are hampered severely.

More than 50% of milk comes from the buffaloes in India, however, their reproductive performance is severely compromised during summer months is due to inefficiency in maintaining the thermo-regulation under high environmental temperature and relative humidity being poorly developed heat dissipation mechanism in them, less number of sweat glands and dark colour. Heat stress in lactating animals results in dramatic reduction in roughage intake, gut motility and rumination which alters dietary protein utilization and body protein metabolism. Apart from this, high THI can influence disease resistance also in livestock. There are reports of reduction in feed consumption of poultry birds by 5% for every 1°C rise in temperature between 32–38 °C to reduce heat from dissipated in metabolic activities.

Strategies to ameliorate heat stress

In dairy animals, heat stress is a crucial event that significantly affects production, reproduction, and health, and its economic impact is enormous. Therefore, a multidisciplinary approach should be implemented to formulate ameliorative strategies for heat stress involving shelter management, microclimatic modification, feeding and nutrient management and genetic selection of animals for improvement. In social science-based studies, the farmers' reported coping strategies against heat stress were feeding fresh fodder and clean water, feeding and milking in cool hours, offering extra concentrate, providing shade (tree or housing), bathing of the animals and improving living space by a decrease in herd size. Identification of genotype adapted to climatic stress and formulation of region-specific climate-resilient breeding strategies of livestock to select heat-tolerant livestock. Further, climate-resilient bovine herd management practices are a big challenge for balancing production by maintaining fertility and metabolic diseases without compromising welfare.

Modification of micro environment

During the heat stress period, the dairy animals can be cooled in two ways, either by improving the heat dissipation mechanism or by cooling the nearby environment of the animal through micro-climatic modification.

Nutritional management

During heat stress, the major challenge for dairy animals is the insufficiency of nutrient supply and the reduced dry matter intake as a coping mechanism to reduce the heat increment.Therefore, nutrient-enriched feed in the form of good quality green fodder, concentrate, bypass fat, and protein should be supplemented to improve dairy animals' production and reproduction performance during hot weather conditions.

Genetic modification

Identification and selection of heat-tolerant high-producing breeds and further use for breeding can help to cope up with heat stress even in crossbreeding. Therefore, in the base population, genetic diversity needs to be maintained. The change in genetic biodiversity under changing climate scenario is unnoticed at farmers' level and needs attention.

General tips for heat stress management in dairy animals:

- Farmers can quickly identify the animal is in heat stress or not by simply monitoring respiration rate. If the respiration rate is more than 80 breaths per minute, heat stress is a clear indication.
- The more straightforward way to understand when heat stress started is that if human being starts feeling the stress as for animals, it already started.
- Adequate space should be provided during the heat stress period to the dairy animals for effective heat dissipation, especially tie stalls, which are commonly observed at farmers' doorsteps and present-day small commercial dairy farms.
- Shades must be provided, especially during the summer months, to reduce the heat load from radiation. The roof should be reflective. Roof painted with white paint and insulated with puff or straw and covered with seasonal vegetable plants like bottle gourd, pumpkin and ridge gourd grown on earth is quite effective in reducing the inside temperature of the shed.
- The fresh and cool drinking water facility under shaded areas should be ensured for effective heat stress management.
- Holding and milking areas must have adequate ventilation, air circulation, and cooling facilities as less attention has been given to Indian conditions.
- In hot-dry weather, misting is quite effective in cooling the environment, which further helps cool the animals. Fogging is very effective but under closed conditions and when the temperature is high and humidity is low. In fogging, desalinated water is generally recommended; otherwise, nozzle blocking is a common problem.
- In hot-humid conditions, sprinkling for a limited period along with fanning is quite effective. In closed housing for such a cooling system, proper ventilation must be ensured to reduce the humidity buildup.
- Wallowing is very effective for buffaloes due to their black skin colour and fewer sweat glands. Natural ponds are very common in the village area and quite effective amelioration of heat through wallowing. Artificially build 50 ft. wide X 100 ft. long and 4 to 6 ft. depth wallowing pond is suitable for 100 animals.
- Using geothermal energy can be an alternative for cooling closed sheds of the dairy farm by using the earth's temperature at a depth of 15 to 20ft through pipelines for reducing the temperature by 8-10^{O}C.
- In the heat stress period, four to five days of adequate cooling, especially around breeding, can enhance the fertility of dairy animals.
- Optimum body condition score maintenance in different stages of physiological state and especially the animals are going to calve in heat stress period can be an effective strategy.

References

Annual Report, 2017-18. ICAR-Central Research Institute for DrylandAgriculture, Hyderabad, India, Pp-181.

FAO (2012) Enduring farms: climate change, smallholders and traditional farming communities.Food and Agriculture Organization.www.fao.org/nr/water/docs/Enduring_Farms.pdf

IGFRI. 2013. Indian Grassland and Fodder Research Institute. Vision 2050.IGFRI, Jhansi, India, Pp-40.

Pankaj, P.K. and Ramana, D.B.V. (2013).Climate resilient small ruminant production in dry lands.In Climate Resilient small ruminant production (ed. Sahoo *et al*).Published by NICRA and CSWRI. Pp 69-74.

Pankaj, P.K., Sudheer, D., V. Maruthi, K.S. Reddy, D.B.V. Ramana, K. Sami Reddy and B. Singh. 2018. Scientific forage management for improving livestock production in rainfed lands. Technical Bulletin - 01/ 2018.ICAR-Central Research Institute for Dryland Agriculture, Hyderabad, Pp-40.

Upadhaya, R.C., Ashutosh Kumar, A., Gupta, S.K., Gupta, S.V., Singh, S.V. and Nikita Rani (2009).Inventory of methane emission from livestock in India.In, Global climate change and Indian agriculture.*Case studies from the ICAR Network project. P.K. Aggarwal (Ed), ICAR, New Delhi.*, pp 117-122.

Upadhaya, R.C., Singh, S.V., Kumar, A., Gupta, S.K. and Ashutosh (2007).Impact of climate change on Milk production of Murrah buffaloes.*Italian J. Anim. Sci.*,**6**(2):1329-1332.

Insurance based climatic risk management in rainfed crops

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Introduction

Climate is the primary determinant of agricultural productivity. The fundamental principle of agriculture depends on how crop responses with weather and soil conditions. Hence, any abnormality of exterior optimum weather circumstances disturbs the normal crop growth and development (Bal and Minhas, 2017).Already, the productivity of Indian agriculture is limited by its high dependency on monsoon rainfall which is most often erratic and inadequate in its distribution. In the recent years, climatic change/variability has become the biggest challenging factor that affects agriculture in India.Each year there are climatic change events that translate into climate change risks. These climate related risks arise from ‘normal’ day-to-day, seasonal, and year-to-year variability in climate as well as regional climate differences and weather patterns. Agricultural systems are managed ecosystems. There are also indications that a warming climate would favour an increase in the intensity and frequency of extreme events and we are already witnessing some of these such as heat waves and precipitation extremes. Being situated amidst the tropics, tough road lies ahead for India (IPCC, 2021). Environmental stresses such as erratic, insufficient and extreme rainfall, extreme temperatures, drought, flood, storms and others limit yield and productivity of many cultivated crop plants. There are likely to be regional winners and losers from climate change, given that the potential for net reductions in crop yields is greatest in warmer, low latitude areas and semi-arid areas of the world. This implies that climate change may affect the comparative advantage of agricultural production regions. Changes in comparative advantage can be expected to shift geographically the areas in which specific crops are grown, both within countries and internationally.

Generally, developing countries are vulnerable to climate change because they depend heavily on agriculture, they tend to be relatively warm already, they lack infrastructure to respond well to increased variability, and they lack capital to invest in innovative adaptations. Concerns about mitigating and adapting to climate change are now renewing the impetus for investments in agricultural research and are emerging as additional innovation priorities. In the coming decades, the development and effective diffusion of new agricultural technologies will largely shape how and how well farmers mitigate and adapt to climate change. Even though interventions are available in term of mitigation and adaptation technologies, insurance especially weather-based gives a protection to the farming community in case of any climate related extremity or aberration.

In India, the sheer size of the population involved n agriculture and the fact that 60% of the crop production is under rained condition highlight the need for income stabilization program for the farmers. Reducing weather vulnerability may well be the most critical challenge facing agrarian development in the country and effective mechanism for transferring risk can go a long way in catalysing investment and growth. Looking at the above facts, in this chapter, an effort has been made to include salient aspects for managing climate risk through weather-based insurance so that farmers can at least minimize their losses in spite of technological interventions during climatic aberrations.

Before discussing about insurance and especially weather-based insurance, one must know about various types of climatic risk/aberration that affects the agricultural output.

Climate Risk

Risk is the chance of something happening that will have an impact and risk is measured in terms of a combination of theconsequences of an event and their likelihoods.Risk may have apositive or negative impact.If we examine the climate trend over time, whatfeatures would we identify to ascertain anychanges? There is strong consensus that globalclimate is changing within the region and globally.In 2021, a report by Inter-governmental Panel on ClimateChange,acknowledged asthe most authoritative analysis of information onclimate change, concluded that unless major reductions in carbon dioxide (CO_2) and other greenhouse gas emissions occur in the coming decades, global warming of 1.5°C and 2°C will be exceeded during the twenty-first century. They have also predicted an increase in the frequency and intensity of hot extremes, marineheatwaves, and heavy precipitation, agricultural and ecological droughts in some regions,and proportion of intense tropical cyclones, as well as reductions in Arctic sea ice, snowcover and permafrost.The global water cycle, including its variability, global monsoon precipitation, and the severity of wet and dry periods, are expected to become more intense as a result of continued global warming.Ocean and land carbon sinks are expected to be less efficient at slowing CO_2 accumulation in the atmosphere under scenarios with increased CO_2 emissions (IPCC, 2021).

The projected change in climate in the future will have negative impact on crops and livestock, majorly. A few positive impacts envisaged are increase length of growing season in temperate regions and the impact of CO_2 fertilization on crops. The relation between climate change and risk to food security is depicted in Fig. 1 and the impact of climate variability and change on biotic and abiotic components of ecosystem is described in Table 1.

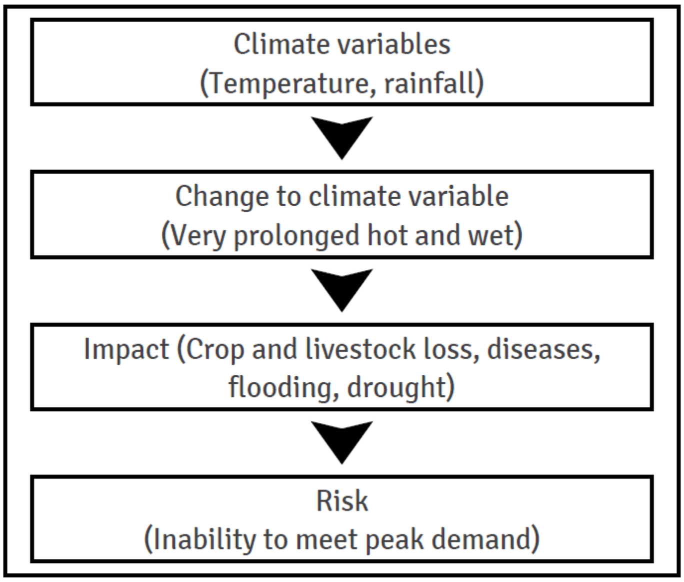

Fig. 1 Link between climate change and risk

Table 1: Impacts of change inweather/climaticvariables on biotic and abiotic components of ecosystem

Change to climate variable	**Examples of impacts**
Higher mean temperatures	Increased evaporation and decreased water balance. o Increased severity of droughts
Higher maximum temperatures, increased more hot days and more heat waves	Increased incidence of crop and livestock loss. o Increased heat stress in livestock and wildlife. o Increased risk of damage to crops. o Issues with pollination and fruit setting o More chances of sun burn o Leads to early and low-yield harvests
Higher minimum temperatures	Decreased risk of damage to crops. o Extended range and activity of some pest and disease vectors. o Low yield harvest due to more respirational loss
Decrease in precipitation	Decreased average runoff, stream flow. o Decreased water resources. o Increased risk of damage to crops
Increased severity of drought	Decreased crop yields /productivity. o Increased forest fire danger
More intense rain	Increased flood, landslide and mudslide damage. o Increased flood runoff. o Increased soil erosion.
Hailstorm	Mechanical damage to crops, livestock, poultry o Flower and fruit drop o Damage extent depends of stage of the crop o Bacterial and fungal infection in the damaged twigs or branches
Lowering of minimum temperature	Frost/ cold wave damage o Reduced size and lowering of quality f fruits o Water soaked scorched appearance and lead to plant mortality o Kill of the bud and reduced orchard productivity
Cyclone	Mechanical damage to crops, livestock, poultry o More harmful neat the time of harvest o Damaged tree trunks and limbs can act as entry points for pests and diseases.

Climate risk management

Climate risk management is a process for incorporating knowledge and information about climate-related events, trends, forecasts and projections into decision making to increase or maintain benefits and reduce potential harm or losses. It is a multi-disciplinary activity that calls for an integrated consideration of socio-economic and environmental issues.Many of the institutions in this country are highly vulnerable and are currently experiencing significant losses and damage due to lack of adequate disaster preparedness within the central and local government levels. These effects will affect every person and public or private institution at all levels; from strategic management to operational activities. There is therefore need to have a robust insurance mechanism to equip farmers, against the climatic risks especially regions dependent only on rain.There are several ways, the climatic risk can be managed namely adaptation, mitigation and insurance. In this chapter, we will mainly focus on the insurance aspect related to managing risk in agricultural fields.

Insurance

In any of the crop insurance, following phases of the crop damage are enclosed:

- Localized/regional catastrophes: It covers regional natural calamities and dangers caused due to hailstorm, landslide disturbing inaccessible agricultural farms in the reported area
- Crop-establishment risk: covers problems in seedling transplanting or crop sowing or seed germination failure due to shortfall in precipitation or opposing seasonal circumstances.
- On-field crop damage: Wide-ranging risk indemnification to protect crop yield losses due to non-avoidable hazards, like occurrence of dry spells, flood damage, damage due to hailstorm, cyclonic activities.
- Post-harvest fatalities: It shields damages for up to an extreme period of two weeks from crop harvesting.

Following are some of the features and benefits of crop insurance:

- The circumstance that the insurance will afford monetary provision in the disastrous occurrence of crop damage. It will therefore be a useful tool in the progress of crop production.
- Inspire growers to implement progressive and innovative/ risk taking farming strategies and advanced technology in agriculture.
- Crop insurance supports farmers in maintaining flow of farming credit.
- On a broad aspect, not only the protected farmer who will get benefit from the crop insurance, whole community will be benefitted either directly and indirectly through preserving crop production & occupation, excises, generation or market fees etc.
- Alternative significant advantage is that crop insurance rationalizes loss evaluation procedures and also aids to shapeup precise statistical background for crop production.

In India, various types of insurance schemes have been put into implementation since 1972 (Table 2). Those were either formally put into service and few were put as pilot test in selected districts.

Table 2: Crop insurance products and its advancement in India

No.	Name of the scheme	Period
1	Scheme based on individual approach	1972-1978
2	Pilot Crop Insurance Scheme (PCIS)	1979-1984
3	Comprehensive Crop Insurance Scheme (CCIS)	1985-1999
4	National Agricultural Insurance Scheme (NAIS) and Modified – NAIS	1999-2000: 2012-13
5	Pilot - Weather Based Crop Insurance Scheme (WBCIS)	2007-08: 2012-13
6	National Crop Insurance Programme (NCIP)	2013-14: 2016-17
7	Restructured -Weather Based Crop Insurance Scheme (RWBCIS)	2013-14: 2015-16
8	Pradhan Mantri FasalBima Yojana (PMFBY)	Since 2016
9	Unified Package Insurance Scheme (UPIS)	2016 (Pilot basis)

Weather based insurance

Weather based insurance can play a vital role as an alternative ex ante risk coping instrument to enable poor farmers cope with weather-related production risk and reduce their overall vulnerability to climate variability and change. Weather insurance seeks to provide farmers compensation in case of happening or non-happening of a specific weather event that is likely to have bearing on the crop yields.

In other words, the weather index measures a specific weather variable (e.g., rainfall, temperature, RH, wind speed etc.) and pays indemnities based no on the actual losses experienced by the crop but an insurer is compensated each time the appreciated value of the index surpasses or falls below of a pre-defined threshold value. The indemnification can be planned to safeguard against index non-conformities that are predicted to cause crop failures (Clarke et al., 2012).

The initial euphoria with weather-based insurance in India had a lot to do with its reduced susceptibility to the problems intrinsic in traditional multi-peril crop insurance. For the insured, the most important advantage is the prospect of receiving timely indemnity payouts that goes a long way in protecting their overall income, improving their risk profile and thereby enhancing access to bank credit, as opposed to the traditional scheme where the delayed claim settlement procedure negates the very objective of insurance.

Pradhan Mantri FasalBima Yojana (PMFBY)

PMFBY was started by Govt. of India to provide insurance coverage and financial support to the farmers in the event of failure of any of the notified crop as a result of natural calamities,pests& diseases. The purpose was also to stabilise the income of farmers to ensure their continuance in farming; to encourage farmers to adopt innovative and modern agricultural practices and; to ensure flow of credit to the agriculture sector. Unlike weather-based crop insurance, compensation is given to clients based on the damage occurred to the specified crop in the notified area.

Risks covered under the scheme

- Yield Losses (standing crops, on notified area basis). Comprehensive risk insurance is provided to cover yield losses due to non-preventable risks, such as Natural Fire and Lightning, Storm, Hailstorm, Cyclone, Typhoon, Tempest, Hurricane, Tornado. Risks due to Flood, Inundation and Landslide, Drought, Dry spells, Pests/ Diseases also will be covered.
- In cases where majority of the insured farmers of a notified area, having intent to sow/plant and incurred expenditure for the purpose, are prevented from sowing/planting the insured crop due to adverse weather conditions, shall be eligible for indemnity claims up to a maximum of 25 per cent of the sum-insured.
- In post-harvest losses, coverage will be available up to a maximum period of 14 days from harvesting for those crops which are kept in “cut & spread” condition to dry in the field.
- For certain localized problems, Loss / damage resulting from occurrence of identified localized risks like hailstorm, landslide, and Inundation affecting isolated farms in the notified area would also be covered.

Unit of insurance

The Scheme shall be implemented on an ‘Area Approach basis’ i.e., defined areas for each notified crop for widespread calamities with the assumption that all the insured farmers, in a Unit of Insurance, to be defined as “Notified Area” for a crop, face similar risk exposures, incur to a large extent, identical cost of production per hectare, earn comparable farm income per hectare, and experience similar extent of crop loss due to the operation of an insured peril, in the notified area. Defined Area (i.e., unit area of insurance) is Village/Village Panchayat level by whatsoever name these areas may be called for major crops and for other crops it may be a unit of size above the level of Village/Village Panchayat. In due course of time, the Unit of Insurance can be a Geo-Fenced/Geo-mapped region having homogenous Risk Profile for the notified crop. For Risks of Localized calamities and Post-Harvest losses on account of defined peril, the Unit of Insurance for loss assessment shall be the affected insured field of the individual farmer.

Farmers to be covered

All farmers growing notified crops in a notified area during the season who have insurable interest in the crop are eligible. To address the demand of farmers, the scheme has been made voluntary for all farmers from Kharif 2020. Earlier to Kharif 2020, the enrollment under the scheme was compulsory for following categories of farmers:

- Farmers in the notified area who possess a Crop Loan account/KCC account (called as Loanee Farmers) to whom credit limit is sanctioned/renewed for the notified crop during the crop season. and
- Such other farmers whom the Government may decide to include from time to time.
- **Voluntary coverage:** Voluntary coverage may be obtained by all farmers not covered above, including Crop KCC/Crop Loan Account holders whose credit limit is not renewed.

