ICAR-CRIDA & MANAGE, Hyderabad

Innovative Extension Strategies for Sustainable Natural Resource Management in Rainfed Agriculture

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This e-book is a compilation of resource material obtained from various subject experts for ICAR-CRIDA & MANAGE collaborative online training program on "Innovative Extension Strategies for Sustainable Natural Resource Management in Rainfed Agriculture" conducted from 30 October to 03 November, 2023. This e-book is designed for researchers, academicians, extension workers and scholars engaged in natural resource management, rainfed agriculture etc. Neither the publisher nor the contributors, authors and editors assume any liability for any damage or injury to persons or property from any use of methods, instructions, or ideas contained in the e-book. No part of this publication may be reproduced or transmitted without prior permission of the publisher/editor/authors. Publisher and editor do not give warranty for any error or omissions regarding the materials in this e-book.

Published for Dr.P.Chandra Shekara, Director General, National Institute of Agricultural Extension Management (MANAGE), Hyderabad, India by Dr.Srinivasacharyulu Attaluri, Program Officer, MANAGE and printed at MANAGE, Hyderabad as e-publication.

Foreword

ICAR-Central Research Institute for Dryland Agriculture is a premier national research institute under the Indian Council of Agricultural Research (ICAR), Ministry of Agriculture and Farmers' Welfare, Govt. of India, New Delhi with a mandate to carry out basic and applied research in rainfed farming. ICAR-CRIDA is also working closely with different stakeholders towards the development of rainfed agriculture in general and climate resilient agriculture in particular.

It is a pleasure to note that, ICAR-CRIDA, Hyderabad and MANAGE, Hyderabad, Telangana is organizing a collaborative training program on ***Innovative Extension Strategies for Sustainable Natural Resource Management in Rainfed Agriculture*** and coming up with a joint publication as e-book on "Innovative Extension Strategies for Sustainable Natural Resource Management in Rainfed Agriculture" as an outcome of this training program.

I wish the program be very purposeful and meaningful to the participants and also the e-book will be useful for various stakeholders across the country. I extend my best wishes for the success of the program. I would like to compliment the efforts of Course Directors from ICAR-CRIDA and MANAGE for this valuable publication.

Dr. V. K. Singh

Director, ICAR-CRIDA

Foreword

Rainfed agriculture occupies 67 percent of net sown area, contributing 44 percent of food grain production and supporting 40 percent of the population. Even after realization of full irrigation potential of the country, 50 percent of net sown area will continue as rainfed and rainfed crop yields are about 50% lower than yields obtained under irrigated conditions. The low productivity of rainfed agricultural systems is the main factor that accentuates hunger, poverty, unemployment. Because of rainfall dependence, farmers can cultivate their crops during only one growing season per year, with high vulnerability to periodic droughts and flooding.

Innovations in Natural Resource Management for rainfed condition like construction of reservoir to capture of water for irrigation are a key factor to consider for the transformation to irrigated agriculture. To make agriculture successful under rainfed condition more innovations need to be brought under this and has to reach the stakeholder, farmers, and scientist to plan accordingly for development under rainfed condition. In this context, National Institute of Agricultural Extension Management in collaboration with Central Research Institute for Dryland Agriculture organized an online training program on Innovations Extension Strategies for Sustainable Natural Resource Management in Rainfed condition.

I appreciate the effort and work of all the authors and editors of this book in compilation of information on Innovative Extension Strategies for Sustainable Natural Resource Management in Rainfed Agriculture.

(Dr. P. Chandra Shekara)
Director General, MANAGE

Preface

This e-book is an outcome of collaborative online training program on "Innovative Extension Strategies for Sustainable Natural Resource Management in Rainfed Agriculture" jointly organized by ICAR-CRIDA & MANAGE, Hyderabad during 30 October-03 November, 2023. It is a result of collective efforts, experience, knowledge and wisdom of several authors. This book is intended for research scholars, extension professionals and department officials who are the key players in the technology transfer. Bringing views of experts from different fields of agriculture through this training programme suffice opportunities for cross-learnings among trainees.

Looking into theme of the training, experts from ICAR-CRIDA, MANAGE, ICAR Headquarter, ICAR-CMFRI and Kerala Agricultural University (KAU) have been called for providing a common platform for the officials involved in the field of agriculture and allied sectors to understand the subject. We wish to place on record the cooperation and support received from all the authors and staff at ICAR-CRIDA and MANAGE who contributed in various ways for timely publication of this book. This book has enlightened with climate resilient agriculture, IPM in rainfed crops, extension models for effective dissemination of livestock technologies, farmers centric natural resource development for socio economic empowerment in rainfed areas, impact of Natural Resource Management (NRM) technologies, conservation social science, farm mechanization in rainfed agriculture, digital extension, gender issues in agriculture and other related topics. We hope this book will be a reference for different stakeholders working in this sector. The valuable suggestions for future improvements are always welcome.

October, 2023 **Editors**

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List of Abbreviations

Abbreviation	Full form
AEA	Agro-Ecosystem Analysis
AI	Artificial Intelligence
AICRPDA	All India Coordinated Research Project for Dryland Agriculture
AICRPAM	All India Coordinated Research Project on Agrometeorology
ASER	Annual Survey of Education Report
ATMA	Agricultural Technology Management Agency
BBF	Broad bed Furrow
BUR	Biennial Update Report
CA	Conservation Agriculture
CAZRI	Central Arid Zone Research Institute
CBA	Cost Benefit Analysis
CEA	Cost Effectiveness Analysis
CER	Cost Effectiveness Ratio
CHC	Custom Hiring Centers
CIBA	Central Institute of Brackishwater Aquaculture
CIFA	Central Institute of Freshwater Aquaculture
CIFRI	Central Inland Fisheries Research Institute
CIG	Commodity Interest Group
CITH	Central Institute of Temperate Horticulture
CLCC	Customized Leaf Colour Chart
CMFRI	Central Marine Fisheries Research Institute
CPRI	Central Potato Research Institute
CRIDA	Central Research Institute for Dryland Agriculture
CSV	Climate Smart Villages
CT	Conventional Tillage
CTGC	Carbon dioxide and Temperature Gradient Chamber
DAM	Digital Agriculture Mission
DCS	Division of Crop Science
DID	Difference-In-Difference
DIY	Do-It Yourself

DOGR	Directorate of Onion and Garlic Research
DRM	Division of Resource Management
eNAM	electronic National Agriculture Market
ESM	Economic Surplus Method
FACE	Free Air Carbon dioxide Enrichment
FATE	Free Air Temperature Elevation
FFE	Farmer-to-Farmer Extension
FFP	Farmer FIRST Programme
FFS	Farmer Field School
FIF	Field Information Facilitator
FPOs	Farmer Producer Organizations
FQCS	Fertilizer Quality Control System
FSR	Farming System Research
GDP	Gross Domestic Product
GHG	Green House Gas
IA	Impact Assessment
IARI	Indian Agricultural Research Institute
ICAR	Indian Council of Agricultural Research
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICT	Information and Communications Technology
IDEA	India Digital Ecosystem of Agriculture
IFFCO	Indian Farmers Fertiliser Cooperative
IFPRI	International Food Policy Research Institute
IIFSR	Indian Institute of Farming Systems Research
IIHR	Indian Institute of Horticultural Research
IISS	Indian Institute of Soil Science
IIVR	Indian Institute of Vegetable Research
INDCs	Intended Nationally Determined Contributions
ITK	Indigenous Technical Knowledge
IVLP	Institute Village Linkage Programme
IVR	Interactive Voice Response
IVRI	Indian Veterinary Research Institute

KCC	Kisan Call Centres
LEIIPM	Low External Input Integrated Pest Management
LEISA	Low External Input for Sustainable Agriculture
MAS	Marker Assisted selection
ML	Machine Learning
NABARD	National Bank for Agriculture and Rural Development
NAEP	National Agricultural Extension Policy
NAMAs	Nationally Appropriate Mitigation Actions
NAPCC	National Action Plan on Climate Change
NBPGR	National Bureau of Plant Genetic Resources
NDRI	National Dairy Research Institute
NEE	Net Ecosystem Exchange
NeGP-A	National e-Governance Plan in Agriculture
NGO	Non-Governmental Organization
NGRCA	National Gender Resource Centre in Agriculture
NICRA	National Innovations on Climate Resilient Agriculture
NMSA	National Mission for Sustainable Agriculture
NPV	Net Present Value
NRCL	National Research Centre on Litchi
NRM	Natural Resource Management
NRRI	National Rice Research Institute
NWDPRA	National Watershed Development Project for Rainfed Area
ORP	Operational Research Project
PALM	Participatory Learning Methods
PAS	Public Address System
PAR	Participatory Action Research
PAME	Participatory, Assessment, Monitoring and Evaluation
PGS	Participatory Guarantee System
PI	Principal Investigator
PMFBY	Pradhan Mantri Fasal Bima Yojana
PMKSY	Pradhan Mantri Krishi Sinchai Yojana
PRA	Participatory Rural Appraisal

PRAP	Participatory Rural Appraisal and Planning
RCT	Resource Conservation Technology
RRA	Rapid Rural Appraisal
SDA	Section of Design and Analysis
SDGs	Sustainable Development Goals
SHC	Soil Health Card
SHG	Self Help Group
SIC	Scientist In-Charge
SMBC	Soil Microbial Biomass Carbon
SMS	Short Message Services
SNRM	Sustainable Natural Resource Management
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SST	Surface Sea Temperature
TDC	Technology Demonstration Component
TOT	Transfer of Technology
VCRMC	Village Climate Risk Management Committee

1. Climate Resilient Agriculture: Indian Perspective

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Climate change is one of the greatest ecological, economic, and social challenges we are facing today is, predominantly accredited to greenhouse gas (GHG) emissions from anthropogenic activity. Agriculture and food production systems are highly vulnerable to climate change. The food security and water security has been adversely affected by climate change thereby hindering efforts to meet Sustainable Development Goals (SDGs). Extreme weather aberrations, such as erratic rainfall, floods, drought and heat waves have a substantial impact on food security, particularly in rural areas where large population of small-scale farmers are largely dependent on rainfed agriculture for their livelihood. The yield of staple foods is anticipated to reduce by 30% owing to crop failure and lower productivity due to these irregularities. The steady decline in natural resource base puts forth a daunting challenge to produce more with low carbon and energy footprints to ensure food, nutritional and environmental security for the vast majority of people.

South Asia is categorized as one of the most vulnerable among the several highly populated regions of the world. Countries like India are more vulnerable, although climate change impacts are being witnessed all over the world, in view of the huge population dependent on agriculture and excessive pressure on natural resources. India, an agrarian country with over 157.3 Mha of cultivated area and with more than 55 percent rural households depending primarily on agriculture, is the most populous and largest country in South Asia. With only 2.4 percent of land and 4 percent of the water resources at its disposal, the Indian agricultural production system faces the daunting task of feeding 17.7 percent of the global population. Among the various production process in India, 19 percent of GHG emissions is contributed from agriculture sector, the second largest sector after energy. One of the greatest predicaments Indian agriculture have to face in order to curb the challenges due to climate change will be to ensure that food production is in line with both poverty reduction and environmental preservation.

Extreme weather events have become increasingly common globally in recent decades (IPCC 2012; IPCC 2014). The frequency of extreme weather events such as heavy rainfall, heat waves and intense tropical cyclones are increasing every year and India is also feeling the effects of such weather events which ultimately triggers great damage to crops and rural economies. As per the IMD report (2022), the temperatures were consistently 3°C-8°C above normal in several parts of the country like the western Himalayas, the plains of Punjab, Haryana, Delhi, Rajasthan and Uttar Pradesh, breaking many decadal and some all-time records. Heatwaves were felt in states like Odisha, Madhya Pradesh, Gujarat, Chhattisgarh, Telangana and Jharkhand towards the end of March with temperature varying from 40°C-44°C which continued till end of April month. The incidences of forest fires also increased with heat waves with around 300 large forest fires in Uttarakhand. Approximately 70 percent of India was affected by heatwaves. The extreme temperature increase can significantly reduce crop yields resulting in reproductive failure in many crops along with enhanced water stress. In India, the incursion of cold winds into north-western and central India (when westerly disturbances pass over the region) effects cold waves usually during November to March (IMD, 2023). Retreating galciers, expansion of arid regions in several parts of the country and shortening of the growing season are some of the other adverse consequences encountered with the changing climate scenario. Climate change will have severe implications on agriculture in India based on climate change projections. The rise in minimum temperature is expected to more than the rise in maximum temperature. The northern part of the country is projected to face the adversities of rise in temperature compared to southern part of the country. The rainfall during kharif is expected to be highly variable with increase in temperature during post rainy seasons.

Impact on crops

In view of shifts in seasons, increase in temperatures and changes in rainfall pattern, the crops may encounter major abiotic stresses like drought, flood, heat and cold, resulting in substantial yield losses. The impacts of these stresses may vary with region, crop and cropping systems, soils and management practices. There could be some positive impact from climate change due to location specificity owing to change in thermal and moisture regimes. The fertilization effect caused by the increase in CO_2 concentration in the atmosphere may contribute to enhanced crop productivity along with other positive impacts like expansion of the areas available for production of tropical and/or subtropical crops and reduction of damages of winter crops by frosting. The global warming will induce negative impact on crop quantity and quality owing to reduced growing period arising from high temperature rise, increase weed infestation and pest occurrences, decline in soil fertility and increased soil erosion due the erratic rainfall. The long dry spells during the early season, mid-season and terminal drought affect the crop production adversely (Sharma *et al*., 2006). The delayed onset of monsoon, prolonged dry spell soon after the onset of monsoon may culminate in early season drought. Whereas, the insufficient soil moisture availability during the crop growth, between two successive rainfall, can cause midseason drought. The terminal (late season) drought happens as a result of early withdrawal of monsoons.

The climate change impact assessment carried out using the crop simulation models projected that rainfed rice yields in India will reduce by 20 percent in 2050 and 47 percent in 2080 while, irrigated rice yields are projected to reduce by 3.5 percent in 2050 and 5 percent in 2080 scenarios. The adaptation of suitable mitigation strategies will improve irrigated rice yield by about 17 percent and rainfed rice yield by about 20 percent based on the simulations. The wheat yield is projected to reduce by 19.3 percent and 40 percent by 2050 and 2080 respectively. With every 1^0C rise in temperature, yield is predicted to reduce by 6 million tones. By adjusting time of sowing, adoption of suitable varieties, and fertilizer and irrigation management strategies is expected to increase yield by >10 percent. The kharif maize is projected to reduce by 18-23 percent by 2050 and 2080 and increase yield by 10 percent by 2050 through apt adaptation strategies. Climate change reduces crop yields and lower nutrition quality of produce.

Climate resilient agriculture

Farming must become more resilient to disruptive events like floods and droughts through improving agricultural water and soil management, to enhance the sustainable agricultural productivity and incomes of smallholder farmers, as they constitute 86 percent farm households, who are most vulnerable to the effects of climate change. The prospects of global food security will be determined by resilience of global agricultural systems to climate change and their ability to recover.

Adaptation strategies in the agricultural sector can be of both short-term and long-term actions. The short-term responses comprise, new irrigation schemes, providing crop and livestock insurance and development of stress resistant crop varieties, whereas amendment of irrigation systems, land management development is some of the long-term responses envisaged. The farmers need to amend the production and farm management practices, by adjusting planting time, supplementing irrigation, intercropping, adopting conservation agriculture and undertaking more climate-resilient crop varieties to ensure that agricultural practices are sufficiently resilient and sustainable to cope with the impacts of climate change. The Intergovernmental Panel on Climate Change defines resilience as 'the ability of a system and its component parts to anticipate, absorb, accommodate or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration or improvement of its essential basic structures and functions'. Climate resilient agriculture (CRA) must consider the overall sustainability of its results to achieve long-lasting positive results. As several of the SDGs pertain to climate change, agricultural production, conservation of natural resources, economic and food security, a well-designed CRA approach can also contribute to the priority goals set in the sustainability agenda 2030. Thus CRA, encompassing adaptation and mitigation strategies is an essential pre-requisite for sustainable development in the face of changing climate.

Mitigation strategies for CRA

Adaptation and mitigation strategies including use of climate resilient crops and varieties, improved agricultural practices for diverse agro-ecological regions are crucial to successfully cope with climate variability and enhance climate change adaptation (Venkateswarlu *et al*., 2011; Aggarwal *et al*., 2018). A range of climate-resilient practices, technologies and strategies are adopted by farmers and other stakeholders to alleviate the harmful effects of climate change. Some of the major strategies of adaptation to climate change include growing tolerant crop varieties, conservation agriculture, site specific nutrient management practices along with climate smart irrigation practices like micro-irrigation. Some of the climate resilient practices that can be adopted by the farmers are discussed below.

Climate resilient crop varieties

Indian National Agricultural Research System (NARS) along with several ICAR institutes has developed several improved varieties of crops with enhanced tolerance to various abiotic stresses like heat, flood, submergence. The farming communities can utilize these varieties during extreme weather events. The adverse impact of climate change can be surmounted by adopting climate resilient crop varieties along with suitable adaptation and mitigation strategies by lowering the yield losses under stress conditions. The development and identification of climate resilient varieties with enhanced tolerance to various abiotic stresses are essential to sustain and improve crop yields and to cope with the challenges of climate change. For instance, heat stress can be mitigated by developing thermo-tolerant crop varieties through genetic improvement.

The cultivation of these varieties with suitable adaptation and mitigation strategies can offset production losses. Tolerance to any abiotic stress can generally be characterized as the ability of a particular crop to grow and produce economic yield closest to its genetic potential under high stress (Maheswari *et al*., 2019). 8 varieties of rice, maize, lentil, green gram was developed and released for abiotic stress under NICRA program along with wheat genotypes with high yield potential, heat stress tolerance, maize genotypes with high yield potential, drought tolerance and black gram resilient to heat, drought and photo-thermoperiods. One of the crucial resources to efficiently cope with weather aberrations and enhance resilience of the farming community is development of stress tolerant crop varieties. The ability to cope to vulnerable environments along with reducing the risk associated can be enhanced by adopting stress tolerant climate resilient varieties in consort with the proper management practices.

Crop diversification

Diversification of cropping system can help in reducing the carbon footprint of crops by 32 % to 315% (Yang *et al*., 2014). Diversification of the existing cropping system with non-cereal crops are reported to have a lower emission of greenhouse gasses (Yadav *et al*., 2018). The diversification of cropping systems with the introduction of legumes as cash crops, cover crops or intercrops represents a key strategy to reduce N fertilizer needs at the crop- and rotation scale (Bedoussac *et al*., 2015; Plaza-Bonilla *et al*., 2017b). The leguminous crop has a lower C and water footprint as compared to cereals due to the lesser release of GHG (Kumar *et al*., 2020). However, to maximize the benefits, the introduction of legumes requires the adaptation of the cropping system (Plaza-Bonilla *et al*., 2017b). Pathak *et al*., (2010) calculated the Global warming potential (GWP) of different crop production from different field experiments conducted at Indian Agricultural Research Institute, New Delhi and reported that carbon foot print values of wheat, pulse, oilseed, cauliflower, brinjal, and potato are 0.12, 0.31, 0.42, 0.03, 0.03, and 0.02 kg CO2 eq. kg-1 produce respectively. In the Indo-Gangetic Plain (IGP), conventional rice wheat cropping system (RWCS) is a major source of GHG and also have a greater GWP owing to higher emissions of CH_4. The adoption of direct seeding of rice and zero tillage in wheat along with residue application can significantly reduce GHG emission. This study indicated that, GWP can be reduced by 44-47 percent by replacing the conventional system of convention tilled wheat-transplanted puddled rice by zero tilled wheat-direct seeded rice or zero tilled wheat + rice residue-direct seeded rice without any significant reduction in system productivity (Gupta *et al*., 2016).

Conservation agriculture

Conservation agriculture (CA), a sustainable approach to agricultural production that seeks to enhance food security while safeguarding the environment, is conducive in developing climate resilient agricultural systems. CA is beneficial in terms of its three principles; minimum soil disturbance, permanent soil cover and crop diversification (Williams *et al*., 2018) and also provides opportunities for obtaining sustainable crop yield, increasing input use efficiency, improving soil properties and also mitigating greenhouse gas (GHG) emissions (Chakrabarthi *et al*., 2014). It reduces vulnerability to weather events such as drought, augments natural resource base and thereby enhances the potential of farmers to adapt to climate change. CA can be a panacea for all the challenges like decline in yield, groundwater depletion, inefficient resource use and decline in natural resource, at national and international level. CA is practiced in 205.4 Mha (102 countries) globally and in 3.5 Mha in India. Some crop management options based on the principles of CA are zero tillage (ZT), raised bed planting, direct seeded rice, incorporation of crop residues, crop diversification and site-specific nutrient management (Hobbs *et al*., 2008, Pittelkow *et al*., 2015, Pathak *et al*., 2012, Mittal *et al*., 2018). ZT improves soil health, crop productivity, and curtails the fuel requirement leading to a significant decline in CO_2 emission (Mondal *et al*., 2019). Thus, it could be an appropriate technology for reducing energy input and C-footprint (Yadav *et al*., 2020). CA based tillage practices enhanced yield and C sustainability index in all the cereal based cropping systems (Jat *et al*., 2011).

Residue management in rice-wheat cropping system is a tedious task owing to short time span between rice harvesting and sowing of next wheat crop. The large-scale pollution and carbon emissions, emanating from the burning of these residues contributes to regional as well as global climate change. The practice of residue retention in regions where CA is widely adopted can curtail the pollution from residue burning to a great extent. The carbon footprint reduced by 32 to 315 percent from the diversification of cropping system (Yang *et al*., 2014). The diversification of cropping systems with legumes as cover crops or intercrops is a key strategy to reduce N fertilizer application (Bedoussac *et al*., 2015; Plaza-Bonilla *et al*., 2017b) and lower GHG emissions (Yadav *et al*., 2018). The C and energy footprint from leguminous crops are lower than from cereals owing to reduced GHG emissions (Kumar *et al*., 2020). Such integrated activities are widely adopted in view of their potential as climate adaptation and mitigation strategies to achieve improved crop productivity and food security (Mbow *et al*., 2014). Some of the machineries developed to curb the adversities due to residue burning are use of balers (to manage the crop residues making them into bundles, which are then used in biomass based powerplants as fuel), Straw chopper cum shredder, paddy straw combine harvester with straw management system, rotovator (incorporation of paddy straw) and reversible MB plough. The straws can also be used as livestock feed, bedding material, and also as soil mulch in orchards.

Nutrient management strategies

The injudicious application of fertilizers like Nitrogen and Phosphorus to enhance the crop productivity to feed the growing human population has led to pollution of freshwaters, eutrophication and acidification of terrestrial and coastal ecosystems and thereby decreasing biodiversity. The sustainability of our world depends fundamentally on nutrients. The administration of balanced fertilization is a fundamental issue for higher crop productivity and agricultural sustainability. One of the key nutrients required for a fertile soil is Nitrogen. The average nutrient use efficiency of nitrogen since the last decade is around 30 percent. The major factors contributing to the low and declining crop responses are injudicious fertilizers application and N losses due to improper water management through irrigation systems. Moreover, the manufacture and use of nitrogen fertilizers are associated with high energy and carbon footprints along their life cycle. The direct correlation between N_2O emissions and nitrogen fertilizer application advocates, reduced nitrogen application to curtail the emissions. Integrated nutrient management (INM) has good potential to mitigate climate change. The nitrogen requirement of rice could be reduced by 25 percent from administration of need-based nitrogen management (component of INM) by leaf colour chart (Ali *et al*., 2015). INM practices enhances the buffering capacity of soils to nutrients and water, soil C sequestration and increase nutrient use efficiency. The increasing cost of production, labour shortage and increasing awareness on environmental sustainability are forcing the stakeholders to adopt precision approach. The administration of balanced fertilization based on the fertility status of a particular site had led to site specific nutrient management approach. It ensures that all nutrients are applied at proper rates and ratios considering the spatial variability associated with the fields attending to the crop's nutrient requirements.

Impact of different mitigation strategies adopted in NICRA villages

To cope with droughts and to sustain higher productivity in a particular zone, suitable site- specific adaptation strategies like climate resilient crops and cultivars along with resource management technologies are to be identified. The potential of different agronomic practices like introduction of alternate varieties, manipulation of sowing time was evaluated from the studies conducted at farmers' field.

Occurrence of drought is very frequent and the risk involved in successful cultivation of crops depends on the nature of drought, its duration, and frequency within the season. Real time response measures have to be taken up to cope with drought. Moisture conservation through in-situ conservation measures, enhancing water use efficiency through rain water harvesting and efficient irrigation methods have to be considered. Drought tolerant cultivars, site specific nutrient management, crop residue management for conserving soil moisture are some of the management strategies that can alleviate the vagaries of drought during a cropping season. The spread of these technologies and eventually their adoption by as many farmers as possible is required for drought proofing of a village (Rao *et al*., 2016d). The loss minimization achieved through adoption of different mitigation strategies during stress year (2018) was about Rs. 10.27 crores compared to farmers' practice. The income enhanced due to interventions during normal year (2021) was about Rs. 8.60 crores compared to farmers' practice in NICRA villages. The resilience achieved with the implementation of different strategies for mitigating drought in Ahmednagar, a frequently drought prone region of Maharashtra is given below.

Table 1.1: Impact of different technologies adopted in frequently drought prone regions of Ahmednagar, Maharashtra

Technology		Yield loss minimization during stress year (q/ha)	Resilience achieved during stress year (%)	Yield enhancement during normal year (%)
Short duration drought escaping variety of soybean (Phule Sangam and MACS-1188)		2	54	30
Short duration variety of rabi sorghum (Phule Suchitra)		2	95	08
	Rabi onion	15	97	12

Pre-sowing & supplemental irrigation for rabi crops	Wheat	2	92	06
	Chickpea	3	84	38
Drip irrigation and organic mulching for pomegranate		19	83	02
Improved fodder variety of sorghum (Phule godhan, Sugargraze and CoFS-29)		6	93	47

Mitigation of the adverse effect of floods in the NICRA village at Wakhrwan, Phulwama district through establishment of 10 polyhouses cultivating offseason vegetables like cauliflower (*var*. Snow Ball-16), tomato (*var*. Shalimar-I) and Brinjal (*var.* Shalimar Brinjal hybrid-I) gave net returns of Rs. 70,000/ polyhouse. This intervention contributed to higher returns in this area along with enhanced production of vegetables (Rao *et al*., 2016d). Renovation of drainage channels, land configuration and planting techniques, flood tolerant cultivars, post flooding management practices are some of the interventions that can be implemented to minimize the impact of floods and cyclones. In the Bambam Purwa village of Gonda district, Uttar Pradesh, inclusion of interventions like use of flood tolerant variety, Bina Dhan 11, zero tillage planting of wheat under delayed sowing, late sown wheat cultivars K-9533 & K-9162 and short duration Toria variety (Uttara) as catch crop enhanced income by Rs.10890/ha, Rs.13475/ha, Rs. 11550/ha and Rs.26550/ha respectively. Adoption of climate resilient technologies effected monetary benefits of Rs.86 lakhs during the stress year (2019). Some of the technological options that can be implemented for resilience to floods in Dhubri, Assam are use of winter rice varieties (Gitesh, Ranjit, Bahadur Sub-1) for medium land, Dipholu, Swarna Sub-1for low land rice, Joymati, Naveen as summer rice, medium land winter rice (Luit) for post floods, desilting of channels for encountering flash floods during April-May, catch crop before flood using greengram (SGC-16) and crop diversification (mustard after rice).

Heat waves occur in different parts of the country as a result of extreme positive departures from the normal maximum temperature. In the NICRA village, Bathinda district, Punjab, the high temperature during 3rd to 4th week of March, 2022 resulted in shrinking of the wheat grain. However, the extend of yield reduction was less in wheat sown during October. The heat stress was observed low in fields where wheat was sown with happy seeder because the stubble mulch prevented roots from direct heat and minimized the yield loss compared to wheat sown with other methods.

Table 1.2: Resilience achieved with implementation of technologies adopted for heat wave at Killi Nihal Singh Wala Village, Bathinda district, Punjab

Technology	Resilience achieved (%)
Direct seeded rice / Short duration (PR-121, PR-126, PR-127)	101
Wheat sown with happy seeder: (HD-3086)	102
Wheat sown with super seeder: (HD-3086)	100
Crop residue management	100
Heat stress tolerant Gobhi sarson (GSC-7)	104
Summer moong (SML-832)	96
Spray of KNO_3 in wheat (2 sprays of 2% KNO_3)	102
Spray of KNO_3 in cotton (4 sprays of 2% KNO_3 and first spray at flower initiation stage, other at 7 days intervals)	99
Fodder Maize (J-1006)	117
Mineral mixture supplement feed (litres/animal/day)	108

Prevalence of extreme low temperature in association with incursion of dry cold winds from north into the subcontinent is known as cold waves. n India, a cold wave is considered to be severe when the night temperature drops below its daily normal by 7°C or more, when normal minimum temperature is 10°C or more. If the normal minimum temperature is less than 10°C, then 5°C or more below normal is called the severe cold wave condition. Some of the crop-based interventions undertaken against cold wave and frost in the Eastern zone of Uttar Pradesh at Yamnanagar are direct seeded rice, zero till sown wheat, residue retention with happy seeder and intercropping in sugarcane. Whereas some of the natural resource management interventions are laser land leveling, soil test-based nutrient application and green manuring with sesbania (Rao *et al*., 2016).

Policies and cchemes for CRA

To tackle the adverse impacts of climate change on agriculture and minimize the negative effect of agricultural practices on climate change, mainstreaming suitable policies into national and economic development is imperative. India has developed its policy responses via several missions and programmes to enhance climate resilience. The droughts of mid-sixties catalyzed the Govt. to invest on dryland research significantly. Subsequently, the Indian Council of Agricultural Research (ICAR) launched AICRPDA in 1970-71 and AICRPAM in 1983 to bring stability in food grain production in the face of varying weather conditions, at Hyderabad, India. The National Action Plan on Climate Change (NAPCC) was released by the Prime Minister on 30th June 2008, with 8 sub-missions to enable the country to adapt to climate change and enhance the ecological sustainability of the development. The eight National Missions that form the core of the NAPCC are- National Solar Mission, National Mission for Enhanced Energy Efficiency, National Mission on Sustainable Habitat, National Water Mission, National Mission for Sustaining the Himalayan Ecosystem, National Mission for a Green India, National Mission for Sustainable Agriculture and National Mission on Strategic Knowledge for Climate Change. These missions represent interdisciplinary, long-term and integrated strategies for achieving key goals in the context of climate change. The National Mission for Sustainable Agriculture is a scheme formulated by the Government to make agriculture more resilient to climate change. To meet the challenges of sustaining domestic food production in the face of changing climate, the ICAR launched a flagship network research project 'National Innovations in Climate Resilient Agriculture' (NICRA) in 2011. The project aims to develop and promote climate resilient technologies in agriculture, which addresses vulnerable areas of the country and the outputs of the project help the districts and regions prone to extreme weather conditions like droughts, floods, frost, heat waves, etc. to cope with such extreme events. The project is implemented through components viz. strategic research, technology demonstration and capacity building in 151 clusters of villages in each one of the identified climatically vulnerable districts to demonstrate proven technologies and enhance adaptive capacity of farmers.

District Agricultural Contingency plans are prepared and departments are sensitized for enhancing adoption of contingency measures. All the 650 district plans are placed in the 'farmer portal' of the Ministry of Agriculture, Government of India (http://www.farmer.gov.in) and also in the ICAR / CRIDA website (http://www.crida.in) for downloading the full plan by stakeholders for operational use. Some of the other prominent national schemes implemented by the country based on the convergence approach to benefit farmers in strengthening the agriculture system in the country include the Soil Health Card Scheme, Pradhan Mantri Krishi Sinchai Yojana (PMKSY), Paramparagat Krishi Vikas Yojana, National Agriculture Market, Agriculture Contingency Plan, Rainfed Area Development Programme, National Watershed Development Project for Rainfed Area (NWDPRA) and Pradhan Mantri Fasal Bima Yojana (PMFBY).

