Climate Resilient Rainfed Agriculture: Experiences from India

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Abstract Rainfed agriculture is practiced in 52% of net cultivated area in India and contributes to about 40% of country's food production, thus important for country's food security and economy. Climate change impacts are evident in rainfed agriculture in India. Efforts have been made through national initiatives towards climate resilient rainfed agriculture and to enhance the adaptive capacity of farmers. On-farm participatory demonstration of climate resilient practices cluster village mode helped to cope with delayed onset of monsoon and in-season drought. Establishing village level institutions such as village climate risk management committees, custom hiring centres for farm mechanization, nutrient banks, seed and fodder production systems and mechanism for agro-advisories proved to be building climate resilient villages. It is also important to build resilience at agricultural landscape level (watershed) for sustainable and risk resilient rainfed agriculture. Capacity building of farmers enhanced their adaptive capacity. Preparation and implementation of Agriculture Contingency Plans enhanced the preparedness for weather aberrations and policy

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support. Several resilient technologies have been integrated into national, state and district programmes for achieving climate resilient rainfed agriculture. The proven climate resilient technologies in India could be upscaled in similar rainfed agroecologies in other countries. Climate resilience in rainfed agriculture can be better addressed through risk and vulnerability assessment at sub-district level; scaling out resilient technologies through government programmes, better preparedness for weather aberration and capacity building of stakeholders. The knowledge built and experiences gained in India trigger to propose a global programme for research and development in climate resilient rainfed agriculture and inter-governmental and multi-institutional arrangements for upscaling of proven climate resilient practices in the similar rainfed agro-ecoclogy domains in various countries. Further, development of regional centres of excellence in climate resilient rainfed agriculture for research and development and capacity building and human resources development is also suggested.

Keywords Climate Resilient Agriculture · Rainfed agriculture · Drylands · Contingency planning · India

Introduction

Rainfed-drylands are an important biome, occupying more than 41% of the global land area and comprising grasslands, agricultural lands, forests and urban areas. Drylands provide much of the World's food and fiber while maintaining habitats that supports biodiversity and provide ecosystem services (UNCCD 2017). Climate change, which is expected to manifest as increased frequency and intensity of extreme climate events including droughts (IPCC 2015), is particularly of concern in drylands where species and communities already have to cope with dramatic variations in temperature and droughts (UNCCD 2017). Climate change is a significant driver of land degradation in drylands. In some dryland areas, increased land surface air temperature, evapotranspiration and decreased precipitation amount, in interaction with climate variability and human activities, have contributed to desertification. These areas include Sub-Saharan Africa, parts of East and Central Asia, and Australia. About 25–30% of drylands already suffer some form of land degradation (Bai et al. 2008; Quang et al. 2014). In drylands, the most widespread form of land degradation is soil erosion with 87% of degradation being caused by water or wind (FAO 2005). Land degradation in drylands can also manifest itself through the loss of soil organic carbon (IUCN 2015). The depletion of water, either as soil moisture, groundwater, flowing rivers or reservoirs, disrupts water cycles and leads to water scarcity (Koohafkan and Stewart 2008; UNCCD 2017). Water scarcity affects among other things the length of growing season.

The climate change impacts are evident on agricultural production and productivity in general and rainfed agriculture in particular, in many countries. There have been many research, development and policy initiatives in many countries to address the impacts of climate in rainfed agriculture. However, the policies, approaches, programmes and activities vary to develop and implement strategies for achieving climate resilient rainfed agriculture across the countries. In the process, there could be huge knowledge, experiences, expertise and even shortfalls in addressing climate resilience in rainfed agriculture. Understanding all these and learning from each other's knowledge and experiences is necessary to concretize policies, programmes , long term and short term strategies and actions to achieve climate resilient rainfed agriculture. The aim of this chapter is to (i) share the experiences from India in addressing climate resilient rainfed agriculture through village/landscape level approaches/interventions, and (ii) sensitize the stakeholders about various initiatives, programmes, actions and strategies in India.

The human population in India accounts for 17.74% of World population, 4.2% of World's water and 2.4% of the World's total area. Agriculture in India contributes to 15.4% of GDP (Gross Domestic Product) and 10.6% earning of total exports. 52% of workforce is engaged in agriculture. 52% net sown area in India is rainfed. Rainfed agriculture is crucial to country's economy and food security since it contributes to about 40% of the total food grain production (85% of coarse cereals, 83% of pulses and 70.5% of oilseeds), supports two-thirds of livestock and 40% of human population. Furthermore, rainfed agriculture influences livelihoods of 80% of small and marginal farmers. Even if full irrigation potential is created, still 40% of net cultivated area will remain as rainfed agriculture which would continue to be a major food grain production domain (CRIDA Vision 2050; Ravindra Chary et al. 2015). In India, the estimated countrywide agricultural production loss in 2030 will be over $7 billion that will severely affect the income of 10% of the population. However, this could be reduced by 80%, if cost-effective climate resilience measures are implemented (ECA 2009).