Highlights of the scheme

- There will be a uniform premium of only 2% to be paid by farmers for all Kharif crops and 1.5% for all Rabi crops. In case of annual commercial and horticultural crops, the premium to be paid by farmers will be only 5%. The premium rates to be paid by farmers are very low and balance premium will be paid by the Government to provide full insured amount to the farmers against crop loss on account of natural calamities.
- There is no upper limit on Government subsidy. Even if balance premium is 90%, it will be borne by the Government.
- Earlier, there was a provision of capping the premium rate which resulted in low claims being paid to farmers. This capping was done to limit Government outgo on the premium subsidy. This capping has now been removed and farmers will get claim against full sum insured without any reduction.
- The use of technology will be encouraged to a great extent. Smart phones will be used to capture and upload data of crop cutting to reduce the delays in claim payment to farmers. Remote sensing will be used to reduce the number of crops cutting experiments.
- PMFBY is a replacement scheme of NAIS / MNAIS, there will be exemption from Service Tax liability of all the services involved in the implementation of the scheme. It is estimated that the new scheme will ensure about 75-80 per cent of subsidy for the farmers in insurance premium.

Conclusion

Now a days, farmers are educated whose livelihood is reliant on the achievement and catastrophe of his crop grown under field conditions. Simultaneously, the information technology period has prepared the farmers about the significance of weather in crop growth and development. Out of ~121 million farmers of India, only 20 per cent availed crop loans and only three fourth of those are insured. The rest 80 per cent (approximately 96 million) are either supported with self-funding or rest on other sources for their monetary necessities. Most of the farmers are unaware to the bureaucratic and other necessities of official commercial organizations and, consequently, shy away from them. Consequently, while the official loanees are indemnified obligatorily under the NAIS, only about 15 % of the non-loanee farmers get indemnification cover willingly. This is rather symptomatic of the massive insurance possibility that survives for addressing the requirements of the farming sector and uplifting the overall efficacies as also the competitiveness of the agriculture community. This also indicates the wonderful potential of agriculture insurance in the nation as a concept, which can alleviate the contrary impacts that such hesitations would have on the individual farmers. Looking at the above contexts, implementable crop insurance schemes can improve the decision making and boost confidence among the farming community of this country.

References

Bal, S.K. and Minhas, P.S. (2017) Atmospheric Stressors: Challenges and Coping Strategies. In: P.S. Minhas et al. (eds) Abiotic Stress Management for Resilient Agriculture. Springer Nature Singapore Pte. Ltd., pp. 9-50. https://doi.org/10.1007/978-981-10-5744-1_2

Clarke, D.J., MahulKolli, O., Rao, N. and Verma, N. (2012) Weather Based Crop Insurance in India, Policy Research Working Paper 5985. The World Bank. http://econ.worldbank.org

IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press.In Press.

Use of Agromet Advisories for crop management during weather uncertainties at field level

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Climate is a very important natural resource decides a crop of a location. Indian agriculture is prone to weather/climate related problems since ages despite the advancement in technology. Crop requires weather from sowing to harvest for its growth, attaining different stages time to time, for functioning internal physiological processes. Meteorological events like onset of monsoon, rainfall distribution, dryspells & droughts, heavy rainfall, gusty winds, heat & cold waves, frost conditions, hail storms, flash floods and cyclones reduces the crop performance, damages the crop within no time and leave the farmer in a difficult situation. Poor farmers at the subsistence level have very little cash in their hand. Most of their input investments goes for crop protection, which they get through loans at high interest rates. When there is failure of crop due to extreme variability in climate such as droughts etc., the poor farmers lose their entire investment and struggle under severe pressures.

Major risks in agriculture are categorized into production, financial and marketing. Under the production, weather plays a major role right from field preparation to procurement of seed, fertilizer, sowing and intercultural operations, management of pest disease infestation, fixing harvest time, storage of produce. whereas under financial risk, basic risk is again with weather. one extreme weather event like hailstorm, flood, cyclone and drought may damage the crop and lead to loss of crop. This intern impacts the farmer with investment loss and debts. Finally, if a farmer could not find a good market and price, he will be at loss due to reduced income.

In India, major crops are grown during June to September under the summer monsoon rains which starts from the month of June. So, the onset of monsoon itself decides which crop and variety to be sown and what kind of field operations are required according to the distribution of monsoon rains. Forecasting of weather play an important role here for taking any decision at field level. Normal agronomic advisories do not have the weather input before fixing any field operation. But Agromet advisory (AAS) is the value addition to advisory based on weather forecast.

The Agromet Advisory Services provide a very special kind of inputs to the farmers as advisories that can make a tremendous difference to the agriculture production by taking the advantage of benevolent weather and minimize the adverse impact of malevolent weather.

Way back to1945, IMD started regular weather services for farmers in in the form of a “Farmers’ Weather Bulletin” and broadcasts through All India Radio in regional languages. In 1971, on the recommendation of the National Commission on Agriculture (NCA), it launched

Agrometeorological Advisory Services (AAS), a comprehensive tool tailored to farmers' need. Then in 1975-1976, the U.S. National Aeronautics and Space Administration (NASA), conducted a Satellite Instructional & Television Experiment (SITE) with IMD and agricultural agencies that led to the production of crop specific weather-based agronomic advisories for different regions of the country. These integrated Agromet Advisory Services were further developed in 2007 and have steadily been improved by collaborating with ICAR and SAUs.

Now IMD started issuing several kinds of forecasts for the policy makers, farmers, general public and scientists and business purposes. the following are the variety of forecasts issued by IMD and their use in agriculture

- Short range forecast – valid for 24-48 hours,
  used for deciding the Application of irrigation water, fertilizers, harvesting etc.,
- Medium range forecast – valid for 3-10 days
  Sowing, transplanting, irrigation, fertilizers, plant protection, measures, harvesting and threshing etc.,
- Long range forecast - more than 30 days, month, season etc., Crop
  planning, Selection of cultivar etc.,
- Nowcasting is the forecast within 6 hours time
  Used for thunder storms, heavy rains in a particular area, Sometimes Hail prediction (half hour before only), wind prediction
- Extended Range Forecast for 15 days and above
  Used for planning of farm operations

With the advancement in forecast technology, now India is capable of forecasting the weather from seasonal scale to Nowcasting with confidence at national level to block level. Whereas Value addition to these forecast for the benefit of farmers is done by All India Coordinated Research Project on Agrometeorology(AICRPAM) under Indian Council of Agricultural Research under Ministry of Agriculture and Farmers Welfare, Government of India, through its research partners in State Agricultural Universities in collaboration with farmers at field level. The combination of these value added forecasts and advisories are called 'Agromet Advisories' developed and disseminated to farmers using traditional 'Dandora' method to latest mobile apps and web based applications like 'mKisan'. This has a potential to change the face of India in terms of food security and poverty alleviation. Agro-meteorological service rendered by India Meteorological Department (IMD), Ministry of Earth Sciences is a step to contribute to weather information based crop/livestock management strategies and operations dedicated to enhancing crop production in a sustainable manner. These AAS are benefitting the farmer to take the farm level decisions and helping the district level authorities to plan accordingly.

Agromet advisories are farmers bulletins prepared with following information

- Prevailing weather
- Soil and crop condition
- Weather prediction.
- Measures / practices / suggestions based on weather forecast

Agro-advisory bulletin consist of three parts:

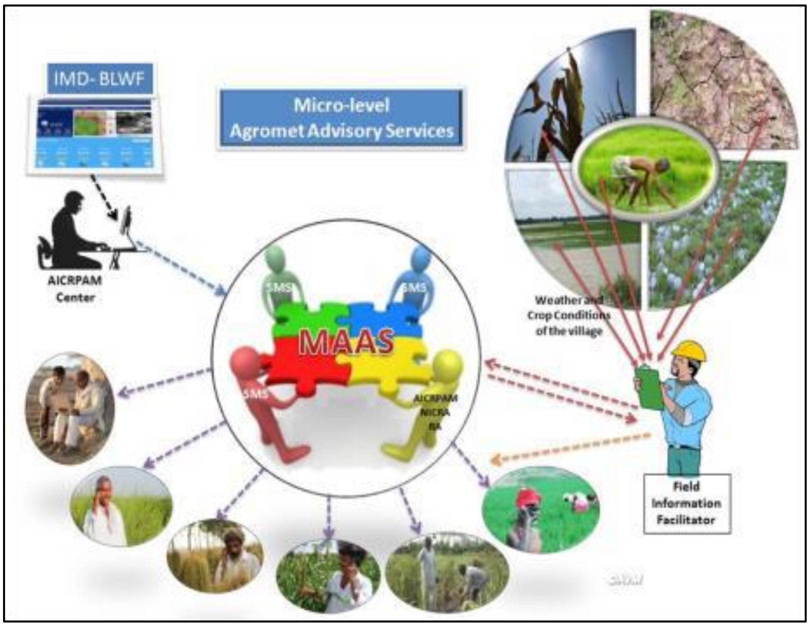
1. Weather events occurred during past week and weather forecast for five days ahead. (RF, WS, WD, RH, max & min T)
2. It contains actual information on state and stage of crop growth, ongoing agricultural operations, disease and insect pest occurrence.

3. It provides value added information on various farm activities to be taken based on weather

IMD initiated district level agromet advisories with medium range weather forecasts on weekly basis and the crop information at district level will be collected by AFMUs and GKMS centers. By integrating this information, Agrometeorologists and other SMSs discuss and devise Agromet advisories, which are then disseminated to the farmers through different forms of ICTs. Further, feedback is collected from the farmers to evaluate the performance of the advisories provided. The lacunae will be identified for further improvement in agromet advisories.

Microlevel Agromet Advisory Services

District level Agromet advisories make a blanket recommendation of advisories, which may not be viable for block level. Therefore, looking into the exigency, AICRPAM developed a methodology for issuing the advisories at block level. The microlevel agromet advisories are prepared at block level. Agrometeorologist collects the block level forecasts and appraises the current weather situation in the block to the subject matter specialists of the local KVK. A 'Farm Information Facilitator' (FIF) was recruited, who is acting as the interface between the farmers and the subject matter specialists (SMS) at KVK. He collects the information about the crop condition, farmer’s observations / queries and pass it on to the KVK SMS. Afterwards, Agrometeorologist and SMSs discuss the situation, develops the Agromet Advisories, hand it over to FIF for communicating to the Farmers of the village, and disseminate the same using other ICTs to reach all the farmers in the villages of the block. Feedback will be collected for evaluation and improvement of the Agromet advisories at micro level.

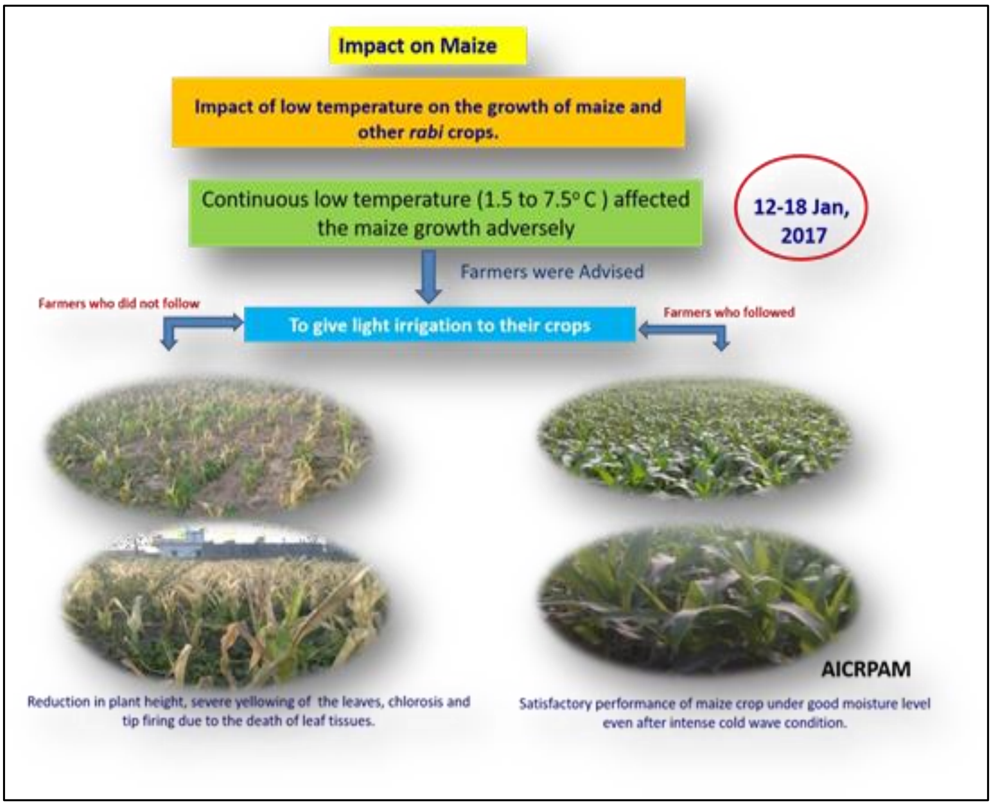


Dissemination mechanism

Information of weather need to reach the farmer as soon as possible so that he can take any decision to manage his crop. The Information Communication Technology in different ways enabled the dissemination of agromet advisories easy, multi lingual compatibility and timely. The AAS prepared are in English and local language and communicated through SMS, Email, notice boards at Panchayat office and the other places where all the farmer/ people gather, M Kisan etc.

AAS Issued to Farmers (An Example)

Farmers are provided with the Realized weather information, weather forecast for next five days and finally the measures to be taken for managing the crop from different problems may occur due to uncertainties in weather for next 5 days.



Impact of outputs on production

The effectiveness of Agromet Advisories are assessed based on economic gains accrued by farmer with each or seasonal aggregate of advisories. The examples of case studies/success stories describing the impact of Agromet advisories at different locations in monetary terms are as under:

Region	Village	Crop	B:C Ratio	
			AAS-farmer	Non-AAS farmer
Akola, Maharashtra	Yelgaon	Soybean	2.17	1.76
Bangalore, Karnataka	Patrenahalli and Nayanahalli	Grape	9.21	5.45
Palampur, Himachal Pradesh	Dhamrol	Maize	2.74	0.73
Parbhani, Maharashtra	Shekta	Cotton	2.26	1.88
Udaipur, Rajasthan	Nakli	Maize	1.93	1.28
Anantapur, Andhra Pradesh	Yagantipalli	Pigeon pea	3.1	2.48
Kovilpatti, Tamilnadu	Allikundam	Okra	2.41	1.98

Akola, Maharashtra	Devpur	Soybean	1.85	1.54
Palampur, Himachal Pradesh	Gwardu	Maize	1.22	0.77
Udaipur, Rajasthan	Nakli	Maize	1.22	0.59
Kovilpatti, Tamilnadu	Allikundam	Cotton	2.30	1.71
Mohanpur, West Bengal	Bongheri	Lathyrus	1.5	1.2

Issues

- Messages are too big and technical
- English is the main language used
- Messages are issued by Government as well as private operators and Farmer is confused
- Need to create awareness to the farmers on how to understand use the messages

Risk and Vulnerability assessment for adaptation planning

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Introduction

Climate change has emerged as a potent threat to sustainability of food security and agriculture. The Coupled Model Inter-comparison Project (CMIP) 5 projections for India show that the average climate is likely to be warmer by 1.7 to 2.0^0 C for 2030s and by 3.3 – 4.8^0 C for 2080s compared to the pre-industrial times. The precipitation is likely to increase by 5 to 6 per cent and 6 to 14 per cent, for 2030s and 2080, respectively. Agriculture, being a biological production process, is obviously affected by climate and hence the projected change in climate will have implications to sustainability of agricultural production and of livelihoods of those dependent on agriculture. Indian agriculture, dominated by small holders with low adaptive capacity, is vulnerable to adverse impacts of climate change. Intensified adaptation efforts are needed in spite of the Paris Agreement arrived at COP 21 to limit warming to 1.5^{0}C. Adaptation requires resources in terms of investments and interventions. However, considering climate and climate change are spatially variable, not all regions are equally impacted by climate change and vary with their capacities to adapt and shocks to adapt to. A well planned and better targeted adaptation is critical to building resilience to agriculture and to farmers' livelihoods. Assessment of risk and vulnerability informs policy and programme planning towards this. Since district is the basic unit of administration in India, risk and vulnerability assessment at the district level will be of more policy relevance. This policy brief presents the summary of such district level assessment of risk and vulnerability to climate change as detailed in Rama Rao *et al*. (2019).

Vulnerability – meaning and concepts

'Vulnerability' has emerged as a cross-cutting multidisciplinary theme of research in the current context, characterized by rapid changes in environmental, economic and social systems (O'Brien et al., 2004). The dictionary meaning of the word 'vulnerable' means propensity to be harmed. However, the word vulnerability has been used and vulnerability was assessed without actually being defined in many different contexts. Vulnerability is an *ex ante* concept in that what is likely to happen in future is the focus of analysis and thus the analysis has to lead to making decisions as to what is to be done in the present. Further, vulnerability of *what* to *what* are to be clearly defined along with the preference criteria for evaluation (Ionescu *et al*., 2009).

Vulnerability and its assessment received attention in three important areas of research: disaster management, economic development and climate change. The disaster management literature sees vulnerability as susceptibility to a climatic disaster and is often concerned with the location of the system or entity. On the other hand, the vulnerability research in the broader area of economic development is concerned with vulnerability to, poverty for example, wherein the interest is to assess whether or not an economic decision making unit becomes worse off (in terms of outcomes) in the event of a climatic or non-climatic shock given its characteristics. Vulnerability is viewed both as a component of poverty as well as a determinant of poverty in the literature on poverty.

Vulnerability is sometimes seen as a threshold value or tipping point which can be described as a degree of acceptable damage (Joakim et al., 2015). The shifting of the threshold or tipping points is seen as the responses to moderate or deal with vulnerability. Though there is a vast literature on the theoretical development in the conceptualization and analysis of vulnerability, this discussion is limited to vulnerability and assessment in the context of climate change only.

Evolution of vulnerability assessment

Vulnerability assessment is generally done in a number of different contexts and in view of different stakeholders. However, three important contexts for vulnerability assessment can be identified. These three contexts have different goals, varying information needs and thus will lead to different policy implications. These three contexts are related to fixing long term mitigation targets, identification of vulnerable regions for providing international assistance and for recommending adaptation measures for different regions or sectors. The evolution of vulnerability assessment in terms of focus, frameworks and methods broadly reflect these three decision contexts. The assessments concerned with mitigation aspects focus on biophysical impacts of climate change and are usually referred to as impact assessments. Following such impact assessments are the first and second generation vulnerability assessments that increasingly recognized the importance of non-climatic factors in determining vulnerability. These vulnerability assessments are then followed by what are referred to as adaptation policy assessments whose purpose is to identify adaptation strategies and are more policy oriented. These assessments clearly recognize the 'facilitation' and 'implementing' aspects of both mitigation and adaptation and differentiate between adaptive capacity and adaptation. The key characteristics of these four broad classes of vulnerability assessment are summarized in table 1.

Table 1.Key features of different stages of climate change vulnerability assessments

	Impact Assessment	**First generation VA**	**Second generation VA**	**Adaptation Policy Assessment**
Focus	Mitigation policy	Mitigation policy	International assistance	Adaptation policy
Analytical approach	Positive	Mainly positive	Mainly positive	Normative
Main result	Potential impacts	Pre-adaptation vulnerability	Post-adaptation vulnerability	Adaptation strategies
Time horizon	Long term	Long term	Mid to long term	Short to long term
Consideration of non-climatic factors	Little	Partial	Full	Full
Integration of natural and social sciences	Low	Low to medium	Medium to high	High
Stakeholder consultation	Low	Low	Medium	High
Typical question	What are biophysical impacts of CC?	What socioeconomic impacts are likely to result from CC?	How vulnerable are systems or entities to CC after after feasible adaptation?	What adaptation options can be recommended to reduce vulnerability?