Way forward

The adoption of CRA practices in not free from challenges despite the various arbitrations made by the Government through several policies and schemes. In order to promote and scale CRA across all states in India, a well-structured and long-term strategy based on the lessons learned from developed and developing countries is required. The insights gained from the evolving perspectives on CRA can be used to develop strategies for the transformation and development of Indian agriculture, linking it to the key components of sustainability, including Sustainable Development Goals (SDGs). Climate-smart village (CSV) is one of the ways to scale up adaptation options. It combines institutional and technological solutions to address climate variability in agriculture through the use of participatory approach. The goal of CSV is to identify and improve the best CSA solutions that work best in the region. This would help policy makers, agriculture professionals and local and international investors to develop future agriculture strategies. The adoption of location-specific conservation strategies for water-efficient agriculture, including cover crops, in situ moisture conservation, rainwater collection, groundwater recharge, regionally adapted cropping systems can be promoted and the farmers can be provided with opportunities to demonstrate these technologies on their fields. Climate change initiatives such as INCCA, NAPA, NMSA, NICRA, NDMA can be integrated with ongoing national agricultural policies/programmes of food security, disaster management, natural resource conservation and livelihood promotion, to enable stakeholders to benefit from new technology and methods. A multi-intervention approach inclusive of crop management practices need to be adopted to promote climate resilient crops. The relevant officials can be sensitized about the diverse impacts of global climate change through trainings and capacity building programmes at regional level. The knowledge acquired on the various adaptation and mitigation measures need to be shared among the stakeholders via suitable platforms for wider acceptance and adoption. Digital agriculture through use of ICT and emerging technologies could play an important role in helping to adopt various climate smart interventions. A comprehensive CRA approach can contribute to achieving the sustainability agenda 2030's key goals, since many of SDG goals address climate change, agriculture production, conservation of natural resources and ensured food security.

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2. Climate Resilient Agriculture in India: Experience from National Innovations in Climate Resilient Agriculture (NICRA)

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The agriculture in India is highly vulnerable to climate change with 51 percent cultivated area under rainfed conditions. One or other part of the country is experiencing frequent extreme weather events causing sizeable loss to yield and income to the farmers at micro scale and to the Nation's economy at macroeconomic level. The smallholders (less than 2 ha) constitute 86.08 percent of the total numbers of the holdings in India. These small and marginal farmers are highly vulnerable to various stresses induced due to the changing climate. Mostly, cereals are the staple food of India, with the changing climate its production will be affected resulting in higher food prices. Increase in frequency and magnitude of heat waves, droughts, inland and coastal flooding, sea level rise and tropical cyclone etc. would decrease food stability and increases risk of food security. India is likely to lose 2.8 percent of its GDP because of climate change impact by 2050 and leads to significant reduction in living standards.

Climate change projections suggest that an increase in temperature by 2 to 3.5°C would reduce net agricultural income by 25 percent. Although an increase in carbon dioxide is likely to be beneficial to several crops, associated increase in temperature and increased variability in rainfall would considerably affect food production. The AR-5 of IPCC indicates a probability of 10 to 40 percent loss in crop production by the year 2080-2100. It is also evident through modeling studies that loss of 4 to 5 million tons in wheat production in future with every 1°C rise in temperature. Climate change is likely to aggravate the heat stress in dairy animals and adversely affect their productive and reproductive capabilities. A preliminary estimate indicates that global warming is likely to reduce milk production in India to the tune of 1.6 million by 2020. Increasing sea and river water temperature is likely to affect fish breeding, migration and harvest. Indian coastline, which is about 7,517 km, is vulnerable to climate change impacts such as water intrusion and coastal salinity. A rise in temperature as low as 1°C could have a profound impact on survival and the geographical distribution of different fresh water &marine fish species. Therefore, it is very important for farmers and other stakeholders to adopt climate resilient technologies and reduce the losses. Simple adaptations such as change in planting dates and crop varieties could help reduce the adverse effects of climate change to some extent. In the recent past increased extreme weather events have been experienced in some or other parts of the country viz., droughts (2000-2004, 2006, 2009, 2011, 2012, 2014 & 2015), floods (2005, 2006, 2012, 2014 & 2015), cyclones (2012, 2015), heat wave (2003, 2004, 2005, 2007, 2010 & 2016), cold wave (2005, 2006, 2008, 2011, 2012, 2013 and 2017), hailstorm (2014, 2015). Increased number of mid-season droughts and high intensity rains that take away fertile soil leading to water stress reduced food production, stability and livelihoods of the farmers in the country. Small changes in temperature and rainfall would have significant effect on the quality of cereals, fruits, aromatic and medicinal plants. Pests and diseases are highly dependent upon temperature and humidity, and therefore will greatly be influenced by climate change. The recent outbreak of whitefly on cotton in northwest India and pink bollworm at several cotton growing areas of the country is attributed to aberrant changes in weather. Therefore, it is evident that climate change has become an important area of concern for India to ensure food and nutritional security for growing population. To meet the challenges of sustaining domestic food production in the face of changing climate and generate information on adaptation and mitigation in agriculture to contribute to global fora like UNFCC, it is important to have concerted research on this important subject. With this background, Indian Council of Agricultural Research (ICAR), under the Ministry of Agriculture and Farmers Welfare launched a network '*National Innovations in Climate Resilient Agriculture*' (NICRA) during the year 2011. NICRA aims to evolve crop varieties tolerant to climatic stresses like floods, droughts, frost, inundation due to cyclones and heat waves. 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 Chamber (CTGC), high performance computers, automatic weather stations, growth chambers, rainout shelters, animal calorimeter, shipping vessel, flux towers and satellite receiving station were established in the research institutes across the country under NICRA project.

Technology Demonstration Component (TDC) under NICRA aims to demonstration of location specific practices and technologies to enable farmers cope with current climatic variability. Demonstration of available location-specific technologies related to natural resource management, crop production, livestock and fisheries is being taken up in the climatically vulnerable districts for enhancing the adaptive capacity and resilience against climatic variability. Technologies with a potential to cope with climate variability are being demonstrated under Technology Demonstration Component (TDC) in 151 most vulnerable districts selected across the country through KVKs.

Institutional intervention Component under NICRA aims at creating enabling support system in the village comprising of strengthening of existing institutions or initiating new ones (Village Level Climate Risk Management Committees (VCRMC)), establishment and management of Custom Hiring Centers (CHCs) for farm implements, seed bank, fodder bank, creation of commodity groups, water sharing groups, community nursery and initiating collective marketing by tapping value chains. 100 CHCs for farm machinery were setup under NICRA project, which are being managed by VCRMC comprising of villagers. Module on use of ICT for knowledge empowerment of the communities in terms of climate risk management is also being planned in select KVKs for generation of locally relevant content and its dissemination in text and voice enabled formats. 151 KVKs associated under NICRA projects have also taken initiatives such as participatory village level seed production of short duration, drought and flood tolerant varieties, establishment of seed banks involving these varieties were established in the KVKs, demonstration and of improved varieties of fodder seeds and establishment of fodder bank in NICRA villages. Details on the research under this project is as under.

Climate smart crop varieties

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 redgram wild 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 was developed for identifying QTL for various abiotic stresses in these crops for utilization in Maker Assisted Selection (MAS) breeding.

Natural resource management

GHG emissions (CO_2, CH_4& N_2O) due to implementation of climate resilient interventions in various production systems (annual and/perennial crops, irrigated rice, inputs, livestock, forestry and land use change) were converted to an equivalent value (tonne CO_2 equivalent) in 7 villages of Gujarat and Rajasthan, which were found to be negative suggesting a sink in GHG emissions. Direct-seeded rice (DSR) with mungbean residue incorporation, brown manuring (BM) with *sesbania,* rice residue retention (RR) in zero till (ZT) wheat/*rabi* crops are important conservation agriculture (CA) practices. It was observed that mung bean residue (MBR) + DSR – ZTW – ZT summer mung bean (ZTSMB) gave highest system productivity, net return, water productivity and low GWP. In long term efforts to assess CA practices on productivity enhancement, nutrient use efficiency, soil health and quality, it was observed that seed (3.8 t ha^{-1}) and stover (5.6 t ha^{-1}) yields in maize in CA were on par with conventional system. Also, significantly higher grain (5.3 t ha^{-1}), stover (6.5 t ha^{-1}) yields and harvest index (0.44) were realized with balanced fertilization with NPKSZnB. Analysis of Resource Conservation Technologies (RCT) in NEH zone indicated that Conventional Tillage (CT) has higher cumulative soil respiration (> 18%) compared to zero tillage. Agroforestry offset carbon dioxide from atmosphere is 0.77 tons of $CO_2 ha^{-1}$ $year^{-1}$and agroforestry system are estimated to mitigate 109.34 million tonnes CO_2 annually from 142.0 million ha of agriculture land. Further, it is estimated to offset 33 per cent of total GHGs emissions from agriculture sector annually at country level. The net eco-system methane exchange during rice growth period was the highest between active tillering to maximum tillering stage in rice. The diurnal variations in mean Net Eco-system Exchange (NEE) in submerged rice eco-system in both dry and wet seasons varied from + 0.2 to - 1.2 and + 0.4 to - 0.8 mg CO_2 m^{-2} s^{-1}. The cumulative seasonal methane emission was reduced by 75% in aerobic rice as compared to continuously flooded rice. The seasonal emissions were lower in slow-release N fertilizer, especially, when applied on the basis of Customized Leaf Colour Chart (CLCC). Zero tillage in wheat lowered the GWP as compared to tilled wheat. Similarly, CO_2, CH_4 and N_2O fluxes were influenced by tillage / anchored residue and anchored residues of 10 and 30 cm in zero till reduced the N_2O emissions in rainfed pigeonpea-castor system. In efforts on 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 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. GHG emissions quantified from Conservation Agriculture (CA)–15-20 percent reduction, RCTs (Biochar, zero tillage, reduced tillage, mulching etc.). C Sequestration in different agroforestry systems (16-22 t C ha^{-1}).

Greenhouse gas emission from agriculture and allied sector

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. Facilities like, Eddy Covariance towers are established at IARI, New Delhi and National Rice Research Institute (NRRI), Cuttack for continuously monitoring the GHG emissions from the crop fields during growing season so as to quantify precisely the extent of GHG emissions from the paddy systems. Research Facilities like Rainout shelter, Carbon dioxide Temperature Gradient Chamber (CTGC), Free Air Carbon Dioxide Enrichment (FACE), Free Air Temperature Enrichment (FATE) etc. have been established to understand the impact of elevated carbon dioxide (eCO_2) and temperature and develop crop varieties that can withstand these stresses. Practices which can further reduce the GHG emissions such as improved systems of paddy cultivation, fertilizer management, improved fertilizer materials, crop diversification, etc. are explored for further reducing the GHG emissions from the paddy-based systems. The proven mitigation practices, which can reduce the GHG emissions, are being demonstrated to farmers as part of the TDC of NICRA. The TDC of NICRA is being implemented in 121 climatically vulnerable districts of the country by taking one or cluster of villages in each of the vulnerable district.

Location specific, crop specific mitigation practices such as system of rice intensification, direct seeded rice cultivation (dry and wet methods of cultivation), soil test based fertilizer application, rational application of nitrogen, integration of trees especially fruit trees in the arable systems, efficient irrigation systems such as drip method and sprinkler method of application which can reduce the energy use while irrigating field crops, demonstration of zero tillage cultivation as an alternate to burning crop residues in rice-wheat systems of Punjab and Haryana where large quantities of rice residues are being burnt, integration of green manure crops in the existing cropping systems, promotion of green fodder crops and greater use of green fodder for livestock, etc. are being demonstrated as part of the technology demonstration component of NICRA in the 121 climatically vulnerable districts of the country. 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.

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 behavior 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 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.

Livestock

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 Mizoram are 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 behavior, 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 farmers 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.

Fisheries

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.

Micro level agro-advisory

Under ICAR-NICRA project a concept of micro level Agromet advisories at block level was developed and on a pilot basis with the help block level forecasts provided by IMD, Agrometeorologists of AICRPAM cooperating centers and KVK subject matter specialists initiated in 25 selected blocks in 25 selected districts. AICRPAM introduced a new concept "Field Information Facilitators (FIFs)" who acts as the interface between the farmer and AICRPAM and KVK for Crop data collection and dissemination of MAAS.

The Dissemination mechanism was strengthened with different methods used by the AICRPAM centers viz. Dandora, pasting posters at different important places where people frequently watch, through SMS to the mobile phones of the farmers who are registered with AICRPAM center and KVKs. Special mobile applications were also developed by AICRPAM centers for dissemination of AAS. The feedback obtained from the farmers stated that many of them were satisfied with the timely Agromet advisories which are benefitted them a lot. some of the success stories presented below. In reality expansion of these services throughout the country will benefit of farming community and helps in doubling of their income.

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
- GHG inventory by NICRA partner institutes contributes to BUR reports
- 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.

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.

Conclusion

NICRA is a unique project, which brings all sectors of agriculture viz. crops, horticulture, livestock, fisheries, NRM and extension scientists on one platform for addressing climate concerns. It is very important to sustain the efforts made in the past few years and take forward the project for some more years. Over the past five years, the state-of-the-art infrastructure facilities have been established, standardized and put in to function in core institutes of ICAR to undertake the climate change research. Manpower (Scientists, Research Associates, Research Fellows, Technical Officers etc.) have been trained to handle and operate these facilities. However, some of these precious research facilities are yet to be utilized to the full potential. In other words, a large platform related to climate change research has been created in the country. 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. Whereas, many are under different stages of development which may require few more years to be released as variety/hybrid/breed. Simulation modeling to assess the impact of climate change at regional level is still at initial stage. Standardization of minimum data sets and compilation of data from different sources have shown good progress. In the next phase, these data sets will be used for modeling. Capacity building for this activity will be emphasized and a dedicated group will be formulized. Research, essentially long term in nature, should continue further to achieve the intended outputs and outcomes.

Though there are some positive lessons and experiences emerging out of technology demonstration component, there is still considerable need to continue this activity to identify and demonstrate technologies that help deal with climate change. 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.

The commitments of the country to emission reductions require generate appropriate information and data on emissions as well as options that help reduce emissions. Techniques standardized so far under NICRA for estimation of GHG emissions from different management practices will be used for further reducing the carbon footprint of production systems in the country. Government of India has committed for the reduction of emission intensity of GDP by 32-35 percent 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. The system-wide impacts and responses to climate change need to be understood better and more comprehensively. The efforts in this direction, which have begun, recently have to be taken through their logical course for such an understanding is necessary to identify and prioritize various adaptation options. To sum up, the activities initiated few years back under NICRA should 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.

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3. NRM Interventions to Enhance Crop Productivity and Farmers Income in Rainfed Agriculture

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In every year, about 75 billion tons of soil is eroded from the arable lands across the globe and mostly agricultural land is losing around 13.0 to 40.0 t ha^{-1} y^{-1} and it is faster than the rate of renewal of soil (Borrelli *et al*., 2017). Generally, soil degradation occurs naturally but human interference can accelerate the soil degradation and its associated impacts on crop production (Rickson *et al*., 2015). In India, 53.0 percent of total geographical area suffers from soil erosion with an average rate of 16.0 t $ha^{-1}y^{-1}$ (Prasannakumar *et al*., 2011). Out of 120.72 M ha degraded land in the country, 82.57 M ha is deteriorated due to water induced erosion (Biswas *et al*., 2019). Runoff water removes the fertile top soil, carries it to the downstream and finally results in the sedimentation of drainage channels and waterbodies which in turn reduces the storage capacity. The loss of fertile top soil adversely affects the root growth, moisture storage, crop yields and leads to ecological collapse. Soil erosion is a widespread form of land degradation and planning and adoption of suitable management strategies to control the erosion is important. Soil erosion depends on various factors like rainfall, soil type, vegetation and land use/land cover. Mechanical as well as vegetative measures are generally used as soil and water conservation measures to control the soil erosion.

Rainfed agriculture

Out of 140.30 m ha net cropped area in India, nearly 83.90 m ha is the net rainfed area and the remaining 56.40 m ha is the irrigated area. In India, rainfed agriculture contributes 40 percent of the food, supports 40 percent of the population and 60% of livestock and these agro-ecosystems are low in farm productivity (Rao *et al*., 2017). In semi-arid regions, the mean annual rainfall ranges from 400 to 1000 mm, and is highly uncertain and erratic. As a result, prolonged dry spells are common in drylands, results in reduction of crop yield or even crop failure. These semi-arid regions are subjected to medium to high soil erosion which carries away the fertile top oil and it further reduces the crop productivity. Climate change is another phenomenon which is having severe impact in the drylands and it is expected to increase the surface temperature, high intensity rains and may decrease the number of rainy days in many parts of the country

(Rao *et al*., 2017). In this chapter, an attempt is made to summarize some important in-situ moisture conservation technologies, water harvesting and its efficient use for the development of agricultural systems and for improving its production and productivity.

Soil and water conservation interventions for enhancing crop productivity

Broadly, the *in-situ* soil conservation measures are classified into soil management practices and land management practices. The soil management practices are temporary in nature which may last for one crop season and could be taken up by farmers themselves or with the support from developmental programmes. The land management practices are semi-permanent in nature and need involvement of external agency for planning and implementation. Common soil management practices include conservation furrows, mulching, ridging, sowing across slope, tied ridges, tillage, BBF, soil amendments like tank silt etc. and land management practices include contour bunds, field bunds, khadins, graded bunds, small basins, terraces, lock and spill drains, stone bunds etc. Some land management practices like contour bunds, field bunds need arrangement to harvest runoff on slopes. The various vegetative measures for reducing the sediments and nutrients losses are vegetative filter strips, riparian forest buffer, conservation cover, contour buffer strips, alley cropping, and grassed waterways. Live-bunds or vegetative barriers are the alternative biological measures, which effectively conserves soil and water by moderating the surface runoff and allowing them increased infiltration time (Krishna Rao *et al*., 2022). Under raised bed planting, chickpea grain yield increased by 15.9 percent to 16.8 percent over flatbed techniques (Pramanik *et al*., 2009).

Broad Bed and Furrow System

Broad bed and furrow system involve preparation of broad bed of 90-120 cm, furrow of 45 cm and sowing of crop at a row spacing of 30 cm. During high rainfall events, BBF drains the excess water through furrows, and during scarcity period, it stores the water and increases the moisture availability. BBF technique is a climate smart technique for growing of soybean and chickpea under rainfed condition in Marathwada Region and on-farm trials revealed that BBF system resulted in 35 percent more yield in soybean and 21 percent more yield in chickpea compared with farmers' practice (Asewar *et al*., 2017). Broad bed furrow (BBF) system for groundnut in Chickaballapur district of Karnataka increased the rainwater use efficiency and economic water use efficiency by 18.7 to 85.5 percent as compared to flatbed sowing (Singh *et al*., 2021).

Ridge-furrow system

The ridge-furrow system with alternate ridges and furrows is one of the innovative water-saving technologies which aim to drastically increase the precipitation use efficiency in rainfed farming systems of arid and semi-arid areas. Ridges and furrows are made across the slope at the onset of monsoon. The width of furrow is 45 cm and height is 20 cm. The ridge and furrow system performed better in medium as well as high rainfall areas. In high rainfall regions, this system serves as drainage as well as moisture conservation measure (Krishna Rao *et al*., 2022).

Conservation furrows

Conservation furrows is another promising technology in red soils receiving rainfall of 500-600 mm or more with moderate slope (0.2-0.4%) (Pratibha *et al*., 2017). A conservation furrow can be opened in between crop rows at 45 days after sowing to conserves the rainwater and reduces the soil and nutrient losses from crop fields. In the scarce rainfall zone of Andhra Pradesh, *in-situ* moisture conservation through opening of conservation furrows recorded 9 percent higher seed yield of pigeonpea (738 kg/ha) compared to control (Chary and Gopinath, 2022).

Compartmental bunding

Compartmental bunding for moisture conservation is very common in northern dry zone of Karnataka. Kharif cropping is not possible in medium to deep black soils and infiltration rate is low results in more runoff. Compartmental bunding involves preparation of 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 of 0.15 m height are formed using 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. Compartmental bunds provide more opportunity time for water to infiltrate into the soil and help to conserve more soil moisture (Reddy *et al*., 2022). In a study at Vijayapura, runoff in compartmental bunded plots was 6.8 percent compared to 15.6 percent in conventional practice (Chary and Gopinath, 2022).

Contour cultivation

Contour farming/contour cultivation is practiced on lands having a medium slope with permeable soils, where farming operations such as ploughing, sowing or planting are carried out along the contour. This system helps to reduce the velocity of runoff by impounding water in series of depressions and thus decrease the chance of developing rills in the fields. Even though contour cultivation is more effective on slopes ranging 2 and 10 percent, it can be practised in steep slopes also. Contour cultivation is difficult to adopt in small and narrow fields. In such cases, cultivation across the slope is a viable alternative. Field bunds/contour bunds in Kalburgi district minimized the erosion and increased the yield of pigeonpea by 2.0 q/ha, and compartmental bunding in Gadag, Belgavi, and Kalaburgi districts increased the sorghum yield by 21 to 36 percent (Singh *et al*., 2021).

In-situ moisture conservation for tree crops and horticultural crops

In-situ moisture conservation for tree crops and horticultural crops include half-moon terraces, staggered trenches, reverse terraces, catch pits, tree base terracing, continuous terraces etc. Adoption of modified crescent bunds and coconut husk burial for cashew garden grown on steep slopes reduced the annual runoff to 22.3 and 20.4 percent of the annual rainfall compared to 36.9 percent of the annual rainfall in control, reduced the soil loss (47 and 49% of control) and nutrient loss. It increased the mean soil moisture content, growth of plants, yield of cashew (6.45 and 6.60 t/ha respectively compared to 4.88 t/ha in control for the first 5 harvests) and net profit from cashew garden (40% more than control) (Rejani and Yadukumar, 2010).

Mulching

Mulches reduce the impact of rain drops on soil surface, reduces evaporation, control weeds and reduces soil temperature in hot climate. Crop residue management or mulching increases the infiltration capacity of the soil, percolation, moisture holding capacity of the soil, organic carbon content and soil texture in rainfed regions. The application of gliricidia loppings in rainfed areas improved the water holding capacity of the soil, reduced the soil erosion and improved the nutrient status of the soil (Yadukumar *et al*., 2008; Rao *et al*., 2011).

Water harvesting and supplemental irrigation

In drylands, the evapotranspiration exceeds the available rainfall which in turn results in over-exploitation of groundwater resources for irrigation. Under changing climatic scenarios, the rainfall is predicted to be more erratic with high intensity rainfall events and prolonged dry spells in many parts of the country. Increase in atmospheric and surface temperatures increases the evaporation rates of water from the earth's surface which in turn increases the crop water requirement. But the high intensity rainfall of short duration can result in high runoff potential which may not be able to conserve in the soil profile. In this case, water harvesting structures like farm ponds, percolation tanks and check dams could be constructed to harvest the runoff water and use it for supplemental irrigation. The efficient utilization of farm pond water could be done with the adoption of drips, sprinklers, rainguns etc. The application of harvested farm pond water by efficient water application methods like drip and sprinkler increased the water use efficiency, area under irrigation and finally the crop yield. Rao *et al*., 2019 studied the impact of farm ponds in Anantapur and Chittoor districts of Andhra Pradesh and Adilabad in Telangana and found that the profitability from farm pond was higher in Adilabad receiving higher annual rainfall with 69 percent of ponds generating an additional income of more than Rs. 20000 per year as compared to 8 percent in Anantapur with less annual rainfall. Singh *et al*., 2021 reported the impact of life-saving irrigation from water harvested in farm ponds, check dams, and community ponds for saving the crops from dry spells of more than 20 days in Northern Karnataka and it increased the crop yields by 25 to 54 percent compared to unirrigated fields. In rainfed alfisols, the combined use of supplemental irrigation and application of soil amendments such as tank silt or compost can contribute significantly towards greater productivity (Reddy *et al*., 2022).

Advanced techniques to plan interventions

Identifying suitable soil and water interventions using survey for large areas is a time-consuming task and, hence, planning of soil and water conservation interventions and water harvesting structures can be done using geospatial techniques. Many researchers reported that geospatial technology has immense potential in site suitability studies for water harvesting structures (Rejani *et al*., 2017; Tiwari *et al*., 2018). For planning of site-specific in-situ soil and water conservation interventions, selected thematic layers was intersected and the criteria pertaining to each intervention was applied in GIS for identifying the suitable locations. This methodology was applied for identifying the suitable locations of different *in-situ* soil and water conservation interventions and was validated for Western Vidarbha zone of Maharashtra and Northern dry zone of Karnataka (Rejani *et al*., 2022a; Rejani *et al*., 2022b). Adoption of interventions could be prioritized based on the vulnerability of the area to soil erosion.

Conclusion

This chapter deals with different in situ soil and water conservation interventions and water harvesting technologies adopted in semi-arid regions of India and its impacts on crop productivity. In low rainfall areas, in situ moisture conservation is priority.

Wherever, runoff exceeds the storage that could be handled by in situ moisture conservation techniques, adoption of water harvesting structures for irrigation or groundwater recharge needs to be adopted. The water harvesting structure, farm pond could be considered as a simple climate resilient technology coupled with in-situ moisture conservation in rainfed agriculture and can be adopted by individual farmers and was found to be more profitable in black soils. Also, site specific planning and implementation of different *in-situ* moisture conservation interventions and water harvesting technologies are very essential.

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4. NRM Interventions in Dryland Horticulture

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Dryland farming systems do not use irrigation but depend on precipitation to meet crop requirements. For this reason, it is essential that the producer first evaluate the effect of conversion from irrigated to dryland farming based on crop yields, crop production costs, and farm profits from neighbors in similar geographical and climatic contexts in order to assess associated risks. This assessment will help the producer determine how much of their land to transfer and its feasibility in relation to type of crop, crop yield, production costs, and total potential profit. The most common dryland crops are pasture and small grains, however, row crops such as sorghum, corn, or cotton may also withstand dryland farming depending on geographical location. Record keeping will help the producer monitor changes over time in order to assess long term risk and economic feasibility.

Indian agriculture is predominantly a rainfed agriculture under which both dry farming and Dryland agriculture included. Dryfarming was the earlier concept for which amount of rainfall (less than 500 mm annually) remained the deciding factor for more than 50 years. In modern concept, Dryland areas are those where the balance of moisture is always on the deficit side. In other words, annual evapotranspiration exceeds precipitation. In Dryland agriculture, there is no consideration of amount of rainfall. It may appear quite strange to a layman that even those areas, which receive 1100 mm or more rainfall annually, fall in the category of Dryland agriculture under this concept. To be more specific, the average annual rainfall of Varanasi is around 1100mm and the annual potential evaporation is 1500mm. Thus, the average moisture deficit so created is bound to affect crop production under Dryland situation ultimately leading to total or partial crop failure. Accordingly, the crop production is either low or extremely uncertain and instable which are the real problems of dryland.

The success of crop production in these areas depends on the amount and distribution of rainfall, as these influences the stored soil moisture and moisture used by crops. The amount of water used by the crop and stored in soil is governed by the water balance equation: $ET = P - (R + S)$. When the balance of the equation shifted towards right, precipitation (P) is higher than ET, there may be water logging or it may even lead to runoff (R) and flooding. On the other hand, if the balance shifts towards left, ET becomes higher than P, resulting in drought of various severities. In fact, the balance of the equation is controlled by the weather, season, crops and cropping pattern.

About 95 mha (67%) cropped area is rainfed, which account for 44 percent of food grain basket of the country. Water is one of the most important natural resources vital for economic development of a nation. The per capita per annum water availability presently at the level of 2001 m^3 will reduce to the stress level of 1700 m^3 in the next 2-3 decades. Source of all water is precipitation. The average annual rainfall over the Indian sub-continent has been estimated at 1200 mm. On this basis annual precipitation including snowfall in estimated at 400 m.ha.m (4000 km^3). However, the distribution across the country varies from less than 100 mm in extreme arid areas of western Rajasthan to greater than 3600 mm in the NE states and 1000 mm from east coast to 2500-3000mm in the west coast. Table 1 shows the details information on rainfall and monsoon pattern in India. About 300 m ha m of this resource is generated during June to September and another 100 m ha m is during rest of the year.

The present irrigation potential of the country is 33 percent. Even if ultimate potential is utilized in next decade, about 50 percent of the area will still remain rainfed. The current food production of the country is about 200 million tons, which has to be increased to 300 m tons by 2020 to feed growing population. There is no scope to expand the cultivated area due to various human activities. Future requirement has to be met through vertical growth by intensification as well as diversification of agriculture. Sustainable cropping pattern including legumes, trees, high value crops like vegetable as well as fruits, and animal as a component are being developed for different parts of the county.

Table 4.1: Rainwater availability

Season/Period	M.ha.m	Percent
Winter (Jan-Feb)	12	03
Pre-monsoon (March-May)	52	13
South-West monsoon (June-Sept)	296	74
North-East monsoon (Oct-Dec)	40	10
Total	400	100

It has now been recognized that handy horticultural crops must be incorporated into cropping system in dryland. Vegetable farming in our country has been an age-old enterprise of small and resource poor farmers who represent the major share in dry land areas. Because of quick growing and short duration characters, vegetable crops easily fit in the system well. Owing to perennial nature and deep root system of fruit trees, these are able to utilize the moisture commonly stored in deeper soil profile, they easily adapt to the marginal agro-ecological conditions such as undulating uplands, gullied and ravined lands, mining and industrial waste lands and poor sandy plains and can thus ameliorate the degraded ecology. On proper establishment fruit trees sustain the income of growers by providing permanent and assured income from fruits, fuel wood, and fodder. The trees also provide nutritive product to alleviate the problem of malnutrition and improve health standard of the people.

Nearly two third of a total of 169.65 mha land under arable area and permanent crops in India is rainfed. The productivity of horticultural crops in dryland is, however, very low, extremely irregular, and variable depending upon the extent and pattern of rainfall. Besides water scarcity the other production constraints in drylands are;

1. Abiotic stresses due to extremes temperature and atmospheric humidity,
2. Biotic stress due to damage caused by wild animals, rodents birds, insect, and diseases
3. Poor, degraded and marginal soil condition
4. Difficult condition to execute agro techniques, and
5. Difficulty in post-harvest handling and marketing owing to limited and inefficient transport and market infrastructure.

Scientific management for efficient utilization of the resources, particularly water, can significantly improve and stabilize the productivity of horticultural crops in drylands.

Selection of crops

In dryland areas, crops should be able to complete maximal vegetative growth and reproductive phase during the period of maximum water availability. During the monsoon up to September starting from May in south India and from July in North India, soil and atmospheric moisture stress is low. The fruits such as ber, guava, pomegranate, custard apple, Indian gooseberry and sour lime, depending upon the aridity of location, conform to this prerequisite. The crops must have xeric characters, *eg.* deep root system (as in mango, ber, walnut), summer dormancy (as in ber), high bound water in the tissues (as in cactus, pear, fig), reduced leaf area (as in Indian gooseberry), leaf surface having shrunken stomata, thick cuticle wax coating and pubescence (as in fig, ber, phalsa, tamarind), and ability to adapt shallow soils, rocky, gravelly, and undulating wastelands (*eg.* pomegranate, anola, cashew, *Buchanaria lanzan*). In high rainfall areas, crop selection is based on the resistance to disease and pests owing to high humid conditions and adaptability to water stagnation (Table 7.2).

Table 4.2: Fruit crops for drylands in different rainfall zones

Rainfall (mm)	Plains	Plateaus and sub mountain regions
>500	Kherji, Ber, Phalasa, Indian Fig, Karonda, Ker, Gonda or lasoda, Jhaber	Custardapple, Bael, Karonda, Ber, Ker, Jhaber, Jamun, Pilu
500-1000	Ber, Aonla, Jamun, Wood apple, Custard apple, Mahua, Wild datepalm, Indian Almond, Guava, Sour Lime, Lemon, Mango, Tamrind	Doula, Bach, Ber, Custard apple, Chironji, Wood apple, Karonda, Indian Almond, Mango, Sour Lime, Lemon, Grape fruit, Pomegranate
>1000	Mango, Litchi, Jack fruit, Mandarin, Avaocado, Tamarind, Jamun, Mahua, Kokum	Mango, Jack fruit, Guava, Tamarind, Mahua, Cashewnut, Chery, Pomegranate

Vegetable crops for dryland

Among the vegetable crops, bottle gourds (*Lagenaria siceraria*), ridge gourd (*Luffa acutangula*), sponge gourd *Luffa cylindrica*), water melon (*Citrllus lanatus*), round melon (*Citrulus lantus* var. fistulosus), long melon (*Cucumis melo* var. utillisimus), bitter gourd (*Momordica charantia*), snap melon (*Cucumis melo* var. momordica), kachari (*Cucumis callosus*), Arya (*Cucumis sp.*), drumstick (*Morinqua deifera*), cluster bean (*Cyamopsis tetragonoloba*), cowpea (*Vigna unguiculata*), okra (*Abelmoscous esculentus*), amaranth (*Amaranthus sp.*), brinjal, chilli and tomato are common.