The key challenges for Climate Resilient Rainfed Agriculture in India are briefly presented below:

- ***Climate change/variability impacts***: The rainfed agriculture is totally dependent on south-west monsoon and thus, is synonymous with risk due to erratic monsoon (Ravindra Chary et al. 2010). A decrease of one standard deviation from the mean annual rainfall often leads to a complete loss of the crop. Dry spells of 2 to 4 weeks during critical crop growing stages cause partial or complete crop failure (Rockstorm and Falkenmark 2000). Climate change and climate variability impacts Indian agriculture in general and more pronounced on rainfed agriculture. A district level climatic analysis in the country revealed spatial shifts of climate zones in about 27% of the geographical area in the country i.e. a substantial increase of arid region in Gujarat, a decrease of arid region in Haryana, and increase in semi-arid region in Madhya Pradesh, Tamil Nadu and Uttar Pradesh due to shift of climate from dry sub-humid to semi-arid. Likewise, the moist sub-humid pockets in Chhattisgarh, Orissa, Jharkhand, Madhya Pradesh and Maharashtra states shifted to dry sub-humid to a larger extent (Raju et al. 2013). These climate shifts in rainfed areas will have larger implications for crop planning, water resources assessment and prioritizing drought proofing programmes

. The Coupled Model Inter-comparison Project Phase 5 (CMIP5) based model ensemble, based on new-emission scenarios termed as Representative Concentration Pathways (RCPs), projects a warming of 1.5, 2.4, 2.8 and 4.3 °C for India under the RCP2.6, RCP4.5, RCP6.0 and RCP8.5 scenarios, respectively, for 2080s (2071–2100) compared to the baseline period of 1961–1990 (Chaturvedi et al. 2012). The CMIP5 based ensemble projects an all-India precipitation increase of 6, 10, 9, and 14% increase under the RCP2.6, RCP4.5, RCP6.0 and RCP8.5 scenarios, respectively, for 2080s compared to the 1961–1990 baseline. A consistent increase in seasonal mean rainfall during the summer monsoon periods has been projected. Instrumental records suggest, a significant negative rainfall trends in the eastern parts of Madhya Pradesh, Chhattisgarh and parts of Bihar, Uttar Pradesh, parts of northwest and Northeast India and a small pocket in Tamil Nadu. Significant increase in rainfall is also evident in Jammu & Kashmir and in some parts of southern peninsula (Venkateswarlu et al. 2012). Rainfall is likely to decline by 5 to 10% over southern parts of India, whereas 10 to 20% increase is likely over other regions. There is a probable decrease in the number of rainydays over major parts of the country pointing at likely increase of extreme events. The recent ensemble models project that the frequency of extreme precipitation days (e.g. >40 mm/day) are likely to increase. Rainfed crops are likely to be worst hit by climate change because of the limited options for coping with variability of rainfall and temperature. Climatic risks like droughts and floods, poor water and nutrient retention capacity of soil and low soil organic matter (SOM) impact rainfed agriculture highly vulnerable, requiring a different outlook and strategy.

- ***Resource poor operational land resource base***: Out of 138.3 Million total operational land holdings in the country, 58.14 Million operational land holdings are totally unirrigated, out of which 85% account to marginal and small operational holdings (37.06 m marginal and 11.69 m small) while the total operational holdings under partly irrigated operational holdings are 17.21 m out of which 80% marginal (9.6 m) and small (3.49 m) operational holdings (DES 2011). The challenge is to sustain these unirrigated and partly irrigated operational holdings in respect of stabilized productivity and profitability along with enhanced livelihoods at the backdrop of the impacting climate change/variability.
- ***Bridging yield gaps***: The large yield gaps remain in several rained crops and regions between yields obtained at research stations and on farmers' fields (Ravindra Chary et al. 2012). In several disadvantaged areas, particularly in chronic drought prone areas, the yield gaps will continue to remain large even in 2050, both due to non-adoption of technologies and non-availability of tailor-made agro-ecology specific package of practices.
- ***Enhancing water productivity***: The basic resource which determines the success of rainfed agriculture is water availability. As the demand for water from non-farm sectors increases and availability to agriculture declines, the conflicts between upstream and downstream users may increase over time. Fallout of such process is the possible conversion of existing productive irrigated lands to rainfed lands

(Sikka et al. 2016). A 4 °C rise in temperature and a 10% decrease in rainfall is expected to reduce the stream-flow by 33% in mean annual, 15% in pre-monsoon, 35% in monsoon, 32% in post-monsoon and 21% in winter seasons. The National Water Mission, institutionalized under the National Action Plan for Climate Change, has set the target to improve the efficiency of water use by at least 20%. In a given land use setting, climatic variables especially temperature and rainfall regulate the irrigation water demand. At present in India, blue and green water availability is above the 1300 m^3/capita/year threshold. However, with climate change, blue-green water availability is estimated to decrease to less than 1300 m^3/capita/year, implying that by 2050, all of India could be exposed to water stress.

- ***Maintaining soil health and productivity***: The soils in rainfed areas belong to Entisols, Inceptisols, Vertisols, Alfisols, Aridisols and Oxisols and are characterized with multiple constraints that limit crop production and realizing optimum yields. Presently, on an average, the soil organic carbon is 5 g/kg in soils in rainfed areas whereas the desired level is 11 g/kg. Change in rainfall intensity could cause more soil erosion. Harnessing the synergy between soil moisture and applied nutrients in rainfed crops is a major challenge due to erratic distribution of rainfall.
- ***Low and skewed farm mechanization***: Farm mechanization in rainfed areas is very low due to small and marginal holdings, resource poor farmers etc. In view of the short window for sowing of rainfed crops and also for moisture availability period, farm mechanization in small farm holdings is very crucial in timely and precision agricultural operations and in large areas.