Source: Fussel and Klein (2006)

Approaches to vulnerability assessment

'Outcome vulnerability is conceptualized as 'end point' analysis where in the impact of climate change is examined on productivity or production of a particular crop or animal species either through simulation modeling or through physical experimentation. This is also referred to as biophysical impact assessment or first generation vulnerability assessment. Such assessments 'superimpose future climate scenarios on an otherwise constant world to estimate the potential impacts of anthropogenic climate change on a climate-sensitive system' (Fussel and Klein, 2006). The emphasis gradually shifted to derive policy lessons from vulnerability assessment as the purpose of such assessment was to identify strategies that reduce vulnerability of the systems or populations concerned.

The socio-economic approach to vulnerability assessment proposes that the attributes of the system or entity of interest predispose it to the adverse impacts of an external shock (climate change or variability) (Adger and Kelly, 1999) and thus it is referred to as 'starting point analysis'. In this case, vulnerability is regarded as a pre-existing condition (Alexandra Jurgilvech et al., 2017) in terms of health, education, wealth, etc. of the individuals and the differential endowments of individuals are responsible for varying vulnerability.

The integrated approach combines both these approaches integrating bio-physical and socio-economic dimensions of vulnerability. As the vulnerability assessments evolved, more non-climatic data became a part of such assessments.

Current vulnerability analyses the current risks to the system of interest whereas *future vulnerability* assessments are concerned with future risks. Vulnerability assessment is considered static or dynamic whether the temporal changes in the predisposing conditions and/or risk are considered in the analysis.

Conceptualization of impacts and vulnerability

Figure 1 depicts hypothetical trajectories for the level of climate-related impacts (caused by anthropogenic climate change as well as natural variability) on a climate-sensitive system. The lowest trajectory denotes the (unrealistic) reference case of an undisturbed climate where variations in the level of impacts over time are solely caused by changes in non-climatic factors. The illustrative trajectory shows an initial increase in climate-related impacts (e.g., due to population growth) followed by a substantial decrease later (e.g., due to economic development). The other trajectories present the impacts associated with a single climate change scenario for four different assumptions regarding adaptation. They include (in descending order of impacts) the 'dumb farmer', who does not react to changing climate conditions at all; the 'typical farmer', who adjusts management practices in reaction to persistent climate changes only; the 'smart farmer', who uses available information on expected climate conditions to adjust to them proactively; and the 'clairvoyant farmer', who has perfect foresight of future climate conditions and faces no restrictions in implementing adaptation measures.Depending on the level of adaptation assumed, assessment results may fall anywhere in the range spanned by the 'dumb farmer' and the 'clairvoyant farmer' trajectories in Figure 1.

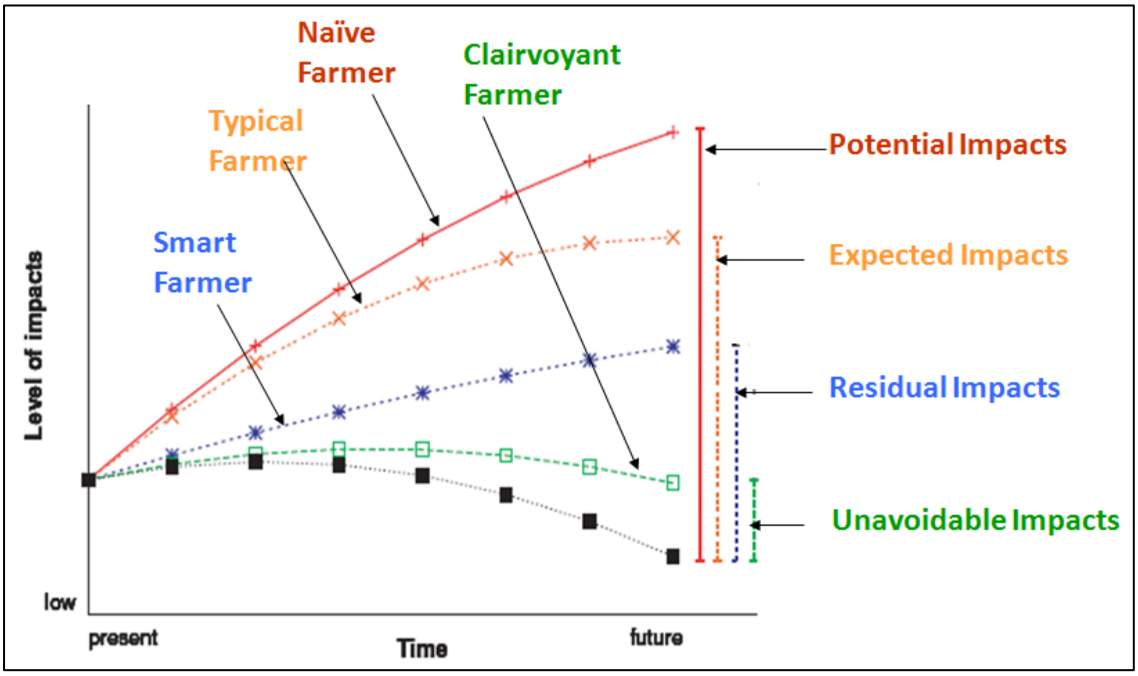

Fig 1. Conceptualization of impacts and vulnerability (Source: Fussel and Kelin, 2006)

The IPCC-AR4 framework of vulnerability assessment

There were a plethora of studies on climate change vulnerability starting in 2000s as the national governments and international community are increasingly concerned about dealing with climate change. Though there are varying conceptualizations and definitions of vulnerability in the context of climate change, the one given by the IPCC is adopted in a large number of studies (Schneider et al., 2007). IPCC in its 3rd and 4th Assessment Reports define vulnerability a "The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" (McCarthy et al., 2001, 2001, 2007). This conceptualization views vulnerability as a residual impact of climate change: the sensitivity and exposure together determine the potential impact which will be moderated by adaptation. Adaptation is the manifestation of adaptive capacity.

Sensitivity is defined as "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli". It is determined by demographic and environmental conditions of the region concerned. Exposure is defined as "the nature and degree to which a system is exposed to significant climatic variations". Thus, exposure relates to climate stress upon a particular unit of analysis (Gbetibouo and Ringler 2009). "A more complete measure of exposure to future climate change would require consideration of projected changes in climate in each analysis unit" (Eriyagama et al., 2012). Adaptive capacity is "the ability of a system to adjust to climate change, including climate variability and extremes, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. It is considered to be "a function of wealth, technology, education, information, skills, infrastructure, access to resources, stability and management capabilities" (McCarthy et al., 2001).

In this framework, adaptive capacity is largely consistent with socioeconomic approach and sensitivity with biophysical approach and both are internal dimensions. The component of exposure is viewed as an external dimension. While higher exposure and sensitivity mean higher vulnerability, higher adaptive capacity implies lower vulnerability and hence is inversely related to vulnerability.

Although lack of standard methods for combining the biophysical and socioeconomic dimensions is a limitation to this approach, it can be helpful in making policy decisions (Deressa et al., 2008).

This definition and framework of vulnerability is depicted in Figure 2.

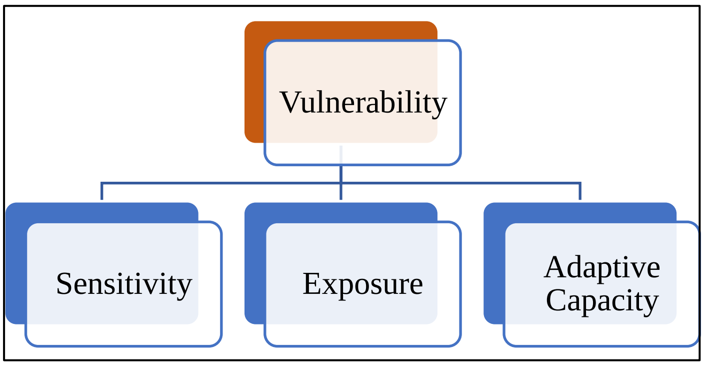

Fig 2. Components of vulnerability

3.1 Change of vulnerability assessment framework by IPCC with AR-5

The literature on vulnerability and its assessment is continually evolving drawing on works in different fields. The dynamic trait of vulnerability and its components is not adequately addressed in the Third and Fourth Assessment Reports of the IPCC. The recent literature suggests that the risks due to climate change are also a result of complex interactions among social and ecological systems and the hazards arising out of climate change rather than being externally generated alone. Various facets of these interactions have to be carefully differentiated to understand risk to inform policy making for risk management. The AR 5 framework (Fig 3) emphasizes these aspects as well as that the very components of vulnerability and risk will also interact with the contextual factors of development pathways and the climate systems (Oppenheimer, et al., 2014). Also, inclusion of 'exposure' as a component of vulnerability as in AR 4framework, may trigger decisions that may potentially lead to maladaptation given the uncertainty associated with climate projections.

3.2 Vulnerability – a component of risk assessment

The AR5 proposes a different framework where in vulnerability is placed as one of the determinants of risk, the other two being 'exposure' and 'hazard'. The definitions given by AR 5 for risk and its components (Oppenheimer, et al., 2014) are given below:

Exposure: The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

Vulnerability: The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.A broad set of factors such as wealth, social status, and gender determine vulnerability and exposure to climate-related risk.

Impacts: (Consequences, Outcomes) Effects on natural and human systems. In this report, the term impacts is used primarily to refer to the effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction ofclimate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes. The impacts of climate change on geophysical systems, including floods, droughts, and sea level rise, are a subset of impacts called physical impacts.

Hazard: The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. In this report, the term hazard usually refers to climate-related physical events or trends or their physical impacts.

Risk: The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur.
Risk = (Probability of Events or Trends) × Consequences
Risk results from the interaction of vulnerability, exposure, and hazard.

The AR4 and AR5 definitions and frameworks view the terms vulnerability and exposure differently. Exposure in the AR 4 terminology is related to climate related shocks that a system is exposed to whereas the AR 5 describes it being related to the individuals, systems, etc. being exposed to the 'hazard' which is a concept introduced in AR 5 framework. Vulnerability, as per AR5, is more a predisposition to an external shock and whether it will lead to risk depends on whether the vulnerable system is located (exposure) in a place where the 'hazards' are likely to occur. Thus, a highly vulnerable system may not suffer risk due to climate change or a less vulnerable system may face risk if it is placed where severe hazard incidence is possible. Thus, the relationship between these three components of risk are more explicit and policy relevant. The AR5 vulnerability framework is closer to the disaster management conceptualization which is considered more appropriate in the context of climate change.

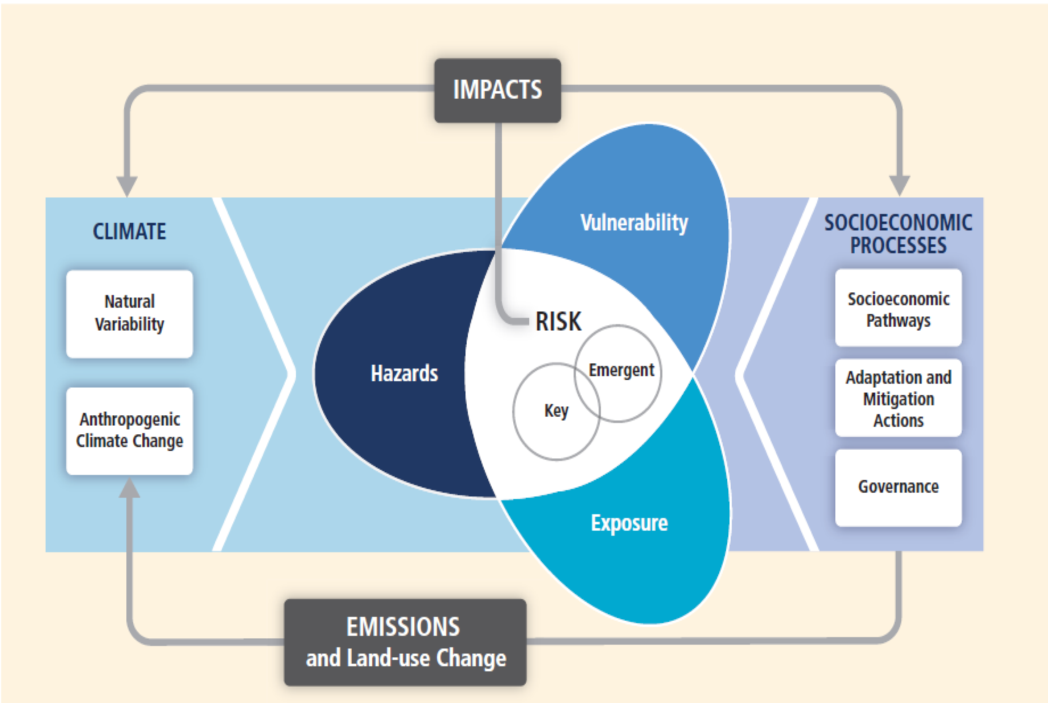

Fig 3. Framework of vulnerability and risk (Source: Oppenheimer et al., 2016)

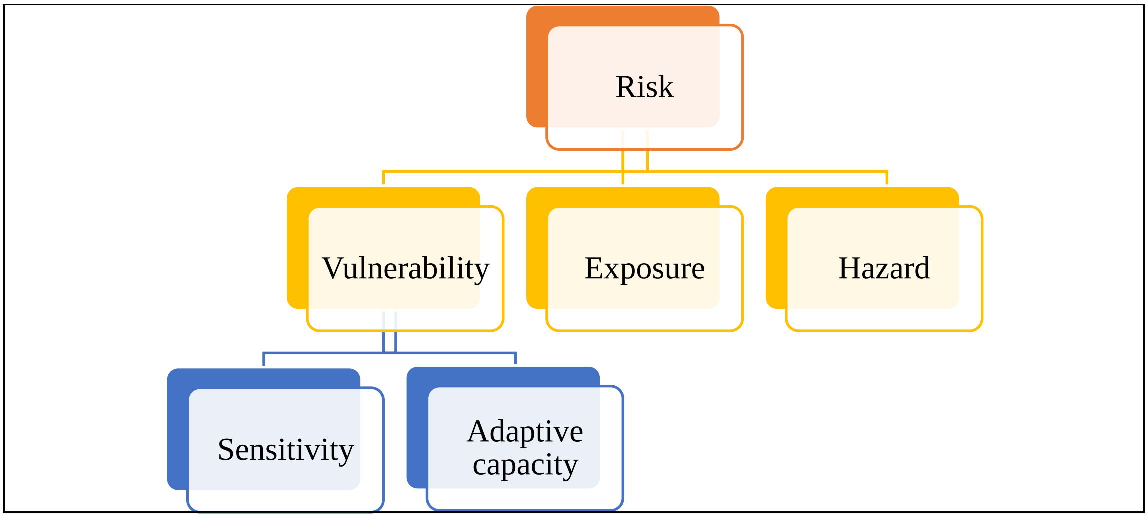

Fig 4. Dimensions of risk and vulnerability

The AR5 risk conceptualization furthers the risk analysis by identifying two kinds of risk: key risks and emergent risks. Key risks are potentially severe consequences arising when systems with high vulnerability interact with severe hazards. Different criteria are suggested to categorize a risk as key which are based on the magnitude of the risk, high vulnerability of a particular group of population, criticality of the sector in the economy. Emergent risks are those that are not direct consequences of climate change hazard but are results of responses to climate change. For example, migration of population from a region due to climate change related hazards may increase the vulnerability and thus risk of receiving regions; similarly increased groundwater extraction during a drought may increase the vulnerability and risk in future. Thus, emergent risks are a result of spatial linkages and temporal dynamics related to responses to changing climate.

Thus AR5 framework places more emphasis on identifying and managing risk and thus views vulnerability as a determinant. Such conceptualization and framework will be more relevant to policy making.

Methods of vulnerability assessment

Vulnerability, being a theoretical concept and multidimensional (Hinkel, 2001), is 'notoriously difficult to measure' (Crane et al., 2017). Considering that the definition of IPCC is the most adopted one in the context of climate change vulnerability, any assessment should ideally capture the future climate, examine its potential impact on agricultural performance (e.g. crop growth and yield) and then see how adaptation action reduces that impact. The resultant impact is considered as vulnerability. Such an operationalization of vulnerability assessment was done through crop simulation modeling (e.g. Olsen et al., 2000; Pathak and Wassmann, 2009; Boomiraj et al, 2010; Srivastava et al., 2010, Abdul Harris et al., 2013) and econometric methods (e.g. Ajay Kumar and Pritee Sharma (2013); Narayanan and Sahu, (2016); Praveen Kumar et al., (2014). Such methods are data and skill intensive and cannot easily be scaled up.

'Indicator method' is the most used method in assessing vulnerability for identifying hot spots of vulnerability to climate change. The method involves identification of indicators of different dimensions of vulnerability and risk, normalization and aggregation. The individual indicators can be combined into component and final indices of risk or vulnerability using weights derived from a variety of methods such as principal component analysis, factor analysis, analytical hierarchical process, expert consultation, etc. The choice of such methods is dependent on the nature of data, skills available, etc. The process of constructing vulnerability indices following indicator method is depicted in the following figure 5.

Fig 5. Process of building vulnerability and /risk index

Summary and conclusion

The term vulnerability has emerged as an area of multidisciplinary research in different thematic areas such as disaster management, poverty measurement and climate change. The term has been defined and interpreted in many different ways. In the context of climate change, the definitions and frameworks suggested by the IPCC have been often used and many different vulnerability assessments used these frameworks. Vulnerability assessments have over time became more multidisciplinary, more integrating in terms of climatic and non-climatic information, more stakeholder participatory and more policy oriented. Though many approached and methods of vulnerability are evident in the literature, the choice of such approach and method should be more determined by the context and purpose of vulnerability assessment.

References

Abdul Haris AV, Sandeep Biswas, Vandna Chhabra *et al*. (2013) Impact of climate change on wheat and winter maize over a sub-humid climatic environment. Curr Sci 104 (2): p 206-214

Adger, Kelly (1999) Social vulnerability to climate change and the architecture of entitlements. Miti and Adapt Stratg for Glob Change. 4: p 253-266

Ajay Kumar, Pritee Sharma (2013) Impact of Climate Variation on Agricultural Productivity and Food Security in Rural India. Economics Discussion Papers. No 2013-43, Kiel Institute for the World Economy. http:// www.economics-ejournal.org/economics/discussionpapers/2013-43. Accessed on 20.08.2018

Alexandra Jurgilevich, AleksiRasanen, Fanny Groundstroem et al (2017) A systematic review of dynamics in climate risk and vulnerability assessments. Environ Res Lett12. 013002 doi: 10.1088/1748-9326/aa5508

Boomiraj K, Chakrabarti B, Aggarwal PK et al (2010) Assessing the vulnerability of Indian mustard to climate change. Agric Ecosyst Environ 138: 265–273

Crane TA, Delaney A, Tamas PA et al (2017) A systematic review of local vulnerability to climate change in developing country agriculture. WIREs Climt Change 8e464.doi: 10.1002/wcc.464

Deressa T, Hassen R, Alemu T, Yesuf M, Ringler C (2008) 'Analyzing the determinants of farmers' choice of adaptation measures and perceptions of climate change in the Nile Basin of Ethiopia. International Food Policy Research Institute (IFPRI) Discussion Paper No. 00798, Washington

Eriyagama N, Smakhtin V, Chandrapala L et al (2012) Impacts of climate change on water resources and agriculture in Sri Lanka: A Review and Preliminary Vulnerability Mapping. IWMI Res Rep 135, 43

Fussel H M, Kelin R J T (2006) Climate Change Vulnerability Assessments: An Evolution of Conceptual Thinking. Clim Change 75: 301–329. DOI: 10.1007/s10584-006-0329-3

Gbetibouo GA, Ringler C (2009) Mapping South African farming sector vulnerability to climate change and variability: A sub-national assessment, IFPRI Discussion Paper 00885. Washington, DC, USA: Int Food Poli Res Instit (IFPRI)

Hinkel J (2011) Indicators of vulnerability and adaptive capacity: Towards a clarification of the science-policy interface, Glob Environ Change21: p 198-208

Ionescu C, Richard JTK, Jochen Hinkel et al (2008) Towards a Formal Framework of Vulnerability to Climate Change, Environ Model Assess

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. Averty, M. Tignor and H.L. Miller (eds). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Joakim EP, MortschLOulahen G (2015) Using vulnerability and resilience concepts to advance climate change adaptation. *Environ Hazard* 14: 137-55

McCarthy JJ, Canziani OF, Lear NAY et al (2001) Climate Change 2001: Impacts, Adaptation, and Vulnerability. Cambridge University, Press pp 1032

Narayanan K, Sahu S K (2016) Effects of climate change on household economy and adaptive responses among agricultural households in Eastern Coast of India. Curr Sci 110 (7): 1240-1250

O'Brien K, Leichenko R, Kelkar U et al (2004) Mapping Vulnerability to Multiple Stressors: Climate Change and Economic Globalization in India. Glob Environ Change 14 (4): 303-313

Olsen JE, Bocher PK, Jensen Y (2000) Comparison of scales of climate and soil data for aggregating simulated yields in winter wheat in Denmark. Agric Ecosyst Environ 82(3): 213–228

Oppenheimer M, Campos M, Warren R et al (2014) Emergent risks and key vulnerabilities. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir,M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1039-1099.