Selection of varieties

Cultivars differ in their adaptability to different climatic condition. Varietal variation in endurance to drought has also been observed in horticultural crops. Early ripening cultivars seem to escape stress conditions caused by receding soil moisture stored in the soil during monsoon. Suitable cultivars of some fruits and vegetable crops have been identified (Table 7.3).

Ber cultivars such as Gola, Seb and Mundia for extremely dry area, Banarasi Karaka, Kaithli, Umeran and Maharawali for dry regions and Sanaur - 2, Umran and Mehrum for comparatively humid regions have been recommended (Anonymous, 1985). In northern India Gola ripens earliest; Kaithli and Mundia are mid-season cultivars, and Umran is a late cultivar (Anonymous, 1983). Anola varieties selected for drylands are Kanchan, Krishna, NA-6 and NA-7. Selected cultivars of bael such as Narendra Bael-5 and

Narendra Bael-9 have medium sized fruit with smooth surface, yellow skin, moderate fiber and soft flesh.

From the vast area under wild plantation of custard apple, good plant types such as Balanagar, Maumoth and Red Sitaphal have been selected. Some interspecific (Red Sitaphal x Maumoth) and interspecific (Pinks Maumoth x Balanagar and Bullock's Heart x Red Sitaphal or Balanagar) hybrids are considered promising because of high yield of fruits, low seed content and long shelf life eg., Arka Sachan (Anonymous, 1991). Cultivars of some fruits have been identified as drought resistant, eg. Balanagar – Mango; Kohir Safed and Safed Jam – Guava; Gola, Seb, and Mundia – Ber; Chakaiya – Anola; Muskat, Ganesh, Baseein seedless and Jalor seedless – Pomegranate and Balanagar–Custard apple.

Planting

The planting system to be adopted in dryland depends largely upon the topography of the land, fruitt species and soil type. In the plains, planting is generally done is square or rectangular system. On sloppy lands, fruit trees are planted on contour terraces, trenches and bunds, and micro-catchments. The trenches and bunds made across the slope are staggered. In micro-catchments, which may be triangular or rectangular, trees are planted at the lowest point where runoff accumulates. The spacing between rows and trees in such a runoff harvesting system has to be suitably varied and adjusted. The plant density will obviously vary depending largely upon the extent of rainfall, which influences runoff quantity.

Water management

Orchard soil moisture status, particularly during fruit development period, greatly affects productivity of the trees. Under dryland conditions, such measures as water harvesting, mulching and weed control are adopted to maintain optimum moisture availability in the root zone of the trees.

Water harvesting

Water supply to the plant can be improved by water harvesting using *in-situ* or *ex-situ* system. It has been observed that micro catchment slope greater than 5percent did not significantly affect runoff at Jodhpur and that the highest ber yields were obtained when 0.5 percent and 5 percent slopes had 8.5 m and 7m length of run, and 72m^2 and 54 m^2 catchments area per trees, respectively (Sharma *et al.* 1982, 1986). A good number of fruits such as fig, almond, plum, olive, pomegranate, pistachio, peach, apricot, grape wine, sour and sweet cherries and apple have been cultivated in micro-catchments in Avdat and Shivta highlands under rainfall pattern of Israel (Evenari *et al.* 1971). Work done at Aruppukottai (Tamilnadu) and Anantpur (Andhra Pradesh) has indicated usefulness of *in-situ* water harvesting technique for fruit production (Anonymous, 1989).

At Hyderabad, micro-reliefs of 3 m width and 25cm height, spaced 9m from ridge to ridge, have been used to store extra rainwater for fruit trees such as kagzi lime, coorg mandarin, and sweet orange with tomato and okra as intercrops (Singh and Vishnumorthy, 1988).

The hilly, rocky and aggraded lands can generate runoff for cultivation of fruits and vegetables. In nearby watersheds, the runoff can also be collected in small or large ponds and recycled for irrigation at critical stages of plant growth and development.

Mulching

Intense aridity in dry regions causes considerable evaporative losses. Mulching with organic materials (eg. hay, straw, dry leaves and local weeds) has been found highly beneficial in reducing these losses. The practice also suppresses weed growth, prevents erosion and adds organic matter to the soil (Gupta, 1995). Black polythene mulch is very effective in western India (Anonymous, 1989). Although, local organic mulch materials are cheaper than polythene mulches, these require proper care to maintain effective cover thickness. Leaf mulch has been used to conserve soil moisture in Sapota orchards in Karnataka, Tamil Nadu and Andhra Pradesh. Sugarcane trash mulch is pomegranate fig and custard apple was found effective in Maharashtra (Anonymous 1989). At the Indian Institute of Horticultural Research (IIHR) Bangalore, mulching the tree basins could considerably reduce fruit cracking in litchi.

Table 4.3: Popular cultivars of fruit and vegetable crops in drylands of India

Crop	Cultivars
Fruit	
Ber	Gola, Mundia, Kaithi, Banarasi Karka, Early Umran
Aonla	Kanchan, Krishna, Balawant, NA-6, Na-7
Pomegranate	P-23, P-26, IIHR Selection, Mridula
Custard apple	Balanagar, Maumoth, Red Sitaphal, Arka Sahan
Guava	Allahabad Safed, Sardar, Kohir Safeda, Safed Jam
Papaya	Pusa Delicious, Honey Dew, Pusa Mejesty, Pusa Dwarf, Pusa Gaint
Bael	NB-5, NB-9
Sapota	Kalipatti, Cricket Ball

Fig	Poona, Blackqschiq
Mango	Banglora, Neelum, Kesar, Bombay Green
Sweet orange	Mosambi, Kodur Sathgudi, Valencia, Blood Red, Malta
Lime	Tenali, Promalini, Vikram
Tamarind	PKM-1, Pratisthan, Yogeshwari.
Vegetables	
Tomato	Pusa Ruby, Pusa Early Dwarf, Puas-120, Sweet-72, S-12, Mangala, Punjab Chhuhara
Chilli	Pusa Jwala, Mathania, Sindhur, Pant C-1, Arka Mohini, Arka Gauraav, Arka Basant, Bharat, Indira
Cowpea	Pusa Dofasali, Pusa Phalgumi, Pusa Barasati, Pusa Rituraj
Cluster bean	Pusa Sadabahar, Pusa Mausami, Pusa Navbahar, Durga Bahar
Brinjal	Pusa Purole Long, Pusa Purple Round, Pusa Kranti, Pusa Anmol, Arka Shhel, Arka Kusumakar, Arka Navnnet
Radish	Arka Nishant.
Pumpkin	Arka Chandan, CO-1, CO-2
Amaranthus	Choti Chaulti, Badi Chaulai, CO-1, CO-2
Okra	Pusa Makhamali, Panjab Padmini, Parabhani Kranti, Arka Anamika
Muskmelon	Pusa Sharabati, Pusa Madhuras, Hara Madhu, Punjab Sunheri, Durgapur Madhi
Water melon	Sugar Baby, Arka Manik, Arka Jyoti Kesar, Durgapur Meetha
Bottle gourd	Pusa Summer Prolific Round, Pusa Summer Prolific Long, Pusa Meghadoot, Pusa Manjari, Pusa Naveen
Bitter gourd	Arka Harit, Pride of Gujarat, Pusa Do Mausami
Ridge gourd	Pusa Rasadar
Sponge gourd	Pusa Chikani
Round melon	Arka Tinda
Drumstick	PKM-1
Onion	Arka Niketan, Arka Kalyan, Pusa Red, Nasik Red, Pusa Ratnar, Pusa White Round, Pusa White Flat, Patna Red, Arka Pitambar (for export).

Anti-transpirants

Transpiration losses can be reduced using:

Radiation reflectants: Spraying 4-6 percent Kaolin or 0.5-1.0 percent liquid Paraffin or 1.5 percent Power oil - reduced plant water losses. (Pareek and Sharma, 1991).

- Stomata closing chemicals:
- Phenyl mercuric acetate (PMA)
- Decinyl succinic acid (DSA)
- Abscisic acid (ABA)
- Acetyl alcohol,

Cause stomata closer and reduced transpiration (Jones and Mansfield, 1971; Chundawat, 1990). Plastic films Shelter belt and wind breaks can reduce evapotranspiration by reducing wind speed and stabilizing microclimate (Muthana *et al*., 1984).

Weed control

Special significance in rainfed orchards in reducing soil moisture losses. Harrowing between tree rows after first rain is most beneficial. Timely weeding is essential to improve fruit quality even in high rainfall region. Application of pre-emergence weedicides – Diuron, Bromacil and Atrazine @ 2 - 3 kg ha^{-1} (Pareek and Vishal Nath 1996).

Nutrient management

Application of organic manure at pit filling. In low rainfall areas-application should coincide with rains. N application in 2-3 splits doses at critical stages.

In Ber orchards

- 10-15 Kg organic manure + annual application of 100 g N, 50 g P_2O_5 and 50 g K_2O per tree.
- Fertilizer doses should be raised with the age of plants and soil fertility of region.
- 15-20 Kg FYM per tree – found beneficial in Anola, Custard apple and tamarind At MPKV, Rahuri – In addition to 50 Kg FYM, 625g N, 225g P_2O_5 and 225g K_2O to 5 year old Pomegranate tree (Anonymous, 1983).
- In 6-7 years, old Fig trees planted at 5 m x 5 m fertilization of 900g N + 250g K improved fruit production (Anonymous, 1985).
- At Banglore – 500g N + 250g P + 125g K produced 6 times higher yield than control (Anonymous, 1989).
- Micronutrients – Often deficient in semi-arid and arid soil. Foliar feeding of nitrogen (0.5-2.0 % urea), Zinc (0.05-1.0 % $ZnSo_4$), and boron (0.05-1.0 % borax) has given beneficial results in these areas (Pareek and Sharma, 1991).
- Salinity and alkalinity – Pose problems in some dryland areas. Runoff during rainy

season may be used to leach out these salts. In medium rainfall regions of eastern Uttar Pradesh FYM, pond soil, gypsum and pyrite in sodic soils resulted in better – Anola and bael plants (Pareek and Vishal Nath, 1996).

Cropping system

- Under drylands monoculture is risk prone due to crop failures.
- Suitable tree-crop combination, besides alleviating the risk, also generates extra income, improves productivity per unit area / volume as a result of efficient use of natural resources and inputs, and ameliorates and improve adverse agro-climate.
- Agri-horti combination with legume intercrops such as mungbean, moth bean, cluster bean and cowpea are beneficial.
- In rainfed orchards of guava and ber cluster bean, okra and cowpea in rainy season proved promising in medium rainfall region of Gujarat (Raturi and Hiwale, 1988)
- At Godhara - Cluster bean with ber gave a net return of Rs. 14,630 ha^{-1}. Brinjal and Chillies also good.
- At Hyderabad – Cowpea, mungbean and Horse gram in ber orchards and Bitter gourd, tomato and Okra in acid lime orchards.
- At Varanasi – intercropping high value crops (Okra) one row in 2 rows of Pigeon pea (60 cm) resulted in monetary advantage of Rs.17, 976 ha^{-1}.
- In areas with large livestock population – Horti-postural system is beneficial.
- In arid areas – Khejri (*Prosopis cineraria*) + ber + Dhaman (*Cenchrus ciliaris, C. setigerus*) or sewan (*Lasiurus sindicus*).
- In semi-arid areas – Perennial trees (mango, mahua, tamarind, sapota, jackfruit and palmyra palm) could be grown with fodder crops.
- Horti-silviculture – wood for packaging and fuel.
- In low rainfall (300-500 mm) zone – Khejri or ber or drum stick + vegetables.
- In 500-700 mm rainfall – mango or ber or anola or guava + pomegranate or sourlime or lemon or drumstick + solanaceous or leguminous or cucurbitaceous vegetables.
- In 700-1000 mm rainfall – mango or jackfruit or Mahua or Palmyra palm or tamarind or guava + sour lime or lemon or pomegranate or anola + vegetables

Pest and disease management

Wild animals, rodents, birds and insects (termites) create serious problem to green belts in drylands. Heptachlor dust (5%) in pits (50 g pit^{-1}).

1. Fruit fly (*Carpomyia vesuviana*) serious damage to ber

- First spray at pea stage 0.03 percent Monocrotophos.
- 2nd Spray 15 DAF 0.05 percent Fenathion.
- 3rd spray 15 DAS 0.1 percent Carbaryl XLR.
- If necessary, during fruit maturity weekly spray with 0.5 percent Malathion mixed with 0.5 percent gur or sugar. This schedule is also effective against fruit borer (*Meridarchis scyrodes*) in south & west.
- Collection and distribution of fallen fruits and digging soil under tree canopy decreases infestation.

2. Pomegranate butter fly (*Virachola isocrates*) damages fruits.
   - Bagging fruits with butter paper give good protection.
   - For control - 0.002 percent Deltamethrin and 0.2 percent Carbaryl 50 WP spray in rotation at 21-day intervals from fruit set.
3. Ber Powdery mildew
   - 0.01 percent Dinocap or Carbendazim or Triadeomorph or Thiophenate methyl and 0.2 percent Wettable sulphur 2-4 times at 15-20 day interval.
4. Black leaf spot (*Isariopsis indica*) found under more humid condition
   - 2-3 spray of 0.2 percent Captafol or Copper Oxyl-Chloride or Mancozeb and 0.1 percent Carbendazim at 15-day intervals.

- For control of leaf and fruit spot in pomegranate - Foliar spray with 0.25 percent Ziram and 1 percent Bordeaux mixture at 15-day intervals.
- For control of ring rust of Anola - 4 spray of 0.2 percent Chlorothalonil at 15-day intervals just after initiation of the symptoms.

Table 4.4: Classification of the regions on the basis of Aridity Index

Climate Zone	Aridity Ratio	% of World Covered
Hyper-arid	<0.05	7.5
Arid	0.05-0.20	12.5
Semi-arid	0.21-0.50	17.5
Dry sub-humid	0.51-0.65	9.9
Humid	>0.65	39.2
Cold	>0.65	13.6

Source: WMO-UNEP Report (1996): Interactions of Desertification and Climate

Table 4.5: Classification of rainfall zones in India

Classification of Rainfall	Zone	Net Sown Area (%)	Rainfall
Zones in India			
(RFin mm)			
<500	Arid	16	Very low
500-750	Semi-arid	17	Low
750-1100	Dry sub-humid	35	Medium
1100-1400	Moist sub-humid	24	High
>1400	Humid mountains	8	Very high

Source: Ramakrishna (1997)

Table 4.6: Climatic conditions in different regions

Region	Climate Type
Saurashtra, Kutchch, Western Rajasthan, Bellary (Karnataka), Anantapur (A.P.) and Tirunelveli (T.N.)	Arid
The area from Kanyakumari in the south to Punjab in the north, covering practically the whole of the Peninsula, east of western ghats and Gaya-Jumai area in Bihar	Semi-arid
Northern parts of Punjab, Harayana, Uttar Pradesh, Bihar, West Bengal, Orissa, Madhya Pradesh, Vidarbha and northern parts of A.P., and from Chennai to Nagapattanam (T.N.)	Sub-humid (moist or dry)
NE region, west coast and adjoining hills	Per-humid and humid zones

Table 4.7: Probability of occurrence of drought in different meteorological sub-divisions

Meteorological Sub-Division	Frequency of Deficient Rainfall (75% of normal or less)
Assam	Very rare, once in 15 years
West Bengal, Madhya Pradesh, Konkan, Bihar and Orissa	Once in 5 years
South Interior Karnataka, Eastern Uttar Pradesh and Vidarbha	Once in 4 years
East Rajasthan, Gujarat and Western Uttar Pradesh	Once in 3 years
West Rajasthan, Tamil Nadu, Jammu & Kashmir and Telangana Region of Andhra Pradesh	Once in 2.5 years

Source: Ministry of Statistics and Programme Implementation, Govt. of India. www.indiastat.com.

Table 4.8: Administrative districts frequently affected by drought

States	Districts
Andhra Pradesh	Anantapur, Chittoor, Cuddapah, Hyderabad, Kurnool, Mehaboobnagar, Nalgonda, Prakasam
Bihar	Munger, Nawadah, Palamau, Rphtas, Bhojpur, Aurangabad, Gaya
Haryana	Bhiwani, Gurgao, Mahendragarh, Rohtak
Jammu & Kashmir	Doda, Udhampur
Karnataka	Bangalore, Belgaum, Bellary, Bijapur, Chitradurga, Chickmangalur, Dharwad, Gulbarga, Hassan, Kolar, Mandya, Mysore, Raichur, Tumkur
Madhya Pradesh	Betul, Datia, Dewas, Dhar, Jhabuva, Khandak, Khargaon, Shahdol, Shahjapur, Sidhi, Ujjain
Maharashtra	Ahmednagar, Aurangabad, Beed, Nanded, Nashik, Osmanabad, Pune, Parbhani, Sangli, Satara, Sholapur
Orissa	Phulbani, Kalakhandi, Bolangir, Kendrapada

Source: Ministry of Statistics and Programme Implementation, Govt. of India. www.indiastat.com

Supportive practices

- Lands < 22.5 cm depth of soil should be cultivated with Agroforestry and dryland horticulture including ber, custard apple, amla, woodapple, jambhul etc.
- Horticulture: Ber, pomegranate, woodapple, custard apple, tamarind, amla.
- Agro horticulture- Ber + greengram/ clusterbean/ cowpea for grain purpose Ber + pearlmillet (fodder)
- Introduction and spread of Stylosanthes hamata Leucaena leucocephala, dryland horticulture, agro-forestry based land capping etc.
- Developing strategies for meeting aberrant weather with alternate crops and agroforestry, dryland horticulture, silvi-pastures etc.

Arable wastelands

- Agri-horticulture: Fruit crops (mango/citrus/sapota/pomegranate/custard apple/ aonla
- litchi/jackfruit/phalsa) + field crops (pulses/oilseeds). Hybrid mango varieties viz. Pusa
- Amrapalli and Pusa Mallika are becoming increasingly popular in the zone.
- Alley cropping: Leucaena + turmeric/ ginger

Constraints of production in rainfed areas

The rainfed lands suffer from a number of biophysical and socio-economic constraints which affect productivity of crops and livestock. These include low and erratic rainfall, land degradation and poor productivity (Abrol and Katyal, 1994), low level of input use and technology adoption, low draft power availability (Mayande and Katyal, 1996), inadequate fodder availability low productive livestock (Singh, 1997), and resource poor farmers and inadequate credit availability.

Strategies for sustained food production in rainfed region

Identification of viable rainfed technologies

A number of economically viable rainfed technologies have been developed over the years in the country to address the problems of food production in rainfed agriculture through CRIDA and its network centres for the last three decades. These technologies have been evolved after refining them in farmers' field through Operational Research Projects, Institute Village Linkage Program (IVLP) and farm science centres. These include simple practices like off-season tillage in rainfed Alfisols and related soils for better moisture conservation and weed control. Farmers in Operational Research Project (ORP) areas of Hyderabad adopted this practice in sorghum and castor and realized yield advantage by 40 percent over traditional practice. Lack of adequate draft power with many small farmers, however, is one of the major constraints to popularize this practice. Custom hiring of tractor is effective solution of farm mechanization on these lands.

Soil and rain water conservation techniques

Efficient conservation of rainwater is the central issue in successful dryland farming. Extensive trials conducted by the soil conservation and dryland research centres have led to the identification of a number of inter-terrace land treatments besides contour and graded bunds. These techniques are location specific and the benefits from their adoption are highly variable depending on the rainfall intensity, slope and texture of the soil besides the prevailing crop/cropping system. (Katyal and Das, 1993).

Farmers have not widely adopted mechanical measures like contour bunds, graded bunds, grassing of waterways and construction of farm ponds without the government support due to financial constraints. However, studies at Hyderabad, Bangalore and Anantapur revealed that more than 80 percent farmers follow simple conservation measures like sowing across the slope, opening of dead furrows and key line cultivation. The yield improvement by adoption of soil and water conservation measures vary between 12 and 20 percent which are at times not convincing enough to farmers. However, cumulative effects are significantly visible at some locations. Since such measures help in long-term conservation of resources, these are implemented through the Government of India or the respective State Government sponsored watershed management programmes.

Timely planting of crops

Timely sowing and precision are essential for getting good plant stand, higher yield and optimum utilization of rainfall and reduction in the incidence of pests and diseases. A number of demonstrations have been taken up in farmers' fields through ORPs, KVKs and IVLP programmes in different rainfed regions of the country. In case of sorghum and castor in farmers' fields of Hyderabad, a fifteen-day delay in sowing led to reduction of 300 and 850 kg/ha compared to normal sowing. Inadequate availability of farm implements and draft are major constraints. However, seeding and intercultural experiments developed by CRIDA and AICRPDA centres helped in overcoming the constraints to some extent.

Adoption of improved crop varieties

A number of improved varieties and hybrids were evaluated in the farmers' fields to identify suitable ones for matching growing periods for inter and sequence rainfed cropping systems. For example, farmers gained additional benefit ranging from Rs. 2000-4000/ha by adopting improved varieties of sorghum, castor and sunflower in Alfisols of Hyderabad.

Nutrient management

Fertilizer recommendations in rainfed crop production have been made primarily for NPK along with the conjunctive use of chemical, organic and bio-fertilizer. Inclusion of legumes in cropping systems can supplement fertilizer N to the extent of about 20 kg N per ha. Conjunctive use of fertilizer N with FYM, cropping of luecaena and gliricidia help in reducing the requirement of fertilizer by 50 percent.

Alternate land use systems

Despite evolving a number of production technologies, arable cropping in drylands continues to suffer from instability due to aberrant weather. To provide stability to farm income and also utilize the marginal lands for production of fodder, fuel wood and fibre, a number of alternative land use systems were evolved based on location specific experimentation and cafeteria studies (Singh, 1988). In addition to the above general guidelines, specific experiments have been carried out to develop land use practices for different categories of soils across the centres integrating annual crops with the perennial component in order to utilize the off-season rainfall (Katyal *et al.,* 1994). Different alternate land use systems include agri-silviculture, silvi-pasture, agri-horticulture, alley cropping etc.

Integration of livestock with rainfed farming systems

Live stock is treated as a part of farming system in rainfed agriculture in India. The soil, plant, animal cycle is the basis for all feed used by the animals. The livestock in the rainfed regions are weak. Farmers in this area often sell their cattle due to the scarcity of fodder. In India the land holdings are being reduced with increased population pressure. Hence, land not suitable for agriculture has to be diverted for raising fodder need of animals through the appropriate alternate land use system such as improved pasture, silvipasture, hortipasture and tree techniques.

Integration of the technologies through watershed approaches

The concept of watershed is important in efficient management of water resources. As the entire process of agricultural development depends upon the status of water resources, the watershed with distinct hydrological boundary is considered ideal for taking up a development programme. In brief, planning and designing of all soil conservation structures are carried out considering the peak runoff. In this context, the watershed concept is of practical significance. Also, the entire development needs are to be taken up on topographic considerations from ridge to valley.

Resource conservation measures

Details about conservation measures adopted in cultivated lands have been delineated by Katyal *et al.,* (1994). Based on the nature and type of barriers and their cost, the conservation measures in arable lands can be divided into three categories:

(i) Hardware treatments (ii) Medium software treatments and (iii) Software treatments.

Farming system approach

Of late, it has been increasingly recognized that unlike irrigated areas, it is difficult to develop profitable technologies for heterogeneous agro-ecological and socio-economic conditions of small holders in arid and semi-arid regions. Since, the problems are complex, addressing only a component of the farming system, *e.g.* crop variety, fertilizer use or even crop husbandry is not expected to bring about a significant increase in the productivity as witnessed in irrigated areas. The extension strategy should be such as to match this challenge. The farming systems perspective, dovetailed on watershed approach therefore can be the appropriate management strategy for such regions.

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5. Soil Management for Sustainable Rainfed Agriculture

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Agriculture, the primary source of sustenance for humans, is a vital component of the global economy and a significant contributor to the gross domestic product of many nations. In India, the agricultural sector and its related industries make up approximately 17 percent of the country's GDP and provide employment for a significant portion of the population. Approximately 68 percent of India's net cultivated land, or 97 mha, is dryland or rainfed, and it is responsible for producing 44 percent of the country's food needs while supporting 40 percent of the human population and 60 percent of livestock. It is also crucial for producing key crops such as maize, rice, millet, soybean, oilseeds, and cotton. Despite the potential for full irrigation, it is estimated that agricultural production on 75 mha will continue to rely solely on rainfall.

The principal difficulty in rainfed agriculture lies in sustaining the livelihoods of the majority of small and marginal farmers, whose well-being is directly impacted. The challenges faced by rainfed areas are multiple and complex in nature. The primary obstacles in rainfed agriculture include climate variability, drought, land degradation, altered cropping patterns, and fragile ecosystems. These challenges have resulted in diminished crop productivity, unpredictable yields, elevated costs of cultivation, and widespread rural poverty. Climate variability is expected to have the most significant influence on rainfed agriculture, as rising temperatures, irregular rainfall, and prolonged dry spells can severely reduce the yield of rainfed crops. Some of the challenges faced by rainfed agriculture include insufficient and uneven rainfall distribution, extended gaps between rainfall, premature or delayed monsoon onset, dry spells, low soil moisture retention capacity, and poor soil fertility. Despite urbanization, challenges such as starvation, poverty, and the vulnerability of livelihoods to natural disasters are intensified by climatic variability, population growth, and degrading natural resource bases, which will continue to be most acute in rural semi-arid regions. In developing countries, the majority of the poor, whose livelihoods depend on agriculture, are trapped in a downward spiral of poverty due to the overexploitation of natural resources. A bleak picture of water scarcity, degraded environments, drought, and land degradation resulting from soil erosion by wind and water and low rainwater utilization efficiency will emerge upon examining the inventories of natural resources in rainfed regions.

Ensuring India's food security is a formidable challenge due to the need to increase dry land productivity to meet the majority of the country's rising food demand. Furthermore, per unit land area productivity in irrigated areas is approaching a plateau, which exacerbates the situation. The lack of food and livelihood security at the farm level in resource-poor regions hampers the ability of the growing population to remain in rural areas. Therefore, to address these challenges, it is crucial to adopt adaptation strategies in rainfed agriculture to mitigate the impact of climate variability. Implementing climate-smart agricultural practices is essential to enhance crop productivity, increase resilience, and reduce greenhouse gas emissions in rainfed agriculture in India. The semi-arid tropics are characterized by diverse crops and cropping systems due to varying soil types and growing periods. Additionally, these areas have resource-poor farmers and inadequate infrastructure. To address these concerns, various strategies such as moisture storage, moisture retention, and enhanced availability during intra-seasonal rainfall abnormalities through soil in weather-proofing agriculture can be employed. These strategies have the potential to significantly benefit the farming community in these regions.

Potential of rainfed agriculture

Rainfed agriculture, which is characterized by high yields, is primarily found in temperate regions with reliable rainfall and fertile soils. These regions have the potential to produce up to 5-6 t/ha of crops, even in tropical regions, particularly in sub-humid and humid zones. Field experiments conducted by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Patancheru have demonstrated that improved land, water, and nutrient management in rainfed agriculture can lead to higher yields. For instance, sorghum/pigeonpea intercrops managed with improved techniques produced an average of 5.1 t/ha, which is significantly higher than the 1.1 t/ha yield from traditional farming practices. The traditional system relies on soil moisture stored from the previous rainy season, while the improved system utilizes improved land, water, and nutrient management practices. As a result, the improved system achieved an annual grain yield increase of 82 kg/ha/year compared to 23 kg/ha/year in the traditional system. The large yield gap between the attainable yield and potential yield indicates that there is a significant potential for rainfed agriculture that has yet to be tapped. Moreover, the improved management system continues to provide increased productivity and improved soil quality, including physical, chemical, and biological parameters, as well as increased carbon sequestration of 330 kg C/ha/year. To achieve food security in the developing world, it is crucial to unlock the vast potential of rainfed agriculture through knowledge-based management of natural resources. Soil management plays a critical role in enhancing agricultural productivity in rainfed areas in the semi-arid tropics.

Sustainable NRM

The primary focus of natural resource management for agriculture over the past five decades has been to increase the area under intensive agriculture in order to meet the demand for food, feed, and fiber. Land and water management played a crucial role during the Green Revolution, which led to self-sufficiency. However, over time, natural resources have been subjected to various degrading influences and indiscriminate exploitation. Developing resource-use efficient agro-techniques is essential for sustainable agricultural growth and addresses urgent environmental concerns. Strategic areas of research and development that can be explored include enhancing soil quality, implementing soil water conservation strategies, technologies to enhance carbon sequestration, developing cropping practices to minimize nitrogen losses, and exploring indigenous and efficient cropping systems. Sustainable Natural Resource Management (SNRM), which involves managing resources to meet current needs without compromising their quality to meet the needs of future generations, is crucial. In light of the changing climate, the adoption of climate-resilient dryland farming is imperative. Resilience can be defined as the ability of an ecosystem to recover from and resist abiotic and biotic stresses that affect crop production. The resilience of rainfed farming ecosystems to unclear and changing environments can only be achieved through the strategic deployment of technology and innovations in a spatial and temporal context.

Rainfed farming is a common practice in India, as the country has a high degree of spatial and temporal variability in rainfall and temperature. This variability ranges from tropical temperatures in the southern part of the country to continental climates with extreme temperatures in north-western India. The climate of rainfed-dryland farming ranges from arid, semi-arid to subhumid, with an average annual rainfall of 412-1378 mm. The length of the growing season varies from 60-90 days in arid regions to 180-210 days in subhumid regions. India is divided into 20 homogenous agroecological regions based on topography, climate, soils, and effective growing seasons. The dominant soil orders in rainfed production systems in India are Inceptisols, followed by Entisols, Alfisols, Vertisols, Mixed soils, Aridisols, Mollisols, Ultisols, and Oxisols. The majority of soils in rainfed areas are coarse-textured, which results in low water and nutrient retention capacity, making crops susceptible to drought stress and nutrient deficiencies. Additionally, low soil organic matter leads to reduced aggregate stability and increased soil erosion. The formation of crusts in Alfisols and the clayey texture of Vertisols result in low infiltration rates.

Sustainable soil management

In rainfed agricultural systems, soil-related factors are the primary constraints to sustainable production, including physical, chemical, and biological factors. Soils in drylands are significantly impacted by climate change, including altered rainfall patterns, soil temperature, and runoff patterns. Since soils are multidimensional porous systems, numerous physical, chemical, and biological/biochemical processes occur, which can result in a loss of soil capacity to perform its functions. Soil chemical degradation refers to any undesirable changes in chemical properties, which can have direct or indirect adverse effects on soil quality, reducing productivity. Apart from minerals, organic matter, salts, water, and air, soils contain fauna, primarily consisting of bacteria, actinomycetes, fungi, earthworms, and other animals. Higher temperatures increase the rate of chemical and biochemical reactions, which in turn affects soil respiration. Increased respiration can contribute to more carbon dioxide from soil microbes and roots. Changes in soil carbon status are a concern under changing temperature and rainfall regimes in drylands, as soil carbon is essential for crop growth and development, water and nutrient retention, and decomposition processes in the soil. High and extreme precipitation can increase runoff due to the inability of soils to absorb and hold water, resulting in increased erosion in dry agroecosystems. Extended dry periods can reduce vegetation cover, leading to substantial runoff and the loss of soil nutrients. Soil moisture stress can also hinder surface decomposition and nutrient recycling, affecting crop productivity.

Soil quality

The primary cause of decreased agricultural productivity under rainfed conditions in India is the deterioration of soil quality. To improve soil quality, certain management practices can be implemented, such as timely tillage at optimal moisture content, reducing secondary tillage, implementing crop rotations, incorporating cover crops, and using organic fertilizers to enhance soil organic matter (SOM). The primary strategy for improving soil quality in rainfed conditions is to restore SOM. The goal is to integrate management practices that enhance the soil's biological, chemical, and physical properties relevant to crop production. Some important management practices that can be adopted to restore soil quality include controlling erosion, addressing nutrient deficiencies, and implementing integrated nutrient management (INM). Improving soil quality can result in increased crop yields. For example, wheat yields can be increased by 20-70 kg ha^{-1}, rice yields can be increased by 10-50 kg ha^{-1}, and maize yields can be increased by 30-300 kg $ha^{-1}$for every 1 Mg ha^{-1}increase in the soil organic carbon (SOC) pool in the root zone (Lal, 2006). Additionally, reducing tillage depth and intensity by converting from ploughing to shallow non-inversion tillage can significantly improve indicators of soil quality in the topsoil layer of 0–10cm. The relative differences between tillage systems resulted in 25 percent higher soil organic carbon, 32 percent higher microbial biomass, and 34 percent higher dehydrogenase activity with reduced tillage compared to ploughing (Krauss *et al*., 2020).