Materials and Methods

Climate risks are best addressed through adaptation which can bring immediate benefits and also can reduce the adverse impacts of climate change. Climate Resilient Agriculture (CRA) encompasses adaptation and mitigation strategies to meet the many challenges posed by climate change (Ravindra Chary et al. 2013). CRA means the incorporation of adaptation, mitigation and other practices in agriculture which increases the capacity of the system to respond to various climate related disturbances by resisting damage and ensures quick recovery. Such perturbations and disturbances can include events such as drought, flood, heat/cold wave erratic rainfall pattern, pest outbreaks and other perceived threats caused by changing climate. It is the ability of the system to bounce back and essentially involves judicious and improved management of natural resources, land, water, soil and genetic resources through adoption of best bet practices (NAAS 2013). The major initiatives launched in the domain of climate change research and climate resilient agriculture are briefly presented below:

i. ***Network Project on Climate Change (NPCC)***: The Indian Council of Agriculture Research (ICAR), Ministry of Agriculture & Farmers Welfare, Government of India launched Network Project on Climate Change (NPCC) in 2004 with the objectives of quantifying the sensitivities of food production systems to different scenarios of climate change, adaptation and mitigation strategies in agro-ecosystems and to provide policy support. The important outputs related to rainfed agriculture from NPCC indicated increased emphasis on soil conservation in peninsular and central India because of projected high run-off and soil losses due to changes in rainfall, and emphasis on agro-forestry systems in sub-tropical climates for maximum carbon sequestration potential (Naresh Kumar et al. 2012).

ii. ***National Mission for Sustainable Agriculture (NMSA)***: The National Action Plan on Climate Change (NAPCC) was formulated in 2010 consisting of 8 National Missions to represent multi-pronged, long term and integrated strategies for addressing climate change impacts. The National Mission for Sustainable Agriculture (NMSA), one of the eight missions of NAPCC, aimed at devising strategies to make Indian agriculture more resilient to climate change and to promote sustainable agriculture through a series of adaptation measures focusing on ten key dimensions encompassing Indian agriculture viz. improved crop seeds, livestock and fish cultures, water use efficiency, pest management, improved farm practices, nutrient management, agricultural insurance, credit support, markets, access to information and livelihood diversification. Subsequently, these measures had been embedded and mainstreamed into various Missions/Progammes/Schemes of Ministry of Agriculture & Farmers Welfare, Government of India with a special emphasis on soil & water conservation, water use efficiency, soil health management and rainfed area development.

iii. ***National Initiative on Climate Resilient Agriculture (NICRA)***: ICAR launched the flagship project on National Initiative on Climate Resilient Agriculture (NICRA) in 2011 (now called National Innovations in Climate Resilient Agriculture) with the objectives to undertake strategic research on adaptation and mitigation; to validate and demonstrate climate resilient technologies on farmers' fields; to strengthen the capacity of the stakeholders in climate resilient agriculture and to draw policy guidelines. The major components under NICRA are: (a) strategic research (b) Technology demonstration component, and (c) capacity building of stakeholders.

Results and Discussion

The experiences from various initiatives in India, particularly NICRA that could contribute to achieve climate resilient rainfed agriculture are briefly presented:

Strategic research: The state of art climate research facilities under NICRA were developed at ICAR institutes (Venkateswarlu et al. 2013; Climate Change Research Infrastructure 2019). District level vulnerability atlas was developed (Rama Rao et al. 2013) which guided NICRA-TDC programmes and many other climate research/policy programmes by national institutes, ministries/departments, state governments and non-government organizations. This atlas has been revised in 2020 by adopting IPCC AR 5 Report as Risk assessment of Indian agriculture to climate change (Rama Rao et al. 2019). Short duration drought tolerant varieties of rice and pulses were developed suitable for diverse rainfed agroecologies (Ravindra Chary et al. 2019a).

Technology demonstration: The TDC programme under NICRA is being implemented initially in 100 climatically vulnerable districts (Venkateswarlu et al. 2012). The programme is now being expanded to 151 village clusters (446 villages) representing 151 climatically vulnerable districts through Krishi Vigyan Kendras (KVKs) i.e. Farm Science Centres (FSCs), network centres of All India Coordinated Research Project for Dryland Agriculture (AICRPDA) and ICAR Institutes. A bottom-up participatory methodology was adopted for selection of villages' and implementing TDC programme in NICRA villages. ICAR/Central Research Institute for Dryland Agriculture (CRIDA) as lead institute had been planning, coordinating and monitoring TDC progaramme involving ICAR-Agriculture Technology Application Research Institutes (ATARIs) at Zonal level monitoring and KVKs/FSCs for implementing the programme in the villages. The programme in the villages is being implemented by establishing Village Level Institutions (VLIs) such as Village Climate Risk Management Committee, Custom Hiring Centre (CHC), seed production systems, fodder systems, nutrient banks and mechanisms for agromet-advisories.

The VCRMC is a unique institution formed with the approval of the village decision making body and played a greater role in identifying and implementation of need based climate risk resilient interventions. CHC enabled hiring of energy efficient, even gender friendly farm implements/machinery at affordable cost for timely and precision execution of agricultural operations in larger areas particularly in small farm holdings especially for sowing and intercultural operations as soil moisture status provides a limited sowing window in rainfed agro-ecosystems. The seed production systems by individual or community in the village served as an emergency seed supply system when farmers experienced shortage of seeds, where there is a need for re-sowing of crop. Further, this system provided timely availability of seeds of short duration drought tolerant varieties of rainfed crops in time and for faster seed replacement. The fodder production systems provided high biomass in short time and bridge the fodder scarcity during the annual dry seasons and also during the long dry spells and helped in the preservation and storage of surplus fodder, availability of nutritious fodder during the period of fodder scarcity and enhance nutritive value of crop residue and other cellulosic waste for animal feeding. Planting of high biomass yielding and fast-growing grasses and shrubs suitable for fodder not only increases fodder availability, but also reduces erosion. The concept of 'Nutrient Bank' is being evolved wherein the essential manures and fertilizers, soil amendments, foliar spray chemicals and biofertilizers are maintained locally and made available in time by the local community. The nutrient banks help farmers in restoring the productive capacity of soils and local environments. Other activities in the villages include issue of soil health cards to farmers for site-specific nutrient management, agromet advisories through centres of All India Coordinated Research Project on Agrometeorology (AICRPAM) and KVKs/FSCs.