Praveen Kumar N S, Paul K S R, Krishna Reddy K et al (2014) Assessment of Vulnerability and Impact of Climate Change on Crop Production in Krishna river basin of Andhra Pradesh. Int J Curr Agri Res 3(2): 62-66

Pathak H, Wassmann R (2009) Quantitative evaluation of climatic variability and risks for wheat yield in India Climatic Change. Doi: 10.1007/s10584-008-9463-4 93:157–175

Rama Rao CA, Raju BMK, Subba Rao AVM et al (2013) Atlas on Vulnerability of Indian Agriculture to Climate Change. Central Research Institute for Dryland Agriculture, Hyderabad P 116

Rama Rao, C.A., Raju, B.M.K., Adlul Islam, Subba Rao, A.V.M., Rao, K.V., Ravindra Chary, G., Nagarjuna Kumar, R., Prabhakar, M., Sammi Reddy, K., Bhaskar, S., Chaudhari, S.K., 2019. Risk and vulnerability assessment of Indian agriculture to climate change. National Innovations in Climate Resilient Agriculture, ICAR-CRIDA, Hyderabad, India, P.124

Rama Rao CA, Raju BMK, Subba Rao AVM et al (2016) A District Level Assessment of Vulnerability of Indian Agriculture to Climate Change. Curr Sci 110(10): 1939-1946

Rama Rao CA, Raju BMK, Subba Rao AVM et al (2017) Assessing vulnerability and adaptation of agriculture to climate change in Andhra Pradesh. Ind J Agri Econ 72(3): 375-384

Schneider S H, Semenov S, Patwardhan, A (2007) Assessing key vulnerabilities and the risk from climate change Climate Change 2007: Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change M L Parry et al (eds) Cambridge, UK: Cambridge University Press: 779–810

Srivastava A, Naresh Kumar S, Aggarwal PK (2010) Assessment on vulnerability of sorghum to climate change in India. Agric Ecosyst Environ 138: 160–169.

Farmers' Perceptions, Attitudes and Adaptations towards Climate Change in India

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Introduction

Global climate change is widely viewed as one of the most significant challenges society is facing today. Agriculture, upon which society depends for the food, feed, and fiber that enable sustainable livelihoods, is one of the sectors that is most vulnerable to shifts in climate (IPCC 2007; NRC 2010). In particular, arid and semi-arid areas are often challenged by the demands of existing climatic variability, and it is expected that climate change will have significant implications for water resources in these areas (Miller et al. 1997; Sivakumar et al. 2005).

Countries especially like India are highly vulnerable in view of the large population depending on agriculture and excessive pressure on natural resources. Bapuji Rao et al. (2014) found a decline in paddy yield by about 411–859 kg/ha due to a rise in 1^0 C temperatures. Thestudies conducted by the Indian Agricultural Research Institute (IARI) and other institutions shows the possibility that for every 1°C rise in temperature annual wheat production would decrease by 3% whereas production of rice would decrease by 10% (Aggarwal et al. 2004). Further Pathak et al. (2003) concluded that negative trends in solar radiation and an increase in minimum temperature has resulted in declining trends in productivity of rice and wheat in the Indo-Gangetic plains of India. According to National Rainfed Area Authority of India (NRAA 2013), about 60% of the total cultivated area in India still relies on natural rainfall (rainfed agriculture) and hence changes to rainfall patterns are a significant threat to India's agrarian economy. In addition, drought increases the chance of food insecurity, shortage of drinking water, health problems, migration for work, and debt etc. Udmale et al. (2014) reported that recurring drought is a major challenge in Maharashtra State, Central India.

The vulnerability of communities to climate change is influenced by the ways in which they are affected by climate conditions and by the manner in which they can moderate effects or risks through adaptive strategies (Adger 2006; Fussel and Klein 2006; Smit and Wandel 2006). Although, the choice of adaptation interventions depends on a country's peculiar circumstances, Vincent (2007)identified the main factors constituting the adaptive capacity of a country to include, economic well-being and stability, demographic structure, global interconnectivity, institutional stability and well-being, and natural resource dependence. According to Smit & Pilifosova (2001, p. 879), "Adaptive capacity is the potential or ability of a system, region, or community to adapt to the effects or impacts of climate change." Adaptive capacity is determined by various factors including recognition of the need to adapt, willingness to undertake adaptation, and the availability of, and ability to deploy, resources (Brown 2010).

The objectives of the present study are to identify farmers perceptions/ knowledge, attitudes towards climate change (here we focus on one of the implications of climate change in semi-arid areas, i.e. water scarcity leading to droughts), to find out their major farm-level adaptation measures, to find out the relationship between different socioeconomic characteristics of farmers with their adaptation strategies and, suggesting appropriate research/policy issues which can help in facilitating farmers adaptation to climate change. Drought (in this study) is considered to have set in when rainfall and soil moisture availability to plants has dropped to such a level that it adversely affects the crop yield and hence agriculturalprofitability. Farmers perceptions are the most important predictor of adaptive action. Risk perceptions are an important predictor of adaptive intentions given that researchers have found strong relationships between positive attitudes towards adaptation and higher levels of perceived climate risks (Roesch-McNally et al. 2017; Brody et al. 2008; Arbuckle et al. 2013). Therefore, a higher perception of climate risks will influence an individual's decision to adopt adaptation strategies (O'Connor et al. 1999; Schattman et al. 2016). It is essential to know how perceptions and actions influence one another, to understand what physical changes in climate may prompt a change in farmers' opinion, and by extension, a change in action. Beyond understanding opinions regarding the concept of climate change, understanding perceptions of climate change is of particular importance because it will influence the adaptive behavior that individuals are likely to take. Opinions are views or judgement formed about something (here climate change), not necessarily based on facts, whereas, perceptions are becoming aware through involving senses which results in action/behavior. Identifying the knowledge, attitude, and farmers' adaptation behavior to climate change is vital in order to facilitate a societal response to the changes in climate that scientists have predicted. Hence, the present study is planned to understand whether or not all factors i.e. farmers internal, external, socioeconomic help adaptive actions towards climate change.

2. Methods

The study was conducted in the three different states of India viz., Andhra Pradesh, Karnataka and Maharashtra where All India Coordinated Research Project for Dryland Agriculture (AICRPDA) centers are located duly reflecting chronic drought conditions in red and black soils. The selected AICRPDA centers (districts) are Anantapuramu in Andhra Pradesh, Bijapur in Karnataka, Akola and Solapur in Maharashtra (figure 1). These districts were selected for the study because, here rainfed area is more than irrigated area and rainfall is the most critical factor affecting crop production. The average annual rainfall is 560 mm, 553 mm, 800 mm and 545 mm in Anantapuramu, Bijapur, Akola and Solapur respectively. Climate is semi-arid in Anantapuramu and Bijapur; Akola has a tropical savanna climate bordering humid subtropical climate, while, Solapur has an arid and semi-arid climate. Major crops grown in Anantapuramu are groundnut; sorghum, maize, bajra and wheat are the major crops in Bijapur;cotton, soybean and sorghum are the essential crops grown in Akola; major cropsgrown include sorghum, wheat and sugarcane in Solapur. The average landholding size in all the districts is less than 2 hectares. The common characteristic across the four locations are farmers are resource poor with low education, meager land holdings, low incomes and low risk taking capacity

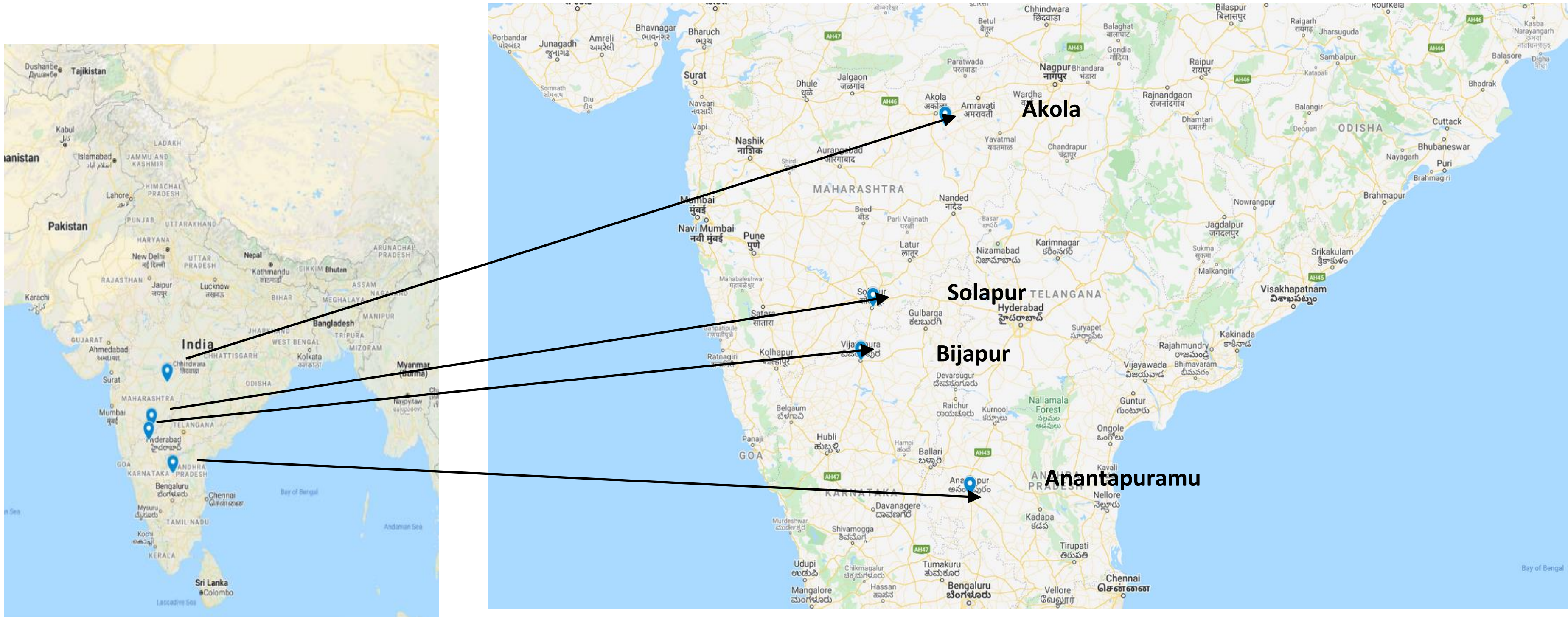


Figure 1. Map showing selected study districts of India

A sample of 240 households at the rate of 60 from each center was selected randomly for data collection representing a minimum of 20% of the population of selected area. One district was selected under each center. From each district one mandal (a mandal is a unit of administration above village and below district level in a state and comprises several villages) and from each mandal two villages were selected. From each village, thirty farmers were selected for data collection. Simple random sampling was followed for selection of villages and farmers. Data was collected using a structured and pre-tested interview questionnaire from the farmers. Focus group discussion (FGD) and interviews were conducted to elicit data from farmers. These tools were helpful in collecting both qualitative and quantitative data. Two FGDs were conducted in each village and each group had ten farmers. The FGDs were not mixed gender. Thirty household interviews were conducted in each village. The main theme on which data collected was about farmers' knowledge on climate change and its' impacts on agriculture. *Eguvapalli* and *Chakraipet* were the villages selected from Anantapuramu, while, *Varkhed* and *Kajaleshwar* were the villages from Akola. *Mangrul* and *Mundewadi* were the villages selected from Solapur, while, *Honnutagi* and *Hadagali* were the villages from Bijapur. Frequency, Percent analysis, correlation and regression coefficients and adaptation indices were used for data analysis. Likert method of summated ratings procedure was used for constructing attitude scale. The attitudes in the study are ordinal scales viz., Agree (A), Undecided (UD) and Disagree (DA) on a three-point continuum with scoring of 1, 2 and 3 assigned to A, UD and DA respectively. Since attitudes precede actions, this component is important in predicting farmers' behavior. In this study, it was found that majority of farmers positively agree with attitude towards climate change statements which point to current and future positive adaptation actions towards climate change.

The steps followed for constructing the Likert type of scale to measure the attitude of farmers towards climate change was as follows (Likert 1932):

i) *Collection of statements:* As such, 60 statements representing the attitude of farmers towards climate change were collected randomly after consulting with scientists, experts in the area and review of available literature.
ii) *Editing of the statements:* These statements were edited according to the criteria laid down (Edwards 1957). Finally, out of 60, 49 statements, which satisfied the criteria, were selected.
iii) *Selection of statements and scoring technique:* The selected 49 statements were administered to a group of 60 respondents from the non-sample area. The respondents were asked to indicate their degree of agreement or disagreement with each on a three-point continuum i.e. Agree (A), Undecided (UD) and Disagree (DA). The scores for positive statements were assigned as 3, 2 and 1 for A, UD and DA respectively. For negative statements, the scoring was reversed. The scores were then summed up to find out the total score of each respondent for all statements. The subjects were then arranged in an array based on the total score obtained by them. The top 25 percent of the subjects with highest score (high group) and 25 percent of the subjects with lowest score (low group) were used as criteria groups.
iv) *Critical ratio (t value):* The critical ratio i.e. t-value which is a measure of the extent to which a given statement differentiates between the high and low groups of respondents for each statement was calculated. Finally, 22 statements were selected whose t-values were equal to or greater than 1.75. In order to avoid agreement bias, positively and negatively worded statements were included interchangeably.
v) *Reliability:* The reliability of the scale was found out by using split-half method which was 0.82, which was high. Split-half reliability is determined by dividing the total set of items (e.g., questions) relating to a construct of interest into halves(e.g., odd-numbered and

even-numbered questions) and comparing the results obtained from the two subsets of items thus created.

vi) *Validity:* As all the possible items covering the universe of content were selected by discussion with experts, resource personnel and available literature on the subject, the present scale satisfied the content validity.

3. Results and Discussion

3.1 Farmers Perceptions towards Climate Change

Perception of climate change is a necessary prerequisite for adaptation. From table 1, it is evident that prolonged dry spells, rise in temperatures and rainfall outside rainy season are the major farmers' perceptions towards climate changein all the selected study locations. The focus group discussions suggested that farmers perceive the rainy period to be shorter now, coming at random compared to the previously longer and more reliable periods with heavy rainfall. Farmers perceived the late onset and less frequent more intense rainfall as 'shorter duration rains'. Farmers perceived that the signs for forecasting rain like clouds, wind movement etc. has lost accuracy in recent years, a possible explanation of climate change. It has been observed by the researchers in this study that prolonged dry spells has become a recurrent phenomenon year after year. Therefore, farmers are unsure of when the next rain would occur. In this context, adaptation by water harvesting and storage assumes significant importance for providing critical and supplemental irrigation to the crops as and when required. Another disturbing characteristic of the south west monsoon in the kharif season is heavy rains towards the end of the crop growing period and subsequent damage to the crop produce coinciding with harvesting period. This is untold misery for farmers' after toiling hard for the entire season. Similar studies in Ethiopia and South Africa revealed that farmers experienced increased temperature and decreased rainfall(Bryan et al. 2009). Similar observations of rise in temperatures and decreased rainfall were reported in their studies by Vedwan and Rhoades 2001; Hageback et al. 2005; Dejene 2011. Results of a study conducted in Bundi district of Rajasthan, India revealed farmers' perceptions to climate changeas increase in temperatures, decreased rainfall and long dry spells. Studies in several other developing countries indicate that most farmers perceive temperatures to have become warmer and rainfall reduced over the past decade or two (Gbetibouo 2008; Dinar et al. 2008; Mubaya et al. 2010; Deressa et al. 2011).

Table 1. Farmers Perceptions regarding Climate Change

S. No.	Major Farmers' Perceptions	%*			
		Anantapuramu	Akola	Solapur	Bijapur
1.	Prolonged dry spells.	80	45	63	27
2.	Rise in temperatures.	78	92	50	28
3.	Delayed and shorter rains.	70	63	48	50
4.	Extended breaks in monsoon.	63	43	32	28
5.	Rainfall outside rainy season.	43	41	42	52

*Multiple responses

3.2 Farmers Adaptations towards Climate Change

The present study revealed the following adaptations practiced by the farmers towards climate change in the four study locations.Table 2 indicated that buying insurance, changing planting dates and cropping pattern, diversify to livestock and work as labor were the major adaptation measures followed by farmers towards climate changein the selected four study locations. Usually, farmers in Anantapuramu sow groundnut during July last week every year. But recent trend shows that if one rain occurs during summer month of May or early June, some of the farmers are going for sowing to reap some benefit thinking the worst case scenario may occur during that year i.e., drought. This finding is consistent with similar study by Swanson et al. (2008) which reported that crop insurance was widely used by farmers in foremost region of Canada (which is under similar agro-ecological conditions) and the common feeling was that even though it might not provide sufficient returns for losses incurred it does offer some protection. It has allowed them to continue farming. Agricultural insurance can help people to cope with the financial losses incurred as a result of weather extremes. Insurance supports farmers as one of the adaptation processes and prevents them from falling into absolute poverty. Apart from stabilizing household incomes by reducing the economic risk, insurance can also enhance farmers willingness to adapt, to make use of innovations and invest in new technologies (Anna et al. 2011). Changing crops has been demonstrated in the literature as a common adaptive behavior by farmers in the face of changing circumstances (Kristjanson et al., 2012; Olesen et al. 2011; Westengen and Brysting 2014). In a study in the Ejura-Sekyedumase district of Ghana, it was found that 93% of farmers were of the opinion that the timing of rains is now irregular and unpredictable (Francis et al. 2011).

Some of the values in the table 2 show '0' because these are the absolute values showing absolute percent. Zero means no farmer had adopted that particular adaptation measure in question. Hence, no mean and error values are presented here. Large values are because these are multiple responses taken from farmers.