According to Van Eerd *et al*., (2014), the soil quality index was influenced by factors such as aggregate stability percent, penetrometer resistance, potentially mineralizable N, and P concentration, in addition to crop rotation. In their study, soil quality was found to be highest under a soybean-winter wheat rotation compared to monocropping. Sharma *et al*., (2005) conducted a long-term experiment to identify key indicators of soil quality for semiarid tropical Alfisols and found that applying 90 kg N ha^{-1} under minimum tillage, even without residue, was effective in maintaining high soil quality index. Other parameters contributing to the soil quality index included available N, K, S, microbial biomass carbon, and hydraulic conductivity. In a long-term study on the effect of conventional and reduced tillage along with conjunctive nutrient-use treatments in the semi-arid tropics of Alfisol at Hyderabad under the sorghum-mung bean system, Sharma *et al*., (2009) found that tillage significantly influenced hydraulic conductivity, while conjunctive nutrient-use treatments significantly influenced physical, chemical, and biological soil-quality parameters. Prasad *et al*., (2016) conducted a study on the effect of different tillage intensities and sources of nitrogen on crop yields, soil organic carbon, and C fractions in an Alfisol over a 10-year period. They found that reducing tillage intensity and applying various N sources enhanced SOC marginally and the C sequestration rate. The substitution of 50 percent of the recommended N with an organic source enhanced crop yields and soil carbon, and therefore could serve as a potential alternative for residue retention for crops.

Conservation Agriculture (CA)

Conservation Agriculture (CA), a sustainable method of agricultural production that aims to enhance food security and protect the environment, is a crucial strategy for developing climate-resilient agricultural systems. It is one of the most effective ways to increase soil productivity and conserve moisture. The three principles of CA are minimum soil disturbance, permanent soil cover, and crop diversification (Williams et al., 2018). By following these principles, farmers can adapt to climate change by reducing their vulnerability to weather events and increasing the natural resource base. CA can be practiced on all types of agricultural land, but it is particularly important for soil and water management in hot tropical regions with water constraints. Soil inversion in these environments can lead to the rapid oxidation of organic matter and increased soil erosion, but conservation agriculture practices can prevent these issues. Some crop management options that are based on the principles of CA include zero tillage, raised bed planting, direct seeded rice, incorporation of crop residues, crop diversification, and site-specific nutrient management. By using these methods, farmers can improve soil health, crop productivity, and reduce the amount of fuel required, leading to a significant decrease in CO_2 emissions (Mondal *et al*., 2019). Additionally, conservation agriculture is an appropriate technology for reducing energy input and C-footprint (Yadav *et al*., 2020).

The study carried out by Somasundaram *et al*., (2019) examined the impact of reduced tillage combined with residue retention in various cropping systems on soil properties and crop yields in a Vertisol of a semiarid region in central India. The results showed that soil penetration resistance was significantly higher with reduced tillage compared to conventional tillage, and Soil Organic Carbon (SOC) was greater under the former. Moreover, significant differences were reported between reduced and conventional tillage in terms of different carbon fractions. The implementation of short-term Conservation Agriculture (CA)-based management practices affects soil porosity and pore connectivity, particularly in the surface soil layer, where pores act as a network controlling water and air flow, which impacts soil water-holding capacity, infiltration capacity, and oxygen and water availability. Adoption of short-term CA-based management practices resulted in a decline in total and macro-porosity. In Italy, Piccoli et al. found that the adoption of CA for five years significantly increased the portion of ultra-micro-porosity but did not affect macro-porosity. The reduction in macro-and/or total porosity and increase in micro-porosity indicate higher soil compaction in the upper soil layer under short-term CA-based management practices. On the other hand, Abdallah *et al*., (2021) reported that long-term adoption of CA practices increases total porosity and the fraction of macro-pores.

Integrated Nutrient Management (INM)

Soil fertility and nutrient depletion is a pressing concern in smallholder rainfed agriculture. The excessive application of fertilizers such as Nitrogen and Phosphorus to boost crop productivity and feed the expanding human population has led to detrimental effects on the soil ecosystem. Adopting integrated nutrient management strategies can improve soil health by promoting nutrient and water use efficiency, thereby enhancing crop productivity. A crucial aspect for higher crop productivity and sustainable agriculture is the implementation of balanced fertilization. Nitrogen is a vital nutrient for fertile soil, and its nutrient use efficiency is approximately 30 percent. Inappropriate fertilizer application and N losses due to inadequate water management through irrigation systems are significant factors contributing to low and declining crop responses. Employing balanced fertilization based on the specific fertility status of a particular site, using a site-specific nutrient management approach, ensures that all nutrients are applied at the proper rates and ratios. In India, farmers' participatory watershed management trials in over 300 villages have shown that current subsistence farming has depleted soils not only in macronutrients but also in micronutrients such as zinc and boron, as well as secondary nutrients like sulfur, beyond critical limits. A notable increase in crop yields was observed after using micronutrient amendments, with an additional increase of 70-120 percent when both micronutrients and adequate levels of nitrogen and phosphorus were applied to rainfed crops in farmers' fields. This demonstrates that investments in soil fertility can improve water management. A long-term field experiment conducted over six years to investigate the effects of mineral fertilizers and organic amendments on SOC stocks, carbon sequestration, and SOC sequestration rates in maize and blackgram crops in dry semi-arid Vertisols revealed that the highest SOC profile stock and concomitant carbon buildup were achieved with the combined application of organic amendments and mineral fertilizers (Srinivasa Rao *et al*., 2019).

Alternate land use system

The rainfed regions are susceptible to severe land degradation. Land degradation signifies a diminished capacity of ecosystems or landscapes to sustain the functions or services necessary for supporting livelihoods. Continuous agricultural production, particularly in marginal and fragile lands, over a period of time results in the degradation of the natural resource base, leading to an impact on water resources. Soil degradation, including the loss of organic matter, physical degradation of soil, nutrient depletion, and chemical degradation of soil, soil erosion, and sedimentation, are issues that need to be addressed. Land use changes have a significant influence on soil nutrient and carbon dynamics. Crop diversification practices, such as agri-horticultural and agro-forestry systems, have the potential to enhance soil physical properties, nutrient cycling, and sustain soil organic matter. Promoting scientific agroforestry is crucial in combating climate change. Agroforestry improves soil and water quality by reducing nutrient runoff, enhancing carbon sequestration, improving soil quality, and providing better erosion control. Agroforestry offers a range of environmental and socioeconomic benefits. Soil quality in agroforestry systems is improved through increased levels of organic matter, diverse microbial populations, and improved nutrient cycling, leading to increased crop productivity and the ability to cope with drought. Research by Udawatta *et al*., (2014), Rivest *et al*., (2013), and Kim *et al*., (2016) supports these findings. In conclusion, agroforestry has several advantages for both the environment and the economy.

Soil Health Card (SHC)

One of the key strategies for improving soil health and management is the use of soil health cards. These cards are based on soil analysis data and provide nutrient recommendations for predominant crops, as well as information on site-specific nutrient management, balanced nutrition, and integrated nutrient management options. By promoting the use of available organic manures, soil health cards can help improve soil organic carbon levels and address multiple nutrient deficiencies in the soil (Srinivasa Rao *et al*., 2014).

To achieve sustainable productivity and bridge yield gaps, it is crucial to focus on improving soil quality by building Soil Organic Matter (SOM) for soil health restoration. The efficient and integrated use of soil and water management practices is essential for making rainfed farming more economical and sustainable. It is important to disseminate knowledge about these practices to stakeholders through suitable platforms located in every district of the country to realize productivity enhancements and large-scale impacts.

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6. Low-Cost External Input IPM in Rainfed Crops

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Crop production in rainfed regions is by nature dependent on monsoon behaviour and is therefore highly risky. Rainfed regions are also highly heterogeneous in terms of land terrain, soil productivity, climate and socio-economic conditions, all of which influence the crop productivity. Another important factor that affects crop production is the incidence of pests and diseases. Considering the poor capacity of the farmers to invest on plant protection measures, the incidence of pests and diseases often leads to significant losses of productivity and income to the farmers. Thus, there is considerable scope to develop a system that is diverse and less prone to pests and diseases (Risch, 1983). When other pest management technologies are superimposed on such systems, it becomes much easier and cheaper for the farmer to manage the pests rather than in monocultures which are more prone to pest incidence and require considerable investments in pest management. Low External Input Integrated Pest Management (LEIIPM) seeks to optimize the use of local available resources by combining the different components of farming system which is the major crux of Low External Input for Sustainable Agriculture (LEISA).

In recent years, the value of low external inputs and traditional techniques, including non-chemical alternatives, have been increasingly urged. These are viewed as technology options that could help create sustainable systems and decrease or avoid the needs for expensive and undesirable chemical inputs. There is a need for investment in low external input and non-chemical alternatives that include farmer empowerment. In agriculture, the fight against harmful organisms is essential, and it is therefore necessary to develop appropriate technologies to regulate and control pests. Environmentally-friendly, biological options that do make use of preparation of plant-based pesticides on the farm do exist. These options are based on natural crop protection approaches that make use of the diversity found in nature itself. Many countries have initiated IPM programme and due emphasis is given to Low external input IPM as a part of LEISA. Experiments were conducted to find out whether it is possible to have Low external input IPM measures as modules for the control of insect pests of pigeonpea. A range of treatments cultural, mechanical, crude extracts and different ITK techniques which are proven to be effective were identified and integrated as IPM modules and evaluated in terms of pest control and economics. It was expected that to provide usable cost-effective pest control package, which in turn can be used for organic farming also.

Options of LEIIPM

LEIIPM has two major principles which are akin to cultural control of insect pests. It has been defined as the tactful use of regular farm practices to delay or reduce insect pest attack. This involves the manipulation of the environment to make the 'less favourable' for insect pests and 'more favourable' for crop growth. Pest control is sought through a reduction in initial colonization of the pest, a reduction in reproduction and survival and an increased dispersal from the system. It is cost effective and ecologically safe approach in pest management. Researchers have examined how manipulation of various practices like time of sowing, tillage crop rotation, intercropping etc. are helpful in managing the pests through LEIIPM.

Time of sowing

The crop sowing should be done in such a way that its most susceptible growth stages coincide with time when the pest is least abundant and minimizing the damage. Sowing immediately with onset of monsoon is effective in the control of shoot fly and stem borers in sorghum. Incidence of groundnut bud necrosis and sesamum phyllody were found to be low in early sown crops.

Pod borer incidence on pigeonpea was reported to be less when the crop was sown simultaneously by all the farmers. This is because the pest is distributed over a larger area (in the same phase of life cycle) reducing the intensity of the pest. Also, it should be seen that varieties of same duration are sown in given area so that pest inoculums is not carried over to the long duration varieties from the short duration. Synchronized sowing is recommended to avoid pest distribution for long time.

Tillage

Reduction of population of insect pests and carry over to the next crop could be achieved with off seasonal tillage or summer ploughings. Ploughing after harvest is a cultural practice known to destroy stubble, weeds and other vegetation, which serve as alternate hosts of insect pests. Tillage exposes the insect (larval and pupal stages) to their natural enemies, predators (birds) and to adverse climatic factors such as high temperatures and low humidity besides causing physical damage to insect. Tillage especially after harvest minimized the incidence of stem borer in sorghum; root grubs in groundnut and also pod borers in pigeonpea crops.

Crop rotation

The rotation of crops is essentially a means of maintaining soil fertility so that an appropriate sequence of crops used in a rotation can produce better average yields than continuous cultivation of the same crop (mono cropping). At the same time crop rotation is also helpful in reducing pest infestation. This is achieved when dissimilar crops are rotated to interrupt continuity of food chain of pests with a narrow range of hosts. For e.g. rotation with sorghum and groundnut reduces important insect pests (Sorghum stem borer and groundnut leaf miner). Obviously crop rotation is most effective against pest species that have a narrow host range and limited range of dispersal.

Crop-crop diversity

Crop diversification and rotation are essential elements of LEIIPM. Diversification can enhance economic stability by allowing the risks of production agriculture to be spread over a greater number of crops. Ideally, the crop mix should be complementary in nature.

Pest pressures may be reduced in diversified systems for various reasons, most important being the encouragement of beneficial insect diversity and abundance and reduced ability of pests to locate their preferred feed. Providing already diversified growers with an additional benefit from combining certain crops should be a valuable contribution. Several studies indicated that diversification practices such as intercropping are beneficial because of lower damage by insect pests in these systems (Risch *et al*., 1983).

Significance of intercropping

The crop diversity is of several ways like crop-weed diversity, crop-border diversity and crop-crop diversity. By introduction of one crop in existing crop, crop-crop diversity can be created or enhanced (Baliddawa, 1985). Intercropping is the most popular form of crop-crop diversity.

Biotic, structural, chemical and micro climatic factors apparently constitute associational resistance, which probably reduce the pest infestation. The general reduction of pest infestation was noted in early reviews on intercropping (Srinivasa Rao *et al*., 2002). The factors that influenced pest; population in intercropping might be physical protection from wind, shading, prevention of dispersal, production of adverse stimuli, olfactory stimuli camouflaged by main crop, presence of natural enemies and availability of food. Research in diversified agro-ecosystem demonstrated that these systems tend to support less herbivores load than corresponding monoculture. However, the generalization that diversity decreases the pest problems does not hold true for many types of situations and pests. Similarly, the intercropped system may not necessarily reduce pest density nor do increase yield.

The growth behavior of pigeonpea makes it less competitive for resources when grown with other short season crops. Availability of cultivars with different durations of maturity offers scope for manipulation of crop environment for low pest incidence (in terms of choice of appropriate duration and intercrop). The impact of duration and intercropping on insect pests and natural enemies was well documented (Srinivasa Rao *et al*., 2003). It is therefore important to identify an effective combination of non-chemical measures, evaluation of their efficacy and development management strategy for LEIIPM. The significant effect of intercropping on various insect pests across different crops was mentioned by Srinivasa Rao (2007) and observed that in majority of the systems reduction of pest and proliferation of natural enemies was noticed across different field crops.

Intercropping

A method was evaluated for the selection of vegetable crops suitable for intercropping and compatible pest management. The method tested was based upon ecological principles that predict the diversified systems should be less prone to attach by pests, owing to reduced ability of pest insects to locate their preferred food plants and enhanced activity of beneficial insects. The results showed that intercropping per se increased beneficial insect diversity. Largely certain crops determined abundance of pest insects e.g., broccoli, which attracted large number of crucifer flea beetles. Diversifying plots resulted in improved natural enemy complexes. Litterick *et al*., (2002) opined that pest control strategies in LEIIPM are mainly preventive rather than curative. The balance and management of cropped and uncropped areas, crop species and variety choice and the temporal and spatial pattern of the crop rotations used all aim to maintain a diverse population of beneficial organisms including competitors, parasites and predators of pests.

Cover crops for diversification

Cover crops can be beneficial for intensive agricultural production in a number of ways. Water penetration and infiltration can be improved by root growth of a cover crop and by returning organic matter to soils. Increased organic matter may improve the soil's ability to retain moisture. If leguminous cover crops are grown, soil nitrogen can be increased through nitrogen fixation (Venkateswarlu *et al*., 2005). Grasses are particularly helpful in promoting soil structure and soil aggregating stability because of their fibrous root systems. Microbial activity, often stimulated by cover crop root exudates and organic matter additions to soils, has also been shown to promote aggregate stability. As microbes decompose organic matter, nutrients are released. Weed suppression for subsequent crops may be another benefit. Furthermore, cover crops can provide a favourable environment to attract and sustain beneficial arthropods.

Ngouajio and McGiffen (2004) evaluated the effect of cover crops and management systems on weed and insect populations in lettuce (*Lactuca sativa*). Cover crops treatments included cowpea (*Vigna unguiculata*), sudangrass (Sorghum bicolor), and the traditional summer dry fallow. Over the two years, cover crops had no effect on insect populations in lettuce, as neither cover crop is an alternate host for lettuce insect pests. However, the population of cabbage loopers [(Tricoplusia ni (Hubner)] increased at the end of each growing season in cowpea mulch plots. The cowpea cover crop suppressed weeds and increased yield. The integrated system reduced production inputs. The number insecticide applications were reduced from four to one without an increase in insect damage. Cowpea cover crop offered many advantages in vegetable-based cropping systems. Additional crops were often included in a grower's operation for greater diversification. It was suggested to maintain insectary plantings in or near fields to provide a habitat and food source for beneficial arthropods.

Trap crop

Crops that attract pests away the main crop have potential for the crop production. If the alternate crop (trap crop) is maintained in vigorous state, the pest may never even leave the trap crop. If the pest population builds up and begins to leave the trap crop, the trap crop can be mowed or sprayed to prevent damage to main crop. The trap crop can also serve as an additional reservoir of beneficial predators and parasites. The main crop seldom needs insecticidal treatment. There are most successful cases of use of Indian mustard and African marigold as trap crops against diamond back moth, *Plutella xylostella* in cabbage and tomato fruit borer *Helicoverpa armigera* in tomato. Crop such as alfalfa is used in organic production of strawberries and cotton in abroad. Use of trap crops like okra, canabinus, marigold, castor, early pigeonpea, coriander, maize are recommended for south and central India. However, in North zone okra should not be used as trap crop and cotton should not be grown in and around citrus orchards to avoid the spread of CLCV disease.

Biorationals

The final rule states that farmers may use some naturally occurring chemical controls as a last resort. Organic chemical controls include 'biorational' pesticides that are derived from natural sources, particle film barriers, botanical pesticides made from plants, and compost teas. Products derived from neem tree are one of the important components of non-pesticidal approach which have proven their efficacy under field conditions and are now being routinely adopted by the farmers. Use of neem in pest management can be considered as one of the best examples of LEISA and if successfully adopted can be a role model for the so-called 'alternate agriculture'. The main advantages of neem-based products are: i. Available locally in the villages or on the farmer's fields, ii. The technology of preparation of extracts and application is fairly simple which the ordinary farmers can adopt easily, iii. Neem products are renewable, viz., available every year, iv. Neem products do not leave residues in the environment, i.e. soil, groundwater and food products like grain, vegetables and fruits. They are relatively safe to the natural enemies and birds.

Recommended uses of neem products at the farm level

Following are some recommended uses of neem products at the farm level. These practices can be adopted by the farmers with least external inputs and are based on extensive research during the last one decade in India and abroad. The methods of preparation were given as suggested by Venkateswarlu and Srinivasa Rao (2006).

Aqueous Neem Seed Kernel Extracts (NSKE)

This is prepared by mixing 5 percent finely ground powder/paste of well dried neem seeds in water. The seed powder is tied in a cloth, immersed in water over-night, and stirred well to make a ready to spray suspension. The suspension needs to be filtered through a double layered cloth while filling the sprayer. The main advantage of the suspension is its effectiveness since it is prepared freshly and the drawback is that it cannot be stored for long since it is water extract. Farmers need to collect neem fruits well ahead of the cropping season, depulp and dry them under shade. Moisture control in the depulped seeds is critical in maintaining the quantity of the active ingredient. Drying seeds upto a moisture content of 8 percent is recommended for short term storage.

Use of neem oil

Neem oil is mixed in water at 0.5 to 2 percent concentration, emulsified well and sprayed on the crop. Adding soap solution (5 ml/litre) or a commercial emulsifier is important as spraying of neem oil alone or oil not properly mixed with the water can damage the crop due to the phytotoxicity. The quality of neem oil is very important. The active ingredients in neem oil like azadirachtin and salanin remain stable only upto 65°C. Therefore, oil expelled from cold expellers where the temperature is regulated during expelling is most effective. Farmers can also use hand expelled oil without any loss of active ingredients. Because of the variation in the quality of neem oil used by the farmers, the effectiveness of the product differs from place to place.

Use of neem cake

Neem cake is used for soil amendment @ 0.25 to 0.5 t/ha and it has variety of effects such as control of nematodes, soil borne fungi and as nitrification inhibitor. Unlike kernel extracts and neem oil, which can be used against specific crop pests more effectively, neem cake can be used for a variety of crops to and fruit trees to achieve multiple benefits of increased nitrogen use efficiency and control of soil borne pests and diseases.

Other plant products

Like neem, pongamia and custard apple are other plant species with good potential in IPM and LEIIPM. Pongamia seed powder extracts, oil and cake can be used in similar manner as that of neem. Combined use of neem and pongamia oil in 5:1 ratio was found to be more effective than neem oil alone. Custard apple leaf extracts and seed extracts are also quite effective. Leaf extracts are prepared by grinding 50g fresh leaves in one litre or boiling in water till dark colour is obtained. Cooled extract is filtered and sprayed. In case of seed extracts 500g powder can be suspended in 10 litres. After 12hrs soaking, it is ready for spray.

Other options

Bird perches

Keeping 3-4’ bamboo stakes in fields is effective as bird perches to invite insectivorous birds against tobacco caterpillar in groundnut, semilooper in castor and gram caterpillar in pigeonpea. Sometimes trap crop of sunflower in groundnut crop also acts as bird perch. Farmers that produce with organic methods reduce risk of poor yields by promoting biodiversity. Common game birds such as the ring-necked pheasant and the northern bobwhite often reside in agriculture landscapes, and are a natural capital yielded from high demands of recreational hunting. Because bird species richness and population are typically higher on organic farm systems, promoting biodiversity (predators and birds) and can be seen as logical and economical.

Mulching

Adoption of suitable mulches with either sorghum straw or glyricidia retains the moisture and decreases the infestation of termites.

Control of Queen termite

The Queen termite creates the colony by laying eggs and tending to the colony until enough workers and nymphs are produced to care for the colony. She can live for more than ten years and produce hundreds to eight six thousands of eggs per day. Colonies can have several million termites with the help of chemical means is difficult. Collection and destruction of queen termite is the only way to control the termites.

Conclusion

LEIIPM is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. It combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved. This is the philosophy of LEISA and the above-mentioned various options of pest control can be used as per the availability and convenience and crop aimed. The principle of LEIIPM is akin to non-pesticidal approaches of pest management. The protection and conservation of natural enemies is central core of LEIIPM and can be achieved through habitat management and biodiversity. Species found in most LEIIPM provides a means of agricultural sustainability by reducing amount of human input (e.g. fertilizers, pesticides).

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7. Farm Mechanization in Rainfed Agriculture

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Rainfed agriculture accounts for about 52 percent of the total sown area of the country and about 45 percent of the total food grain production. Farmers of rainfed agriculture always face challenges due to unstable monsoon, fragmented land holdings, crisis of agricultural power availability, non-availability of equipment to suit agricultural power availability, and many things which affect the low productivity of rainfed agriculture. Secondly, the problem of changing climate is increasing day by day. Pollution due to contaminated air is increasing in the atmosphere, due to which global warming and weather are being affected. If global warming and air pollution are to be controlled then the use of fossil fuels has to be reduced in agriculture and industry as well. In India, out of total diesel consumption, agriculture sector alone accounts for 13 percent (Nielsen, 2013). On other hand, It is estimated that in the coming days (by 2030), the requirement of farm power to supply grain production will be more than 4 kW/ha (Annual Report, ICAR, 2021) which is presently about 2.1 kW/ha. From this, it is certain that in the coming days the production of tractors, power tillers, irrigation pumps etc. will have to be increased for increasing the productivity in agriculture. But adopting these will lead to more use of fossil fuels which will further affect the atmosphere.

There is another concern in agricultural mechanization where small and medium farmers need suitable tools and equipment. In India, 85 percent of the total agricultural area (140 million hectares) is owned by small and medium farmers with land holdings size of 2 hectares or less per holder. Due to inability of this class of farmers to purchase expensive tools and tractors, they do farming by hiring tractors and machines on rent. Here too, it is worth noting that due to the rapid increase in the prices of fossil fuels day by day, there has been a huge increase in the rent of tractors and equipment, which is seen affecting the small farmers.

Conserving natural resources particularly water & soil without compromising agricultural productivity is also a major challenge for researchers due to weather vagaries. Productivity related factors like soil moisture availability, soil erosion etc. are closely associated with monsoon. In this direction, reshaping of existing agricultural mechanization is required to improvise on-farm water productivity, achieving precision and timeliness and use of renewable energy for mechanization. Considering all these aspects ICAR-CRIDA, Hyderabad has developed improved machinery and the same is discussed in this chapter.

Mechanization for rainfed agriculture

Various improved machineries are available commercially right from for tillage to harvesting and threshing operations covering most of the cropping systems across agroecological zones in India. Tillage and threshing are being done by machinery. Tractor drawn tillage machinery like MB plough, disc harrow, tyne cultivators, rotavators etc. are widely adopted by the farmers. Crop specific threshers are also being used by all category of the farmers. Mechanization status of these operations is reached nearly by 70 percent either through individual ownership or custom hiring. However, mechanization of seeding and planting is still not up to the mark (24%) which need more emphasis on development of improved machinery to meet the aspirations of rainfed farmers for sowing.

Seed sowing and planting machinery

Bullock-drawn sowing equipment made of wood is prevalent for small holders. In local languages they are called Tifan/Dufan (Marathi), Goru (Telugu), Coorgi (Kannada). In this, seeds and fertilizers are added manually which requires 3-4 skilled workers. Since the quality of seed control depends on the skills of the workers, there is often inequality in seed distribution. After germination, the seeds have to be replanted several times. There is uncertainty of uniform seed germination with conventional equipment and also increase in cost of cultivation. In view of these errors, it is highly necessary to adopt modern/advanced equipment to meet precision and timeliness. Many types of advanced sowing equipment have been developed by private and government agencies and are available in the open market. Bullock-drawn equipment with one to four rows has proved suitable for small and medium farmers. In these, seed fall is controlled by a special plate placed in the seed box. On the basis of mechanical construction, they are called fluted roller, inclined (oblique) plate planter, horizontal (horizontal) and vertical (vertical) plate planter.

CRIDA planter (bull drawn and tractor driven)

ICAR-CRIDA has developed seed sowing equipment ranging from 2 to 9 rows on the principle of inclined plate metering mechanism. Metering plates are designed for various crop sowing based on recommendation of seed rate and plant-to-plant spacing. Metering mechanism precisely pickup the seed from seed box and drop through plastic pipe by gravity. In this, equipment up to four rows are bullock power driven and 6-11 rows are tractor-driven. Three row bullock drawn planter is shown in Figure 7.1. Bullock drawn are mostly suitable for small & medium land holders having field capacity of 2-3 ha/day. The capacity of tractor drawn equipment is 6-8 hectares per day. This equipment is suitable for multi-crop sowing. Where bullock power is not available, tractor drivers can also do farming for small holders by renting tractor driven planters. Due to its accuracy in sowing multiple crops and seeds, this device has become quite popular among the farmers particularly Southern and Central Part of the India.

Figure 7.1: 3-Row bullock drawn planter

Figure 7.2: CRIDA 9-Row planter

Economic advantages of mechanized sowing over conventional sowing

- ❖ Precision metering mechanism results 15-20 percent saving in seed and fertilizer application
- ❖ Increase in productivity by 12-34 percent
- ❖ Increase in cropping intensity by 5-22 percent
- ❖ Increase in gross return by 30-45 percent
- ❖ Facilitates to enhance livelihood through custom hiring service

Sowing equipment/planters for maintaining soil moisture

Tractor drawn planters have modified to Broad Bed Furrow (BBF) Planter and Raise Bed Planter for improvising water use efficiency in rainfed agriculture

CRIDA BBF planter

Most of the time during dry spell there is poor germination due to non-availability of soil moisture. BBF planter facilitates water availability during dry spell. It is modified version of CRIDA tractor drawn planter (Figure 7.3). Iron furrowers are fixed on both the sides of the cultivator to create a furrows of 30 cm depth and width of 15-20 cm. Size of the furrowers are variable to meet the location specific requirement-based soil type and cropping system. Between these two furrows, 4-5 rows are sown with a planter.

Figure 7.3: CRIDA BBF planter

Due to BBF technology, rain water gets retained in the drain and slowly percolate the moisture to the depth of the ground. Which results in increase of soil moisture by 25-30 percent as compared to normal method of sowing. In case of drought, deep moisture protects the crop to a great extent. On the contrary, if there is excessive rainfall then the water is taken out of the field through drains. Due to climate change in rainfed farming, the problem of drought and flood is increasing day by day, hence equipment like BBF has become a boon for the farmers. Small to big landholders have started adopting this equipment on a large scale. BBF planter has proved to be very effective in soybean cropping system (Figure 7.4) due to increased yield. If compared to traditional sowing method, landholders claim that BBF planter results in savings of 12-15 percent in soybean seed and 14-21 percent increase in yield. Maintaining soil moisture over extended periods to combat drought is a key factor in increasing crop yield. On the contrary, in case of excessive rainfall, due to drainage of water from the field, there is more air circulation in the soil which has a positive effect on the yield.

Figure 7.4: Soybean sowing with CRIDA-BBF planter on farmers field (Curtesy: KVK, Jalana)

CRIDA Raised bed planter

Raised bed planter mainly consist of ridgers (02), shaper and planter mounting on the tyne cultivator. Ridgers make the furrow besides bed and shaper able to compact raised bed with 5 cm height above furrows. The wings of ridgers were specially designed so that the top soil disturbance was minimized to reduce the germination loss. The bed shaping frame was adjustable for 60-120 cm to suit the different crop row requirements. Machine operates for multiple use like weeding and spraying by attaching sprayers and weeding tools (Figure 7.5). It is suitable for rainfed crops like maize, redgram, soybean etc. It conserves the moisture by 20-40 percent and increase in yield by 15-35 percent in tested field condition.

Figure 7.5: Sowing with CRIDA raise bed planter

Precision-cum-herbicide planter

Along with sowing, weed control herbicide can be sprayed in this machine (Figure 7.6). It has individual seed cum fertilizer box along with pesticide tank attached on top of each furrow opener. A 150-watt pump is used for spraying. This pump is powered by the tractor's battery through an inverter. A line of nozzles for spraying herbicide has been installed at the rear of the sowing machine. Due to this, herbicide is sprayed immediately after sowing. Both these processes run together. After sowing, the seeds are covered with soil with the help of a blade fitted behind the furrow opener and sprinkled on top. The sowing area capacity of this machine is 3 hectares per day.

Figure 7.6: Precision Planter cum herbicide applicator

High ground clearance platform for small horsepower tractors

As far as weeding and spraying operations in row crops are concerned, there is very little tractor-based mechanization. Development of suitable and high ground clearance platforms for tractor operation in row crops is highly essential so that weeding and spraying operations can be done using tractors even when the height of the crop is high in row crop systems. High ground clearance platform with tractor, developed by ICAR-CRIDA, Hyderabad is shown in Figure 7.7. It is very important to promote such equipment in agriculture. With such kind of development farmers can able to do weeding or spraying operations in row crop even at vegetative growth stage in time. The weeding efficiency was 80-85 percent and in a hour operation it covers about 2 ha. Conventionally, field capacity was 1 ha/day for spraying using power sprayer. More or less similar field capacity found with bullock drawn weeding equipment in wide row crops which indicated that there was increase in 12-15 times higher field capacity of the improved tractor drawn spraying and weeding using high ground clearance platform than conventional practices.

Figure 7.7: Spraying with tractor driven sprayer using high ground clearance platform

Solar-cum-battery operated equipment

Ample of solar energy is available in India which can be used for field operations to minimize dependency on fossil-fuel. CRIDA experience revealed that small farm tools like rotary tiller, blade harrow, mini ridgers, 3-tyne cultivators could be operated successfully on 1.5 solar powered prime mover when available solar radiations are in the range of 5-6 kWh/m^2/day. Filed capacity of the machine were ranged from 0.06 ha/hr to 0.12 ha/hr. Machine can be operated on battery of equivalent power if sufficient solar power is not available. A three tyne cultivator operating on 1.5 hp solar-cum-battery operated prime mover is shown in Figure 7.8.

Figure 7.8: Solar power operated 3-tyne cultivator

Advantages of solar-cum-battery operated equipment over engine operated equipment are, (i) low operational cost (ii) reduced vibration and noise (iii) emission free operations (iv) multiple use etc.