The major interventions demonstrated to address the drought/dry spells were under four modules:

(i) *Natural Resources Interventions*—focused on *in-situ* moisture conservation (broad-bed and furrow, ridge and furrow, field bunds, contour bunding, compartmental bunding, conservation furrow/tillage, deep ploughing, trench cum bunding, mulching, tank silt application); *ex-situ* rainwater management (farm ponds, check dams, recharge of tube/open wells, community ponds/tanks, nala desilting), and efficient utilization of water through microirrigation systems; soil fertility improvement, improving soil carbon, site-specific nutrient management (soil health cards, soil reclamation, green manuring);

(ii) *Crop-based Interventions*—focused on introduction and demonstration of drought tolerant varieties, inter-cropping systems and crop diversification;

(iii) *Livestock-based Interventions*- focused on improved breeds, green fodder production, preventive vaccination, mineral mixture/concentrate feed, breed upgrading, backyard poultry, shelter management and silage/hay making; and

(iv) *Institutional Interventions*—focused on establishing village level institutions such as VCRMC, CHC.

Agroecology-specific rainwater management technologies are being developed and have larger scope in drought mitigation (Rejani et al. 2015; Ravindra Chary et al. 2016). Water harvesting facilities created in NICRA villages helped to enhance cropping intensity up to 140% in several villages. Timely agromet/agro-advisories were disseminated through messages, social media, WhatsApp web and electronic media. Seed banks established in NICRA villages produced huge quantity of seed of the resilient crops which helped in the spread of the promising varieties in the NICRA village clusters. Custom hiring centers supported farmers for timely field operations even during the lockdown. Several extension activities were taken up in NICRA villages, such as awareness programmes, field days, exposure visits and farmers days. Convergence with the ongoing national/state/district development programs are facilitated in upscaling of climate resilient practices. All these interventions, particularly, the NRM and crop based interventions, led to realizing better yields of rainfed crops and drought proofing even during deficit rainfall/drought years in various rainfall zones including the zones having less than 500 mm rainfall (Prasad et al. 2014; Ravindra Chary et al. 2019b).

Preparation and operationalization of District Agriculture Contingency Plans (DACPs): The DACPs were prepared for 650 districts in the country. Each DACP provides information on contingency measures to cope with delayed onset of monsoon, drought, flood, high intensity rainfall events, frost, heatwave, cold wave and cyclones in field crops, horticulture crops, and the coping measures were suggested to address before, during and after occurrence of extreme weather events in livestock, fisheries and poultry sectors. The farming situation-wise contingency measures to cope with delayed onset of monsoon (2,4,6, and 8 weeks delay) and early, mid-season and terminal drought for all the 650 rural districts in the country (Venkateswarlu et al.

2011; Umate et al. 2011; Rajendra Prasad et al. 2013; Prasad et al. 2012; Subba Reddy et al. 2008; Ravindra Chary et al. 2016). The DACPs are available on www.icar-crida.res.in; www.agricoop.in.

The challenge was operationalization of DACPs in various states/districts through agriculture departments. The Ministry of Agriculture & Farmers Welfare, Govt. of India and ICAR-CRIDA takes the lead through regular pre-monsoon and sometimes during monsoon (depending on the monsoon situation in the states/districts) state level interface meetings forsensitizing the state/district agriculture and allied sector departments (water resources, irrigation, watershed, animal husbandry, horticulture) for developing action plans for preparedness and real-time response to cope with delayed onset of monsoon and deficit/excess rainfall situations. The experience so far has been that the officials of state and district agriculture and allied departments were thoroughly sensitized for not only developing action plans but also were implemented particularly for arranging quality seed of drought tolerant varieties of rainfed crops, dissemination of agromet/agro-advisories, capacity building of department functionaries and farmers.

Real Time Contingency Planning (RTCP) implementation to cope with the drought/dry spells: Real Time Contingency Planning (RTCP) is conceptualized in All India Coordinated Research Project for Dryland Agriculture (AICRPDA) as "any contingency measure, either technology related (land, soil, water, crop) or institutional and policy based, which is implemented based on real time weather pattern (including extreme events) in any crop growing season" (Srinivas Rao et al. 2016) and implemented under NICRA in 54 villages in 14 states in diverse rainfed agroecologies (climates, rainfall zones, soil types and rainfed production systems) as two-pronged approach, i.e. (i) preparedness, and (ii) implementing contingency measures on real-time basis. The RTCP aims first to establish a crop with optimum plant population during the delayed onset of monsoon, to ensure better performance of crops during seasonal drought and extreme events, enhance performance, improve productivity and income, and to enhance the adaptive capacity of the small and marginal farmers. The preparedness emphasizes on a combination of tolerant variety/cropping system, rainwater/soil/crop/nutrient management practices along with timely availability of inputs while real-time basis implementation focus on the crop/soil/moisture/nutrient management measures to cope with delayed onset of monsoon, seasonal drought, floods and other extreme events (AICRPDA-NICRA Annual Reports 2012–13; 2013–14; 2014–15; 2015–16; 2016–17; 2017–18; 2019–20).