Agricultural adaptation involves two types of modifications in production systems (this was observed both in the field sites and literature). The first is increased diversification that involves engaging in production activities that are drought tolerant and or resistant to temperature stresses as well as activities that make efficient use and take full advantage of the prevailing water and temperature conditions, among other factors. Crop diversification can serve as insurance against rainfall variability as different crops are affected differently by climate events (Orindi and Eriksen 2005; Adger et al. 2003). The second strategy focuses on crop management practices geared towards ensuring that critical crop growth stages do not coincide with very harsh climatic conditions such as mid-season droughts. Crop management practices that can be used include modifying the length of the growing period and changing planting and harvesting dates (Orindi and Eriksen 2005). Smallholder farmers can adapt to climate change by changing planting dates and diversifying crops (Gbetibouo 2009). Similar reports of planting different crops as an adaptation strategy by 74% of farmers in a study (Ayanwuyi et al. 2010) in Oyo state of Nigeria.

Under diversify to livestock in these dryland regions usually means that the farmers would rear sheep and goat, and sell them as a contingent strategy to tide over the situation particularly, if monsoon fails and drought occurs. Small farmers usually migrate during the event of failure of monsoon to work as contract labour which also serves as one of the adaptation practices in rainfed areas (Ravi Shankar et al. 2013). Water harvesting is one particular practice that has proved to be climate resilient among farmers and reaped rich dividends to them. Farm ponds, percolation tanks and bunds across the slope are a common and welcome sight in the study villages to the researchers. Water harvesting along with the use of modern micro-irrigation practices such as sprinkler and drip irrigation as an adaptation strategy is well established and should be promoted aggressively in similar dry regions of the world. Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) is one government program in India which has clearly made impacts in the lives of rural people by providing 100 days of employment to poor people by way of labor and improving the groundwater resource of the area. Dry regions like Anantapuramu have been benefited enormously by constructing water harvesting pits/structures wherever possible with technical checks. "The rainwater harvested is helping us during periods of dry spell. Groundwater levels are increasing as well, providing us enough for irrigation and cattle rearing'' said a farmer from Anantapuramu. These farm ponds are vital to increase storage of rain water, to improve recharge of bore wells, and to provide wage employment to agricultural labor. Rain Water Harvesting (RWH) increases the amount of water available for agriculture and livelihoods through the capture and storage of runoff, while at the same time reducing the intensity of peak flows following high-intensity rainfall events. Itis therefore often highlighted as a practical response to dryness (i.e., long-term aridity and low seasonal precipitation) and rainfall variability, both of which are projected to become more acute over time in some dryland areas (Dile et al. 2013; Vohland and Barry 2009). A globalmeta-analysis of changes in crop production due to the adoption of RWH techniques noted an average increase in yields of 78%, ranging from –28% to 468% (Bouma and Wosten 2016).

Table 2. Farmers Adaptations towards Climate Change

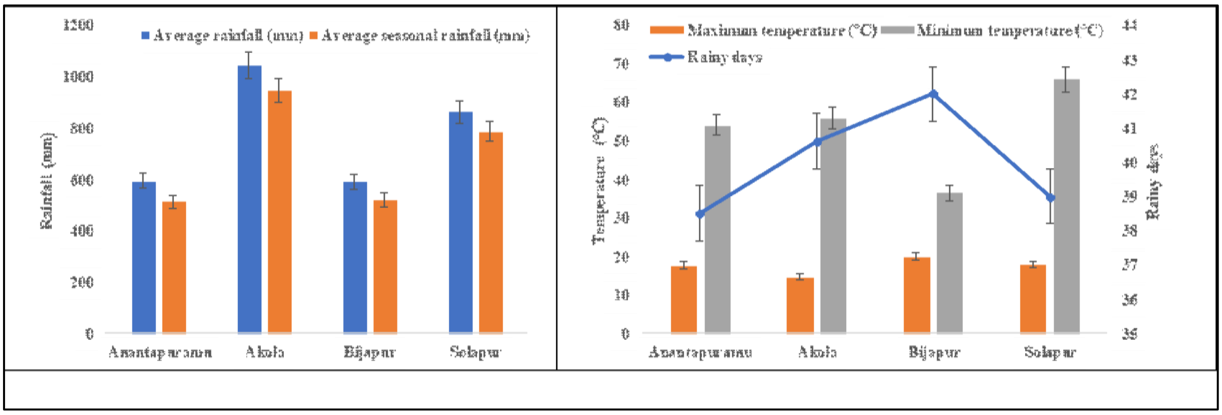
S. No.	Major Farmers' Adaptations	%*			
		Anantapuramu	Akola	Solapur	Bijapur
1.	Buy insurance.	93	0	15	25
2.	Change in planting dates and cropping pattern.	87	68	77	45
3.	Planting different crops.	0	0	65	35
4.	Diversify to livestock.	65	0	27	23
5.	Work as labour.	60	0	0	0
6.	Construct water harvesting structures under MGNREGA.	58	0	50	0
7.	Timely availability of inputs.	0	60	0	0
8.	Drought resistant crops.	0	60	0	0
9.	Contingency crop planning.	0	53	0	0
10.	Spray urea.	0	52	0	30

*Multiple responses

MGNREGA: Mahatma Gandhi National Rural Employment Guarantee Act (a Government of India sponsored social security scheme in rural areas).

3.3 Trend analysis of annual rainfall and temperature over the four study districts

The long-term meteorological variables viz., annual rainfall and temperature were subjected to trend analysis for the four study districts from 1976-2019 and it was observed that the average rainfall was 594 mm., 1046 mm., 590 mm. and 861 mm. for Anantapuramu, Akola, Bijapur and Solapur respectively. The average seasonal rainfall (from May to October) for the above four districts were 512 mm., 945 mm., 520 mm. and 786 mm. respectively in that order. The maximum temperature was the highest for Bijapur at 42^{0}C and the minimum temperature showed highest for Akola at 14.6 ^{0}C. Rainy days were highest for Solapur at 66, while least rainy days were observed in Bijapur at 36.4. After comparing this trend data with actual farmers' perceptions data (table 1), results coincided on two parameters. First in Anantapuramu, average seasonal rainfall was lowest at 512 mm. which was reflected in highest percent of farmers' (70%) among four study districts indicating delayed and shorter rains. Second, rainy days were least in Bijapur (36.4), which was reflected in highest percent of farmers' (52%) among four districts indicating rainfall outside rainy season.



Average long-term rainfall characteristics (1976-2019)Average long-term temperature and rainy days

characteristics (1976-2019)

Figure 2. Long term meteorological variables trend in selected semi-arid districts of India (Source: Author's own compilation)

3.4 Computation of adaptation index to assess the extent of farmers' adaptation to climate change

Adaptation was judged through assigning score of 1 for each practice/measure adapted. In the present study, total adaptation measures were 10, and hence maximum adaptation score that could be obtained is 10, while minimum adaptation score that could be obtained by a farmer is 0. The ten adaptation measures in the study were 'buy insurance', 'change in planting dates and cropping pattern', 'planting different crops, diversify to livestock', 'work as labor', 'construct water harvesting structures under MGNREGA', 'timely availability of inputs', 'drought resistant crops', 'contingency crop planning' and 'spray urea'. These were recommended after consulting with scientists, experts in the area and review of available literature. Since all the ten measures were considered under adaptation and analysis was done with this assumption, 'spray urea' in this study was considered as adaptation measure and not as a coping strategy. Adaptation index was computed for assessing the extent of adaptation.

Adaptation index = Adapted measures/Total recommended measures x 100.

The index values were in decimals and were rounded off to the nearest number in the first place. Later, the decimal values were reinstated in table 3. However, being an absolute measurement there is no point in indicating the error values. The mean adaptation index for the four study locations are presented in table 3. Farmers in Anantapuramu showed high adaptation when compared with other three locations as they are more receptive (higher perceptions of climate change than other three districts) and already adapting to climate change when compared to other centers. Also, they are accustomed to perpetual droughts year in and out.A higher adaptation index in this study infers higher resilience to combat drought and vice versa.

Table 3. Adaptation index of farmers

Statistic/Category	**Anantapuramu (n=60)**	**Akola (n=60)**	**Solapur (n=60)**	**Bijapur (n=60)**
Mean Adaptation index	67.3	38.2	32.6	28.9

3.4 Attitude of farmers towards climate change

Attitude in this study means the degree of positive or negative feelings, beliefs of farmers towards climate change in agriculture and allied fields. Since attitudes precede actions, this component is important in predicting farmers' behavior in the present study.

Attitudes of farmers towards climate change provide feedback to the research for developing tools for the decision support systems. Farmers attitudes towards climate change are likely to be affected by their opinion about acceptable adaptation strategies. A majority of the farmers (more than half of the sample population) agreed with all the attitude statements in the four study locations as given above in table 4. Of particular interest is the way with which farmers echoed similar response about the rise in temperatures, decrease in total amount of rain, incidence of pests and diseases and that human activity is responsible for climate change. It is known that some people strongly believe that climate change is occurring and attribute it to human activity, others do not believe that it is happening, and still others are uncertain (Maibach et al. 2009). While majority of farmers believe that local or traditional knowledge systems can offer solutions to climate change, they, also acknowledge to the fact that of late traditional knowledge/indicators for rain prediction are failing. This is one area which spurs research interest. Majority of farmers from table 4 acknowledge that God has provided for every one's need and not to every one's greed. Farmers from three out of four study locations in statement no. 11 disagreed to the fact that they do not take climate change into account while thinking about their future. Farmers were eager to have more information on options or choices to respond to climate change. Simultaneously, adaptation to other problems is more important than adaptation to climate change for farmers. This suggests that climate change is one of the many problems (not the foremost) that farmers are facing in their daily decision matrix like availability of inputs, credit, government support mechanisms and markets etc. Farmers felt that government support to adapt to climate change is inadequate and needs to be further accelerated like by conducting awareness campaigns, trainings and education etc. Farmers have put tremendous responsibility upon scientists to solve the climate change threat and scientists should live up to the responsibility in providing good crop varieties that should possess drought tolerant and flood resistant characteristics. In this analysis, it was found that majority of farmers positively agree with attitude towards climate change statements which augurs well for current and future adaptation actions. It is critically important to understand what factor shape attitudes toward responses to climate change (Dunlap 2010)

Table 4. Farmers agreement with attitude towards Climate change in Anantapuramu, Akola, Solapur and Bijapur

S. No.	Attitude statement	Agree (%)				Undecided (%)				Disagree (%)			
		An	Ak	S	B	An	Ak	S	B	An	Ak	S	B
1.	Climate change is a serious problem.	92	93	97	97	3	4	0	0	5	3	3	3
2.	Climate change is affecting my farming.	95	92	98	95	5	2	0	3	0	6	2	2
3.	Average temperatures are increasing.	95	88	92	94	5	5	5	3	0	7	3	3
4.	Human activity is responsible for climate change.	95	87	67	87	5	0	13	7	0	13	20	6
5.	Climate change affects small and marginal farmers more.	93	67	75	82	7	0	5	3	0	33	20	15
6.	Climate change impacted food production of my farm.	97	97	90	90	3	3	2	3	0	0	8	7
7.	Climate change affected incidence of pests and diseases.	75	93	95	93	23	7	2	3	2	0	3	4
8.	Cropping seasons in my village are changing.	85	50	72	87	12	12	2	3	3	38	26	10
9.	Local knowledge system of the area can offer solutions to climate change problems.	83	13	72	65	12	27	3	20	5	60	25	15
10.	Climate change is the anger of God for the avarice and ill ways of humans towards nature.	77	78	72	80	15	9	0	2	8	13	28	18
11.	I do not take climate change into account when thinking about my future.	73	25	32	25	15	17	10	25	12	58	58	50
12.	I am uncertain about the ability of my farm to cope with climate change.	83	75	68	55	12	15	10	27	5	10	22	18
13.	I would like more information on options to respond to climate change.	80	92	92	87	5	8	3	3	15	0	5	10
14.	I think adaptation to other problems is more important than adaptation to climate change.	53	58	60	56	2	5	15	13	45	37	25	31
15.	Prolonged dry spells experienced during kharif are part of natural climate variability.	80	70	90	92	15	13	3	3	5	17	7	5
16.	I will be more interested in climate change when I know how it will affect rainfall distribution in my farm.	85	72	95	83	12	11	0	10	3	17	5	7
17.	Rainfall patterns are changing.	92	90	95	97	8	10	2	0	0	0	3	3
18.	In response to change in rainfall patterns, I have changed the time of planting/harvesting in my farm.	87	63	97	82	11	0	2	8	2	37	1	10
19.	Farmers have much bigger challenges to deal with than climate change.	90	47	85	75	8	16	2	5	2	37	13	20

20.	Government should do more to help farmers adapt to climate change.	82	95	85	88	15	0	0	2	3	5	15	10
21.	Scientists can solve the problems of climate change.	90	83	80	87	10	0	5	3	0	17	15	10
22.	The seriousness of climate change has been exaggerated.	85	45	42	51	15	22	25	29	0	33	33	20

An: Anantapuramu; **Ak:** Akola; **S:** Solapur and **B:** Bijapur

3.5 Correlation and Regression analysis

Coefficient of correlation between farmers' adaptation to climate change and six selected socio-economic variables was computed and compared (table 5). Age was negatively significant at 0.01 level of probability while, education, family size, farm size and annual income were positively significant at 0.01 probability level. The relationship of farming experience with farmers' adaptation to climate change was negative though not significant.

Table 5. Correlation coefficients between major socio-economic variables and farmers adaptation to climate change (pooled sample) n=240

S. No.	Socio-economic variables	'r' value
1.	Age	-0.318**
2.	Education	0.265**
3.	Family size	0.323*
4.	Farming experience	-0.196
5.	Farm size	0.388**
6.	Annual income	0.592**

***Significant at 5% level of significance**

****Significant at 1% level of significance**

Further, in order to determine the combined effect of all the socio-economic variables in explaining variation in farmers' adaptation to climate change, multiple linear regression analysis was carried out and the results are presented in table 6. Family size, farm size and annual income were found to be contributing positively and significantly at 0.01 level of probability with farmers' adaptation to climate change. Education was found to be contributing positively and significantly with farmers' adaptation while, age was contributing negatively and significantly with farmers' adaptation at 0.05 level of probability.

The more the age, the lesser would be the farmers' adaptation to climate change. With age, farmers become fixed in their thinking patterns and hence the less inclination towards adaptation. The more the farmers are educated, the greater would be the chances of adaptation. This was due to the fact that educated farmers' does not rely on one source of information and would refer to multiple sources and take the best course of action, their adaptation to climate change would be higher. Farmers with higher level of education are more likely to adapt successfully to climate change than those with lower level of education, as high level of education has a link with access to information on improved technologies and production challenges (Daberkow and McBride 2003). The relationship between family size and adaptation was positively significant. As members in a family increase, their risk orientation also increases and, hence the higher the adaptation to climate change. Increasing household size increases the likelihood of adaptation. This finding is in line with the argument, which assumes that a large family size is normally associated with a higher labor endowment, which would enable a household to accomplish various agricultural tasks, especially during peak seasons (Croppenstedtet al. 2003). Farming experience was found to be positive though, not significant. The R^2 value was less than 50 in the study and non-significant farming experience contributed in part to this result. Higher farming experience accounts for increasing the likelihood of taking up adaptation strategies. This is because experienced farmers have more knowledge and wisdom about changes in climatic elements, and on best agricultural practices to adopt. The same understanding holds good for relation between annual incomes with farmers' adaptation to climate change which was positively significant. The greater the farm size, the higher the adaptation of farmers to climate change due to more adaptive capacity. With increase in acreage, the adaptation process hastens and even if some decisions go wrong, the farmer can as well compensate by the large holdings. Gbetibouo (2009) found a positive relationship between farm size and the adaptation to climate change. The author also argued that adoption of an innovation tends to take place earlier on larger farms than on smaller farms. The relative importance of these socio-economic variables reflects both the economic environment and external social relations of farmers that pave the way for collective nature of enhanced adaptation towards climate change. The identified variables help policy makers to provide targeted extension and advisory services to enrich climate change understanding and support appropriate farm-level climate change adaptations.

Table 6. Regression coefficients of major socio-economic variables with farmers adaptation to climate change (pooled sample) n=240

S. No.	Socio-economic variables	Regression coefficient	Standard error	't' value
1.	Age	-0.487	0.232	-2.09*
2.	Education	0.984	0.477	2.06*
3.	Family size	0.215	0.092	2.33**
4.	Farming experience	0.349	0.288	1.21
5.	Farm size	1.733	0.347	4.99**
6.	Annual income	0.076	0.014	5.34**

R^2 = 0.41

***Significant at 5% level of significance**

****Significant at 1% level of significance**

3.6 Barriers to climate change adaptation

The major barriers to climate change adaptation identified from the study locations were lack of access to credit, labour and access to water. From farmer's point of view, awareness about adaptation practices is by itself not sufficient, but has to be supported with capital and labor for successful adaptation. Measures which need attention by policy makers regarding climate change adaptation that were expressed by farmers were pollution control, afforestation and development of irrigation projects.Limits to adaptation are dynamic, site specific and determined through the interaction of biophysical changes with social and institutional conditions. Exceeding the limits of adaptation will trigger escalating losses or result in undesirable changes, such as forced migration, conflicts, or poverty.

4. Conclusion

Present study suggested major perceptions of climate change among farmers were prolonged dry spells, rise in temperatures, and delayed and shorter rains. Major adaptations towards climate change were insurance, change in planting dates and cropping pattern, diversify to livestock and work as labor. These identified adaptation (crop management) strategies along with those that aim at soil management like conservation tillage, mulching, nutrient recycling etc. and water management like irrigation scheduling, water harvesting etc. too should be promoted and supported by governmental and non-governmental agencies if, farming situations in India has to be made resilient to climate change impacts. Integrated crop, soil and water management measures can be employed to reduce soil degradation and increase the resilience of agricultural production systems to the impacts of climate change. These measures include crop diversification and adoption of drought-resilient ecologicallyappropriate plants, reduced tillage, adoption of improved irrigation techniques (e.g. drip irrigation) and moisture conservation methods (e.g. rainwater harvesting using indigenous and local practices), and maintaining vegetation and mulch cover (IPCC 2019). The numerical value of adaptation index was found to be a good indicator to suggest an area was climate resilient or not.

A better comprehension of farmer's perceptions towards climate change, current adaptation decisions, is needed to promote effective futuristic agricultural adaptation policies. Here, even though difficult, we need to account for how the external factors (like policies, infrastructure, information, forecasts) influence farmers' expectations and actual experiences of rainfall. Results from Mitter *et al*. (2019) emphasize that not only climate change and adaptation appraisal affect the formation of agricultural adaptation intention and avoidance, but personal, farm and regional characteristics are also of importance as well. This finding supports conceptual and empirical literature proposing that adaptation is often a response to a mix of climatic and non-climatic factors (Mitter *et al*., 2018). Since attitudes precede actions, it can be safely assumed that the attitudes of farmers (here found positive) towards climate change precede their future positive adaptation actions.

Agricultural extension and education are crucial to farmers in providing climate resilient knowledge and practices for successful adaptation. Both extension and meteorological organizations should focus and pay attention to the socio-economic contributing factors to adaptation before they embark with their interventions that enhance the productivity and competitiveness of farmers. Emphasis should be given to water harvesting techniques to increase the extent of irrigation coverage. As farm-level adaptation becomes an increasingly important across the world, policies at all levels will need to be accounted for appropriate factors, including perceptions and how perceptions affect human behaviour and adaptive actions. Policy responses to droughts based on proactive drought preparedness and drought risk mitigation are more efficient in limiting drought-caused damages than reactive drought relief efforts. Actions required for the enhancement of adaptive capacity are essentially equivalent to those that promote sustainable development and equity. Adaptation through transformation (in the present study diversify to livestock and work as labor) has the potential to become an inclusive, engaging and empowering process that contributes to alternative and sustainable development pathways which needs to be encouraged.