Conclusion

Mechanized sowing attempts for achieving precision and timeliness resulted into saving in seed and fertilizer, further, improved sowing technologies like broad bed furrow and raised bed planting methods enhances in-situ rainwater use efficiency which contributes in higher productivity in rainfed agriculture. Apart from this, solar energy could be an option for small farm holders for operating small tools.

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8. Drought Challenges in Cotton Cultivation: Understanding Responses, Monitoring Stress and Advancing Tolerance Strategies

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Cotton (*Gossypium* Spp.) is one of the most important commercial crops grown in more than 50 countries across the world primarily due to its inherent lint value. India contributes second maximum (5.84 Mt) to the world's cotton production followed by USA and Pakistan (CCI, 2023). Though, India contributes highest to the world's cotton area (~38%) and production (~23.0 %), the productivity (443.0 kg/ha) is much below the world average (~771.0 kg/ha) and is one of the lowest among the major cotton growing countries (USDA, 2023). Among different abiotic stresses, drought is considered as most important stress which is disturbing agrarian welfare worldwide by limiting plant growth and productivity more than any other environmental factor. The frequent onset of drought around the world is mainly due to reduced precipitation and changed rainfall patterns (Lobell *et al*., 2011). India is a country where agriculture is the major occupation and majority of the farm holdings are occupied by small and marginal farmers who are highly dependent on monsoon rainfall. The delayed onset of monsoon breaks during active months, early withdrawal and erratic distribution makes it more vulnerable to drought. In India, 60% area under cotton cultivation is rainfed with unpredictable and poorly distributed rains, drought is expected to impact the cotton productivity increasingly and adversely.

The main reason for the frequent onset of drought as an effect of change in temperature and rainfall patterns is the change in the global climate. As a result of constant emission of greenhouse gases, the mean annual temperature of the world is expected to increase by 2.5-4.3^{0}C especially in the main crop growing season by 2080 (Tebaldi *et al*., 2007). Such changes in the temperature can aggravate the problem of irregular and untimely rains, which can have direct impact on crop production causing huge economic losses. Drought is set to be on when there is limitation of water supply to the plant roots or loss of water through transpiration is very high (Anjum *et al*., 2011).

Cotton is a perennial and indeterminate shrub being cultivated as annual commercial crop in arid to semi-arid regions of the tropic and subtropics. It possesses inherent ability to tolerate abiotic stresses than other major crops. However, for its optimum production it requires 700-1000 mm of water per growing season which varies with cultivar, length of growing season, temperature, sunshine hours, the amount and distribution of rainfall and the characteristics of soil. Therefore, production of cotton is highly vulnerable to increasingly variable rainfall patterns and diminishing fresh water resources.

Drought: A major obstacle in cotton production

Drought is a perennial environmental constraint, affecting all crops worldwide at enormous cost. Like major agricultural crops, cotton production is negatively impacted by moisture deficit stress. Crops are very much sensitive to the water deficit condition and the degree of sensitivity varies with the crop and its growth stage (Doorenbos and Pruitt, 1977; Saini and Westgate, 2000). Among different abiotic stresses like water deficit, salinity, and temperature extremes which contribute 50% reduction in crop yields worldwide (Boyer, 1982), drought is considered as most devastating factor limiting yield and fibre quality in cotton (Wiggins *et al*., 2013).

Cotton being a perennial by growth habit with indeterminate and complex growth pattern has been described as relatively drought tolerant due to its origin from hot and arid areas (Lee, 1984). Even though it is considered as drought tolerant, it requires 5000 to 8000 cu. m. of water per hectare during growing season for its normal growth and development to provide potential yield. In majority of crop plants including cotton, reproductive development is the most sensitive stage for drought stress (Loka, 2012) followed by seed germination and seedling establishment. Water deficit situation at very early crop growth may result in poor crop stand. Water requirement is higher during peak flowering which is very critical stage as far as effective contribution of developing sink towards yield is concerned to sustain developing squares and young bolls. However, cotton has protective mechanism to overcome water-deficit stresses by accumulation of antioxidants, osmolytes and heat shock proteins but it depends on extent, timing and intensity of the drought with which it occurs (Loka *et al*., 2011).

The main effects of water deficit stress are on plant structure, leaf morphology and cell ultra-structure. Many important nutrients including nitrogen, silicon, magnesium and calcium are up taken by roots along with water. The drought conditions limit the movement of these nutrients via diffusion and mass which leads to retarded plant growth (Barber, 1995). In field conditions, application of fertilizer in drought stress has no effect on crop growth and development because fertilizer needs optimum soil water content to increase yield. It also alters abscisic acid (ABA) and gibberellic acid (GA) hormones which plays a very key role in response to drought stress. ABA controls stomatal conductance and activates various pathways related to drought response (Yoshida *et al*., 2014).

When it comes to impact on yield, it shows reductions in yield up to 50% when compared to those that have been irrigated, especially when the stress factor is imposed during the period between flowering and fructification (Araujo *et al*., 2003). During water stress situation reduced plant height, number of leaves, total dry matter, stomatal conductance, transpiration, net assimilation rate (NAR) and leaf area was observed compared to well-watered control (Patil, 2011). Water shortage greatly influenced plant growth and yield through reduced plant biomass accumulation, shortened the first internodes, premature senescence, death, boll shedding and fruit discoloration (Zlatev and Lidon 2012).

The fundamental stages of fibre development in cotton *viz.,* fiber initiation, elongation, secondary cell wall development and maturation are genetically regulated, but are also affected by the environmental conditions faced by the plant during its lifecycle. Water deficit immediately after flowering leads to severe reduction in fiber length (Pettigrew, 2004). Water deficit situation is detrimental to cotton production system (Pettigrew, 2004). Water is often most important productivity limiting factor in many of the crops. The requirement of water for cotton exists all through its growth and development from emergence to harvest (Gerik *et al*., 1996; Howell, 2001).

Response of cotton to drought stress

For plant growth and development, water is the most limiting factor as it affects the plant morphology as well as physiological functions critically. In arid and semi-arid regions, limited water availability to crops is due to low rainfall and unavailability of sufficient irrigation water, leading to drought conditions. It is one of the most important abiotic stresses having drastic effects on plant growth and crop productivity with most prominent impacts on physiological and metabolic processes of plants (Quisenberry *et al*., 1985; Chen *et al*., 2013), though, it depends on the severity and duration of drought as well as the growth stage and genotype of the target plant or crop canopy (Kramer, 1983). Cotton is a glycophyte therefore, shows higher tolerance to abiotic stresses than other major crops (Parida *et al*., 2007), but the effect of water stress is widely different and vary in terms of severity on growth and yield components whether it is qualitative and quantitative on fiber quality. Drought, as one of the major yield limiting factors for cotton crops affect it from emergence to harvest (Gerik*et al*., 1996; Howell, 2001; Anjum *et al*., 2012) as cotton plants, are highly sensitivity to it during flowering and boll development that determines the yield (Constable and Hearn, 1981; Turner *et al*., 1986; Han and Kang, 2001). Accurate economic estimate of drought stress on cotton is very difficult as the impacts are widespread and varied (Table 8.1).

Table 8.1: Direct and indirect impacts of drought on cotton

Direct Impacts	Indirect impacts
Damage plants systems	Food scarcity
Poor plant health	Reduce income of farmers and agribusiness
Reduction in crop productivity	Increase prices of foods and goods
Reduction in water level	Increase unemployment (companies dealing with agriculture will stop working)
Increase in insect infestation	Increase crime and insecurity
Increase in plant diseases incidence	Cause pollution in the concern area
	Migration

(Source: Ullah et al., 2017)

During flowering and boll development stage, even a short-duration water stress can significantly affect various morphological physiological, biochemical characters as well as at molecular levels in cotton plants, which directly affects the photosynthesis, carbon, nitrogen metabolism, antioxidant metabolism; reduce fiber micronaire, plant height, root length, fresh and dry biomass, chlorophyll and proline content, rate of photosynthesis and expression of drought responsive genes (Eaton and Ergle, 1952; Marani and Amirav, 1971; Ball *et al*., 1994; Bohnert *et al*., 1999; Kohli, *et al*., 1999; Potikha*et al*., 1999; Pettigrew 2001; Ennahali and Earl 2005; Shinozaki and Shinozaki, 2007; Sperdouli and Moustakas, 2012) these effects are probably due to reductions in the photosynthetic capacity of the whole canopy (Pettigrew, 2001).

Morphological and physiological changes in response to drought

Water deficit symptomology includes reduction in the plant's ability to establish and to retain blooms and fruiting structures, causing a direct negative impact on yield (Guinn and Mauney, 1984a; Guinn and Mauney, 1984b; Pettigrew, 2004; Whitaker *et al*., 2008; Mathew *et al*., 2014). On experiencing the drought, plants start modulating its morphology as well as physiology, such as plant height, leaf dry weight, stem dry weight, vegetative biomass leaf area index, node number, canopy; light interception, canopy temperature, root development fiber yield and lint quality etc. (Parida*et al*., 2007; Loka*et* *al*., 2011; Wiggins *et al*., 2013; Mathew *et al*., 2014). But the absence of adequate and timely rainfall, is almost detrimental to the cotton production system (Pettigrew, 2004). When the cotton plant is exposed to extreme drought during reproductive development phase of plant, reduction in flowering sites and increase in boll abscission were usually observed as major symptoms, which ultimately end-up with reduction in lint yield (McMichael and Hesketh, 1982; Turner *et al*., 1986; Pettigrew, 2004). Even drought tolerance indices validated the significant influences of drought stress on yield in cotton (Singh *et al*., 2015).

Luo *et al*. (2016) reported that long-time water deficit reduced the root activity in cotton however mild and initial-stage drought stress enhanced root length initially (Hafeez *et al*., 2015). Smaller crop canopy is another characteristic feature of crops growing under stress due to water deficits representing stunted plant growth (Reddy *et al*., 1997; Mathew *et al*., 2014; Hafeez *et al*., 2015, Li *et al*., 2001; Liu *et al*., 2004). Morphological parameters like root, stem, leaf weight ratio and leaf area ratio were also considerably reduced under drought stress (Hafeez *et al*., 2015). Wilting and rolling of leaves in cotton is a common phenomenon under drought stress due to water loss through leaves (Fang and Xiong, 2015).

In cotton, including stomata closing, root development, cellular adaptations, photosynthesis are the key physiological responses against drought stress (Ullah *et al*., 2017). Physiologically, first effect of water stress is the turgor loss that markedly influences cell growth rate and its final volume (Singh *et al*., 2015), which ultimately damage to cell membranes and cause cell death (Wilkinson and Davies, 2010). At initial stage, it delays the process of germination because embryo needs enough water to initiate the germination (Sakhanokho *et al*., 2004; Hafeez *et al*., 2015). During drought condition, net photosynthetic rate, transpiration rate, stomata conductance, carboxylation efficiency and water potential of cotton leaves decrease significantly (Kumar *et al*., 2001, Deeba *et al*., 2012; Li *et al*., 2012). Plants shows extreme reduction in growth and yield only because of stomata closure, which leads to the decreased CO2 intake, affecting the rate of photosynthesis (Chaves *et al*., 2009; Chastain *et al*., 2014).

Biochemical changes

Plants accumulate different organic and inorganic substances to reduce the osmotic potential in response to any stress as it has negative effects on osmotic balance (Fang and Xiong, 2015); osmotic adjustment occurs in plant cells through accumulation of compatible solutes (such as proline, glycine betaine, and sorbitol,) in the cytosol (Xiong and Zhu, 2002; Mafakheri *et al*., 2010; Fumis and Pedras, 2002) in order to maintain cell turgor and growth. Several workers have reported that sugar and proline content increased under drought stress conditions in drought tolerant plants to protects cells against stress damage. (Krieg, 1983; Rhodes *et al*., 1986; Hare and Cress 1997, Mohammadian *et al*., 2005; Verbruggenand Hermans 2008; Szabadus and Savoure 2010; Chenet *al*., 2013; Hafeez *et al*., 2015). Among all the compatible solutes one of the most common compatible solutes in plants under drought stress is proline (Bray *et al*., 2000). Under drought stress proline and chlorophyll content, cell membrane stability, are also sharply decreased (Hafeez*et al*., 2015). Structures of the membrane proteins also g*et al*ter during drought stress (Muzny *et al*., 2006) in turn leakage of ions increases severely, by increased solubilization and peroxidation of membrane lipids (Huang *et al*., 1997; Sakhanokho *et al*., 2004; Meloni *et al*., 2003; Hafeez *et al*., 2015).

Drought stress reduce the moisture content and lowers the water potentials in the root zone with decrease in transpiration rate (He *et al*., 2005; Hafeezet *al*., 2015). Drought stress imposed the significant decline in chlorophyll a, b and total chlorophyll content (Hafeez *et al*., 2015). Both stomatal and nonstomatal effects reduce leaf net photosynthetic carbon assimilation (AN) and leaf internal CO2 concentration into the leaf during water stress (Ennahali and Earl, 2005; Osório *et al*., 2011; Hafeez *et al*., 2015) which ultimately enhance the photorespiratory pathway, particularly when RuBP oxygenation is high (Ullah *et al*., 2017). Under drought stress, the production of reactive oxygen species ROS increases (Heber, 2002; Carvalho, 2008; Ullah *et al*., 2017), which can be detrimental to proteins, lipids, carbohydrates, and nucleic acids (Dietz and Pfannschmidt, 2011). Approximately 70 percent of total H2O2 production occurs through photorespiration under drought stress (Noctor *et al*., 2002). Drought stress effects on enzyme activities are generally disputable and specifically depend on both the degree of tolerance of plants and the specific mechanism underlying water stress (Kaur *et al*., 2013). In drought sensitive varieties, level of polyethylene glycol (PEG) concentration increases which reduce root length and vigour, increase H_2O_2, malondialdehyde (MDA), and proline contents, decrease or show no change in antioxidant enzyme levels, but increase glutathione reductase activity (Zhang *et al*., 2014). Reduced interception of photosynthetically active radiation (PAR) ultimately reduces yields. Smaller crop canopy is another characteristic feature of crops growing under drought stress (Reddy *et al*., 1997; Mathew *et al*., 2014; Hafeez *et al*., 2015) which reduces the photosynthetically active radiation (PAR) (Reddy *et al*., 1991);

Biosynthesis of the stress hormones, abscisic acid (ABA) and jasmonic acid (JA) are increased during drought stress (Bohnert *et al*., 1995; Blum, 1996; Schroeder *et al*., 2001; Luan, 2002 Ullah *et al*., 2017) participating in various crucial physiological processes during the plant life cycle, including stress responses, development and reproduction (Boudsocq and Lauriere, 2005). Osmotic stress promotes the synthesis of ABA which occurs due to high drought conditions (Boudsocq and Lauriere, 2005) and activates gene expression and adaptive physiological changes (Yamaguchi-Shinozaki and Shinozaki, 2006).

Molecular responses to drought

Plant molecular responses to drought stress include the induction or suppression of drought responsive genes, or ABA-responsive genes, in particular (Bohnert *et al*., 1995; Blum, 1996; Schroeder *et al*., 2001; Luan, 2002). Drought stress induces the expression of stress-related transcription factors and genes, such as ROS scavenging, ABA or mitogen-activated protein kinases (MAPK) signalling genes, (Chen *et al*., 2013; Zhu *et al*., 2013 and Ullah *et al*., 2017;) and the production of ethylene, which in turn activate various drought related pathways to induce tolerance in the plants (Abeles *et al*.,1992). Significant differences in expression levels of the genes related to abscisic acid signaling, ethylene signaling and jasmonic acid signaling pathways have been observed between drought-resistant cultivars and drought-sensitive cultivars of cotton (Chen *et al*., 2013). To protect the biochemical and physiological processes under water stress at the molecular level, heat shock proteins are the ones which express and accumulate in plants. In transgenic plants, overexpression of single HSP; *GHSP26* improved the biochemical parameters like proline content, lipid peroxidation activity as well as physiological parameters such as photosynthesis, osmotic potential and water related attributes. Real-time quantitative PCR of GHSP26 and some other drought responsive genes such as Gh-POD, Gh-RuBisCO, Gh-LHCP PSII, Gh-PIP, Gh-TPS and Gh-LEA supported the higher expression and proved their contribution in inducing the drought tolerance in transgenic plants (Sarwar *et al*., 2017). Transgenic plants showed better performance for photosynthesis, stomatal conductance, transpiration and osmotic potential as it accumulates 30 percent higher proline content.

Several studies have postulated that the LHCP genes were down regulated in stress conditions which play role in collecting and transferring light energy to photosynthetic reaction centers (Hafeez *et al*., 2015). High relative fold expression of the plasma intrinsic protein (PIP) gene was also observed in drought stressed plants (Hafeez *et al*., 2015). Unigenes get expressed differentially in drought-resistant and drought-sensitive cultivars of cotton, DEG (differentially expression gene) analysis showed that the normal biophysical profiles of cotton are affected by drought stress (Chen *et al*., 2013). Relative expression level of drought responsive genes such as *TPS* (trehalose-6-phosphate synthatase), *PIP, Gh-POD* and *LHCP-PSII* have been observed to be expressed at higher levels in *G. arboreum* under different drought stress conditions (Hafeez *et al*., 2015). They respond to this extreme environmental condition due to processes that are triggered by several genes at cellular level such as increase in chlorophyll production, biosynthesis of osmoprotectants, detoxification of reactive oxygen species, stability of proteins and by increasing water uptake (Petropoulos *et al*., 2008).

Chloroplast-plastid-thylakoid- and photosynthesis-related genes are enriched in the down-regulated gene cluster during drought stress. Furthermore, the genes related to cell wall synthesis, external encapsulating structure, response to water deprivation, response to abiotic stimulus, response to abscisic acid stimulus, defense response to bacterium, lignin metabolic process, secondary metabolic process, nucleotide-sugar metabolic process and so on are up-regulated, suggesting that these genes may be important for cotton resistance to drought (Chen *et al*., 2013). These genes may be involved in the different pathways, including amino sugar and nucleotide sugar metabolism, phenylpropanoid biosynthesis, galactose metabolism, arginine and proline metabolism which may be important for cotton resistant to drought stress. TPS is one of the indicators of drought stress condition so the expression level of TPS is increased in drought sensitive plants (Hukin *et al*., 2002; Mahdieh *et al*., 2008; Hadiarto and Tran2011; Hafeez *et al*., 2015).

Monitoring of drought stress in cotton

When the demand for water by cotton exceeds the available supply in a period of insufficient rainfall or irrigation, drought stress can develop and manifest itself through a number of modified phenotypes. The most apparent effect of drought stress on plants is a reduction in height relative to irrigated plants (Pace *et al*., 1999; Pettigrew, 2004b).

In cotton plants, the sensitivity to drought stress during flowering and boll development has been well established (Constable and Hearn, 1981; Turner *et al*., 1986). Lint yield is reduced by decrease in boll production due to reduction in flowering sites and increased boll abscission when the plant is exposed to extreme drought during reproductive development (McMichael and Hesketh, 1982; Turner *et al*., 1986; Pettigrew, 2004). There is a positive correlation between yield and number of bolls produced (Grimes *et al*., 1969), but the biochemical and metabolic processes affecting boll maintenance are not well understood.

Crop sensitivity to water deficit varies by growth stage and is crop-dependent (Doorenbos and Pruitt, 1977; Saini and Westgate, 2000). In many crops, reproductive development is the most sensitive period to drought stress following seed germination and seedling establishment (Saini, 1997), and cotton appears to follow this pattern, as well (Loka, 2012). Cotton is sensitive to water deficit during both flowering and boll development (Constable and Hearn, 1981; Cull *et al*., 1981a, b; Turner *et al*., 1986). Recent research has shown that the developing pollen (Burke *et al*., 2002) and pollen tube growth (Snider *et al*., 2011) are highly sensitive to environmental stress.

Morpho-physiological indicators

Measurements of morpho-physiological indicators in plants of all genotypes have demonstrated considerable reduction in plant height, leaf relative water content, leaf blade expansion and increase in leaf thickness under long-term drought stress. Keeping a check on all these parameters during the sensitive growth stages provides fair enough information about changes occurring and aiding to take the possible measure to recover from stress.

Crop Water Stress Index: The crop water stress index (CWSI) is a valuable tool for monitoring and quantifying water stress as well as for irrigation scheduling.

Chlorophyll fluorescence: Nowadays, the methods of chlorophyll fluorescence control along with the classical measurements of photosynthesis based on gas-exchange analysis are widely used by agronomists in monitoring of crops and their response to environmental stresses (Murchie and Lawson, 2013).

Genetic Improvement through advance breeding programme

Cotton, being a commercially important crop mainly grown in water limited areas (rainfed) received increasing attention for drought tolerance improvement. The particular trait, which is highly quantitative in nature having large G × E interaction, results in unpredictability of its occurrence, severity, timing and duration. Therefore, improvement of cotton to drought tolerance through conventional breeding face many limitations and to gear it up crop improvement programme, deployment of advance breeding techniques like Marker Assisted Selection (MAS), QTL mapping, gene pyramiding and genomic selection are desirable.

Marker Assisted Selection (MAS) for drought tolerance

MAS is an advance breeding strategy to select the gene based on closely linked DNA markers for the gene of interest. At present, the availability of draft genome sequence of *G. raimondii*, *G. arboreum* and now *G. hirsutum* as well as next generation sequencing (NGS) technologies facilitated the development of high throughput marker technologies in cotton (Malik *et al*., 2014). Using this genome database, the markers linked to drought tolerant traits like water use efficiency, root, cellular level tolerance in selecting the drought tolerant plants, in segregating generations that have suitable gene combination will accelerate the breeding program. It has been proposed that single nucleotide polymorphism (SNP) markers will have large influence on MAS in future due to high abundance and development of sophisticated detection systems (Koebner and Summers, 2003).

Cotton, lagging behind for MAS compared to other leading crops due to limited polymorphism and a genetic bottleneck through historic domestication. Continuous selection among the crosses of genetically related parents leads to narrow genetic base and loss of important genes. To meet future sustainable cotton production and productivity under changing climatic conditions, broadening the genetic diversity of cultivars through genomic approaches is much needed. Genomic selection is new approach to improve the quantitative traits in large plant breeding populations that uses whole-genome molecular markers (high density markers and high-throughput genotyping). The implementation of genomic selection in breeding programme would help speed of genetic gain and as a result highly adaptive genotypes will be delivered.

QTL mapping for drought tolerance

QTL mapping is forward genetic technique which identifies the region in the genome, linked to quantitative trait loci on the principal of identifying a connection among phenotype and genotype of the trait. The QTLs identified for drought tolerance in cotton are summarized in Table 8.2.

Table 8.2: QTLs identified for drought tolerance in cotton

Trait	Population	Marker	QTLs identified	Reference
Relative Water content	F2:3	SSR & EST-SSR (524)	2	Saleem *et al.*, 2015
Excised leaf water loss	F2:3	SSR & EST-SSR (524)	1	Saleem *et al.*, 2015
Fresh root weight	BIL (142)	AFLP, SSR & EST-SSR (242)	2	Rahemm *et al.*, 2012
Osmotic potential (OP)	F2:3	SSR (64)	2	Saeed *et al.*, 2011
CIR, OP, WUE, CT, Chlo	F2	RFLP (253)	11(OP),11(CIR),4(CT),7(chor a,b)	Saranga *et al.*, 2004
Carbon Isotope Ratio (CIR)	Comprehensive Meta QTL analysis		4	Said *et al.*, 2013
Canopy Temperature (CT)	Comprehensive Meta QTL analysis		1	Said *et al.*, 2013

The QTLs identified for drought related trait showing high phenotypic variance can be used to introgress the farmers' preferred varieties using marker assisted backcross breeding. Lubbers *et al*., (2006) developed a series of near isogenic lines (NILs) to contain small fragment of the genome of the G. barbadense donor parent within the genetic background of specific G. hirsutum cultivar. This series will be useful to determine the effects of individual QTLs more precisely. It is expected that using this NILs provide a powerful tool to identify Nemours QTLs that can be use to create tolerance for drought in cotton. The Cotton Database Resource (www.cottongen.com) provides information for QTLs, Genome, DNA markers for all four species of cotton which can be used by researches to accelerate the breeding programme.

Gene introgression for drought tolerance

Advancement in the QTL mapping experiments, analysis of genomic data and high throughput laboratory genotyping protocols have enabled us to monitor introgression of two or three desirable genes/ QTLs from different sources into a single background. Drought, being highly quantitative trait, introgression of two to three QTLs or genes is enviable, QTLs for drought related traits were exchanged via MAS between elite cultivars of two cotton species, the resulted Near Isogenic Lines (NILs) manifested in many cases, the expected drought-adaptive traits like net rate of CO2 assimilation, lower stomatal limitation, greater maximum velocity for carboxylation of Rubisco and greater electron transport rate (Levi *et al*., 2009).

Genes identified for drought tolerance in cotton

It has been reported that HSPCB gene responsible for peptide synthesis become activated in leaves of cotton drought tolerant genotypes under water deficit condition (Maqbool *et al*., 2007). GHSP26, an alpha crystalline small heat shock protein gene activates in drought stress condition and improves drought tolerance by regulating cellular metabolism as it assists in protein folding and prevent protein denaturation (Silva *et al*., 2006). Another study under water stress in cotton, a gene TPS was also identified using chromosome-walking technique which participate in biosynthesis of trehalose, an osmolyte that help in protection of proteins under water stress (Kosmas *et al*., 2006). A novel drought resistant gene KC3 has also been identified in cotton (Selvam *et al*., 2009) by physiological and biochemical studies proving the improvement in drought tolerance in cotton.

Traits to concentrate for breeding drought tolerance cotton

The water availability at different stages of development is directly related to quantity and quality of fiber produced. When the water stress is imposed between flowering and fructification stage in large cotton population, showed 50% reduced yield in cotton compared to control treatment (Araujo *et al*., 2003). This finding suggests the impact of water stress on physiology and development of cotton in reproductive stage. Thus, to target water stress studies on both physiological and molecular level are desirable. (Levi *et al*., 2009). Also, other physiological traits, such as relative water content (RWC) (Colom Vazzana, 2003), rupture of the cellular membrane via electrolyte leakages (Mata; Lamattina, 2001) and carbon isotope composition ($^{\delta 13}$C), can be used as indicator for water use efficiency (Saranga *et al*., 2004). These traits have also showed high correlation to drought tolerance in cotton (Silva *et al*., 2007). Drought tolerance indices have been calculated in 16 upland cotton genotypes, and results of calculated correlation coefficient and multivariate analysis showed that geometric mean productivity (GMP), mean productivity (MP), stress tolerance index (STI) were able to genetically discriminate drought sensitive and tolerant genotypes. (Singh *et al*., 2016).

Drought, being highly influenced by environmental factors, identification of drought tolerance recombinants combined with good fiber quality and yield require F2 population to be grown in sufficient number so that maximum number of gene combinations can express themselves. Cotton breeding is in high-transition stage. It is quite possible that 'conventional breeding' together with transgenic breeding and advance breeding approaches like molecular breeding and genomic selection will result in identification of cultivars resilient to climate change.

Induction of drought through exogenous application of different substances

Exogenous application of growth regulators and osmoprotectants at different growth stages of plant can play an important role in effectively enhancing drought tolerance in plants. Osmoprotectants, proline, trehalose, fructans, mannitol, glycine-betaine, helps in mediating osmotic adjustment and protecting subcelleular structures in stressed plants. Apart from acting as osmolyte for osmotic adjustment, proline contributes to scavenging free radicals and buffering cellular redox potential under stress conditions. The foliar application of proline and glycine betaine has found to be effective in overcoming adverse effect of drought stress on cotton (Noreen *et al*., 2013). Exogenous application of glycine betaine has been reported to improve drought tolerance in some plants (Hussain *et al*., 2008). It also known to improve growth under water stress by osmotic adjustment and more photosynthesis, primarily due to a greater stomatal conductance and carboxylation efficiency of Rubisco (Sakamoto and Murata, 2002).

The application of growth regulators helps plants to maintain a fair water balance and chlorophyll content under drought. Application of gibberlic acid under water stressed condition improved yield of cotton by cotton by 18-22 percent (Naidu *et al*., 1998). Exogenous application of gibberellic acid increased the net photosynthetic rate, stomatal conductance and transpiration rate (Litchtfouse *et al*., 2009) and indole-3--acetic acid enhanced net photosynthesis and stomatal conductance in cotton (Kumar *et al*., 2001). The GbRLK which is involved in drought stress pathway by activating ABA signalling pathway was differentially induced by foliar application of JA and MeJA on cotton plants but it was gradually up-regulated when exposed to ABA treatment (Zhao *et al*., 2013)

Conclusion

Doubling the farmer's income is in focus of Indian agriculture research and it is most challenging job. The reduction in yield and quality of the cotton is mainly attributed to biotic and abiotic stresses. Among different abiotic stresses, drought stress is highly accountable for extensive crop loss and will probably worsen in the future due to drastic change in climate. Drought is becoming topic of international research interest and scientists are focusing more on inducing drought tolerance in cotton. Breeding for drought tolerant genotypes is highly complicated under water deficit conditions as there is inadequate knowledge on physiological parameters which reflects the genetic potential for improved productivity and quality of the crop. The drought induced morpho-physiological, biochemical changes and molecular responses in cotton has been studied. To increase the water use efficiency and sustainability of the production system, an indicator capable of quantifying drought stress in terms of yield responses is necessary to have durable information on varietal drought tolerance and defining irrigation thresholds for irrigated fields. Morpho-physiological indicators, crop water stress indicators and chlorophyll fluorescence are considered as valuable tools for monitoring drought stress in cotton. To improve the plant tolerance to drought, traditional breeding programmes along with advanced biotechnological approaches for development of transgenic cotton which can tolerate the various stresses are essential. Application of the exogenous substances like osmoprotectants and growth regulators are known to enhance the tolerance in susceptible plants. Several genes induced by drought stress have been identified by various omics technologies and few of them are studied which is still in early phase. The development of transgenic cotton is mostly done under restricted weather condition and often may not perform better under natural environment. There are thousands of genes which are involved in drought stress tolerance but usually transgenic are developed by transforming single gene which may not give original tolerance to drought. Surprisingly, there are no reports in cotton for enhancing drought tolerance by engineering. Understanding physiological traits which reflects genetic potential for drought tolerance is required. Enhancing drought tolerance in cotton is very much required to face the challenges of changing global climate and to secure future generations from food crisis. Though drought is highly complex perennial trait to understand but proper use of technologies and timely adaptation makes it overcome this adverse situation.

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9. Extension Approaches for Enhancing Productivity in Rainfed Areas

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Agricultural extension is the conscious communication of information to help farmers form sound opinions and make good decisions on farming. According to Ackah-Nyamike (2007), agricultural extension empowers farmers with the requisite knowledge, attitude and practices for enhancing productivity and welfare. In other words, agricultural extension has a philosophy of helping people to help themselves. The traditional view of agricultural extension in developing countries was very much focused on increasing production, improving yields, training farmers, and transferring technology (Davis, 2008). Extension delivery is primarily a government responsibility, though many other actors are involved, including development partners, private firms and non-governmental organizations. The ratio of extension workers to farmers is low at 1:1162 at national level (one agricultural officer serving 1162 farmers) as against recommended ratio of 1:750. The lack of access is compounded by extension agents' lack of funds for transport, further reducing extension worker access to farmers. Also, extension personnel may identify and know the solutions to problems faced by the farmers, and yet may not be able to disseminate the solutions to the farmers due to lack of appropriate extension teaching methods for transferring agricultural technologies. The role of extension personnel is to help farmers form healthy opinions and make good decisions by communicating and providing the information needed by farmers, besides that, they also play a role in helping farmers improve their farming and overall economic wellbeing.

Agricultural technology transfer methods/approaches refer to the techniques used by an extension system as it functions, for example, demonstration, or a visit by an extension agent to a farmer. There are several methods used in extension work. Some of these include individual/household extension method, group method, and mass media method. None of these methods can be singled out as the best one as they all have some advantages and disadvantages. According to Anandajayasekeram *et al.,* (2008), the choice of a method depends on various factors such as the tenure system in the area, community organization, and resources availability. For example, in an area where tenure is communal, or land management is based on communal efforts, a group approach is likely to be more effective than an individual approach. Meetings, field days, and approaches to schools may also be good options. Despite the importance of agricultural extension in communicating relevant information about improved production techniques to farmers, there are limited studies, to the best of our knowledge, that evaluate the effectiveness of the various agricultural technology transfer methods/approaches in India in general and Telangana, Andhra Pradesh (A.P.) states in particular. This paper therefore highlights effectiveness of various agricultural technology transfer (extension approaches) that are being used by the stakeholders of the agricultural extension delivery system in Adilabad district of Telangana and Anantapuramu district of A.P. The specific objectives of the study is to identify the existing extension approaches employed by extension officers of different agencies in study area.