In the selected villages, the bottom-up process included baseline survey and PRA (Participatory Rural Appraisal) to document the initial details about the impacts of weather aberrations on agriculture and to understand the farmers' awareness about climate change/variability and also their traditional wisdom to cope with weather aberrations (AICRPDA-NICRA Annual Report 2012–13). To implement RTCPs, like in NICRA-TDC-KVKs villages, VCRMCs, CHCs, seed production systems, fodder production systems, nutrient banks (vermicomposting units) were established in the AICRPDA-NICRA adopted villages. These village institutions

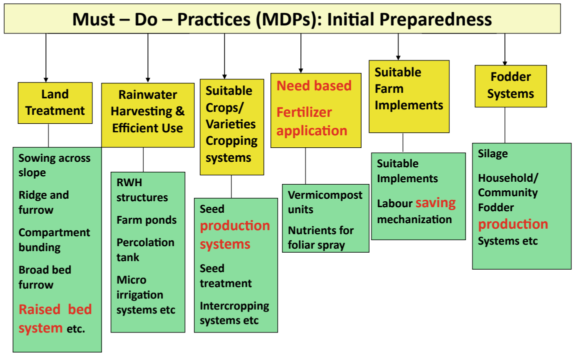

Fig. 1 The must-to-do practices for initial preparedness for RTCP implementation

played greater and decisive role in the initial preparedness and for real time implementation of contingency measures to cope with delayed onset of monsoon and early/midseason/terminal droughts during the cropping season. The must-to-do practices for initial preparedness or RTCP implementation (Srinivas Rao et al. 2016) are shown below (Fig. 1):

The key real-time interventions that helped to cope with delayed onset of monsoon were: introduction (Ravindra Chary et al. 2016) and identification of most suitable crops and short duration drought tolerant varieties and demonstration of cropping systems (Ravindra Chary et al. 2020), re-sowing within a week to 10 days with subsequent rains when germination is less than 30%, thinning; to cope with early season drought were—repeated interculture to break soil crust and remove weeds, avoiding top dressing of fertilizers till favourable soil moisture, *in-situ* moisture conservation through opening conservation furrows; to cope with mid-season drought were—avoiding top dressing of fertilizers till favourable soil moisture, *in-situ* moisture conservation through opening conservation furrows, surface mulching with crop residues, foliar spray of 1% KNO_3 or 0.5% water soluble fertilizers, and providing protective irrigation, if available; and to cope with terminal drought were harvesting crop at physiological maturity with some realizable yield or harvest for fodder, providing protective irrigation, if available or prepare for *rabi* sowing in double cropped areas.

Introduction of drought tolerant varieties gave about 15–35% higher yields compared to local/farmers' varieties (Ravindra Chary et al. 2020). The interventions to mitigate early season drought helped in adaptation of crops and realizing improved yields by 16–30% compared to no contingency measures. RTCP measures of foliar sprays of water soluble NPK (19:19:19) and KNO_3 in mitigating mid-season dry spells gave 15–25% higher yield in different crops compared to no spray. The effect of mid-season and terminal drought on different crops was mitigated mostly by supplementing irrigation from harvested rainwater in farm ponds, and foliar sprays. Supplementary irrigation improved yields by 20–25% in cotton, 40% in groundnut and 40–55% in soybean at different locations. Similarly, foliar spray of 1% KCl in rice during dry spell at flowering-milking stage increased yield by 25% compared to no spray (AICRPDA-NICRA Annual Reports 2013 to 2020). The experiences of RTCP measures implementation were included in the policy documents such as Revised Manual for Drought Management, Ministry of Agriculture & Farmers Welfare, Governmet of India (GoI), National Agriculture Disaster Management Plan, Ministry of Home Affairs, GoI, Revised Common Technical Guidelines for New Generation Watershed Management developed by National Rainfed Area Authority (NRAA) and Department of Land Resources, Ministry of Rural Development & Panchayati Raj, GoI.

Building resilience at Landscape level: On-farm participatory action research was undertaken to build resilience at landscape level in Kavalagi micro-watershed, Karnataka in Southern India by AICPDA centre, Vijayapura. The watershed is predominantly area is rainfed and cultivated with post-monsoon *rabi* crops viz. chickpea and sorghum. The watershed was characterized for land and soil resources and was mapped at 1:4000 scale. The soil units were delineated in to Soil Conservation Units (SCUs) considering soil physical parameters such as slope, depth, texture and erosion and Soil Quality Units (SQUs) were delineated considering the parameters such as EC, OC, pH and calcareousness. These two layers of SCUs and SQUs together were further delineated into homogeneous Land Management Units (LMUs). The on-farm trials on chickpea (cv. JG-11) and sorghum (cv.BJV-44 and cv.M-35–1) were conducted on LMUs-I, III, V and VII for 3 years wherein the seasonal rainfall varied and was deficit up to 30% compared to normal seasonal rainfall. Though, the rainfall was the same for entire watershed in 3 seasons, the yield of crops varied due to spatial variability in characteristics of LMUs. The yield of both chickpea and sorghum was higher on LMU-I > LMU-III > LMU-V > LMU-VII due to limitations in soil physical and chemical characteristics with LMU-I having more favourable land characteristics for crop growth (AICRPDA-NICRA Annual Reports 2017–18; 2018–19; 2019–20). The results revealed that the performance of crops vary due to spatial variability in land and soil characteristics in a landscape though the rainfall is uniform. Therefore, it is emphasized that building resilience of agriculture to be achieved at landscape level with suitable cropping in a favourable land and soil environment.

The experiences of RTCP implementation indicated many opportunities for developing adaptation strategies both as preparedness and real-time response such as: production of seed of alternate crops/varieties by State Seed Corporations, State Agricultural Universities (SAUs) and KVKs: have greater role to provide suitable drought tolerant and short duration seed material during the event of delayed onset of monsoon, establishment of community/village seed banks for production and distribution of quality seeds, promote use of appropriate sowing implements for timely and precision sowing, production of seed of alternate crops/varieties by state seed corporations, SAUs, KVKs, promote use of suitable farm implements for sowing/interculture, rainwater management interventions like water harvesting and storage structures are capital and labour intensive, thus, can be converged with national/state/district programmes, promote use of suitable farm implements for different operations. CHCs have a greater role to play in implementation of

RTCP measures including seed and fertilizer application, *in-situ* moisture conservation practices, water lifting with energy efficient pumps and efficient application, foliar sprays, residue incorporation, construction of farm ponds for efficient rainwater harvesting and reuse, efficient utilization of stored rainwater in farm ponds with micro-irrigation systems could be converged with national/state, timely procurement and supply of inputs like KNO_3, thiourea, KCl for foliar sprays, efficient recycling of crop residues for mulching between crop rows.