References

Adger WN. Vulnerability. Global Environmental Change 2006; 16:268-281. doi:10.1016/j.gloenvcha.2006.02.006

Adger WN, Huq S, Brown K, Conway D and Hulme M. Adaptation to climate change in the developing world. Progress in Development Studies 2003; 3:179-195 doi: 10.1191/1464993403ps060oa

Aggarwal, Joshi, Ingram and Gupta.Adapting Food Systems of the Indo-Gangetic Plains to Global Environmental Change: Key Information Needs to Improve Policy Formulation.Environmental Science & Policy. 2004;7(6): 487–498.

Anna Kalisch, Oliver Zemek and Susanne Schellhardt.Adaptation in Agriculture. In: Adaptation to climate change with a focus on rural areas and India, a cooperative effort of Republic of India and Federal Republic of Germany, New Delhi. 2011; pp 40-83.

Arbuckle JG, Prokopy LS, Haigh T, Hobbs J, Knoot T, Knutson C, Loy A, Mase AS, McGuire J, and Wright Morton L. Climate Change Beliefs, Concerns, Attitudes towards adaptation and mitigation among farmers in the Midwestern United States. Clim. Chang. Lett.2013;117: 943–950.

Ayanwuyi, Kuponiyi E, Ogunlade FA and Oyetoro JO. Farmers Perception of Impact of Climate Changes on Food Crop Production in Ogbomosho Agricultural Zone of Oyo state, Nigeria. Global Journal of Human Social Science. 2010; 10 (7):33-39.

Bapuji Rao B, Santhibhushan Chowdary P, Sandeep V.M, Rao VUM, Venkateswarlu B. Rising minimum temperature trends over India in recent decades: Implications for agricultural production. Global and Planetary Change. 2014;117,1–8. http://dx.doi.org/10.1016/j.gloplacha.2014.03.001

Bouma J and Wosten JHM. How to characterize 'good' and 'greening' in the EU Common Agricultural Policy (CAP): The case of clay soils in the Netherlands. Soil Use Manag. 2016;32: 546–552. doi:10.1111/sum.12289

Brody SD, Zahran A and Grover H. Examining the Relationship between Physical Vulnerability and Public Perceptions of Global Climate Change in the United States. Environ. Behav.2008;40: 72–95.

Brown K. Climate change and development short course: Resilience and Adaptive Capacity (Power Point presentation). Norwich, UK: International Development, University of East Anglia; 2010.

Bryan E, Deressa TT, Gbetibouo GA and Ringler C. Adaptation to Climate Change in Ethiopia and South Africa: Options and Constraints. Environmental Science and Policy. 2009;12(4): 413-426. doi: 10.1016/j.envsci.2008.11.002

Croppenstedt A, Demeke M and Meschi MM. Technology Adoption in the Presence of Constraints: The Case of Fertilizer Demand in Ethiopia. Review of Development Economics. 2003;7 (1): 58-70. doi: 10.1111/1467-9361.00175

Daberkow SG, McBride WD. Farm and operation characteristics affecting the awareness and adaption of precision agriculture technologies in the US.Precision Agriculture. 2003;4: 163-177 doi: 10.1023/A:1024557205871

Dejene K Mengistu. Farmers' perception and knowledge of climate change and their coping strategies to the related hazards: Case study from Adiha, Central Tigray, Ethiopia. Agricultural Sciences.2011; 2:138-145.

Deressa TT, Hassan RM and Ringler C. Perception of and adaptation to climate change by farmers in the Nile basin of Ethiopia. The Journal of Agricultural Science. 2011;149(1): 23-31 doi: 10.4236/as.2011.22020

Dile YT, Karlberg L, Temesgen M and Rockstrom J.The role of water harvesting to achieve sustainable agricultural intensification and resilience against water-related shocks in Sub-Saharan Africa. Agric. Ecosyst. Environ. 2013;181: 69–79. doi: 10.1016/j.agee.2013.09.014

Dinar A, Hassan R, Mendelsohn R and Benhin J. Climate change and agriculture in Africa: Impact assessment and adaptation strategies. Earth scan, London; 2008.

Dunlap RE. Climate change and rural sociology: Broadening the research agenda. Rural Sociology.2010; 75:17-27.doi: 10.1111/j.1549-0831.2009.00010.x

Edwards AL. Techniques of Attitude Scale Construction.Vakils, Feffer & Simons Private Limited, Hague Building, Ballard Estate, Bombay; 1957.

Francis Kemausuor, Ernest Dwamena, Ato Bart-Plange and Nicholas Kyei-Baffour.Farmers' Perception of Climate Change in the Ejura-Sekyedumase District of Ghana.ARPN Journal of Agricultural and Biological Science. 2011; Vol.6, No.10: 26-37.

Fussel HM and Klein RJT. Climate change vulnerability assessments: an evolution of conceptual thinking. Climatic Change 2006; 75:301-329. doi: 10.1007/s10584-006-0329-3

Gbetibouo GA. Understanding farmers' perceptions and adaptations to climate change and variability: the case of the Limpopo Basin, South Africa. (IFPRI Research Brief 15-8), Washington, DC; 2008.

Gbetibouo GA. Understanding Farmers Perceptions and Adaptations to Climate Change and Variability: The case of the Limpopo Basin farmers South Africa. (IFPRI Discussion Paper 849), Washington, D.C. (USA): IFPRI; 2009.

Hageback JM, Sundbery D, Ostroald X Chen and Knutsson P. Climate variability and land use change in Danagou watershed, China-examples of small scale farmers' adaptation. Climatic Change 2005; 72:189-212. doi: 10.1007/s10584-005-5384-7

IPCC. Climate Change: Synthesis report. In: Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change.Pachauri RK, Reisinger A., Editors. IPCC, Geneva, Switzerland;2007:104.

IPCC. Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Shukla PR, Skea J, Calvo Buendia E, Masson-Delmotte V, Portner HO, Roberts DC, Zhai P, Slade R, Connors S, van Diemen R, Ferrat M, Haughey E, Luz S, Neogi S, Pathak M, Petzold J, Portugal Pereira J, Vyas P, Huntley E, Kissick K, Belkacemi M and Malley J, Editors; 2019: In press.

Kristjanson P, Neufeldt H, Gassner A, Mango J, Kyazze F, Desta S, Sayula G, Thiede B, Förch W, Thornton P and Coe R. Are food insecure smallholder households making changes in their farming practices? Evidence from East Africa.Food Security. 2012; 4(3): 381-397. doi: 10.1007/s12571-012-0194-z

Likert R. A technique for the measurement of Attitudes.Archives of Psychology No. 140; 1932.

Maibach E, Roser-Renouf C and Leiserowitz A. Global warming's six Americas: An audience segmentation analysis. New Haven, CT: Yale Project on Climate Change Communication; 2009.

McCarthy JJ, Canziani OF, Leary NA, Dokken DJ and White KS IPCC. In: Climate change 2001: impacts, adaptation and vulnerability, contribution of working group II to the third assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge; 2001:1032.

Miller A, Rhodes SL and MacDonnell LJ. Water allocation in a changing climate: institutions and adaptation. Climatic Change 1997; 35:157-177.doi: 10.1023/A:1005300529862

Mitter H, Schönhart M, Larcher M, Schmid E. The Stimuli Actions-Effects-Responses (SAER)-framework for exploring perceived relationships between private and public climate change adaptation in agriculture. J Environ Manage 2018; 209:286–300. https://doi.org/10.1016/j.jenvman.2017.12.063

Mitter H, Larcher M, Schonhart M, Stottinger, M and Schmid E. Exploring Farmers' Climate Change Perceptions and Adaptation Intentions: Empirical Evidence from Austria. Environ Manage 2019; 63:804–821. https://doi.org/10.1007/s00267-019-01158-7

Mubaya CP, Njuki J, Liwenga E, Mutsvangwa EP and Mugabe FT. Perceived Impacts of Climate Related Parameters on Smallholder Farmers in Zambia and Zimbabwe. Journal of Sustainable Development in Africa 2010; 12(5):170-186.

National Rainfed Area Authority.Planning Commission, Government of India. 2013. Available: http://nraa.gov.in/

National Research Council (NRC).Adapting to the impacts of climate change: America's climate choices. National Academies Press, Washington 2010; doi: 10.17226/12783O'Connor RE, Bord RJ and Fisher A. Risk Perceptions, General Environmental Beliefs, and Willingness to Address Climate Change. Risk Anal. 1999; 19 461–471.

Olesen J, Trnka M, Kersebaum KC, Skjelvag AO, Seguin B, Peltonen-Sainio P, Rossi F, Kozyra J and Micale F. Impacts and adaptation of European crop production systems to climate change. European Journal of Agronomy 2011; 34(2): 96-112. doi: 10.1016/j.eja.2010.11.003

Orindi VA and S Eriksen.Mainstreaming adaptation to climate change in the development process in Uganda. Ecopolicy Series15Nairobi, Kenya: African Centre for Technology Studies (ACTS); 2005.

Pathak H, Ladha JK, Aggarwal PK, Peng S, Das S, Singh Y, Singh B, Kamra SK, Mishra B, Sastri ASRAS, Aggarwal HP, Das DK, Gupta RK. Trends of climatic potential and on-farm yield of rice and wheat in the Indo-Gangetic Plains. Field Crops Research 2003; 80 223-234. 10.1016/S0378-4290(02)00194-6

Ravi Shankar K, Nagasree K, Prasad MS and Venkateswarlu B. Farmers' Knowledge Perceptions and Adaptation Measures towards Climate Change in South India and Role of Extension in Climate Change Adaptation and Mitigation. In Compendium of National Seminar on Futuristic Agricultural Extension for Livelihood Improvement and Sustainable Development, January 19-21, 2013 at ANGRAU, Rajendranagar, Hyderabad 2013; 295-303.

Roesch-McNally GE, Arbuckle JG and Tyndall JT. What Would Farmers Do? Adaptation intentions under a Corn Belt climate change scenario. Agric. Hum. Values2017; 34 333–346.

Schattman R, Conner D and Mendez VE. Farmer perceptions of climate change risk and associated on-farm management strategies in Vermont, northeastern United States. Elementa2016;4: 1–14.

Sivakumar MVK, Das HP, Brunini O. Impacts of present and future climate variability and change on agriculture and forestry in the arid and semi-arid tropics. Climatic Change 2005; 70:31-72. doi: 10.1007/1-4020-4166-7_4

Smit B and Pilifosova O. Adaptation to climate change in the context of sustainable development and equity. In: McCarthy JJ, Canziani OF, Leary NA, Dokken DJ and White KS, editors. Climate Change 2001: Impacts, Adaptation and Vulnerability Cambridge: Cambridge University Press 2001;877-912.

Smit B and Wandel J. Adaptation, adaptive capacity and vulnerability. Global Environmental Change 2006; 16: 282-292. doi: 10.1016/j.gloenvcha.2006.03.008

Swanson D, Henry David V, Christa Rust and Jennifer Medlock.Understanding Adaptive Policy Mechanisms through Farm-Level Studies of Adaptation to Weather Events in Alberta, Canada. Published by the International Institute for Sustainable Development, Canada 2008; 72.

Udmale P, Ichikawa Y, Manandhar S, Ishidaira H, Kiem AS. Farmers' perception of drought impacts, local adaptation and administrative mitigation measures in Maharashtra state, India. International Journal of Disaster Risk Reduction 2014; 10:250–269. Available: http://www.sciencedirect.com/science/article/pii/S2212420914000818-aff0005. doi:10.1016/j.ijdrr.2014.09.011.

Vedwan N and Rhoades RE. Climate change in the western Himalayas of India: A study of local perception and response. Climate Research 2001; 19:109-117. doi: 10.3354/cr019109

Vincent K. Uncertainty in Adaptive capacity and the Importance of Scale. Global Environmental Change 2007; 17, 12–24.

Vohland K and Barry B. A review of in situ rainwater harvesting (RWH) practices modifying landscape functions in African drylands. Agric. Ecosyst. Environ. 2009; 131 119–127. doi: 10.1016/j.agee.2009.01.010

Westengen O and Brysting A. Crop adaptation to climate change in the semi -arid zone in Tanzania: the role of genetic resources and seed systems. Agriculture & Food Security 2014; 3(3), 1-12. doi: 10.1186/2048-7010-3-3

Social interventions and Institutions for community action towards climate resilience

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Introduction

Climate change is likely to have an adverse effect on rural livelihood of the most vulnerable section of society. Institutional and social factors play a key role in shaping vulnerability on households depending on local governance and institutional arrangements. Literature highlights that the success of any adaptation and resilience efforts generally hinges upon the nature of existing formal and informal rural institutions (Mubaya and Mafongoya, 2017). Institutional capacities at the local level contribute to sustainable livelihoods because they buffer or mitigate those factors that endanger or deprive people of their livelihoods (Uphoff and Buck 2006). Institutions can create the incentive frameworks within which households and collectives choose specific adaptation practices. Institutions can be defined as the complexes of norms and behaviours that humans use to organize all forms of repetitive and structured interactions (Ostrom 2005). Although institutions can represent diffuse patterns of behaviour, they can also function as organizations or structures of recognized and accepted roles that serve particular purposes (Uphoff and Buck 2006). They exist in the public, private, and civic sectors in the form of membership organizations or cooperatives. Rural producer organizations represent a hybrid category that includes a variety of membership organizations, cooperatives, or private businesses (Uphoff and Buck 2006). Such organizations are often characterized by highly local, specific, and evolving structures and functions depending on the area (Washington-Ottombre and Pijanowski 2013).

Poor, natural resource-dependent rural households will bear a disproportionate burden of adverse impacts of climate change. Local institutions have shaped how rural residents responded to environmental challenges in the past. They are also the mechanisms that will translate the impact of future external interventions to facilitate adaptation to climate change. Because adaptation to climate change is local, it is critically important to understand better the role of local institutions in shaping adaptation and improving capacities of the most vulnerable social groups (Agrawal et al 2008).

Social interventions

Climate risk is expected to impact rural communities in multiple ways. The word resilience is means understanding how communities might respond to climate change while maintaining and developing critical community functions, for example, ensuring food production and improving wellbeing. Resilience efforts may be divided into absorptive, adaptive, and transformative resilience (Frankenberger, 2013). Jeans *et al*., (2016) define absorptive capacity as the capacity for a community to take action to cope with expected shocks; adaptive capacity is the ability of a community to anticipate shocks that have not yet occurred and to develop flexibility to deal with these shocks in the future; and transformative capacity is the capacity to stop or reduce either risk or vulnerability by creating a new type of system.

Communities can play a vital role in responding to climate-induced risk, but care should be taken to avoid disempowering or over-burdening already vulnerable communities [Allen, 2006]. Hence deployment of suitable social interventions as a strategy is essential to analyse and appraise rural settings.

However, the planning and implementation of community driven climate resilient programmes for adaptation at grass root level needs immense participation of the local village people. FAO (2000) in the guide lines for participatory diagnosis of constraints and opportunities for soil and plant nutrient management mentioned that participatory diagnosis enables the communities and the farm households to participate in the process of understanding and analyzing the existing constraints and opportunities in soil and plant nutrient management and in developing strategies for overcoming these constraints. In this context, it is essential to have the knowledge on participatory techniques and tools for mobilizing communities. This calls out the spirit of conducting participatory exercises like PRA, (Participatory Rural appraisal,) PLA (Participatory learning Action), PRCA (Participatory Rural communication appraisal) etc, at field level to elicit the issues and priorities by villagers. Some of the important tools to appraise rural situation in the shortest time are briefed as follows.

Rapid rural appraisal or RRA developed as a methodology in the 1970s, influenced by Farming Systems Research (FSR) and other methods.

RRA was developed for quick field – oriented results with objectives as follows:

(i) Appraising agricultural and other needs of rural community;

(ii) Prioritizing areas of research tailored to such needs;

(iii) Assessing feasibility of developmental needs and action plans;

(iv) Implementing action plans, monitoring and evaluating them.

Rapid Rural Appraisal or RRA is a way of organizing people for collecting and analyzing information within a short time span. It can be defined as any systematic process of investigation to acquire new information in order to draw and validate inferences, hypotheses, observations and conclusions in a limited period of time .It has flexibility to adjust to situations because it does not imply or recommend a standard set of methods to be applied in each case.

Participatory Rural Appraisal

•PRA is a process of involving local people in the analysis and interpretation of a rural situation

Participatory Rural Appraisal (PRA) is a methodology for interacting with villagers understanding them and learning from them. It involve a set of principles , a process of communication and a menu of methods for seeking villagers participation in putting forward their points of view about any issue and enabling them do their own analysis with a view to make use of such learning

Several otheradaptation mechanisms are there for achieving climate resilience and these were grouped into different categories including structural, behavioural, economic, social, environmental, legislative, religious, and technological. The structural adaptation category involves setting up physical structures in the form of roads, bridges, drainage systems, and earthen ponds, while the social adaptation involve educating people on how to adapt, getting people to rescue affected community members, and providing relief materials. The environmental category includes planting of trees in open spaces in the community, while the economic adaptation category comprises providing financial resources that would aid victims in recovering from climatic shocks. The behavioural adaptation category focus moving away from the affected area to better areas as a means of adaptation, while the legislative category focus on enacting laws as a means of adaptation. Finally, the technological adaptation involves employment of technological advances (for example, providing improved plant varieties).

The most frequently practiced type of intervention in all communities are structural intervention, followed by social, environmental, economic, and behavioural interventions. Local adaptation responses to climate variability can be classified into five categories (Agrawal and Perrin, 2008).

1. ***Mobility*** denotes movements of various types in response to risks and scarcities. It is a common adaptation strategy used by households and communities, particularly in drier parts of the world.

2. ***Storage*** of past surpluses is an effective measure against future livelihood failures. Agricultural households, especially in dry areas, have created indigenous storage infrastructure for seeds and harvested crops and have developed time-tested procedures for drying fruits and meats for storage.

3. ***Diversification*** can occur in relation to on and off farm employment opportunities, productive and non-productive assets and consumption strategies. Scattering of fields in areas where rainfall is unreliable, diversification into different farm management practices and crop cultivars, and using a combination of occupations such as wage labor, animal rearing, and farming are common diversification responses in risky environments.

4. Communal pooling refers to adaptation responses involving joint ownership and sharing of wealth, labor, or incomes across households, or mobilization of resources held collectively during times of scarcity. Communities in dryland areas, for example, increase water rationing and/or often prohibit the consumption of certain foods and forest products, except during times of famine or long-term rainfall failure.

5.***Market exchange*** is perhaps the most versatile mechanism for adaptation. To be fair and effective, it requires well developed markets, exchange instruments, and widespread access. Weather-related insurance schemes for agricultural or pastoralist populations (although very scarce) are an example of market-based adaptation to climate change.

Role of social institutions in creating resilience against climate change

Local institutions shape the effects of climate hazards in three important ways: they influence how households are affected by climate impacts; they shape the ability of households to respond to climate impacts and pursue different adaptation practices; and they mediate the flow of external interventions in the context of adaptation.(Adapted from Agrawal et al 2008)

i.) Local institutions shape the impact of climate change on communities. Institutional and social factors play a key role in shaping vulnerability: the same climate phenomenon will have very different effects on the livelihoods of residents in the region, depending on the nature of local governance and local institutional arrangements. For example, reduced precipitation in a region by 20 percent in a given year will have a less negative impact on farmers who have access to irrigation versus those who rely on rainfed agriculture. The negative effect of crop failure is likely to be reduced if farmers have more equitable access to livelihoods related institutions governing distribution of benefits from communal forests or pastures coupled with transparent communication, as opposed to where institutional access is stratified and information is monopolized by a small group.

ii.) Local institutions shape the way communities respond to climate change. Institutions link individuals with collectives and provide the framework within which households and collectives choose adaptation practices. For example, strong institutional norms around labor sharing will reduce the ability of households to adapt by migrating or diversifying. Social groups that do not have secure rights to land will find it more difficult to diversify asset portfolios or engage in exchange. Closely knit social networks make it easier to undertake communal pooling of resources. Communities that lack access to capital and infrastructure may be unable to use storage or exchange to cope with environmental risks. Without access to markets, communities may be forced to adopt storage of harvests as an adaptation response and invest resources into storage infrastructure.

iii.) Local institutions are the intermediaries for external support to adaptation. Institutions are the media through which external interventions reinforce or undermine existing adaptation practices. Indeed, all external interventions, to be effective, need local institutional collaborations to leverage the impact of interventions. Willing involvement of local institutional partners greatly strengthens the effectiveness of external interventions.