Methodology

A sample of 120 farmers were randomly selected from Telangana state and from Telangana, Adilabad district were selected. The sample agencies selected for the study were Ekalavya Foundation (EF) an NGO, Jain Irrigation (JI) a private extension firm and State Department of Agriculture (SDA) representing the government extension agency. In Adilabad, Gudihatnoor (JI), Indervelly, Sirikonda (EF) and Ichoda (SDA) mandals were selected for the study. Care was taken in selecting the mandals (along with villages and respondent farmers (40 from each agency)) that were mutually exclusive to avoid overlapping of data from each agency i.e., Gudihatnoor was selected to collect data from JI, Indervelly and Sirikonda for EF and Ichoda for data from SDA. The data was collected using a pre-tested interview schedule and focus group discussion from the farmers belonging to each agency. Mean, standard deviation, t-test and Tukey HSD tests were employed for data analysis. Conclusions were drawn based on the interpretation of results.

Similarly, a sample of 120 farmers was randomly selected from the Anantapuramu district of A.P. The average annual rainfall in Anantapuramu is 550 mm. The sample agencies selected for the study were Watershed Support Services and Activities Network (WASSAN) an NGO, Coromandel Fertilizers Limited (CFL) a private extension firm, and the State Department of Agriculture (SDA) representing the government extension agency. In Anantapuramu, Nallacheruvu (WASSAN), Bukkarayasamudram (CFL), and Atmakur (SDA) mandals were selected for the study. Care was taken in selecting the mandals (along with villages and respondent farmers (40 from each agency)) that were mutually exclusive to avoid overlapping of data from each agency i.e., Nallacheruvu was selected to collect data from WASSAN, Bukkarayasamudram for CFL and Atmakur for data from SDA. The data was collected using a pre-tested interview schedule and focus group discussion with the fanners belonging to each agency.

Results and discussion

The main crops in the study villages from Adilabad district in Telangana are cotton, soya and red gram in kharif and maize, chick pea, wheat and water melon in *rabi*. The average annual rainfall in Adilabad is 1000 mm.

Table 9.1: Pooled T-test results for extension approaches from Ekalavya Foundation (EF), Jain Irrigation (JI) and State Dept. of Agriculture (SDA) in Adilabad district

Sl. No.	Extension Approaches	N	Mean
1.	Demonstration	120	5.00
2.	Training	120	3.58
3.	Exposure visit	120	4.30

Sl. No.	Extension Approaches	Mean Difference	t value	Sig. (2-tailed)
1.	Demonstration vs Training	1.425	31.44	0.001**
2.	Demonstration vs Exposure Visit	0.700	16.66	0.001**
3.	Training vs Exposure Visit	-0.725	-11.73	0.001**

***Significant at 0.01 probability level*

Results from table 9.1 indicate that Demonstrations (Group approach) were highly effective extension method followed by Exposure visits and trainings in that order. Results from Shaibu *et al*., (2018) also concur with our findings that the extension approach that was most perceived by farmers to influence adoption was demonstration (with mean value of 4.51). According to Aremu *et al*., (2015) and Anandajayasekeram *et al*., (2008), it is possible to reach large numbers of farmers within a short time at minimal cost and with great impact, using the demonstration method.

In Anantapuramu district of A.P., the main crops in the study villages are ground nut, red gram, paddy, banana, tomato, and other vegetables. The average annual rainfall in Anantapuramu is 550 mm.

Table 9.2: Tukey HSD test results for extension approaches from CFL, Wassan and SDA in Anantapuramu District

Sl. No.	Extension Approaches	N	Mean
1.	Demonstrations	120	3.67
2.	Trainings	120	2.86
3.	Exposure Visits	40	1
4.	Group Meetings	80	2.82
5.	Farmer-to-Farmer Extension (FFE)	40	4.9

The major extension approaches that were used to transmit information to farmers are given in the above table 9.2 Farmer to Farmer Extension (FFE) followed by demonstrations, training, group meetings and exposure visits (group approaches) were highly effective extension approaches in that order. Results from Ewbank *et al.*, (2007) also concur with our findings. The FFE approach has the potential of supplementing existing extension approaches and improves farmers' access to extension services. FFE is effective in serving farmers' needs, institutionally more sustainable, comparably inexpensive, and used in areas where it is inadequate or absent of government extension staff. Furthermore, it is also thought to reach and include many poor farmers, thus increasing the adoption of technologies.

Conclusion

It is imperative that, the agricultural policies of Telangana should be aimed at empowering the Agricultural department, both technically and financially, to train farmers through field demonstrations, exposure visits and trainings since these approaches have proven to be effective in disseminating information to farmers in real time. Similarly, in Anantapuramu district of A.P., FFE followed by demonstrations, training, group meetings, and exposure visits were highly effective extension approaches for dissemination of technologies, information etc. to farmers in the study. It therefore imperative that the agricultural policies of A.P. should be aimed at empowering the Agricultural department, both technically and financially, to train farmers through FFE, Demonstrations, Trainings, Group meetings and Exposure visits since these group approaches have proven to be effective in disseminating information to farmers in real-time. It was found from the study that extension was highly effective in NGOs followed by SDA and private firms in that order in the sample districts in both Telangana and A.P. Technology-led approaches like Information and Communication Technologies (ICTs) (like mobile, SMS, individual (individual farmer or household) and mass media approaches (like TV, radio) was shown less preference by farmers in information seeking in the study.

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10. Conservation Social Science: Understanding and Advancing Natural Resources Conservation Efforts

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Natural resource conservation is the practice of managing and preserving Earth's finite natural resources, including land, water, minerals, forests, wildlife, and biodiversity, to ensure their sustainability and availability for current and future generations. Conservation efforts aim to strike a balance between human exploitation (not exceeding the Earth's capacity to regenerate and replenish) of these resources and the need to protect and maintain the health of ecosystems and the overall environment. The primary goals of natural resource conservation are to prevent resource depletion, reduce environmental degradation, and promote sustainable and responsible resource use. Conservation plays a significant role in providing empirical evidence of human influences on biodiversity (either in the form of destruction or in the form of conservation) despite the fact that research on conservation is biased in some ways (Godet and Devictor, 2018). Hence, without an understanding of the social and cultural factors affecting resource use and conservation, efforts are likely to fall short of their objectives. The success of many of the conservation programmes has also been hampered by a lack of adherence to management plans due to the failure to take into account the social context and realities of beneficiaries and resource users. There is widespread agreement that present conservation tactics are inadequate to address the acceleration of environmental degradation brought on by human activity. This necessitates a pressing need for a deeper comprehension of the relationships between people and the natural world through integrating social science with conservation science (Rebecca et al., 2021). Traditional conservation programmes' guiding ideologies are beginning to change to favour a "people and nature" perspective founded on a deeper knowledge of relational values, culture, and society (Sanborn and Jung, 2021). The human dimension in natural resource conservation is of paramount importance for many of the factors. Conservation social science is an interdisciplinary field that combines elements of sociology, anthropology, psychology, economics, and other social sciences to address the complex and multifaceted challenges of biodiversity conservation and environmental sustainability (Leopold,1986; Cronon, 1992; Cronon, 1996; Newing, 2010; Bennett et al., 2017). This chapter attempts to present a brief history and evolution of conservation social science, its relevance, subjects of study, scale of action, hurdles to incorporating social science into conservation activities, and strategies for increasing the visibility and influence of the same.

Developmental trajectory of conservation social science

The history of conservation social science is rooted in the broader environmental and conservation movements that have evolved over the past century. While the formalisation and recognition of conservation social science as a distinct field is relatively recent, its foundations can be traced back to various key historical developments: The concept of conservation, particularly in the context of natural resources, began to take shape in the 19th century. Figures like Marsh (1864), Muir (1896), and Roosevelt (Miller, 1992; Izatt, Hilary Jan, 2004) played pivotal roles in promoting the preservation of natural areas, which laid the groundwork for future conservation efforts. During the late 19th and early 20th centuries, the science of ecology started to take root. Ecologists like Aldo Leopold emphasised the importance of understanding ecological systems to inform conservation decisions. Leopold's "A Sand County Almanac" (1949) remains a significant work that bridges ecology and social considerations in conservation. The environmental movement of the 1960s, often associated with Carson's "Silent Spring" (1962), was instrumental in raising awareness about the detrimental effects of human activities on the environment. This period marked an increased focus on the human dimensions of environmental problems and the need for interdisciplinary approaches to address them. The fields of environmental sociology (Catton & Riley, 1978) and environmental psychology (Stokols & Altman, 1987) emerged during the 1960s and 1970s. These disciplines explored the social and psychological factors influencing people's attitudes and behaviours toward the environment, thus providing the early foundations for conservation social science. International agreements and initiatives, such as the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 1973 (UN, 2017) and the establishment of protected areas worldwide (Hoffmann, 2022), drew attention to the need for engaging with local communities and understanding their relationships with natural resources. This shift emphasised the importance of social science in conservation. The late 20th century witnessed the gradual formalisation of conservation social science. Conservation organisations and academic institutions recognised the need for interdisciplinary approaches to conservation.

Researchers began to conduct more systematic studies on the human dimensions of conservation, with a particular focus on issues such as community-based conservation, biodiversity conservation, and sustainable resource management. Modern conservation social science discipline started in the 21st Century. It has gained prominence as a distinct field. Academic programs, research centres, and journals dedicated to the discipline have proliferated. Scholars in this field explore a wide range of topics, including the impact of policy on conservation (Meinard, 2017), the role of indigenous knowledge in conservation (Gadgil *et al*., 1993; Singh, 2023), and the development of sustainable practices. The history of conservation social science reflects the evolving recognition of the importance of human interactions with the environment in the context of conservation efforts. It has evolved from a broad focus on ecological preservation to a more holistic understanding of the complex relationship between humans and the natural world, making it a crucial field in contemporary conservation practice and policy (Morelli *et al*., 2016).

Relevance of conservation social science

The fundamental premise of conservation social science is the recognition of the interconnectedness between human societies and the natural environment. This interdisciplinary approach acknowledges that addressing conservation issues requires an understanding of human behaviours, values, and decision-making processes, as well as the ecological dynamics of ecosystems (Chan *et al*., 2016). Conservation social science is essential for recognising the cultural and contextual dimensions of conservation. Different cultures have unique relationships with their environments, and understanding these perspectives is crucial for effective conservation strategies that respect local traditions and values (Kansky & Knight, 2014). Similarly, effective conservation requires not only understanding the behaviours of individuals and communities but also the institutions and governance structures that influence conservation policies and practices. Conservation social science examines the decision-making processes, power dynamics, and policy frameworks that shape environmental outcomes. Because of all these reasons, the integration of social science is very important in natural resource conservation actions.

What are conservation social sciences?

Conservation social sciences are a collection of academic disciplines and research approaches that focus on the human dimensions of conservation and environmental management. These disciplines and approaches contribute to our understanding of how human societies interact with and impact the natural environment. The main conservation social sciences include:

1. ***Environmental Sociology***: Environmental sociology examines the relationship between society and the environment. It investigates how social structures, values, and behaviours influence environmental issues and how these issues, in turn, affect societies (Dunlap & Catton, 1979; Buttel, 2003; Stewart, 2015; Hannigan, 2022).
2. ***Environmental Psychology***: Environmental psychology studies how individuals and groups perceive and respond to the environment. It explores the psychological factors that influence pro-environmental behaviour, attitudes, and preferences (DeYoung, 1999; Gifford *et al*., 2011).
3. ***Human Geography***: Human geography investigates the spatial aspects of human-environment interactions. Researchers in this field explore topics like land use, urban planning, and the distribution of resources in relation to conservation (Buchadas *et al*., 2022; Enrico *et al*., 2022)
4. ***Anthropology***: Anthropology, particularly cultural anthropology, is concerned with understanding the cultural and social aspects of human interactions with the environment. Anthropologists often engage with indigenous and local communities to study their environmental knowledge and practices (Orlove & Brush, 1996).
5. ***Political Science and Policy Studies***: Political science and policy studies in the context of conservation focus on governance, policy development, and the political forces that shape environmental policies and regulations (Ludwig *et al*., 2001; Rose, 2019; Bocking. 2020)
6. ***Economics***: Environmental and ecological economics analyze the economic aspects of conservation and sustainability. This includes the valuation of natural resources and ecosystem services, cost-benefit analysis, and understanding the economic drivers of environmental degradation (Orr, 1991; Sagoff, 2000; Newburn *et al*., 2005)
7. ***Community and Stakeholder Engagement***: This interdisciplinary field focuses on engaging local communities and stakeholders in conservation efforts. It involves participatory approaches, community-based conservation, and dialogue to foster collaboration (Sterling *et al*., 2017; Mussehl *et al*., 2022).
8. ***Environmental Education and Communication***: Conservation social scientists often study the effectiveness of environmental education and communication strategies in

raising awareness and promoting pro-environmental behaviours (Jamsa *et al*., 2023; Terrazo *et al*., 2023).

9. ***Gender Studies***: Gender studies within conservation social sciences examine the roles, rights, and responsibilities of different genders in environmental management and how gender dynamics can impact conservation outcomes (Arya *et al*., 1998; James *et al*., 2021).
10. ***Human-Wildlife Interaction Studies***: This field explores the relationship between humans and wildlife, including human-wildlife conflicts and coexistence, with the aim of finding solutions that benefit both parties (Pooley *et al*., 2021; König *et al*., 2021; Wierucka *et al*., 2023).
11. ***Indigenous and Local Knowledge Systems***: Recognizing and integrating indigenous and local knowledge systems into conservation practices, acknowledging the valuable insights these communities have about their ecosystems (Hill *et al*., 2020; Reyes-García, 2023).
12. ***Ethics and Philosophy:*** Ethics and philosophy within conservation social sciences deal with the ethical principles and moral considerations that underlie conservation decisions and practices (Wheeler and Root-Bernstein, 2020; Reyes-García, 2023; Hill *et al*., 2020; Torrents-Ticó *et al*., 2021).

Scales of action in conservation social science

The concept of "scales of action" refers to the various levels at which conservation social science operates to study, analyze, and influence conservation efforts. These scales range from the individual level, where attitudes and behaviours of people are examined, to community, institutional, regional, national, and even global scales, where the impact of policies, governance structures, and international agreements on conservation outcomes is analyzed (Figure 10.1).

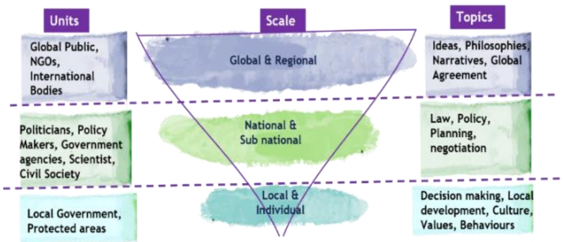

Figure 10.1: Scales of action in conservation social science (Adopted from. Bennett *et al*., 2017)

Conservation social scientists navigate this multi-dimensional landscape to understand and address the intricate interplay of human societies with their natural environments. By recognizing the significance of these scales, conservationists can tailor strategies and interventions that align with the specific contexts and challenges faced in different geographic and social settings, ultimately contributing to more effective and sustainable conservation efforts worldwide. A brief discerption of the scales of action in conservation social science is as follows;

- **Individual Level:** This scale focuses on understanding the attitudes, behaviours, and perceptions of individual people with regard to conservation and the environment. Researchers might study how individuals make decisions related to resource use and conservation practices.
- **Community Level:** At the community level, researchers examine the dynamics within specific communities and how they impact conservation efforts. This may involve studying local traditions, indigenous knowledge, and community-based conservation initiatives.
- **Institutional and Governance Level:** This scale investigates the role of institutions, policies, and governance structures in conservation. Researchers examine how laws, regulations, and decision-making processes affect conservation outcomes. They may also assess the effectiveness of conservation organizations and their strategies.
- **National Level:** Conservation social scientists may examine how national policies, laws, and government initiatives influence conservation efforts. This could involve assessing the allocation of resources, funding for conservation projects, and national priorities related to environmental protection.
- **Regional or Landscape Level:** Conservation social science often addresses larger geographic scales, such as regions or landscapes. This includes analyzing land use patterns, habitat fragmentation, and the impact of development on biodiversity and ecosystems. Researchers explore how multiple stakeholders and interests intersect in these contexts.
- **International and Global Level**: This scale explores international agreements, organizations, and conventions that shape global conservation efforts. Researchers assess transboundary conservation issues, the influence of international policies and treaties, and the role of global actors such as the United Nations and international NGOs.
- **Global Civil Society and Advocacy Level**: This scale involves the study of non-governmental organizations (NGOs), advocacy groups, and civil society movements

engaged in conservation work. Researchers examine their roles in raising awareness, shaping public opinion, and influencing policy at various levels.

- **Knowledge and Communication Level**: Understanding how knowledge is generated, communicated, and utilized in conservation is crucial. This scale encompasses the study of knowledge systems, science communication, and the dissemination of information to the public and decision-makers.

Conservation social science in action

Conservation social science action involves a series of steps to understand, address, and contribute to conservation efforts while considering social, cultural, and economic factors (Figure 10.2). It is an iterative and adaptive process that involves collaboration and interdisciplinary work to address the complex and dynamic challenges of environmental conservation while taking into account the social and cultural contexts in which these challenges exist.

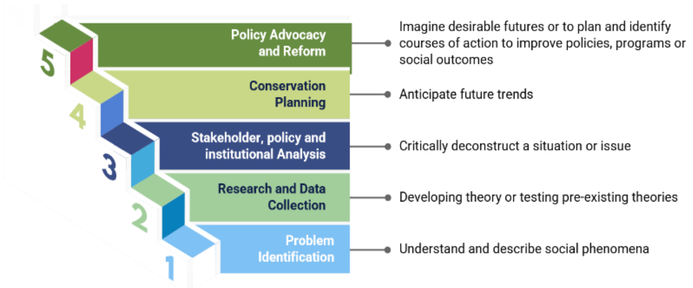

Figure 10.2: Steps in Conservation Social Science action

Conservation social science in action starts with the identification of a specific conservation issue or problem, such as habitat loss, species decline, or ecosystem degradation. This often involves collaboration with natural scientists to understand the ecological aspects of the problem. After the problem identification, efforts are needed to understand the social, economic, and cultural aspects that contribute to the identified conservation problem through data gathering. Social scientists might seek to critically deconstruct a situation or issue in order to construct more effective solutions through the situation analysis and stakeholder analysis. Followed by these actions, social scientists need to anticipate future trends through modelling and forecasting social and/or economic conditions. Finally, social scientists should imagine desirable futures or to plan and identify courses of action to improve policies, programs or social outcomes. It is very important to advocate for policy changes and institutional reforms when necessary to create an enabling environment for sustainable conservation (Bennett *et al.*, 2017; Niemiec *et al.*, 2021).

Key principles of conservation social science

1. **Trans disciplinarity**: Conservation social science emphasizes collaboration between natural scientists and social scientists, ensuring that conservation strategies are grounded in both ecological and social realities. It encourages dialogue and shared understanding to create holistic solutions (Reyers *et al*., 2010; Bennett *et al*., 2017; Deutsch *et al*., 2023).
2. **Stakeholder engagement**: Conservation social science places great emphasis on involving local communities, indigenous groups, and other stakeholders in conservation efforts. Their knowledge and involvement are seen as vital for the long-term success of conservation projects.
3. **Adaptive management**: Conservation social science supports adaptive management strategies that allow for flexibility and learning from experience. Conservation initiatives need to adapt to changing social and ecological conditions, and social science helps monitor and adjust these efforts (Lee, 1999; Frohlich *et al*., 2018; Kaplan-Hallam & Bennett, 2018).

Social science research design in conservation

In conservation science, the social science research design can be applied at various stages. It begins with problem identification and progresses to conservation planning and implementation (Figure 10.3).

Figure 10.3: Social science research design in conservation

Research methods in conservation social science encompass a range of approaches and techniques used to study the human dimensions of conservation, the interactions between people and the environment, and the societal aspects of conservation issues. These methods help researchers understand how human behaviours, attitudes, and institutions impact conservation efforts. Here are some commonly used research methods in conservation social science: surveys and questionnaires, interviews, focus groups, participant observation, case studies, mixed methods research, spatial analysis including geographic information systems, controlled experiments, Participatory Action Research (PAR) etc. The choice of research methods depends on the specific research questions, goals, and the context of the conservation issue being studied. Researchers often use a combination of these methods to provide a holistic understanding of the social aspects of conservation (Newing, 2010; Christopher & Andrew, 2013; Moon *et al*., 2016; Moon *et al*., 2019; Wardropper *et al*., 2021).

Whether and with whom to do conservation social science research will rely on our level of knowledge, the resources we have at our disposal, and the specifics of our study subject. Networking and collaboration within the subject can greatly improve the calibre and significance of the study. It encompasses various levels of study, from individual behaviours and community dynamics to regional and global policy implications (Newing, 2010; Bennett *et al*., 2017). Like in many other scientific fields, conservation social science allows researchers to develop and test theories, examine data, and draw conclusions using both deductive and inductive methods. These two methods are frequently applied at various phases of the research process and have unique qualities (Newing, 2010; Michael. 2015; Bennett, *et al*., 2017).

Case studies of conservation social science and its application

A study by Pradhan *et al*., (2017) utilized a transdisciplinary approach (incorporates both complex environmental and human systems) to examine conservation agriculture practices in the rainfed uplands of Odisha, India, to enhance and promote its implementation. Incorporating input from other disciplines, the transdisciplinary approach seeks to represent scientific knowledge and involves stakeholders in the co-design and execution of field experiments and demonstrations. With the help of this strategy, academics, farmers, communities, and other stakeholders may form powerful relationships that promote the adoption of cutting-edge technology and lead to sustainable results. The study was planned and conducted in four different stages. Co-design and research definition of conservation agriculture were the first steps. Interdisciplinary academic works with farmers, villages, local universities, extension agents, and non-governmental organisations were conducted to explain the technology and its possible effects on farming systems to the stakeholders. Several discussions about local customs and crop choices with stakeholders were followed to identify the potential experimental designs and indicators for the outcome to assess conservation agricultural production systems. Universities and non-governmental organisations gathered the data, while farmers and villagers received training in conducting and overseeing the field experiments. These social science interventions helped to accept the conservation technologies by the farmers in a rapid way and with the support of the district government, farmers in the Keonjhar district are now implementing the reduced tillage maize cowpea intercrop system. Another notable example of the application of conservation social science is in the conservation of endangered species like the Bengal tiger in India. Researchers have used a combination of ethnographic fieldwork and stakeholder engagement to understand the complex relationship between local communities and tiger populations. Through their findings, policies have been developed that respect the cultural values of these communities while also working to protect the tigers' habitat (Saberwal, 1997; Rastogi *et al*., 2012; Vasudeva *et al*., 2021).

Being the national institute with mandated reach areas in marine fisheries and resources management, ICAR-CMFRI, Kochi, has made substantial contributions to resource conservation through the conservation social science discipline. Being a natural resource with a common-pool resource of the fish stock in a particular area, overfishing and resource depletion can notably lead to the classic hypothetical situation of the tragedy of the commons in marine fisheries (Hardin, 1968; Berkes, 1985; Zambrano *et al*., 3023). The integration of social science, particularly extension research, with traditional fisheries science and marine biology research enabled CMFRI to issue timely conservation measures and advisories, allowing the country and its various states to implement various regulatory frameworks that are socially and culturally compatible. The major works in the field of conservation social science are i*) Socioeconomic Impact Studies*: CMFRI conducted studies to assess the socioeconomic impacts of various fisheries management and conservation measures on fishing communities. These studies help in understanding how conservation measures affect the livelihoods and well-being of fisherfolk (Sathiadhas *et al*, 2010). ii) *Stakeholder Engagement, Consultation and Community-Based Management:* CMFRI is active in community-based fisheries management research and promotion. The institute works with a variety of stakeholders, including fishing communities, to get their feedback and perspectives on fisheries management and conservation. This entails researching the role of local communities in resource management as well as the social dynamics involved in such activities, and this collaborative approach guarantees that local knowledge and concerns are included while framing conservation measures (Ramachandran & Thamban, 2015; Ramachandran, and Mohamed, 2015). iii) *Gender and alternative livelihoods in Fisheries:* Understanding gender dynamics is crucial for effective conservation and sustainable management in marine fisheries. CMFRI has also focused on the role of gender in fisheries, particularly by conducting studies on the involvement and empowerment of women in the fishing sector and promoting livelihood diversification options for fishing communities, helping them explore alternative sources of income that reduce pressure on marine resources (Ramachandran, 2012; Vipinkumar *et al*., 2022). iv). *Vulnerability and Resilience Assessments*: CMFRI conducted assessments of the vulnerability of fishing communities to various environmental and social stressors, as well as their resilience strategies to cope with changes (Johnson & Ramachandran, 2017). v). *Ecosystem Services Valuation*: Assessing the value of ecosystem services provided by fisheries and associated environments is a critical aspect of conservation. CMFRI is engaged in such valuation studies to highlight the benefits of conservation efforts (Ramachandran *et al*., 2022). vi). *Behavioural Research and Policy Directions:* Understanding the behavioural aspects of fishing communities, including their responses to regulations and conservation measures, is an important component of conservation social science research. It is an important input for the policymakers while designing more effective and evidence-based policies in the future (Ramachandran *et al*., 2020; Gills *et al*., 2021). vii). *Awareness creation through communication:* The success of natural resource conservation activities is dependent on effective communication. It promotes knowledge dissemination, fosters support, encourages behaviour change, and facilitates collaboration among varied stakeholders. Conservation efforts that employ excellent communication tactics are more likely to achieve their objectives and protect crucial natural resources for future generations. CMFRI has made significant contributions in this sector by examining stakeholders' preferences for various communication modalities over time and designing appropriate communication tools for behavioural interventions. These effective communication strategies helped to bridge gaps between various stakeholders, promote responsible fishing practices, and contribute to the long-term conservation of marine ecosystems (Ramachandran, 2004; Ramachandran *et al*., 2006; Ramachandran, 2013; Gills & Ramachandran, 2019).

Contribution of the social sciences to conservation

The social sciences play a crucial role in conservation efforts by providing insights, methodologies, and tools to understand and address the complex human dimensions of conservation (Table 11.1). The successful conservation is not just about protecting ecosystems and species but also about understanding and working with people to achieve sustainable and effective conservation outcomes. Conservation social science is an integral part of the interdisciplinary approach necessary for long-term conservation success (Kaufman, 2018; Rebecca *et al*., 2021; Sanborn and Jung, 2021; Richter *et al*., 2022). Here are some of the key ways in which the social sciences contribute to conservation:

- **Understanding human behaviour and attitudes**: Social scientists study how people interact with the environment and wildlife, their attitudes, values, and behaviours. This understanding is essential for designing effective conservation strategies, as it helps identify factors that promote or hinder conservation efforts.
- **Community engagement and informed decision-making**: Conservation social science emphasizes community-based and participatory approaches. It involves local communities in decision-making processes, ensuring their needs, knowledge, and perspectives are considered. This fosters a sense of ownership and responsibility for conservation. Conservation social science provides critical insights for decision-makers by identifying the social and cultural factors influencing conservation efforts. Understanding these factors can lead to more informed and effective strategies.
- **Conflict resolution**: Conflicts often arise between conservation initiatives and local communities, especially when there is a perceived threat to livelihoods. Conservation social science helps mediate and resolve conflicts, finding mutually beneficial solutions. This includes compensation mechanisms for damage caused by wildlife and finding ways for people and wildlife to coexist peacefully.
- **Behaviour change**: Behaviour change is a dynamic and ongoing process within conservation social science. It recognises that understanding and influencing human behaviour is just as important as ecological knowledge when it comes to achieving successful conservation. To effectively conserve the environment and protect endangered species, it's essential to influence and promote positive changes in human behaviour. Conservation social science can inform the design of communication campaigns and education programs that encourage behaviour change among the stakeholders.
- **Policy development:** Social scientists can play a vital role in studying the policy landscape and its impacts on conservation by conducting rigorous research, engaging with stakeholders, and providing well-founded recommendations, social scientists can contribute to improving conservation policies, making them more effective, sustainable, and inclusive while addressing the complex human dimensions of conservation.

Table 10.1: Summary of the social sciences' primary contribution to conservation science

Area of Contribution	Process	Probable question to get valid conclusion
Descriptive	• The social sciences can be used to document and describe the diversity of conservation practices	• What is the process by which management boards make decisions? • In environmental governance, who is involved? • What part does science play in management? • What has been the historical use of an area, and by whom? • What effects do various funding models—such as national and corporate funding—have on the conservation agenda?
Diagnostic	• Social science can help to diagnose why conservation is succeeding or failing? • What scales are appropriate for different conservation processes and projects? • How different processes (e.g., collaboration or integration of science) might fail as a result of the interactions between groups?	• How is resistance to or acceptance of a management initiative? • Which elements draw people to a management plan? • Which are the primary disputes pertaining to resource management, and what causes these disputes to arise?
Disruptive	• When the critical social sciences highlight disparities, power dynamics, or systemic problems at the level of individual conservation projects or international conservation organisations, they might be difficult to understand.	• How might a better understanding of social networks help in outreach? • What role do environmental, cultural practices play in disputes over resource use?

Reflexive	• Allow to explore the history and underlying assumptions of conservation • What constitutes ethical or responsible conservation actions • Enable to examine the way that different cultures or groups might think about nature or conservation and the implications for practice	• What influences conservation behaviours come from regional social practices, cultural norms, and social identities? • What elements contribute to varying degrees of civic engagement? • What conflicting perspectives on conservation do locals hold, or do locals hold with external organisations?
Generative	• The lessons learned from examining the contexts, processes, models and ways of thinking about conservation can be generative, producing innovative ways of thinking about or planning conservation. • Guide us to think about new and more appropriate models for conservation – for example, that include culture) or ways of thinking about the future	• Which managerial measures are in place? Who made it? What? • In what ways do local economies and livelihoods influence, or are they influenced by, protected areas? • Which cultural frameworks are being used to influence conservation practice and policy? • Which economic or governance frameworks might be applied to regulate the conduct of corporations? • How may consumer behaviour be influenced by environmental messaging?
Innovative or instrumental	• An instrumental role, for example, in determining what constitutes effective management, governance, or communications strategies for conservation. • Instrumental to conservation in 5 ways - 1) improve management practices and governance processes, 2) enable better conservation designs and models, 3) justify conservation actions, 4) help to achieve ecological outcomes, and 5) facilitate more socially equitable processes and outcomes.	• What kind of response may people expect from a specific conservation? • How can we create persuasive messaging to increase local support for conservation initiatives? • How can we influence customer choices to lessen our impact on the environment? • How do we support the growth of knowledge and the modification of behaviour?

Barriers to engaging with the conservation social sciences

Getting involved in conservation social sciences might be difficult due to a number of obstacles (Fox *et al*., 2006; Rose *et al*., 2018; Deutsch *et al*., 2023). These impediments could stymie the incorporation of social science research and practice into conservation initiatives. Among the major impediments are:

- ✓ Lack of awareness: Many conservation practitioners, policymakers, and even some researchers may not be fully aware of the importance of social sciences in conservation. They may prioritize ecological or biological aspects while overlooking the human dimensions of conservation.
- ✓ Disciplinary silos: Conservation often involves collaboration across various disciplines, including biology, ecology, economics, and sociology. However, disciplinary silos can create barriers to effective communication and cooperation between experts in different fields.
- ✓ Funding priorities: Funding for conservation projects often prioritizes fieldwork, data collection, and biological research over social science research. This can lead to a lack of financial support for social science initiatives and hinder the integration of social science findings into conservation strategies.
- ✓ Perceived complexity: Some conservation professionals may perceive social science research as more complex or less tangible than biological research. This can lead to a lack of understanding of how social science can be practically applied to conservation issues.
- ✓ Time constraints: Conservation projects often operate under tight timelines, making it challenging to incorporate comprehensive social science research and analysis. As a result, social science may be seen as an additional burden rather than a valuable asset.
- ✓ Resistance to change: Resistance to change within conservation organizations or among stakeholders can be a significant barrier. Existing practices and policies may be deeply ingrained, and there may be a reluctance to adopt new approaches informed by social science research.
- ✓ Cultural and language differences: Conservation projects often take place in diverse cultural and linguistic contexts. These differences can pose challenges in effectively engaging with the local social sciences, as well as in communicating research findings and recommendations.