Capacity building: Capacity building is the key for adoption and upscaling of climate resilient practices in rainfed agriculture: Many capacity building programmes including customized training programmes, field days, exposure visits, diagnostic visits, scientist-farmers interaction meetings, exhibition stalls, were organized to sensitize both primary (farmers) and secondary stakeholders (engaged in rainfed agriculture development and policy) on various aspects of climate change/variability and impacts on agriculture and doable resilient practices leading to enhancement in adaptive capacity of the farmers and comprehensive understanding of the secondary stakeholders on the adaptation strategies for climate resilient agriculture.

The Central and state governments have been initiating many programmes /schemes that enable to achieve climate adaptation in rainfed agriculture such as Soil health cards, Pradhan Mantri Krishi Sinchai Yojana (PMKSY)—Micro Irrigation, National Mission on Sustainable Agriculture. Further, mainstreamed proven climate resilient practices in to various schemes/programmes such as Rashtriya Krishi Vikas Yojana, Mahatma Gandhi National Rural Employment Guarantee scheme, National Food Security Mission, Nanaji Deshmukh Project on Climate Resilient Agriculture (PoCRA), Govt. of Maharashtra, Programme on Climate Proofing of Watersheds, National Bank for Agriculture & Rural Development (NABARD) & ICAR- CRIDA (at action plan stage).

The overall experiences/knowledge gained in India through NICRA and AICRPDA on the approaches/frameworks/VLIs/interventions/impacts towards climate resilient rainfed agriculture have been continuously shared with and at international and national institutes, platforms and fora, such as CoP Meetings, United Nations Convention to Combat Desertification (UNCCD), World Resource Institute, G20 countries, Asian Development Bank, United Nations Environmental Programme (UNEP), The International Centre for Integrated Mountain Development (ICIMOD), International Water Management Institute (IWMI), Climate Change, Agriculture and Food security (CCAFS), Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC) countries, South Asian countries, African countries and has been well recognized and appreciated, even to the extent of adoption of the approaches/methodologies/practices by some countries.

Conclusions

In India, rainfed agriculture plays a greater role in country's food security and economy. However, the rainfed agriculture is risk prone and challenged with many factors besides climate change/variability impacts that are already evident. Therefore, concerted efforts were needed to achieve climate resilient rainfed agriculture. Many national initiatives such as NPCC, NMSA, and NICRA have been undertaken to develop action plans/adaptation strategies and contribute to achieve climate resilient rainfed agriculture in India. A strong research network has been laid in the country with NPCC programme for assessing the impacts of climate change on Indian agriculture. NAPCC through its eight National Missions gave the much needed impetus to policy advocacy on addressing climate change in various sectors in India. NICRA established a strong research and extension and upscaling network involving National Agriculture Research System, Ministries, Departments, farmers and other stakeholders for developing climate resilient technologies to cope with droughts/dry spells and dissemination of climate resilient technologies and wider upscaling. A number of climate resilient practices and technologies for rainfed agriculture have been identified. The impacts and opportunities, of these particularly real-time response measures would certainly flag the path for climate resilient rainfed agriculture. The experiences gained in TDC through KVKs and RTCP implementation and building resilience at landscape level through AICRPDA centres for upscaling of climate resilient technologies have been worth emulating and being shared at international, national and state level platforms/fora. The national and state governments have already initiated mainstreaming of these practices and technologies into national/state/district programmes/schemes.

The climate resilience in rainfed agriculture can be better addressed through risk and vulnerability assessment at sub-district level, mainstreaming resilient technologies through strong convergence with government schemes and appropriate policy interventions, strong preparedness for weather aberration (based on long term experiences or trends) along with actually responding to the situation and capacity building of primary and secondary stakeholders. A global programme could be a proposal for research and development in climate resilient rainfed agriculture and inter-governmental and multi-institutional arrangements for upscaling of proven climate resilient practices in the similar rainfed agro-eoclogy domains in various countries. Further, there could be regional centres of excellence in climate resilient rainfed agriculture not only for research and development and also for capacity building and human resources development.

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References

AICRPDA-NICRA Annual Report (2012–13) Managing weather aberrations through real time contingency planning. In: Srinivasa Rao Ch, Ravindra Chary G, Nagarjuna Kumar R, Maruthi Sankar GR, Venkateswarlu B (eds) All India Coordinated Research Project for Dryland Agriculture, Central Research Institute for Dryland Agriculture. India, p 190

AICRPDA-NICRA Annual Report (2013–14) Managing weather Aberrations through real time contingency planning. In: Ravindra Chary G, Gopinath KA (eds) All India Coordinated Research Project for Dryland Agriculture, ICAR-Central Research Institute for Dryland Agriculture. India, p 241

AICRPDA-NICRA Annual Report (2014–15) Managing weather aberrations through real time contingency planning. In: Srinivasa Rao C, Ravindra Chary G, Gopinath KA (eds) All India Coordinated Research Project for Dryland Agriculture, ICAR-Central Research Institute for Dryland Agriculture. India, p 185