Experiences of NICRA

In the light of aforesaid facts, the Indian Council of Agricultural Research (ICAR) launched a flagship initiative '*National Initiative on Climate Resilient Agriculture*' (NICRA) during XI Plan in February 2011, and during XII Plan it is referred as '*National Innovations in Climate Resilient Agriculture*' (NICRA)to meet the challenges of sustaining food production in the context of climate variability. The present note describes how various strategies like demonstration of site specific technology packages on farmers' fields for adapting to current climate riskswere implemented at grassroots level to impart capacities for various stakeholders on climate resilience.

Enhancing the resilience of Indian agriculture to cope with climate variability and climate change is vital to the livelihood security at household and village level, and to meet the food requirements of the country. It is in this context, the crucial component of NICRA, technology demonstration which deals with the deployment of suitable extension methodologies and strategies for adaptation and resilience to Climate Change at grass root level for enhancing climate resilience at village level.

Stakeholder and Community Partnerships

Technology demonstration component of NICRA was implemented in a cluster of villages from each of selected 153 districts which are vulnerable to climate change impacts of extreme events like droughts, floods, cyclones, heat wave, cold wave, frost and salinity. The program was piloted by the KVK or Farm Science Centre, under the technical guidance of Agricultural Technology Application and Research Institutes (ATARI). Indian Council of Agricultural Research (ICAR) Institutes and State agricultural university (SAU) systems located near to selected vulnerable district. At the district level, the project is being implemented by selected KVK/ICAR institute/SAU and at the village level by institutions established in the villages such as Village Climate Risk Management committees (VCRMCs) for ensuring effective participation by farming community.

Community Institutions facilitated and strengthened under ICAR-NICRA

The focus of the programme is not only to demonstrate the climate resilient agriculture technologies but also to institutionalize mechanisms at the village level for continued adoption of climate smart practice in sustainable manner. This also results in strengthening the existing institutional mechanisms at the field level for successful technology adoption and up scaling. It is important to have appropriate institutional mechanism in place for successful implementation and sustainability of any agricultural development programme. Hence ***institutional interventions like community seed bank, fodder bank, farm machinery custom hiring center etc. are being implemented under NICRA through active involvement of farmers /stake holders across the districts***. The activities of these institutions are given below.

Village Climate Risk Management Committee (VCRMC)

A VCRMC representing all the categories of farmers in the village is formed with the approval of gram sabha in all NICRA villages. This committee is fully involved in the NICRA programme and implementation of technological interventions VCRMC participates in all village level discussions including planning, finalizing interventions, selection of target farmers and area, and liaison with gram panchyat and local elected representatives. VCRMC maintains joint bank account which is used for all financial transactions under NICRA including maintaining farmer’s contributions for different activities, handling of payments recovered from custom hiring centres.

Custom Hiring Center

Timely access to farm machinery for sowing, harvesting etc. is an important component of adaptation strategy to deal with climatic variability. Therefore an innovative institutional arrangement in the form of a farm machinery custom hiring center has been created in each of the 100 selected villages. The rates for hiring the machines/ implements are decided by the VCRMC. The revenue generated would be used for repair of farm implements and maintenance of custom hiring centre.

Seed Bank as contingency measure

Provision timely seed for farmers (non hybrids but stress tolerant improved varieties) is one of the most relevant institutional interventions relevant to meet the goal of NICRA. In this process, a group of 20-25 farmers has been selected for seed production of relevant varieties for 2-4 major crops of the village in all the 100 districts. The farmers group is trained and given seed and money to organize the activity.

Fodder Bank for improving livestock productivity

Livestock is one of the most important components of dryland farming systems, which plays a stabilizing role during climatic shocks. Sharp reduction in fodder production from private as well as common lands due to either drought or flash floods is the key impact of climatic variability on livestock production. Hence, Fodder Bank is a very important institutional arrangement for enhancing climate resilience of livestock production systems in dry land/ rainfed regions. Enhancing production, conservation and storage of fodder by involving SHG’s / User groups is the objective.

Capacity building for climate resilience

Adaptation to climate change and mitigation efforts in agriculture, together with keeping up with production challenges, will require more skilful farmers, herders and fisher folk. Formal and informal training resources should be made accessible to them. Capacity development should include strategic thinking for identifying and managing risk and climate variability impacts, technical knowledge for climate-smart agricultural practices, ecosystem management and monitoring, business management decisions, all with a "problem solving" focus. Training programmes should also aim to attract younger generations to agriculture.

Conclusion

The agricultural and allied sectors (crops, livestock, forestry, fisheries etc.) must therefore transformwith use of appropriate social interventions for collective action of various stakeholdersto face challenges of climate variability in order to have food security. It should pave the path for economic growth and poverty reduction with channelized efforts of institutions developing human and social capital which can tackle the effects of climate change impacts.

References

Agrawal, A., Perrin, N., 2008. Climate Adaptation, Local Institutions, and Rural Livelihoods.IFRI Working Paper W081–6. Ann Arbor, Michigan: InternationalForestry Resources and Institutions Program and University of Michigan.

Allen, K.M. Community-based disaster preparedness and climate adaptation: Local capacity-building in the Philippines. Disasters 2006, 30, 81–101. [CrossRef] [PubMed].

Chambers Robert 1994 Participatory Rural Appraisal , Challenges, Problems ,Potentials and paradigm world development Vol 22 No.10 1437-1454

FAO, 1990. Food& Agricultural Organization The conservation and rehabilitation of African lands Z5700/E

FAO 2000 ftp://ftp.fao.org/agl/agll/docs/misc30.pdf

Frankenberger, T.; Mueller, M.; Spangler, T.; Alexander, S. Community Resilience: Conceptual Framework and Measurement Feed the Future Learning Agenda; Westat: Rockville, MD, USA, 2013.

Jeans, H.; Thomas, S.; Castillo, G. The Future Is a Choice: The Oxfam Framework and Guidance for Resilient Development; Oxfam International: Oxford, UK, 2016.

Mubaya, ChipoPlaxedes, and ParamuMafongoya. "The role of institutions in managing local level climate change adaptation in semi-arid Zimbabwe." *Climate Risk Management* 16 (2017): 93-105.

Nagasree,K., K.Ravishankar, Dixit.S, B.Venkateswarlu, Raju BMK SubbaRao AVM and Vijay Jesudasan 2013 An analysis on use of ICT tools for dissemination of Weather based agro advisories *Journal of agrometeorology* 15(spl issue 2) pp110

Uphoff, N., and L. Buck. 2006. Strengthening rural local institutional capacities for sustainable livelihoods and equitable development. World Bank, Washington, D.C., USA.

Washington-Ottombre, C., and B. C. Pijanowski. 2013. Rural organizations and adaptation to climate change and variability in rural Kenya. Regional Environmental Change 13(3):537-550. http://dx.doi.org/10.1007/s10113-012-0343-0

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Extension strategies for promotion of climate resilient farming

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Background

Agriculture throughout the world is transforming from production driven to market driven, which requires new and innovative ways to deliver agricultural extension and advisory services. The national governments and international organizations working in agriculture development have designed and implemented different types of agricultural extension models in various countries and regions. Extension specialists and leaders have developed their own models and practices and tried to bring new innovations in their ongoing programs or initiated new programs to deliver knowledge and technologies to local farmers and communities (P Chandra Shekara in MSU and MANAGE, 2021). Further, the changes in climate provide an opportunity for the farm advisory service providers to evolve innovative approaches in addressing the risks, adapting to and mitigating climate change effects on agriculture and allied sectors. Innovations have the potential to offer solutions as per the local needs and capacities of farming communities (Gatzweiler and Von Braun, 2016).This book chapter deals with some of the innovations in agricultural extension in details and their contribution towards resilient and sustainable agriculture.

Need for innovations in extension

Though extension advisory service providers play a major role in effective use of communication of information, the changing needs of farmers and the challenges related to technology, institutions, behaviour, market ecosystem including climate change demand innovative approaches in extension to address the problems effectively and to help farmers form sound opinions and make good decisions.

Extension evolution In India – A glance

After Independence, the formalized Extension system in India came into existence with the development of Community Development Programme (CDP) in 1952, afterwards, several extension strategies were promoted to benefit the farming community. Some of them were Panchayati Raj (Democratic Decentralization), Intensive Agricultural District Programme (IADP)-1960, High Yielding Variety Programme (HYVP)-1966, Drought Prone Area Programme (DPAP)-1970, Development of Women and Children in Rural Areas (DWCRA)-1982, KrishiVigyan Kendras-1974, Support to State Extension Programmes for Extension Reforms" etc. However, in recent past, the extension is emphasizingentrepreneurship, startups, ICTs etc. There are also specific extension innovations to address the risks of climate change in agriculture and allied sector.

Extension efforts towards Climate smart farming

Extension services play a critical role in agricultural development for food and nutrition security and for improving productivity and livelihoods (FAO 2014). The first step towards adaptation measure to climate change is bringing desirable change among farmers. Several factors influence the behaviour of farmers, which include externals and internals. Externals such as subsidies, climate finance, incentives, the extent of participation, linkages with the stakeholders, relationship with fellow farmers, friends, neighbours and internals such as education, knowledge, awareness, attitude, farm size, family income, family labour on agriculture, etc. Climate smart technologies have become knowledge-intensive, hence, it poses considerable challenges to farmers regarding adoption and continued adoption. In the absence of relevant extension and advisory services, the adoption of climate smart technologies would be less (Hellin et al, 2014). To respond to climate change, a range of different extension innovations to be kept in mind along with necessary support services and incentives such as preserving indigenous knowledge; conducting climate awareness campaigns, organizing training related to climate smart technologies/services, plant health rallies, climate farmers field school, participatory crop planning & water literacy; promoting farmers collectives; the establishment of plant clinics; appointment of climate manager/monsoon manager at the state and district level, providing climate finance and incentive support at farmers level etc. Access to climate information and awareness about climate-associated risks in agriculture is an essential part of mitigation and adaptation. A number of innovations have been taken by agricultural stakeholders across the globe to address the risks and impacts of climate change. Access to climate information has become a crucial part of farm-level decision making regarding adaptation. Likewise, ICT advisories play a major role in providing timely information to farmers to manage crops against the risks of climate change. ICT supported climate extension services are promoted by various public and private institutes. Some of the key innovations in agricultural extension are discussed in detail.

Participatory development and adoption of climate smart technologies and practices

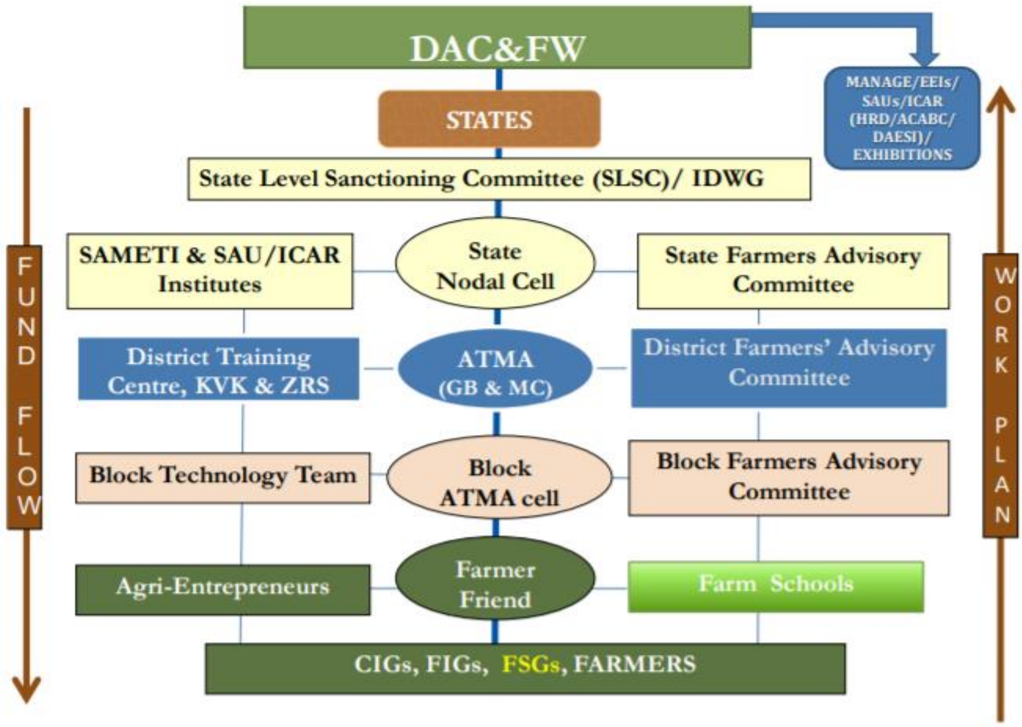
The increased impact of climate change demands greater participation of stakeholders, including agriculture in the development of technologies that address the risks of climate change. The adoption rate of climate smart production technologies and practices is less, this will affect the adaptation capacity of farmers due to mounting risks of climate change such as delayed arrival and uneven distribution of monsoon, long dry spell as well as increased temperature. Therefore, the Extension system needs to identify the vulnerable areas to different vagaries of climate change with the participation of stakeholders, including farmers. Thereafter, the research system needs to develop and introduce climate smart varieties, production practices and services that effectively address the identified risk of climate change. Also, there are several other impactful CSA technologies developed by Agricultural Universities, ICAR-Research Institutes, private sector, NGOs, etc. these improved technologies and services need to be promoted by extension service providers through increased participation of farmers, entrepreneurs, private sectors, etc. As most of the farmers are having small and marginal lands for cultivation, these farmers need adequate incentives and funding support to adopt the recommended technologies and practices foragricultural production.

Farmer Field School Model of Extension Innovation

The Farmer Field School (FFS) model of agricultural extension emerged in Asia in 1980 and was implemented by several institutions and organizations in over 90 countries. FAO and other development organizations have been promoting FFS to address a broad range of problems and technical domains. The FFS model is an intensive, season-long program that focused on experiential learning where farmers met frequently and developed experiments, learned, and shared their skills and knowledge with other farmers in a village. The FFS innovation has several benefits namely Increase in crop production, productivity, and income generation; significant decrease in the use of chemical pesticides; enhanced market and value chain linkages for farmer groups and elimination of intermediary for marketing;favourable local policies and strengthening relationships among communities and local government authorities; enhanced farmers capacities and empowerment as well as leadership skills, program management skills, and problem-solving skills of farmers.

Institution and process innovation in extension in the form of ATMA

The Scheme 'Support to State Extension Programmes for Extension Reforms' aims at making extension system farmer driven and farmer accountable by disseminating technology to farmers through new institutional arrangements viz. Agricultural Technology Management Agency (ATMA) at district level to operationalize the extension reforms on a participatory model. ATMA is encouraging multi-agency extension strategies involving Public/ Private Extension Service Providers, Ensuring an integrated, broad-based extension delivery mechanism consistent with farming system approach with a focus on bottom up planning process, Adopting group approach to extension in line with the identified needs and requirements of the farmers in the form of CIGs & FIGs and consolidate them as Farmers Producer Organizations; Facilitating convergence of farmer centric programmes in planning, execution and implementation and Addressing gender concerns by mobilizing farm women into groups and providing training to them by apportioning 30% of funds earmarked under ATMA.



Farm School as an innovative technology dissemination tool

Farm Schools are being set up in the field of outstanding or achiever farmers. These would be operationalized at Block/Gram Panchayat level by ATMA. The achiever farmers will act as trainers and his farm will act as a school to disseminate the technologies successful farmers to the neighbouring farmers. Farm Schools provide the vital link between the progressive/achiever farmers and other such farmers.There is a funding provision ofRs. 30,000 for organizing each farm school under ATMA. Therefore, the extension functionaries may also organize Farm Schools related to climate change, preferably in a cluster of villages to serve as a mechanism for the farmer to farmer extension. This will have the maximum impact on the production, productivity and income of the farmers.

Farmer Friend as link between extension service providers and farmers

There is a Farmer Friend (FF) for every two census villages under ATMA and these FFs can act as a link between extension and farmers. FFs are mostly progressive farmers (Both men and women) are expected to mobilize the farmers for the formation of Farmers Interest Groups and help in the conduct of field demonstration, KisanGoshties, facilitate in preparation of Village Research Extension Action Plan (VREAP), liaison with Assistant Technology Manager (ATM) for exchange of information related to agri and allied activities at field level. They are also expected to ensure the dissemination of information through multimedia. Hence, the presence of FFs under ATMA may be utilized effectively by the extension functionaries to train them on the latest technologies, dissemination of weather advisories through them, managing extreme events like cyclone, flood, drought etc.

Public Private Partnership for effective Extension Services for CSA

With the increase in importance of climate change, the demand for climate smart technologies, practices and services is increasing. Therefore, the farmers need new skills, market information, and technologies to address the risks of climate change. Thus, the strengths of the private sector may effectively be used for CSA such as delivering services through the use of modern ICTs, promoting new and emerging agricultural technologies and products that have shown potential benefits for increased yields, quality production, mitigation and adaptation.

Further, there is a scope for utilizing the 10% fund earmarked under ATMA for PPP to provide efficient extension advisory services. The public has better backward linkages due to its presence at grassroots level, credibility and network with research organizations. Whereas, the private sector has strength in forward linkages such as input support, credit, insurance, processing and value addition along with marketing. Similarly, NGOs have strength in social mobilization of farmers and farmer collectives. Hence, PPP will help in harnessing the strength of each partner and achieve synergy in providing end to end solution for farmers.

Market led extension approach

To be pro-active beyond the regular objective of maximizing the productivity of the farmers/producers by transferring improved technologies rather farmers should be sensitized on various aspects of produces like quality, consumer‘s preference, market intelligence, processing and value addition and other marketing information. This will help the farming community to realize high returns for the produce, minimize the production costs, and improve the product value and marketability that may help in realizing the concept of doubling farmers‘ income. Due to the increasing risks of climate change, it is expected that there will be increase in cost of cultivation, decrease in production and thereby farm level profitability. Therefore Market Led Extension which focuses on crop diversification, processing and value addition, reduction in market intermediaries, collective marketing etc., would increase the farm level profitability and ensure income stability to the farmers.

Community-Based Organizations

There are various community based organizations or farmer’s collectives such as Commodity Interest Groups (CIGs), Village Producer Organizations (VPOs), Farmers Producers Organizations (FPOs) and Farmer Producer Companies (FPCs) developed at grassroots level under various schemes and programmes to attain synergy.There are 6000 FPOs (including FPCs) in India. These FPOs were promoted by National Bank for Agriculture and Rural Development (NABARD), Small Farmers’ Agri-Business Consortium (SFAC) and state governments (NABARD, 2021). The anticipated adverse impact of climate change include depletion of water table, extreme events (droughts, floods, heatwaves, etc.), management of common property resources, wastelands, fulfilling the demand of fodder shortage to the animals during drought periods, supplying cost effective inputs, ensuring climate resilient seeds during repeated sowing, providing climate risk mechanism (e.g. weather based insurance), etc These above climate induced challengescan effectively be addressed if the extension system channelizes all the services through farmers' collectives than to provide to an individual farmer.

There is also a provision for mobilizing 20 farmer groups per block under the cafeteria of activity of ATMA with funding support for formation, nurturing the groups such as Farmers interest groups/women groups, farmers' organization/commodity organizations, farmers cooperatives, viable groups etc. These provisions may be used for creating climate smart community groups for effectively addressing climate related challenges.