- ✓ Data and methodological challenges: Social science research often involves complex and context-specific methodologies. Gathering and analyzing data related to human behaviour and attitudes can be more challenging than ecological data collection, which may discourage engagement with social sciences.
- ✓ Interpersonal and communication challenges: Effective engagement with social sciences requires strong interpersonal and communication skills. Building trust and rapport with local communities and stakeholders is crucial, but not all conservation professionals have the necessary skills or training.
- ✓ Policy and institutional barriers: Existing policies and institutional structures within conservation organizations may not be conducive to integrating social science findings. Bureaucratic obstacles and a lack of institutional support can hinder the incorporation of social science into conservation strategies.

Conclusion

Understanding the complicated connection between human cultures and the natural environment is critical in furthering conservation efforts. Conservation social science guides decision-making, resolves conflicts, stimulates behaviour change, and supports the development of effective policies by adhering to the principles of transdisciplinarity, stakeholder involvement, and adaptive management and employing a variety of research approaches. This multidisciplinary approach is critical for solving our time's most severe environmental concerns and ensuring harmonious coexistence between humans and the natural world. However, there are numerous challenges to incorporating social science into conservation science. To overcome these barriers to interacting with conservation social sciences, conservation practitioners and social scientists must work together. It entails increasing public awareness of the importance of social science, gaining capital for social scientific research, encouraging multidisciplinary collaboration, and improving the capacity to effectively apply social science findings to conservation efforts. Recognizing the significance of addressing the human dimensions of conservation is a key first step towards overcoming these obstacles and attaining more sustainable and effective conservation outcomes.

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11. Farmers Centric Natural resource development for Socio economic empowerment in Rain fed Areas of Southern Telangana: FFP Experiences

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Rainfed production system is fragile and fraught with many challenges from management of natural resources to bridging yield gaps to deriving livelihood and income source from crop production and value addition. In rainfed ecosystems, the success of crop production depends on effective and timely utilization of available natural resources. Rainfed farming face complex environmental extremes to whom, farmers have traditional wisdom for combatting these adverse weather conditions. These knowledges are the reservoir of untapped potentials to sustain agricultural practices suitable to the local environmental conditions. Most of the technologies generated in the institutions are partially adopted due to lack of active participation of farmers in technology generation and validation processes. Many extension systems and approaches operationalized in rainfed areas were mostly technology centric rather than farmer centric Envisioning doubling farmer income from rainfed areas and improving livelihood and income, a holistic extension approach has been introduced keeping farmer in center, 'Farmers FIRST', an initiative of ICAR, that considers farmer innovations and resources as basis for social action and technological development.

The Farmer FIRST Programme (FFP) is a frontline extension programme of ICAR. It is an initiative and approach to take agriculture beyond the production and productivity of farm, at the same time to protect the smallholder agriculture against heterogenous conditions and risk prone realities of farming through a holistic farm development plans placing emphasis on various domains of a farm: natural resource management, production management of crops, livestock, farm mechanization, horticulture, climate resilient technologies, storage and market, value chains, innovation and information systems by enhancing farmers-scientists interface.

Farmer FIRST Project (FFP) approach is mainly intended to focus on Farmers Farm, Innovations, Resources, Science and Technology to bring social action and technological change. In this concept, Farmers play a significant and centric role in identification of problem, prioritization, conducting demonstrations and evaluation of outcomes. The technological change ensured with appropriate integration of indigenous and research-based knowledge through a series of farmer-scientist interaction mechanisms put in place at field level to gain acceptance, adoption and success. Four pillars and components of FFP approach are enhancing farmer-scientist interface, technology assemblage, application and feedback, partnership and institution building, content mobilization.

Objectives of the project

- To initiate participatory technology development process module-wise (crops, cropping system, horticulture, livestock, soil and water management practices, etc.) relevant to create livelihood options pertaining to small farm holders including women
- To develop viable social institutions through building suitable linkages, farmer-producer group and promoting grass root SHG groups for upscaling of participatory climate resilient rainfed technologies
- To evaluate performance of adopted technologies and farmer's perceptions on participatory technology development process in the intervened clusters for re-evaluation and upscaling of the technologies in other rainfed regions

The location selected for implementation was Pudur Mandal, Vikarabad district of Telangana state was selected in consultation and after a series of meetings, discussions with Joint Director of Agriculture, other officials of State Agricultural Department, officials at Mandal level, Agriculture Officers and progressive farmers.

Enhancing farmers-scientist-interface

This component was strengthened by enabling involvement of researchers for continuous interaction with farm conditions, problem orientation, exchange of knowledge between farmers and other stakeholders, prioritization of problems and setting up of research agenda. A number of trainings cum exposure visits have been imparted to farmers right from cultivation to processing of vegetable crop like the tomato. Farmers learnt the need for procuring quality produce fetching good market price.

Technology assemblage, application and feedback

The Farmers FIRST Project Approach focused on the development of existing farming systems where effective soil and water conservation modules, improved crop varieties, new horticultural techniques, livestock-based technologies, have been integrated into local systems majorly to increase productivity and income of farmers.

Besides, the farm machinery technologies demonstrated, in combination with farmers' resources and innovations, have led to drudgery reduction and livelihood improvement.

Plastic film embedded gabion check dams

In watersheds, loose boulder structures or gabion check dams are constructed in upper reaches to stabilize the gully or stream and reduce the flow velocity and thereby minimizing the soil erosion. Due to pore space of the structure, it will not store the water. In farmers FIRST project, an intervention was made; the gabion structures were embedded with 1 mm HDPE film at the center of the structure. Three HDPE film embedded structures and one structure without plastic film were constructed and evaluated in the farmers' fields/ watershed areas of the project cluster. These plastic films embedded gabion structures reduced the sediment concentration by 70% than the traditional gabion checkdam without using plastic films. These gabions were able to store the rainwater in the range of 9000-15,000 m^3/structure and conserve the rainwater up to 60 percent, increasing the water table in the surrounding wells by 0.6 m. The stored rainwater in each structure was able to provide irrigation to an area of 1 ha.

Micro-irrigation (Drip systems) and fertigation system for vegetable crops and portable raingun system for field crops was designed and installed at different locations of the village mostly to demonstrate effective management of harvested water for high value crops such as chilli, tomato and field crops (sorghum).

Farm pond technology

Farm pond is considered a climate resilient technology where surface runoff from catchment area is collected at a common point which is important from hydrology point of view. Farm pond is dug out in the farmers field through various programmes on the basis of farmer field size. Here, in farmer first project, farm pond size 13*13* 8 cu. ft with storage capacity 38.52 cu m storage capacity dug out in farmer field can irrigate about 0.2 ha field. Likewise, two farm ponds dug out with same size in two villages which can provide protective irrigation to one acre of land particularly in rabi season. It is possible for farmer to cultivate winter vegetables like cabbage and cauliflower, green leafy vegetables etc.

Introduction of improved pigeon pea varieties in *kharif*

In Telangana pigeon pea is grown in about 4.36 lakh hectares mostly grown in Mahabubnagar, Vikarabad, Sangareddy, Adilabad, Komarmbheem Asifabad and Nalgonda. It is grown mostly in kharif) (*Vanakalam)* as rainfed crop but its cultivation is gradually picking in Rabi (yasangi) under irrigated conditions. Pigeon pea can be grown with a temperature ranging from 26°C to 30°C degree in the rainy season (June to October) and 17°C to 22°C. Pigeonpea is very sensitive to low radiation at pod development, therefore flowering during the monsoon and cloudy weather, leads to poor pod formation. It is successfully grown in black cotton soils, well drained with a pH ranging from 7.0 to 8.5. Pigeonpea responds well to poorly tilled and well drained seedbed. Best soil for its cultivation is loam soil with good drainage cultivation.

Improved varieties of pigeon pea – PRG-176, TDRG- 59 and WRG-97 have been demonstrated in farmers' field.

PRG 176 (Ujwala): It is of 130 -135 days. It is suitable to low rainfall, limited moisture, light soils, red chalka soils during kharif (vanakalam) having yield potential of 15-20 q ha^{-1}.

TDRG -59 (Telangana Kandi -2): It is of 170-175 days duration, moderately resistant to Fusarium wilt and sterility mosaic virus with medium bold seed. It has yield potential of 20 q ha^{-1}.

WRGE- 97 (Warangal Kandi -2): It is of 150-165 days duration, which has a greater number of fruiting branches, moderately resistant to Fusarium wilt. Bold and red coloured seeds

Plastic mulches with drip irrigation schedules

Mulches are well known for modifying the energy and water balance at surface of soils and creating more favourable conditions for plant growth. This may include temperature moderation (facilitates more retention of soil moisture and helps in control of temperature fluctuations) and weed control, soil conservation (reduces the deterioration of soil by way of preventing the runoff and soil loss) and after decomposition of organic mulch improves physical, chemical and biological properties of soil, adds nutrients to the soil and ultimately enhances the growth and yield of crops.

Introduction of dual-purpose improved backyard poultry variety, Srinidhi, Vanraja and indigenous breed

To improve nutrient availability of poor households in rural areas of Vikarabad district, Telangana, low input technology backyard poultry farming using Srinidhi, Vanaraja and Kadaknath varieties have been introduced for supplementing the earnings of poor farmers and landless labourers. Srinidhi and Vanraja, dual-purpose poultry varieties developed by ICAR-DPR had potential to produce more eggs and meat than Desi chicken. It can be let on in free range in backyards after 6 weeks of nursery management. Fifty landless and small farmers having prior experience of poultry farming from Pudugurthy and Gangupally village, Pudur Mandal, Vikarabad District, Telangana were selected and given day-old chicks 25 each to them after imparting training program to them. The annual egg production observed was 140-150 numbers and they achieved 3-5 kg weight.

FFP experiences

Outcome: This project has created a strong farmer-scientist bondage for continuous exchange of idea, innovations, resources, feedback for development of appropriate technology and human resource development. A number of trainings cum exposure visits have been imparted to farmers right from cultivation to processing of vegetable crop like the tomato. Farmers learnt the need for procuring quality produce fetching good market price.

Water levels in open well nearest to the gabion structures were raised. Adoption of this technology can increase irrigated area and yield of vegetables. It will increase additional income for farmers. Digging out farmer ponds with support from banks, government subsidies can yield high returns to farmers. Gabion structures has controlled soil erosion. Potential yield of these varieties was about 18- 20 q/ ha. TDRG 59 was found to be root wilt resistant which yielded more than the rest of varieties. PRG 176 was prone to rot wilt disease. New varieties have benefitted farmers yield and income generation. Benefit cost ratio was much higher in the range of 1.50 to 1.87.

All the selected operations in this study fall in the category of moderate physical work load. In all the activities selected, operations with traditional practices demanded more energy expenditure when compared with improved tools; planter, bullock drawn implements, hand weeders, power weeders, power sprayers, and threshers. The energy expenditure in traditional working style ranged from 9.0 to 9.88 kJ/min when compared with 7.81 to 9.26 25 kJ/min of improved tools and practices.

The benefits of staking in vegetable production includes It facilitates spraying and dusting of pesticides/ fungicides, there are comparatively loss chances from incidence of pests, relatively clean, firm and large sized fruits are obtained, It helps in producing healthy fruits, It keeps the fruits above the ground, Training and staking help in better utilization of sunlight and air, It facilitate rapid picking and collection of fruits and It increases the plant stand per unit area.

Benefits derived from poultry introduction were: More eggs (140-150 per year) and meat (3-5 kg) than Desi chicken, Reduced mortality rate of chicks (10-12%) and Net profit per family observed was Rs. 12625.00.

Impact: Through farmer-scientist interaction extension gaps have been identified and interventions planned in participatory mode. Provision for supplemental irrigation for vegetables has improved the yield of enhanced the yield. Possibility of increase in Net returns and cultivation of additional crop with installation of water harvesting structures like farm pond is enhanced.

The total drudgery load calculated after introduction of small farm mechanization intervention infer that the mechanization actions drastically reduced the load on the operators in various farming operations studied in the range of 40 to 64.3%. The maximum total drudgery load reduction was observed in weeding using wheel hoe and minimum in winnowing operation with winnower fan. The other operations in which considerable total drudgery load reduction observed were harvesting using brush cutter (60%), vegetable seedlings transplanting (57.1%) and seed treatment (53.8%) using seed treating drum. Besides, drudgery reduction the various farm implements and machines saved time and improved the productivity in the range of 15-25 percent because of timely operation and efficient utilization of input resources, when compared to farmer practices using traditional tools.

Staking at early growth stage may increase marketable yield as it prevents fruits from touching the soil and thus reduces rotting and incidence of soil born disease. Staking provides support to help keep plants off the ground while assisting in their upward growth habit. Because many diseases and insects start at the ground level, using a structured system to keep them away from ground contact is prudent. The most important reason for staking crops is to increase yield.

Impact of livestock interventions in terms of poultry were: good intervention for landless and small farmers and this has improved farmer's income and nutrient availability at household level.

Farmer led extension model

A Farmer society 'Kranti mutually aided farmer society' a farmer group led extension model, was registered under MACS act of Telangana State started under the farmer first project with 11 famers initially which later expanded to 80-membership of farmers in the society. Farmer Society mainly intended to develop natural resources of village, crops and cropping systems, livestock development and vegetable cultivation. Society also has facilitated in input supply, mobilizing farmers for exposure visits and farmer to farmer information exchange. It also provided loans from members savings. Farmer meet every 5th day of each month to discuss on activities to be carried out in the following month.

Cross learning experienced:

- Farmer led extension model stood as testament for other farmers in adjoining villages to organize themselves into groups. A proposal with regard to formation of another society received which is process of registration under MACS Act of Telangana district cooperative department.
- Farmers association with successful farmers: Farmers were connected to other farmers association and progressive farmers of the districts namely from Medak, Chittoor districts.
- Partnership with state line departments of Agriculture, Horticulture, Animal husbandry and marketing.

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12. Extension Models for Effective Dissemination of Livestock Technologies in Rainfed Regions

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In India, crop-livestock mixed farming is traditional and the combination of livestock with crop production is an effective risk aversion mechanism, developed out of generations of experience of farmers in rainfed areas. The system is a very good example of efficient resource usage, where all the products of the farming operations, local material, household waste etc. with little dependence on outside resources. This is an appropriate and sustainable approach for remote rural areas, where access to outside resources or services is difficult. The system illustrates very well how rural families can match production with resources and available (or unavailable) services and linkages. In semi-arid regions, the combination of trees, cereal crops, leguminous pulses and oilseeds along with a mix of livestock (cows, buffalo and goats) is common. The farmers prefer varieties of crops which are appropriate for local conditions and provide better quality crop residues. They choose trees which provide leaves as well as flowers and pods for feeding animals. They have identified bushes which have protein-rich leaves. They are aware of aquatic plants, mangroves, salt bushes and weeds which can be fed to a different type of animals with beneficial results.

What is participatory extension management?

Participation means that the poor people themselves are involved in identifying the problems they face, determining ways to overcome them, designing realistic plans to achieve these goals, and carrying them out. Solutions devised and fulfilled by the people in need are far more likely to prove successful than those imposed from outside. Participation occupies a central place in development thinking and practice. Governments, funding agencies, donors, and civil society actors including NGOs and multilateral agencies like the World Bank and the International Monetary Fund have all arrived at a near consensus that development cannot be sustainable and long-lasting unless people's participation is made central to the development process. While there is a virtual unanimity about the need for people's participation in development, there is a wide spectrum of views on the concept of participation and the ways of achieving it. The way participation is defined largely depends upon the context and background in which participation is applied.

Steps in Participatory approaches for livestock management

1. Rapport building: The first most requirement of PRA is rapport building and environment creation for free and frank interaction by the villagers. The best way to achieve this condition is that the team members during the study period stay and eat with local people. The team should listen and take part in everyday activities.

2. Do-It-Yourself (DIY): The team members should make efforts to perform the livestock management related activities that the villagers are doing such as grooming, feeding the animals, milking, chaffing the fodder etc. This helps not only in rapport building but provides practical ideas and feelings of complexities of activities.

3. Consultations with the villagers and outsiders: The officials such as development workers, concerned Sarpanches, and villagers should be informed and consulted before initiating the process. The choice of the village must be agreed upon by the top leadership of the district and civic leaders. The site should be accessible for ease of supervision and execution of the project.

4. Secondary data collection: Secondary data like information gathered from reports, newspapers, leaflets, pamphlets, library sources, folklore and other classified documents should be collected from researchers, NGO, departmental reports and documentaries. It is advisable to gather information on a community before going into the field to conduct the actual diagnosis. The data collected and synthesized by the multidisciplinary team can be used and background information to the Action Plans to be developed by the village residents. Furthermore, this data can be used to validate information obtained from the semi-structured interviews.

5. Training of trainers: Training of a core team of facilitators is important as it equips the trainers with the knowledge and skills to train other extension workers and farmers.

6. Diagnosis: Diagnosis is an examination and analysis of any given situation. In the context of PRA diagnosis examines the village residents' practices, opportunities, the problems they encounter and their causes. This crucial information is obtained using various tools such as secondary data (earlier discussed), mapping, transect, Venn diagram and semi-structured interviews etc.

Different Participatory Approaches

1. Rapid Rural Appraisal (RRA): RRA can be defined as a systematic, semi-structured activity conducted on-site by a multidisciplinary team with the aim of quickly and efficiently acquiring new information and hypotheses about rural life and rural resources.

2. Participatory Rural Appraisal (PRA): PRA is a way of enabling the farmers to analyze their living conditions, to share the outcomes and to plan their activities. It is like handing over the stick to the farmers in methods and activities. The Scientist's role is that of a catalyzer, a facilitator and convener of processes within a community, which is prepared to alter their situation.

3. Participatory Learning Methods (PALM): Areas in which it has been successfully applied are participatory planning of natural resource development at the village level and integrated rural development programs dealing with health care, livelihoods and gender issues; participatory impact monitoring and assessment of development programs.

4. Agro-Ecosystem Analysis (AEA): It has been successfully applied to all levels of agrarian ecosystems. The preferred study level is that of the village.

5. Participatory Action Research (PAR): Areas in which it has been successfully applied are community development and rural organizations, adult education; above all, for concretization and mobilization in grass-roots movements.

6. Participatory Assessment, Monitoring and Evaluation (PAME)

7. Farming Systems Research (FSR)

8. Participatory Rural Appraisal and Planning (PRAP)

Livestock extension

The Livestock Extension services include the transfer of technology and strengthening of various infrastructure and support services while building the capabilities of the stakeholders. The extension service should aim at assisting farmers through the educational process to improve livestock farming methods and techniques, increase production efficiency and income, and enable them to improve their quality of life. The Extension service should enable farmers to identify and analyse their production problems and increase their awareness on the scope for improvement. It should motivate those who are hesitant and ignorant about new technologies and systems which can improve the production and income. For the semi-literate and poor livestock keepers, the real extension service means hand-holding or mentoring until they adopt good practices and form a part of the value chain to realize maximum benefits.

Effective Livestock Extension would include helping farmers to identify their production and marketing related constraints through awareness, exposure, exchange of information among other farmers, extension officers and other stakeholders. The farmers should be assisted to make the best use of the technologies and support services through capacity building. Linkages should be established with information sources on agricultural innovations, new technologies, market-related information such as demand-supply and prices. Most important point in livestock extension is to promote Producers' Organisations, to facilitate a platform for value chain and ensure the involvement of various stakeholders to improve the production and profitability.

Present scenario of livestock extension services

1. **Inadequate extension machinery**: State Animal Husbandry Department is the major extension agency, but primarily involved in treatment and breeding, while the extension is limited to delivery of select services.
2. **Lack of clarity**: Extension has an allocation of only 0.4-1 percent of the budget, most of which remains unspent.
3. **Lack of coordination**: No meaningful interaction between Veterinary Education and Research Institutions, Dairy Federations and People's Organisations.
4. **Lack of participatory approach**: Programmes planned at the top are not in tune with the local needs of livestock keepers.
5. **Lack of human resources**: Small number of staff with poor mobility is unable to interact closely with farmers, particularly with women, who contribute 80 percent of the labour for animal husbandry. Due to lack of extension skills among extension workers and poor credibility of their services, farmers are not receptive.
6. **The absence of value chain**: Lack of interest among farmers because of poor income due to weak backward and forward linkages.
7. **Outdated approach**: In the absence of modern skills and tools, extension services are not effective.

Need for a livestock extension policy

1. While agricultural extension programmes are broad-based, Animal Husbandry Extension needs to be tailor-made for specific locations and target groups, depending on the quality of the livestock and capabilities of households.

2. Extension programmes should focus on value chain development, with specific goals and parameters for measurement of the impact.
3. There is a need to reform the linkages between various institutions engaged in livestock husbandry and their coordination to improve the efficiency and productivity, with the effective public-private partnership.

The National Extension Policy should include the following components:

1. Extension services should be synchronized with holistic animal husbandry and veterinary services
2. Decentralized participatory extension services, based on local needs
3. The increased role of Civil Society Organizations, paravets, producer groups and private enterprises including input producer and service providers in value chain development linked with extension
4. Gender and Environment-sensitive extension services
5. Creation of Innovation platforms for facilitating interaction between scientists, policy makers, field technicians and livestock keepers for effective technology development, technology transfer and supportive policies
6. Capacity building: Facilities and appropriate programmes for building capabilities of farmers, extension functionaries and various stakeholders, including scientists and Government officials
7. Review of the formal educational status in Animal Sciences and need for changes to improve their efficiency
8. Aiming towards self-sufficiency by the promotion of producers' hubs, people's organizations and cost recovery of the services
9. Periodic review of the programme: Impact assessment of on-going extension programmes and the introduction of innovative programmes to improve the efficiency and coverage of the extension services.

A participatory approach to improve livestock productivity

This is a process of "participatory learning and action" for all major stakeholders. The process is neither "top-down" nor "bottom-up", but it aims at the institutionalization of the process of the need-based approach. In this approach issues related to the total cooperative system i.e. enhancing the productivity of animals and quality of milk, strengthening of village societies, empowerment of women members, improving feed and other natural resources etc. are being addressed with the participation of producers. The approach envisages using of locally based para-extension workers for improving the accessibility, efficiency and effectiveness of inputs delivery and extension service provided to the farmers. It promotes cooperation and partnership with development and research organizations for addressing aspects like improving natural resources, farmers' awareness, involvement etc. It is a continuous process and not a one-time exercise and involves all the stakeholders.

Steps in farmer based participatory extension approach

The process broadly involves five steps as indicated below:

1. Situation Analysis – involving major stakeholders, to understand current status, constraints, needs and priorities of the producers through:
   a. Information gathering from primary and secondary sources
   b. Identification, characterization and prioritizing of constraints
2. Planning of interventions on the basis of situation analysis and priorities.
3. Implementation of the Plan as per the time frame.
4. Joint monitoring and evaluation of the interventions.
5. Reanalysis of the situation for further considerations and actions.

The process of situation analysis

The Situation Analysis study including needs assessment to be undertaken by involving stakeholders representing different categories and farming systems prevailing. The process involves informal surveys followed by focused group discussions to understand prevailing systems, constraints facing the producers and their suggestions to overcome these constraints.

Situation analysis: examples

Salient findings may vary according to the prevailing situation. The following are the few examples to be perceived:

- ----- % of producers indicated that they keep animals for income generation.
- During the last decade or so, there is a shift from ------- to ------------ in taking up ---------- as their main source of livelihood.
- ------------ is the major dry fodder fed to animals. The fodder crops preferred by farmers for cultivation are ---------------------------.
- Milk producers from rainfed areas seek fodder varieties requiring less water, while producers from irrigated areas asked for high yielding varieties of fodder.

- Preference of animals is mostly related to risk aversion and availability of resources and services.
- Farmer adoption of artificial insemination (AI) for breeding animals is --------.
- ------------ is the most commonly used and preferred component of homemade concentrate mix of the feed given to dairy animals.
- Perception about the quality of milk is related only to ----------- content in milk.

The constraints in livestock farming as perceived by the farmers in dairy farming may be as follows:

  - Scarcity of green and dry fodder
  - High price of concentrates - cattle feed, rice polish etc.
  - Water scarcity due to drought
  - Availability of capital
  - Price paid for milk not remunerative
  - Regular veterinary services
  - Dairying is a labour-intensive job
  - Low yield of the local animal breeds

Planning intervention and implementation

Participatory techniques can help in the in-depth understanding of rural livestock business systems as a whole, the perception of producers (particularly the women), identification and characterization of constraints for improvement in productivity and in choosing appropriate approaches or technologies to overcome the constraints. It has also resulted in awareness regarding the need for planning, training and information dissemination to the producers, based on an assessment of their needs for information, skills and knowledge.

Impacts of participatory extension in the field of livestock management

The major impact on farmers from the adoption of extension management process is the sensitization of the key stakeholders, i.e. extension officers, supervisors and farmers about future challenges and approach needed to meet the challenges. There will be a change in outlook and attitude of the concerned staff at all levels towards each other and their capabilities in the related fields have improved. The process will also draw attention to constraints/ problems given high priority by the farmers and provide a better understanding of reasons for the low adoption of services and inputs provided to them. Thus, the technical inputs and extension service delivery can be made more effective, efficient and need-based.

Who manages extension?

Besides national or regional governments, extension services can be run by NGOs, by cooperatives, by universities or research institutes and by the commercial sector. In India, some extension is provided through the system of dairy cooperatives, which reaches from village-level primary societies to a national federation and has 8 million members. Primary societies are successfully delivering information both on business management and on technical aspects of dairy production such as the use of green fodder and concentrates.

Agencies involved in animal husbandry extension are:

Public Extension Services, like State Government Animal Husbandry Departments, Agriculture Extension Dept: ATMA Programme, Panchayat Raj Institutions, Agricultural/Animal Sciences Universities, Krishi Vigyan Kendras and ICAR Extension Centres.

Private Extension Services, like Farmers' Cooperatives/Federations, Producer Groups/Companies, Processing/Marketing Agencies, Self Help Groups, Paravets/Private Vets, NGOs, Input suppliers: Seeds, feeds, tools, vaccines and medicines, micro-finance groups

Mass Media and Information Technology Centres, like Print media, Newsletters, Radio, Television, Private cable networks, Electronic network: mobile, email/internet, private portals, Local wireless loops, Farm Advisory Centres, Information shops

Major on-going extension programmes in the field of livestock production and management are:

1. State Animal Husbandry Department: Veterinary clinics/Hospitals
2. Animal Husbandry Extension Programme: Major time spent on treatment and data collection
3. Dairy Cooperatives/Processors
4. Agricultural Technology Management Agency (ATMA): Major focus on crop production
5. Krishi Vigyan Kendras: Lack of technical skills/facilities in Animal husbandry
6. Veterinary Colleges/Agricultural Universities: Lack of focus on real problems
7. NGOs and Input supply agencies: often lack credibility and linkages.

How can it be effective in improving livestock productivity?

To increase livestock production, it seems to be extremely important to keep farmers in updated information regarding various production processes and marketing practices. Inadequate access of developing-country farmers to relevant livestock information/technology has an effect on all livestock subsectors and different stages of livestock production. The livestock technology dissemination, therefore, is very important for improved smallholder farmer livestock production and consequently increased family income (Pankaj *et al*., 2014). The strategy for revamping animal husbandry extension are:

1. Farmers' Group based approach for backward and forward linkages.
2. Technology backup by reorienting Livestock Development Officers, KVKs and ATMAs, and strengthening their linkage with Research Institutions and Agri / Vet. Universities.
3. Increased involvement of private service providers, NGOs and self-employed professionals and Synergy between public and private sector service providers.
4. Explore Additional/Alternative Agencies for Extension Delivery.
5. Knowledge and Information management and dissemination.
6. Human Resources Development including Gender mainstreaming.
7. Coordination among various stakeholders, development and facilitating agencies in particular to strengthen the value chains.

Examples of success stories of participatory extension management for improving livestock productivity

The following models were helpful in the dissemination of fodder technologies to small and marginal farmers in the field as well improve fodder production (Pankaj *et* al., 2015) and ultimately the livestock productivity in rural India:

i) Participatory Action Research (PAR) model adapted to improve farmers technological capabilities in fodder production: A Participatory action research (PAR) model is well suited to cater the location-specific need of the farmers (Rao *et al*., 2012).

ii) Need-based capacity building model: which includes Organization of need-based training and capacity building programs on to improve knowledge and skill on improved fodder production technologies, like Intensive rainfed/ irrigated fodder production systems, fodder production systems through alley cropping, non-conventional fodder production systems, hydroponic fodder production systems, year-round forage production systems, etc.

iii) Common Interest Group (CIG) model for mitigating fodder scarcity: Development of Institutions like Common Interest Group (CIG) were able to mitigate fodder scarcity as membership of a co-operative or commodity association increases access to productive resources such as seed, information and training (Rao *et al*., 2012). Later on, a revolving fund may also be developed for fodder development through CIG which will increase the risk-bearing capacity of small and marginal farmers.

iv) Entrepreneurship model for imparting skills to SHG women:

- Production of quality seed by appropriate selection of promising varieties/hybrids.
- Establishment and management of a feed mixture plant by women groups.
- Motivate female farmers for Indigenous Technical Knowledge (ITKs)

v) Forage seed distribution model: Dairy farmers who have undertaken forage production are not able to optimize the yields and maximize the returns due to several reasons. These include poor quality soils, inadequate fertilizer application, moisture scarcity, improper timing of sowing and inadequate facilities to transport and store the forage until it is fed to livestock.

vi) Contingency plan model: Development of Contingency plan (Srinivasa Rao *et al*., 2010) to mitigate drought and sustain fodder production at village level.

- <u>Early season drought:</u> Short duration (50-60 days) fodder crops like sorghum Pusa chari CSH- 14, bajra (Co 8, TNSC1).
- <u>Midseason drought</u>: cultivate winter crops like berseem, Lucerne and in wastelands cultivate Anjan, Stylosanthes *scabra,* etc.
- <u>Late season drought</u>: Avoid multi-cut varieties, cultivate less water required lucerne varieties.

vii) Wallpapers: Poster, display board to create awareness among general people and other stakeholders. It can be also disseminated using a Public Address System (PAS) for crucial climatic circumstances or agro-advisory services. Basically, used in dissemination of urgent information like cyclone, natural climatizes etc.

viii) Demonstration effect approach: Very useful for progressive farmers. Framers were learning by seeing to others.

ix) Educational and methods approaches: These approaches focused on education of farmers and use of various methods - exposure visits, field days, radio and television programs, film shows (cinema), leaflets and posters. These approaches resulted in improved farming practices, productivity and production.

x) Training and Visit approaches: Capacity building of trainers who works in field is important motive of this method. Trained person can be better training to farmers and other stakeholders.

xi) Mass media campaigns: Extension functionary can reach to large number of audiences in very short period of time. The main purpose of this method is to create awareness among stakeholders.

xii) ICT supported farmers: Use of smart phones, videos, radios etc. was done to address the climate change issue by creating awareness among the farmers about the availability of different adaptation and mitigation strategies. It also helps in coordination and monitoring.

xiii) Farmers Field Schools (FFS): It is a non-formal, participatory extension technique that prioritizes farmers and their needs via experience learning. Farmers can discuss and learn from their observations, allowing them to gain new practical knowledge and skills, as well as improve their individual and collective decision-making.

xiv) Climate-Smart Villages (CSVs): The concept of climate resilient village (CRV) – i. to provide stability to farm productivity and household incomes and resilience through livelihood diversification in the face of extreme climatic events like droughts, cyclones, floods, hailstorms, heat wave, frost, and seawater inundation. ii. Development of CRVs warrants establishment of a host of enabling mechanisms to mobilize and empower communities in the decision-making process to manage and recover from climate risks.

Conclusion

There is a need to adopt a holistic and systems approach for sustainable development- instead of considering the livestock sector in isolation – there is a need to link the development of natural resources. Hence, the concerned organization should be prepared to establish linkages with other development and research organizations to overcome constraints or solve problems by taking benefit of their strengths and expertise.

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13. Digital Extension Ecosystem for Indian Agriculture: Prospects and Challenges

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Agriculture, a time-honored profession, is grappling with the daunting task of providing sustenance to an extra 2 billion individuals by 2050 (FAO, 2011). India, characterized by a large number of small and marginal farmers, is particularly susceptible to challenges of climate change, shrinking land holding, increasing population and depleting natural resources. After mechanization, the green revolution, and precision farming, the agriculture sector is being revolutionized by digitization. This new era has been acknowledged by various terms such as agriculture 4.0, smart farming, etc. With the help of technology, digital agriculture has the capacity to drive and assist complex decision making, both on-farm and along the value chain, by changing data into actionable knowledge. Digital agriculture, heralding a new era in farming practices, holds immense potential to mitigate these challenges by equipping farmers with real-time, data-driven insights that empower them to optimize resource management.