AICRPDA-NICRA Annual Report (2015–16) Managing weather aberrations through real time contingency planning. In: Ravindra Chary G, Gopinath KA, Narsimlu B, Srinivasa Rao C (eds) All India Coordinated Research Project for Dryland Agriculture, ICAR-Central Research Institute for Dryland Agriculture. India, p 226

AICRPDA-NICRA Annual Report (2016–17) Managing weather aberrations through real time contingency planning. In: Ravindra Chary G, Gopinath KA, Narsimlu B, Srinivasa Rao C (eds) All India Coordinated Research Project for Dryland Agriculture, ICAR-Central Research Institute for Dryland Agriculture. India, p 190

AICRPDA-NICRA Annual Report (2017–18) Managing weather aberrations through real time contingency planning. In: Ravindra Chary G, Gopinath KA, Narsimlu B, Sammi Reddy K (eds) All India Coordinated Research Project for Dryland Agriculture, ICAR-Central Research Institute for Dryland Agriculture. India, p 176

AICRPDA-NICRA Annual Report (2018–19) Managing weather aberrations through real time contingency planning. In: Ravindra Chary G, Gopinath KA, Narsimlu B (eds) All India Coordinated Research Project for Dryland Agriculture, ICAR-Central Research Institute for Dryland Agriculture. India, p 184

AICRPDA-NICRA Annual Report (2019–20) Managing weather aberrations through real time contingency planning. In: Ravindra Chary G, Gopinath KA, Narsimlu B (eds) All India Coordinated Research Project for Dryland Agriculture, p 189

Bai ZG, Dent DL, Olsson L, Schaepman ME (2008) Proxy global assessment of land degradation. 3(September):223–234

Venkateswarlu B, Maheswari M, Srinivasa Rao M, Rao VUM, Srinivasa Rao C, Reddy KS, Ramana DBV, Rama Rao CA, Vijay Kumar P, Dixit S, Sikka AK (2013) National initiative on climate resilient agriculture (NICRA), Research Highlights (2012–13). Central Research Institute for Dryland Agriculture, Hyderabad, p 111

Chaturvedi RK, Joshi J, Jayaraman M, Bala G, NH Ravindranath (2012) Multi-model climate change projections for India under representative concentration pathways. Curr Sci 103(7):791–802

Climate Change Research Infrastructure (2019) National Innovations in Climate Resilient Agriculture (NICRA), ICAR-Central Research Institute for Dryland Agriculture, Hyderabad, p 79

CRIDA Vision (2050) Central research institute for dryland agriculture. Santoshnagar, Hyderabad, India, p 36

DES (2011) Department of Economics and Statistics, DAC, MoA&FW, GoI, New Delhi

Economics of Climate Adaptation (ECA) (2009) Shaping climate-resilient development: A framework for decision-making, a report of the economics of climate adaptation working group. Climate Works Foundation (CWF), Global Environment Facility (GEF), European Commission (EC), McKinsey & Company (MC), The Rockefeller Foundation (TRF), Standard Chartered Bank (SCB) and Swiss Re (SR). p 164

FAO (2005) Grasslands of the World

IPCC (2015) Climate change 2014: Synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change [Core Writing Team, R.K. Pachauri and L.A. Meyer (Eds.)], vol 218. IPCC, Geneva, Switzerland, p 151

IUCN (2015) Land degradation and climate change: The multiple benefits of sustainable land management in drylands

Koohafkan P, Stewart, BA (2008) Water and cereals in drylands

NAAS (2013) Climate resilient agriculture in India. Policy Paper No.65, National Academy of Agricultural Sciences, New Delhi, p 20

Naresh Kumar S, Singh AK, Aggarwal PK, Rao VUM, Venkateswarlu B (2012) Network project on climate change on impact, adaptation and vulnerability of Indian agriculture to climate change. Central Research Institute for Dryland Agriculture, Hyderabad, pp 1–8

Prasad R, Ravindra Chary G, Rao KV, Prasad YG, Srinivasarao C, Ramana DBV, Sharma NK, Rao VUM, Venkateswarlu B (2013) District level contingency plans for weather aberrations in Himachal Pradesh. CSK HPKV, Palampur, HP and Central Research Institute for Dryland Agriculture. Hyderabad-500 059, India, p 222

Prasad YG, Venkateswarlu, Ravindra Chary G, Srinivasarao Ch, Rao KV, Ramana DBV, Rao VUM, Subba Reddy G, Singh AK (2012) Contingency crop planning for 100 districts in peninsular India. CRIDA, Hyderabad. ICAR-CRIDA, Hyderabad, p 136

Prasad YG, Maheswari M, Dixit S, Srinivasarao Ch, Sikka AK, Venkateswarlu B, Sudhakar N, Prabhu Kumar S, Singh AK, Gogoi AK, Singh AK, Singh YV, Mishra A (2014) Smart practices and technologies for climate resilient agriculture. Central Research Institute for Dryland Agriculture (ICAR), Hyderabad. p 76

Quang BL, Ephraim N, Alisher M (2014) Biomass productivity-based mapping of global land degradation hotspots

Raju BMK, Rao KV, Venkateswarlu B, Rao AVMS, Rama Rao CA, Rao VUM, Rao B, Ravi Kumar N, Dhakar R, Swapna N, Latha P (2013) Revisiting climatic classification in India: a district-level analysis. Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad 500 059, India. *Current Science*, Vol 105, No.4. p 25

Rama Rao CA, Raju BMK, Subba Rao AVM, Rao KV, Rao VUM, Ramachandran K, Venkateswarlu B, Sikka AK (2013) Atlas on vulnerability of Indian agriculture to climate change. Central Research Institute for Dryland Agriculture, Hyderabad p 116