Besides, realizing the importance of Farmers Collectives, MANAGE has recently started an FPO academy to meet the emerging needs related to capacity building and other support services for the establishment and development of FPOs across the country (https://www.manage.gov.in/fpoacademy/fpoacademy.asp). Therefore, the extension functionaries may utilize the services of the FPO academy for the formation and promotion of FPOs.

Capacitating the rural youth for Climate smart farming

The migration of rural youth (men and women) has become a common phenomenon owing to the rising unemployment, especially in rainfed conditions. Hence, it is the right time to train and involve them in climate resilient agriculture such as skilling them on nursery management, promotion of agroforestry, farm pond construction, watershed management, promoting and multiplication of seeds, production of bio inputs (e.g. Vermicomposting, biocontrol agents andbio-pesticides), etc., The youth may also be professionally trained on the dissemination of weather forewarning during extreme events such as cyclone, flood etc, rescuing the trapped people, stranded animals, providing first aids, etc.

The Department of Agriculture, ATMA, KrishiVigyanKendras (KVKs), private institutes, NGOs and other development departments may use the trained youth in climate resilient extension activities. MANAGE is also implementing a flagship scheme of the Government of India such as Skill Development of Rural Youth (STRY) across the country with the help of various Vocational Training Institutions such as KrishiVigyanKendras / Nehru YuvaKendras etc. It aims to impart skill training to rural youth for free of cost (including food and accommodation) on agri-based vocational areas in agriculture & allied areas to promote employment of rural areas and for creating skilled manpower to perform farm and non-farm operations. Hence, the extension institutes including training institutes may utilize this opportunity to train the rural youth on various climate resilient extension activities. Further details of the scheme can be accessed fromhttps://www.manage.gov.in/stry&fcac/stryfcac.asp.

Accelerating agri start-ups to revolutionize agricultural extension

Both central and state governments are creating favourable ecosystems and policy environment for agri startups. Thereby, several start-ups are growing in the agricultural sector.Agri technology start-ups are effective in addressing the existing gaps in extension, technology, marketing, and other services. In India, agri start-ups are focusing on supply chain, infrastructure development, finance and related solutions, farm data analytics and information platforms. A total of 366 agri-based start-ups have come up from 2013 to 2017 (PWC and FICCI, 2018). The strength of the growing agri startups needs to be harnessed for promoting effective agricultural value chain management.

MANAGE is also one of the knowledge partners for implementing RashtriyaKrishiVikasYojana – Remunerative Approaches for Agriculture and Allied Sectors Rejuvenation (RKVY-RAFTAAR) to promote agripreneurship and agribusiness. Hence, under this, MANAGE is providing training and mentorship to ideate and establish enterprises related to agriculture with the grant in aid of Rs. 5 lakhs as seed money and Rs.25 lakhs for a minimum viable enterprise. Further details can be seen from http://cia.manage.gov.in/RKVYSAIP.aspx. So far, about 200 startups have been promoted by MANAGE under RKVY-RAFTAAR in various innovative areas of agriculture and allied sectors. Hence, the extension functionaries may encourage rural youth, progressive farmers etc., to come out with innovative ideas to address the existing gaps in the agricultural sector and utilize the RKVY-RAFTAR initiative of the Government of India for promoting start ups onClimate smart farming.

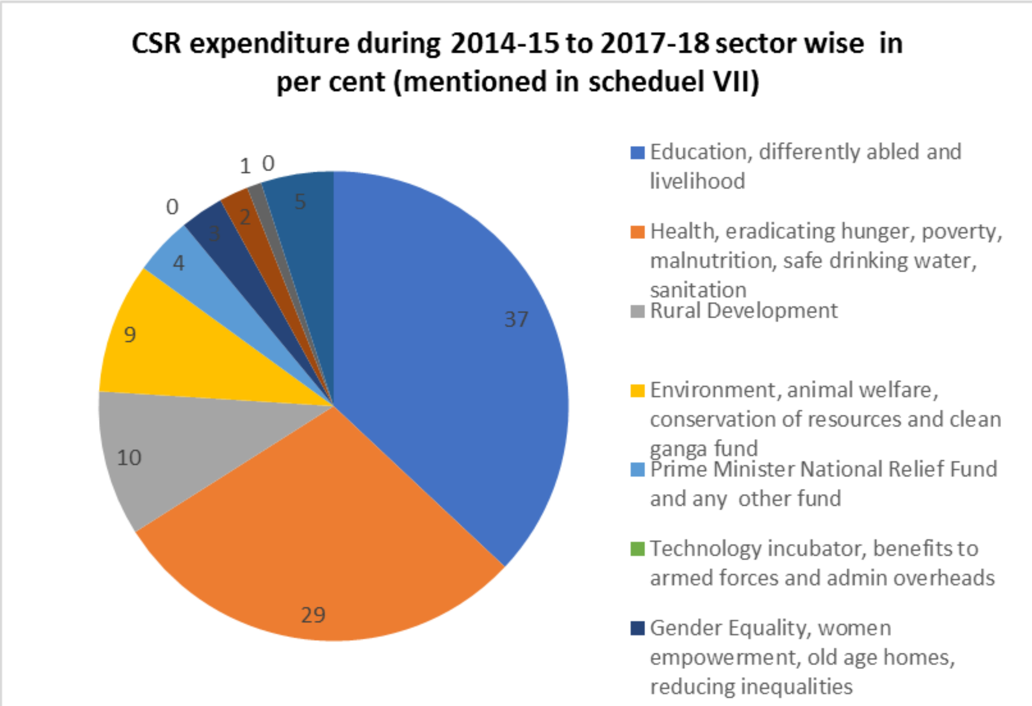
MANAGE is implementing a unique programme of GOI, the Agri-Clinic & Agri-Business Centre, to take better methods of farming to every farmer across the country. It aims to tap the expertise available in the large pool of agriculture graduates and offer professional extension services to innumerable farmers. The graduates in Agriculture and allied sectors such as Horticulture, Sericulture, Veterinary Sciences and other science graduates are trained for 45 days in entrepreneurship. The trained candidates are eligible to avail loans from the bank up to Rs 20 lakh for an individual project (Rs 25 lakhs for extremely successful individual projects) and up to Rs100 lakh for a group project. Around 74520 candidates have been trained as of 30.04.2021 since 2003. Out of them, 31350 candidates have established ventures related to dairy, apiary, mushroom production, tissue culture, biofertilizer production, organic farming etc. The established agripreneurs may be utilized for Climate smart farming to address the risks of climate change.

Model Village System of Extension (MVSE) approach

Model Village System of Extension (MVSE) is an integrated and holistic extension approach where community participation was prioritized for suitable technological interventions in the farmers' field to bring all round development in agriculture and allied sectors in the community in terms of socio-economic upliftment, technological empowerment, self-governance thereby enhancing the futuristic knowledge base and skills through participatory framework. MVSE emphasized oninvolvement of all stakeholders in the process to converge their activities with a stake in the food value chain linking producer to consumer. MVSE is an action research taken up in the farmers' field based on the principle of leveraging the activities, investments and resources from outside agencies/ externally aided projects resulting in higher productivity, ensuring food security and sustainable improvement in overall quality of life by promoting leadership, self-dependency of the community in food chain MVSE approach works on the following principles: Promotes self-governance among the farmers; Skill improvement and leadership development among the community members; Establishing linkage through pluralistic convergence of different stakeholders associated in the sector; Encouraging the market opportunities through commodity based village development (Mohanty et al, 2017). Representative villages may be taken up based on the vulnerability index. For each vulnerability, the available technology can be screened, demonstrated, and transform these selected villages as model villages to showcase the potential of the technologies to other fellow farmers. Due to shortage of manpower in the extension, the model villages help in persuasion and convincing a large number of farmers on climate resilient technologies.

Corporate Social Responsibility (CSR) Funds as innovative funding options for Climate smart farming

The Companies Act, 2013 has mandated the companies having a net worth of Rupees 500 crore or more, or turnover exceeding Rupees 1,000 crore or a net profit of Rupees 5 crore or more, to spend at least 2% of its average net profit made during the preceding three financial years. Accordingly, many corporates are involved in the development of the rural economy by improving the education of rural mass, providing better health services, generating livelihood opportunities etc. through CSR funds. The corporates are also spending their CSR funds in the development of watersheds, agricultural technology, extension delivery and establishing better institutional mechanisms to support farmers (Balasubramani and Vincent, 2019). Though more than 60% of the CSR fund was spent on education and health sectors (GoI, 2019), there is an ample opportunity to bring CSR funds for agricultural development, especially for Climate smart farming with an enabling policy environment and specific regulations. Hence, the research and extension institutes may encourage corporates to spend a significant portion of CSR funds for Research, extension, entrepreneurship, value addition, marketing, innovations, Climate resilient technologies, services etc., in the entire value chain ofagriculture.



Source: *GoI, 2019*

Agrometeorological innovations for weather specific crop plans

Several agrometeorological-based tools help in decision making process and can address several issues related to climate change by providing appropriate weather data and contingency crop plans for farmers. A range of weather/climate information for farmers (real time weather data, weather short-mediumlong range forecast), online climate normal, and climate forecast that provide basis for tactical and strategic adaptation.If these weather data tailored to farmers' needs and expectations, including indicating their use/consequences, they may be extremely valuable in the adaptation process (Sala et al, 2016). For example, Agromet Field Units (AMFUs) are institutions under the IMD's AgrimetDivision, which are designed to specialize in converting weather information into usable advisories for farmers. The AMFU receives district-specific forecasts from the IMD twice a week, each with a five-day lead time, as well as a weekly cumulative rainfall forecast. This results in the preparation of district-wide agro-advisories, which contain (in theory) location and crop-specific farm-level advisories, including descriptions of prevailing weather, soil and crop conditions, and suggestions for taking appropriate measures to minimize losses and optimize inputs in the form of irrigation, fertilizer or pesticides. Under the GrameenKrishiMausamSevaprogramme, AMFU was established in 700 districts in the country. Also, District-Level Agromet Unit (DAMU) is established at KVKs as each district in India has at least one KVK. As part of the GraminKrishiMausamSeva (GKMS) programme, the IMD's AMFU/ DAMU network sends farmers weather forecasts as well as crop- and locationspecific agro advisories via SMSs. IMD also disseminates agromet informationto farmers through public-private partnerships with multiple companies such as Reuters Market Light, IFFCO Kisan Sanchar Limited, NOKIA etc.IMD is also sending weather advisory to farmers through mKisan portal. Moreover, several private sectors are providing agro metrology services

Institutional innovations

Institutional innovations in extension play a major role. Many times farmers are not willing to go for a new cropping system due to a lack of institutional support. However, the innovations in institution such as seed bank, fodder bank, farm machinery bank/Custom Hiring Centre in a cluster of villages or at village level may help in timely agricultural operations, greater field coverage within a short period, cost-effectiveness, efficiency in use of resources and applied inputs, conservation of available soil and water etc. For example, Under National Innovation on Climate Resilient Agriculture (NICRA), during the seed banks

Fodder Banks

During the lean season especially for the rainfed farmers the fodder bank may be introduced in the community lands and can be managed community, and supply the required quantity of fodder to the members of the community

Seed Banks

The seed banks may be promoted, especially in the vulnerable areas by preserving and multiplying different suitable landraces, in case of repeated sowing due to unforeseen season,the members can utilize the suitable landraces and indigenous varieties available in the seed banks at fordable prices.

Similarly, the Custom hiring centres (CHCs) may be promoted as an institutional mechanism to take up timely agricultural operations at a very reasonable cost and address the labour shortage.

Digital innovations in Extension

Access to timely and relevant information is critical in the climate change scenario. The emerging ICT based technologies are playing a key role in dissemination of agricultural technologies, weather information and advisory services. MANAGE has also developed an ICT platform in collaboration with GiZnamely the Network for information on Climate (EX) change (NICE). It is a web-based open source platform, that allows multimodal approach and enables two-way communication to link farmers' needs to knowledge experts on a real time basis. The farmers receive advisories through SMS; field agents also use tablets to disseminate advisories to farmers. Using NICE system, the expert can send advisory to the farmers in a multi-model approach i.e. in the form of SMS, Posters, Video URL, documents etc. The content other than SMS will be delivered to the Tablet of Field Agents. This content is further disseminated to the farmers by the Field Agents in the village. The farmer gets timely, authentic advisory and the content is generated based on their local needs i.e. fully localized content is generated by the experts. Scientists at State Agricultural Universities, KVK and field functionaries are involved in content generation, validation and dissemination process. The feedback from field level functionaries is assessed and based on the need and requirement, the content is generated by the KVK subject matter experts. Both public and private sectors are delivering information through ICTs. There are several ICT tools were developed by both public and private sectors namely m-Krishi, Kisan Portal, Agritech portal of Tamil Nadu Agricultural University, crop expert applications, eNAM, eChoupal, etc. Further, there is scope for developing more ICT based tools and applications. The public/ extension providers or any startups may make a small intervention by developing an ICT platform/app similar to Amazon, Flipkart, Olx etc., this platform can help farmers to source Climate Resilient Inputs and innovative production technologies/practices and market their products.The extension system can also make use of the existing print, electronic and other social media to provide advisory services. The budget earmarked under Farm Information dissemination of ATMA may also be utilized to disseminate the CSA technologies through reliable ICTs.

Conclusion

As agriculture is extremely affected by changing climate in terms of productivity, production and income, the existing extension strategies need to be innovated to enable the farmers to cope with challenges related to crop production, protection, marketing etc. The innovative extension strategies such as participatory development and adoption of climate smart technologies and practices, Institution and process innovation (e.g. ATMA), Farm School, Farmer Friend, Public Private Partnership, Market led extension approach, Community-Based Organizations, rural youth for Climate smart farming, agri start-ups, model village system of extension, corporate social responsibility, agrometeorological innovations, Institutional innovations, digital innovations in Extension etc. may help farmers to address the risks of extreme events and adapt to climate change.

References

Celebic, G., &Rendulic, D. I. (2011).ITdesk.info–project of computer e-education with open access. *Open Society for Idea Exchange*.

Gopalakrishnan.T. & Subramanian.K. (2020). Agrometeorological Advisory Services in India An Assessment. Centre for Science and Environment. New Delhi.

MSU and MANAGE. (2021). Innovations in Agricultural Extension. https://www.canr.msu.edu/extensioninternational/files/00-Innovations_Complete_2021-01-12aa.pdf

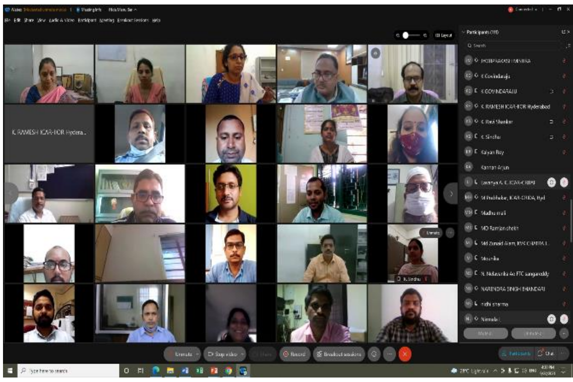
Gatzweiler, F. W., & Von Braun, J. (2016). *Technological and institutional innovations for marginalized smallholders in agricultural development* (p. 435).Springer Nature.

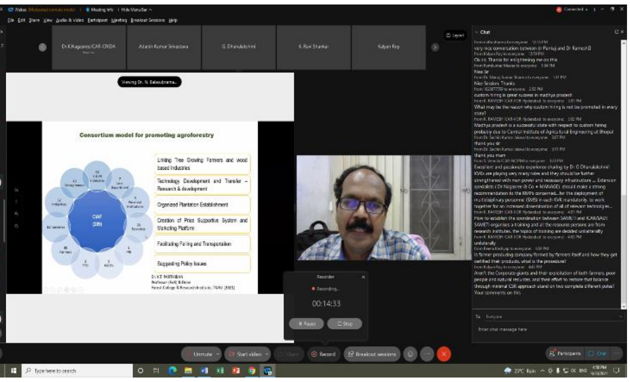
Mohanty, A. K., Rejula, K., Sajesh, V. K., &Sajeev, M. V. (2017). Innovative extension approaches for technology dissemination in fisheries. ICAR-Central Institute of Fisheries Technology.

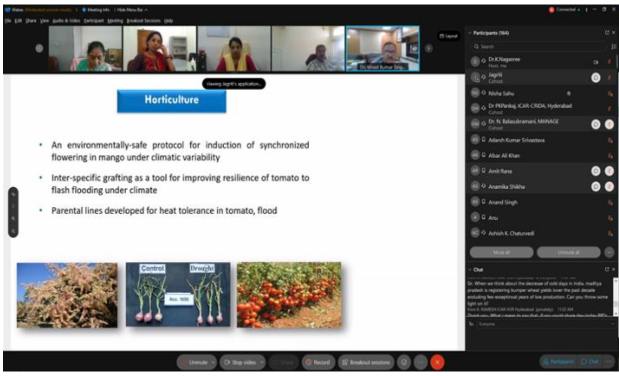
Sala, S., Rossi, F., & David, S. (2016). Supporting agricultural extension towards climate-smart agriculture: an overview of existing tools. *Supporting agricultural extension towards climate-smart agriculture: an overview of existing tools.*

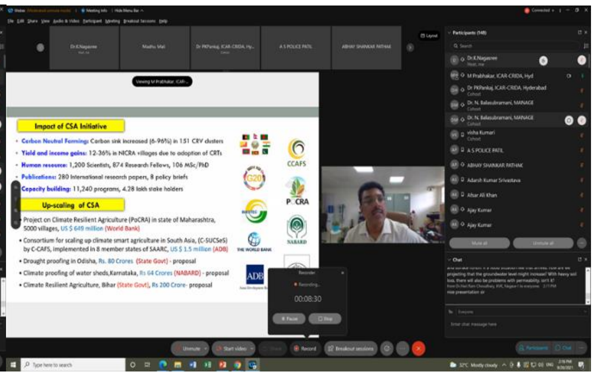
Thamban, C., Jaganathan, D., Kalavathi, S., Anithakumari, P., Chandran, K. P., &Jayasekhar, S. (2016). Innovative Extension Approaches for Plantation Crops.

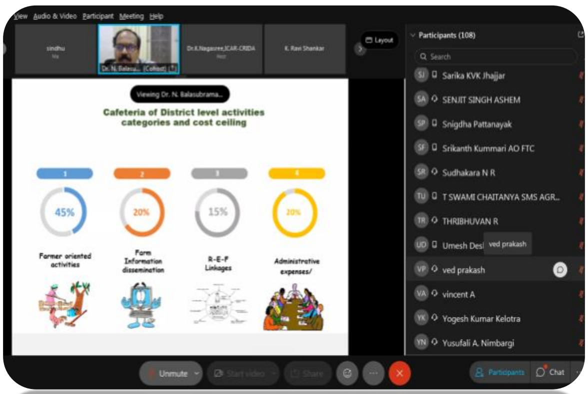
Glimpses of online training programme

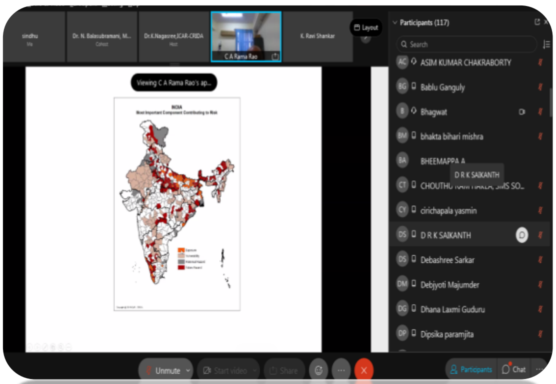












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