Rama Rao CA, Raju, BMK, Islam A, Subba Rao AVM, Rao KV, Ravindra Chary G, Nagarjuna Kumar R, Prabhakar M, Sammi Reddy K, Bhaskar S, Chaudhari SK (2019) Risk and vulnerability assessment of Indian agriculture to climate change, ICAR-Central Research Institute for Dryland Agriculture, Hyderabad, p 124

Ravindra Chary G, Venkateswarlu B, Sharma SK, Mishra JS, Rana DS, Ganesh Kute (2012) Agronomic research in dryland farming in India: an overview. Indian J Agron 57:157–167

Ravindra Chary G (2015) Rainfed agro-economic zones: An approach to integrated land use planning for sustainable rainfed agriculture and rural development. In: Rao MV, Suresh Babu V, Suman Chandra K, Ravindra Chary G (eds) Integrated land use planning for sustainable rainfed agriculture and rural development. Ghosh) Apple Academic Press and NIRD, Hyderabad, pp 179–204

Ravindra Chary G, Vittal KPR, Venkateswarlu B, Mishra PK, Rao GGSN, Pratibha G, Rao KV, Sharma KL, Rajeshwar Rao G (2010). Drought hazards and mitigation measures. In: Jha MK (ed) Natural and anthropogenic disasters: Vulnerability, preparedness and mitigation. Capital Publishing Company, New Delhi and Springer, The Netherlands, pp 197–237

Ravindra Chary G, Srinivasarao Ch, Srinivas K, Maruthi Sankar GR, Nagarjuna Kumar R, Rani N, Kumar P (2013) Adaptation and mitigation strategies to climate change: Perspectives. In: Ravindra Chary G, Srinivasarao Ch, Srinivas K, Maruthi Sankar GR, Nagarjuna Kumar R (eds) Adaptation and mitigation strategies or climate resilient agriculture. ICAR-CRIDA, Hyderabad. pp 17–42

Ravindra Chary G, Srinivasa Rao Ch, Gopinath KA, Sikka AK, Kandpal B, Bhaskar S (2016) Improved agronomic practices for rainfed crops in India. All India Coordinated Research Project

for Dryland Agriculture (AICRPDA), ICAR-Central Research Institute for Dryland Agriculture, Hyderabad-500 059, p 292
Ravindra Chary G, Prabhakar M, Sharma KL, Rama Rao CA, Vanaja M, Srinivasa Rao M, Gopinath KA, Sarkar B, Ramana DBV, Subba Rao AVM, Pankaj PK, Reddy AGK, Prasad JVNS, Bhaskar S, Alagusundaram K (2019a) National Innovations in Climate Resilient Agriculture (NICRA), Research Highlights (2018–19), ICAR-Central Research Institute for Dryland Agriculture, Hyderabad, p 166
Ravindra Chary G, Prasad JVNS, Osman M, Ramana DBV, Nagasree K, Rejani, R, Subba Rao, AVM, Srinivas I, Rama Rao CA, Prabhakar M, Bhaskar S, Singh AK, Alagusundaram K (eds) (2019b) 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-500 059. p 121
Ravindra Chary G, Gopinath KA, Bhaskar S, Prabhakar M, Chaudhari SK, Narsimlu B (eds) (2020) Resilient crops and cropping systems to cope with weather aberrations in rainfed agriculture. All India Coordinated Research Project for Dryland Agriculture (AICRPDA), ICAR-Central Research Institute for Dryland Agriculture, Hyderabad-500 059, p 56
Rejani R, Rao KV, Osman M, Chary GR, Pushpanjali, Sammi Reddy K, Srinivasa Rao Ch (2015) Location specific *in-situ* soil and water conservation interventions for sustainable management of dry lands. J Agrometeorol 17(1):55–60
Rockstorm J, Falkenmark M (2000) Semiarid crop production from a hydrological perspective-gap between potential and actual yields. Crit Rev Plant Sci 19(4):319–346
Sikka AK, Islam A, Kandpal BK (2016) Water resources management under changing climate scenarios. 2016. In: Venkateswarlu B, Ravindra Chary G, Singh G, Shivay YS (eds) Climate resilient agronomy. The Indian society of agronomy, New Delhi, pp 158–181
Srinivasarao Ch, Chary GR, Rani N, Baviskar VS (2016) Real time implementation of agricultural contingency plans to cope with weather aberrations in Indian agriculture. Mausam 67(1):183–194
Subba Reddy G, Ramakrishna YS, Ravindra Chary G, Maruthi Sankar GR (2008) Crop and contingency planning for rainfed regions of India—A compendium by AICRPDA. AICRPDA.ICAR-CRIDA, Hyderabad, p 174
Umate MG, More GR, Prasad YG, Ravindra Chary G, Mandal DK, Ramana DBV, Dipak S, Venkateswarlu B (2011) District level contingency plans for weather aberrations in Marathwada Region. Maharashtra. Maratwada Krishi Vidyapeeth, Parbhani-431 402 and Central Research Institute for Dryland Agriculture, Hyderabad, 500059, India, p 272
UNCCD (2017) Global land outlook. In: Dudley N, Alexander S (eds)
Venkateswarlu B, Singh AK, Prasad YG, Ravindra Chary G, Srinivasa Rao Ch, Rao KV, Ramana DBV, Rao VUM (2011) District level contingency plans for weather aberrations in India. Central Research Institute for Dryland Agriculture, Natural Resource Management Division, Indian Council of Agricultural Research, Hyderabad -500 059, India, p 136
Venkateswarlu B, Kumar S, Dixit S, Srinivasarao Ch, Kokate KD, Singh AK (2012) Demonstration of climate resilient technologies on farmers fields-action plan for 100 vulnerable districts. Central Research Institute for Dryland Agriculture, Hyderabad, p 163