The report on doubling farmers' income by 2022 highlights the transformative potential of digital technologies in revolutionizing agricultural practices and boosting farmers' livelihoods. To achieve the vision of a self-reliant India and the Sustainable Development Goals (SDGs), a paradigm shift from traditional agriculture to digital agriculture is crucial. The Government of India's Digital Agriculture Mission (2021-2025) and the consultation paper on Digital Agriculture Ecosystem represent significant milestones towards the digitalization of Indian agriculture. Digitalization holds immense promise for enhancing the effectiveness of agricultural policy by minimizing adverse impacts and maximizing the benefits of farming. Digital agricultural policy marks a departure from traditional farm policy approaches. It introduces innovative alternatives, enabling real-time data-driven or evidence-based policy interventions to effectively address the challenges faced by the agriculture sector. Consequently, digitalization is steering agricultural policy away from direct intervention towards information-based governance, a shift that is poised to amplify policy outcomes, foster trust within the farming community, and ultimately maximize their satisfaction (Ehlers *et al*., 2021).

Tapping the full potential of the digital revolution for agricultural extension

Advisories are essential to enhancing rural livelihoods, attaining food security, boosting productivity, and promoting agriculture as a source of economic growth for the poorest people (IFPRI, 2020). Many of the current limitations of agricultural advisory (agro-advisory) services are due to imperfect information flows between the stakeholders of a complex knowledge system, including farmers, traders, processors, extension agents, and researchers (Faure *et al*., 2012). Globally, digital extension initiatives are upending newly emerging, data-rich approaches in agriculture (Nettle *et al*., 2018), replacing conventional farmer extension agent engagements with intricate, back-end data collection and analysis procedures (Eastwood *et al*., 2019). Both in developed and developing countries, digital extension initiatives are gaining traction among farmers (Steinke *et al*., 2019). Thus, digital agricultural extension can enable a break from the cycle of low production, vulnerability, and poverty, particularly for smallholders (Davis *et al*., 2018).

Many farmers lack access to reliable sources of up-to-date information on extreme weather events such as droughts, storms, floods, and other natural disasters (Rajkhowa, 2021). Digital agricultural extension utilizes digital tools and services to effectively deliver such information. Extension workers commonly employ Short Message Service (SMS), Interactive Voice Response (IVR), interactive radio, and low-cost video to reach a large number of farmers quickly and provide extension services such as timely reminders, alerts, weather forecasts and best practices to enhance productivity. Traditional extension methods, which involve face-to-face information sharing, are time-consuming, costly, and may not yield the desired benefits for the farming community. However, digital technology can significantly expand the reach of extension services (USAID, 2018). Providing farmers with accurate information is crucial for enabling them to make informed decisions and realize their full potential. Information providers need to maintain strong connections with farmers throughout the cropping cycle. Digital technologies facilitate the creation of farmer networks and maintain connections with service and advisory providers (Yadav *et al.*, 2020).

Recent trend in mobile penetration

- India has emerged as the global leader in the creation and adoption of digital infrastructure and the third-largest in terms of its fintech ecosystem.
- During the lockdown, the number of smartphones in rural India surged more than double, as per the latest Annual Survey for Education Report (ASER). In 2018, around 36 percent of households had a smartphone, which increased to 74.8 percent in 2022, said the report.
- Rural India had more than 425 million internet users, a whopping 44 percent more than urban India, which had 295 million people using the internet regularly, according to a report by Nielson.
- The report titled 'India Internet Report 2023', also mentioned that nearly half of rural India was on the internet, with strong growth of 30 percent, and more headroom for growth in the future.

Drivers of E-Extension

E-extension in India is driven by a number of factors, including:

1.Reduced handset and data costs

The affordability of smartphones and mobile data has been a major driving force behind the adoption of e-extension in India. In recent years, the prices of both handsets and data plans have fallen significantly, making them more accessible to a wider range of people, including farmers. This has enabled farmers to access information and services through e-extension platforms, such as mobile apps and online portals.

2. A large presence of public institutional players

The Indian government has recognized the potential of e-extension to transform agriculture and has launched several initiatives to promote its adoption. These initiatives include:

- Digital Agriculture Mission (DAM): The DAM aims to accelerate the adoption of digital technologies in agriculture, including e-extension. The mission has been allocated a budget of Rs. 1.5 lakh crore for five years.
- National Agriculture Extension Policy (NAEP): The NAEP emphasizes the use of ICTs, including e-extension tools, to enhance the effectiveness of agricultural extension services.

- Pradhan Mantri Krishi Sinchai Yojana (PMKSY): The PMKSY aims to improve irrigation infrastructure and provide farmers with access to timely and accurate information on irrigation practices. This information is often provided through e-extension platforms.

3. ICT initiatives driven by government

The Indian government has also launched several ICT initiatives that are supporting the growth of e-extension. These initiatives include:

- BharatNet: BharatNet is a national optical fiber network that will connect all 250,000 gram panchayats in India. This will provide broadband connectivity to rural areas, which will be essential for the adoption of e-extension services.
- Digital India Program: The Digital India Program aims to provide digital literacy and access to digital services to all citizens of India. This includes initiatives to train farmers on how to use e-extension platforms.

4. Emergence of agri-entrepreneurs

A number of agri-entrepreneurs are also emerging in India. These entrepreneurs are developing innovative e-extension solutions that are tailored to the needs of Indian farmers. These solutions include:

- Mobile apps that provide farmers with access to information on a variety of agricultural topics.
- Online platforms that connect farmers with agricultural experts.
- Digital marketplaces that connect farmers with buyers of their produce.

5. Farmer Produce Organizations (FPOs)

FPOs are farmer-led organizations that are playing an increasingly important role in the adoption of e-extension. FPOs are helping farmers to access e-extension services by:

- Aggregating demand for e-extension services from farmers.
- Providing training to farmers on how to use e-extension platforms.
- Networking with agri-entrepreneurs to develop innovative e-extension solutions.

These drivers of e-extension have the potential to revolutionize Indian agriculture by providing farmers with access to the information and resources they need to succeed. The impact of these drivers will be felt in the years to come as e-extension becomes an increasingly important tool for Indian farmers.

Digital India and its initiatives

Digital India is a flagship program of the Government of India to transform India into a digitally empowered society and a knowledge economy. The program aims to provide universal digital literacy, broadband connectivity, and access to e-governance services to all citizens of India.

National e-Governance Plan in Agriculture (NeGP-A)

NeGP-A is a mission mode project under the Digital India program that aims to provide a comprehensive e-governance framework for the agriculture sector in India. The project aims to improve the efficiency, transparency, and effectiveness of agricultural extension services by leveraging ICTs.

Key initiatives under NeGP-A

- Farmers' Portal: The Farmers' Portal is a one-stop shop for farmers to access a wide range of information and services, including weather forecasts, market prices, crop advisories, and government schemes.
- mKisan Portal: The mKisan Portal is a mobile app that provides farmers with real-time information and advisories on a variety of agricultural topics.
- Kisan Call Centres (KCC): KCCs are toll-free call centers that provide farmers with 24/7 access to agricultural experts.
- Kisan Suvidha App: The Kisan Suvidha App is a mobile app that provides farmers with access to a variety of agricultural services, including soil testing, pest control, and crop insurance.
- Crop Insurance App: The Crop Insurance App is a mobile app that allows farmers to apply for and manage crop insurance policies.
- e-Krishi Samvad: e-Krishi Samvad is a web-based platform that provides farmers with access to a wide range of agricultural information and resources.
- Soil Health Card (SHC) Portal: The SHC Portal is a web-based platform that provides farmers with access to their soil health cards. Soil health cards provide farmers with information on the nutrient status of their soil, which can help them to make better decisions about fertilizer application.
- e-NAM: e-NAM is an electronic National Agricultural Market (NAM) that provides farmers with a transparent and efficient platform to sell their produce.
- Fertilizer Quality Control System (FQCS) Portal: The FQCS Portal is a web-based platform that provides farmers with information on the quality of fertilizers in the market.

- Participatory Guarantee System- India (PGS) Portal: The PGS Portal is a web-based platform that provides farmers with information on the PGS certification process. PGS is a certification system for organic products that is based on farmer participation.

Recent initiatives

- Government has finalized the core concept of India Digital Ecosystem of Agriculture (IDEA) framework which would lay down the architecture for the federated farmers' database.
- Under plan scheme viz. National e-Governance Plan in Agriculture (NeGP-A) wherein, funds are released to the State(s)/UT(s) for project involving use of modern technologies viz. Artificial Intelligence (AI), Machine Learning (ML), Robotics, Drones, Data Analytics, Block Chain etc.
- The Ministry of Agriculture & Farmers' Welfare, Government of India signed a memorandum of understanding with Digital Green under a public-private partnership framework to build a national-level digital extension platform.
- The agricultural ministry and Microsoft India have inked a MoU for a pilot project in 100 villages of six states to promote digital agriculture. Microsoft will start a pilot project in 100 villages in 10 districts of 6 states (UP, Madhya Pradesh, Gujarat, Haryana, Rajasthan and Andhra Pradesh) to develop farmer interface for smart and well-organised agriculture, including post-harvest management and distribution.

Few examples of digital extension service providers in India

Agrostar

It is operating Maharashtra, Gujarat, Rajasthan, Madhya Pradesh and Uttar Pradesh. AgroStar is a platform built to solve ground-level problems dealing with information gaps and accessibility of good quality agri inputs. It has a unique mobile app platform for farmers to – connect and interact with each other, share farm stories, issues related to pests and diseases, and get real-time solutions through AgroStar's agri doctors and the community of experienced farmers. The platform offers agri inputs from over 200+ well known agri input manufacturers associated with AgroStar.

Amnex

Amnex is operating in Gujarat, Andhra Pradesh, Odisha, Maharashtra. It is an enterprise solutions company, works across high impact sectors providing solutions for various industries to transition into an era of digital transformation. Two of its focus industries are agriculture and dairy where it uses Artificial Intelligence (AI), Machine

Learning (ML), Internet of Things (IoT), big data, and predictive modelling to manage these value chains. In agriculture, custom modules of the Farmlive, Croptrack, and Agrogate products can be rolled out for different use cases in an agri value chain. The products could also be configured for various users as well and sold only on a B2B basis.

Bharathagri

It works in Maharashtra (95% business), Karnataka, Andhra Pradesh. BarathAgri, a personalized farm advisory service, uses AI and ML techniques to provide customized farm advisories to farmers. It is a free weather-based pest and disease advisory available to all farmers. It also offers a premium advisory services variant is available to farmers for INR 600 per acre per season. It is rare app where advisory is the revenue generation services.

Big Haat

Bighaat is a pan-India and operates an e-commerce platform for agriculture inputs such as seeds, agro chemicals, crop nutrients and machinery. The platform is accessible to both smartphone and non-smartphone users and also offers its services through a missed call option, where a farmer can dial a toll-free number to place a request for call back from BigHaat. The BigHaat agronomy team would call back and help the farmers. The agronomy team provides a crop advisory service and also assists with placing purchase orders on behalf of the farmers. Furthermore, BigHaat also operates a "Feet on Street" (FOS) model where a trained local team is sent to run content-based campaigns and provides knowledge-based services to build trust and awareness with farmers in a geographical cluster.

Digital Green

It operates in Andhra Pradesh, Bihar, Odisha, Jharkhand, Chattisgarh, Uttar Pradesh, Uttarakhand. Digital Green has a unique video-based peer-to-peer learning solution that emerged out of a Microsoft research project. Its uniqueness lies in the fact that farmers are onboarded as co-producers to create digital content. In order to put this into practice, Digital Green has created a cadre of community resource persons who are trained to create, edit, produce and finally disseminate videos using pico-projectors. These community resource persons scout for progressive farmers in local communities and feature them in videos that are categorized as best practice packages

IFFCO Kisan Sanchar Ltd.

IFFCO Kisan Sanchar *Ltd*. provides voice-based contextualized and actionable advisories provided in the local language on a farmer's mobile phone. It makes use of AI-ML/IoT based data-driven digital ecosystem for, prescriptive and predictive interventions. It does digital profiling of farms, farmers, and continual record-keeping of the issues and their advised solutions. It uses reverse image mapping for pest and disease diagnosis and provides near real-time personalized voice advisories;

Kalgudi

Kalgudi is a web and mobile-based one-stop solution for all actors in an agricultural ecosystem. It uses ML and combines it with field learning to deliver high-quality advisories. It is operating in Andhra Pradesh, Telangana, Karnataka, Odisha, Sikkim. Kalgudi is leveraged by ecosystem partners to provide targeted services to farmers such as training programmes, farm activity reporting, farm advisories. FPOs management is also part of the suite of core services. Kalgudi has an ML demand prediction system for various product and services used by farmers. This ensures that the actors in a value chain consuming Kalgudi core services benefit from advanced technologies like ML. Market linkages for FPOs and rural SHGs.

Digital extension services have the potential to transform Indian agriculture by providing farmers with access to timely, accurate information and advice. However, there are a number of constraints that could hinder the adoption and effectiveness of these services in India. One major constraint is the lack of access to the internet and smartphones. In India, only about 30 percent of households have access to the internet, and smartphone penetration is still relatively low, at around 40 percent. This means that a large number of farmers are unable to access digital extension services. Even for those who do have access to the internet, there can be challenges with connectivity. In rural areas, especially in hilly and remote regions, internet connectivity can be slow, unreliable, and expensive. This can make it difficult for farmers to access and use digital extension services effectively. Another constraint is the lack of digital literacy among farmers. Many farmers in India are not familiar with computers or smartphones, and they may not have the skills to use digital extension services effectively. This lack of digital literacy can be a barrier to adoption and use of these services. Finally, there is a need for more high-quality, relevant digital content in local languages. Much of the digital content available to farmers in India is in English, which is not understood by many farmers. There is a need for more content in Hindi and other local languages that is tailored to the specific needs of farmers in different regions of India. Despite these constraints, there are a number of initiatives underway to promote the adoption and use of digital extension services in India. The government of India is developing a National e-Governance Plan in Agriculture (NeGP-A) that will provide a comprehensive framework for the development and implementation of digital extension services in the country. Additionally, a number of private sector companies are developing innovative digital extension solutions that are tailored to the needs of Indian farmers.

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14. Institutional Interventions for Technology Transfer

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Technology transfer in agricultural extension involves the dissemination of innovative agricultural technologies, practices and knowledge from research institutions to farmers and stakeholders. This process aims to enhance agricultural productivity, efficiency and sustainability. It begins with the development of new technologies through research and development efforts conducted by various institutions and organizations. Before being transferred to the farmers, these technologies undergo validation and adaptation to ensure their suitability across different agro-ecological zones. Extension agencies and community-based institutions play a crucial role in the transfer process by providing training, organizing field demonstrations and disseminating information through various channels. Farmer participation and feedback are essential for the success of technology transfer initiatives, as they help tailor extension efforts to meet the specific needs and challenges faced by farmers. Continuous monitoring and evaluation are conducted to assess the adoption and impact of technologies, guiding further refinement of extension strategies. Overall, technology transfer in agriculture extension contributes to the development and sustainability of the agricultural sector, benefiting farmers and communities by improving livelihoods and food security.

However agricultural technology transfer faces challenges due to the complexity of agricultural systems, lack of awareness among farmers, resource constraints and sustainability concerns. Community institutions are crucial in addressing these challenges by customizing technologies to local contexts, raising awareness, providing education and resources and offering ongoing support services. Their deep understanding of local conditions, ability to mobilize resources and close connections to communities make them essential partners in promoting the adoption of innovative agricultural technologies, ensuring effectiveness, sustainability and responsiveness to farmers' needs.

Role of Institutions in technology transfer

Community based institutions play a vital role in technology transfer within the agricultural sector due to several key reasons.

Connect with rural stakeholders: Firstly, grassroots institutions are deeply embedded within local communities, possessing an intimate understanding of their needs, challenges and cultural contexts. This proximity allows them to tailor technology transfer efforts to suit the specific requirements of farmers in a given area. They can effectively communicate the benefits of new technologies in ways that resonate with local farmers, thereby increasing adoption rates.

Credibility established over the time: Secondly, grassroots institutions often have established trust and credibility within their communities. Farmers are more likely to accept and adopt new technologies when they come recommended or endorsed by familiar and trusted entities. Grassroots organizations, such as farmer cooperatives, community-based organizations, and local agricultural extension services, can leverage this trust to facilitate the adoption of innovative agricultural practices.

Established communication network: Moreover, grassroots institutions serve as conduits for information dissemination and knowledge sharing. They act as intermediaries between research institutions, government agencies and farmers, translating complex scientific information into practical, actionable guidance that is accessible to local communities. By providing training, organizing field demonstrations and offering ongoing support, grassroots institutions bridge the gap between research and practice, ensuring that farmers have the necessary resources and skills to successfully implement new technologies.

Sense of belongingness: Furthermore, grassroots institutions foster a sense of ownership and empowerment among farmers. When farmers are actively involved in decision-making processes and are encouraged to participate in technology transfer initiatives, they are more likely to embrace change and take ownership of their agricultural practices. Grassroots organizations empower farmers to become agents of change within their communities, leading to sustainable and locally-driven agricultural development.

Grassroots institutions play a critical role in technology transfer within the agricultural sector by leveraging their local knowledge, building trust, facilitating information exchange and empowering farmers. Their close connections to communities make them invaluable partners in efforts to promote the adoption of innovative agricultural technologies, ultimately contributing to increased productivity, sustainability and resilience in farming systems.

Institutional interventions for technology transfer: CRIDA experiences

Salaha samiti-initiative-DFID experiences

Salaha samitis were social interventions implemented under a project entitled “Enabling Rural Poor for Better Livelihoods Through Improved Natural Resource Management in SAT India” which was executed by CRIDA in collaboration with two State Agril. Universities Viz., ANGRAU, Hyderabad, UAS, Bangalore, ICRISAT and BAIF a leading NGO. This project was funded by DFID-NRSP, UK and was for a duration of 30 months from October, 2002 to March, 2005

Salaha Samiti is a term where "Salaha" means advice or counsel, and "Samiti" translates to committee or group. In the context of Indian agriculture, a "Salaha Samiti" typically refers to advisory committees or groups formed at the village or community level. These committees are composed of local farmers, agricultural experts, extension workers and government officials.

The primary purpose of a Salaha Samiti is to provide advice, guidance and support to farmers in various aspects of agriculture, including crop selection, cultivation techniques, pest management, soil health, water conservation, and post-harvest practices. These committees serve as platforms for sharing knowledge, exchanging ideas, and addressing common agricultural challenges faced by the community.

Project flow: The PRA exercise was conducted to know the existing situations and formulate the action plans with the participation of the villagers.

As a first step Gramasabhas and Focus Group interactions were held and new Self Help Groups were formed besides existing once. Advisory Committees for the cluster of villages Viz., Salaha Samithis/Central Project Management Committees were formed for each cluster consisting of representative from the selected villages. The Salaha Samithis played a major role in smooth implementation of the project interventions.

The capacity building of the group of farmers from the selected cluster of villages was taken up by training them on employment generation activities like nursery raising, repair of implements, Artificial Insemination, vermicomposting etc.

Additionally, Salaha Samitis served as intermediaries between farmers and project partners advocating for the needs and interests of the farming community and facilitating access to agricultural inputs, adoption of technological interventions, decision making and other support services.

Overall, Salaha Samitis were grassroots institutions that contributed to the development and sustainability of agriculture by fostering collaboration, knowledge-sharing, and collective action within rural communities. They play a vital role in empowering farmers, enhancing agricultural productivity and promoting rural livelihoods.

Stakeholder and community partnerships- Experiences of NICRA

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 (CHC)

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

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

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.

Conclusion

Community institutions are essential for overcoming the challenges associated with agricultural technology transfer. Their close connections to local communities, knowledge of local conditions, and ability to mobilize resources make them valuable partners in efforts to promote the adoption of innovative agricultural technologies. The efforts of institutions in raising awareness, organizing training sessions, and advocating for farmers' needs, these institutions empower rural communities and contribute to the sustainability and productivity of agriculture. Thus, the collaboration between technology transfer initiatives and community institutions is crucial for driving agricultural development and ensuring the welfare of farming communities. By working collaboratively with researchers, policymakers, and farmers, community institutions can help ensure that agricultural technology transfer efforts are effective, sustainable, and responsive to the needs of farmers and their communities.

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15. Gender Issues in Agriculture and Allied Sectors

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Agriculture and allied sectors are the important components of rural livelihoods. Majority of India's population depend on agriculture for a living. Women farmers are the backbone of agriculture and allied sectors in India, contributing to a major share in terms of labour. With the outmigration of men, there is a growing feminisation of agriculture in India, leading to an increasing number of women in different roles such as agricultural labourers, cultivators and entrepreneurs. This has contributed to an increased burden on women as their farm work is treated as an extension to their household work. Women play a key role in agriculture from planting to post-harvest operations. Studies show that women carry out most of the back-bending tasks such as from preparing the land, selecting seeds, preparing and sowing to transplanting the seedlings, applying manure, fertilizers and pesticides, and then harvesting, winnowing and threshing (Pande, 2017). According to Oxfam India, women farmers produce 60-80 percent of food and 90 percent of dairy products (Business Line 2013).

Several studies have shown that women reinvest up to 90 percent of their earnings into their household on food, nutrition, health and education and thereby helping to alleviate poverty. Women also provide unpaid care and domestic work in rural areas. Though women represent half of the labor force in agriculture, women in agriculture and rural areas have less access than men to productive resources, training and information. Women have poor access to extension services and only less than 13 percent of Indian women own land (Sircar, 2016). Similarly, working as casual laborers, women's wages were only 69 percent of male wages (Dewan, 2014). Technological progress has the dual effect of widening women's employment opportunities and at the same time pushing them into less skilled and less mechanized occupations (Krishna Ahooja Patel, 1979 and Ela Bhatt, 1985). Furthermore, women are often under-represented in rural organizations and institutions, and are poorly informed regarding their rights. Women face severe constraints in accessing information, training services, inputs, markets and resources such as water. This prevents them from having an equal say in decision-making processes and reduces their ability to drive collective action, such as membership of agricultural cooperatives or water user associations. For example, women comprised 7.5 percent of total membership of the cooperatives in South Asia (Prakash, 2003). Most of the time they remain largely absent in agriculture-based decision making. According to FAO report, women can improve agricultural productivity by 20-30 percent, if offered the same level of training and resources as men (FAO, 2011). Hence, agriculture and allied sectors can only sustain if the sector embraces gender responsive solutions that enable more women to access information, technology, finance and market opportunities.

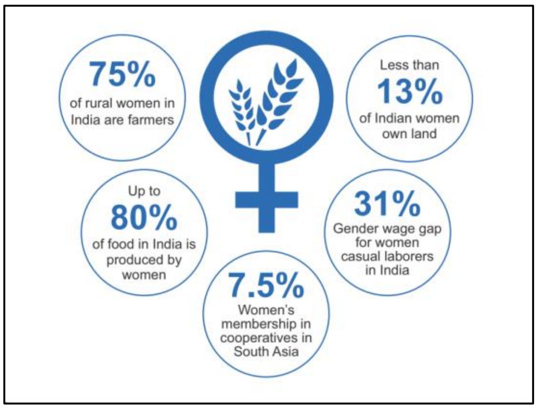

Figure 15.1: Women in Agriculture in India at a Glance (Source: 2030 WRG Report)

Table 15.1: Number of agricultural workers in India 2011

Sl. No.	Particulars	Persons	Male	Female
1.	Total	106,775,330	57,329,100	49,446,230
2.	Rural	102,431,218	54,706,211	47,725,007
3.	Urban	4,344,112	2,622,889	1,721,223

Table 15.2: Work participation rate of India 2011

Sl. No.	Particulars	Persons	Male	Female
1.	Total	39.1	51.7	25.6
2.	Rural	41.7	52.1	30.8
3.	Urban	32.3	50.6	11.9

Table 15.3: Number of cultivators in India 2011

Sl. No.	Particulars	Persons	Male	Female
1.	Total	127,312,851	85,416,498	41,896,353
2.	Rural	124,719,747	83,475,851	41,243,896
3.	Urban	2,593,104	1,940,647	652,457

(Source: Census of India 2011, Registrar General of India, New Delhi)

The role of women in agriculture and allied sectors

Women's role in agriculture has increased significantly even among small and marginal farmers with changing agricultural scenario. Though women constitute a higher proportion of casual agricultural labour in the country, there is a significant gender gap in terms of access to resources, decision making, wage disparities, extension services etc. Their contributions to agriculture are often less-recognized and undervalued, even leading to their exclusion from decision-making processes, access to resources and ownership of land. Women farmers often face gender-based discrimination, limiting their access to credit, technology and extension activities. The contribution of women in agricultural labour force varies across regions and within countries according to age and social class. But most of the time, women are invariably over represented in unpaid, seasonal and part-time work, and the available evidence suggests that women are often paid less than men, for the same work. Patriarchal system inherited in our cultures coupled with interpretations of religious sanctions and illiteracy hinder women's participation in social interactions. This has resulted into women's contribution to agriculture and other sectors in the economy remain concealed and unaccounted for their economic performance measurement as well as invisible in plans and programmes. In fact, most of the time they were discriminated by stereotypes that restrict them to a reproductive role and denied access to productive resources. Leela (1978) found that hunger, disease and indebtedness are an integral part of the life of the women labour.

Rural women perform various labour-intensive jobs such as weeding, grass cutting, separation of seeds from fiber etc. Women are the one who collect wood from fields which is a major fuel source for cooking. Clean drinking water is another major problem in rural areas. Most of the time, fetching water from remote areas is also considered as the duty of women members in the family.

Table 15.4: Number of females (Per 1000 females of age 5 years and above usually engaged in domestic duties in the usual principal status) who carried out specified activities

Sl. No.	Specific activities	Rural	Urban
1.	Maintenance of kitchen garden	241	112
2.	Work in House hold poultry	254	33
3.	Free collection of fish	188	21

4.	Free collection of fire wood	423	67
5.	Husking of paddy (own produced)	74	5
6.	Grinding of food grain (own produced)	69	19
7.	Preparation of meat (own produces)	12	5
8.	Making Baskets etc. (own produced)	28	5
9.	Husking paddy (acquired)	63	34
10.	Grinding food grain (acquired)	72	58
11.	Preparation of meat (acquired)	51	34
12.	Making Baskets etc. (acquired)	47	29
13.	Preparing cow dung cake	424	56
14.	Sewing, tailoring	287	229
15.	Free tuition of own/others children	67	137
16.	Bringing water from House hold premises	366	125
17.	Bringing water from outside village	12	-
18.	Number of females engaged in domestic duties per 1000 female	443	522

(Source: NSS Report No. 550: Participation of Women in Specified Activities along with Domestic Duties, 2009-10)

According to Subathra *et al*., (2020) the main challenges faced by women farmers in agriculture sector are the following:

- Women have unequal land rights. They hardly enjoy land ownership rights directly in their names. Limited rights or access to arable land further limits livelihood options and exacerbates financial strain on women.
- Women have limited access to use of productive resources.
- Women perform all un-mechanized agricultural tasks and perform multiple tasks which add more burdens to them.
- Women have little control over decision making process.
- Poor women farmers are less able to purchase technology to adapt to climate change due to lack of access to credit and agricultural services. They often have low productivity due to an inability to invest in things such as improved seeds and soil replenishment.
- Women farmers in agricultural sector suffer from high illiteracy rate among them. They do not know their legal rights.
- Women earn fewer wages, especially in joint, informal and private sector.

- Lack of market intelligence and inadequate information put women farmers under unfavourable situation with weak bargaining power with the buyers.

Gender issues in agriculture have been a concern for many decades, and despite progress in gender equality, there are still significant disparities between men and women's roles and opportunities in the agricultural sector. To address this, several initiatives are being already undertaken to raise awareness and encourage gender-sensitive policies and practices within the agricultural sector. Department of Agriculture, Cooperation & Farmers' Welfare (DAC&FW), Ministry of Agriculture & Farmers' Welfare (MoA&FW), is mainstreaming gender issues in agriculture by incorporating pro-women initiatives in various schemes, programmes and missions and is allocating at least 30 percent of resources and benefits for women under beneficiary-oriented interventions. The National Gender Resource Centre in Agriculture (NGRCA) is set up within the Department of Agriculture, Cooperation & Farmers' Welfare and reflects the national commitment to the empowerment of women. Achieving gender equality is the fifth goal of United Nation's Sustainable Development Goal (SDG). Achieving this goal, is a key to achieve other goals such as SDG1 (No Poverty) and SDG 2 (Zero Hunger).

To address the existing inequality and recognize the contribution of women to the agriculture and allied sectors, a few recommendations are given below:

- Improving access to inputs such as land and credit is a key step towards women's empowerment. It is important to recognize the labour work of women in the rural economy by accounting for it in monetary terms. More facilities need to be provided to poor rural women for land, agricultural and livestock extension services. Priority should be given to women in accessing credit on soft terms from banks and other financial institutions for setting up businesses, buying properties, and building a home.
- Measures should be taken to enhance women's literacy**.**
- Creating awareness among women of their existing rights. Reducing discrimination through legal reforms is key to achieving gender equality in the long run.
- Encouraging women to participate in decision-making bodies that can help in bringing structural changes in gender relations in society.
- Inducting a sizeable number of well-trained women personnel in training and extension programmes of agricultural development agencies at all levels will help to break the existing barrier for women farmers to involve in extension activities.

Conclusion

Rural Indian women are extensively involved in agricultural activities, but the nature and extent of their involvement differs with variations in agro-production systems. Women make significant and essential contributions to agriculture and rural enterprises. However, given the rich diversity in women's roles, it is important that policies are based on sound data and gender analysis. To achieve gender equality, women should have equal access to productive resources, opportunities, and public services and should be considered as vital development agents who can play a significant role in the economic development of a nation. Similarly, women farmers should be identified as an important link in the development of agriculture sector, as they play a crucial role in agricultural development and allied fields. A balanced focus on the three pillars of economic empowerment, decision-making, and workload redistribution can help foster greater gender equality.

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16. Economic Impact of Natural Resource Management (NRM) Technologies in Rainfed Agriculture

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The methodological challenges in impact assessment for NRM research are associated with interrelationships among natural resources, spatial and temporal dimension of impact, and valuation of environmental benefits and costs. NRM technologies may have the strategies to improve yields, reduce the risk and conservation of the resources under threat.

Impact assessment is important for extension strategies because,

- **Assessment of effectiveness**: Impact analysis helps determine whether the adoption of specific agricultural technologies leads to the desired outcomes. It assesses how well these technologies contribute to improved agricultural productivity, income, and livelihoods.
- **Resource allocation**: Extension services often have limited resources. Impact analysis allows decision-makers to allocate resources more effectively by identifying which technologies are most impactful. It helps prioritize interventions and investments.
- **Targeting and customization**: Understanding the impact of agricultural technologies allows extension services to tailor their approaches to the specific needs and conditions of different farming communities. This customization improves the relevance and effectiveness of extension programs.
- **Learning and adaptation**: Impact analysis provides valuable insights into what works and what doesn't.
- **Evidence-based decision making**: Data and evidence from impact analysis support evidence-based decision-making. Extension approaches that are based on empirical evidence are more likely to succeed and gain the trust of farmers and stakeholders.

Impact assessment

It is a process of evidence-based procedure to assess the effects of technology/projects/interventions in terms of economic, social/environmental effects. A systemic analysis of intervention, related to its contribution to outcome. It is a cause effect relationship change; the relationship is between inputs and changes outputs.

- Technically feasible
- Economically viable
- Socially acceptable
- Safe to environment

Types of impact assessment

1. Economic Impact Assessment Adoption Studies Economic studies (returns to investment)
2. Social and Environment impact assessment

   Effect on poverty, gender issue, food security etc.

   Effect on pollution, sustainability and natural resources etc.

Impact can be examined from two perspectives: after research is completed (ex-post) or during planning (ex-ante). Ex ante impact assessments may be done as an aid to priority setting to estimate the future benefits of different research projects. We often use ex post impact assessments f or positive information on results.

Steps in impact assessment

- Select the technology to be evaluated.
- Select the type of assessment (economic, social, human capital, environmental)
- Identify the needs/ problems/ issues and questions to be asked.
- Level of assessment (farm, regional, national etc.)
- selection of methods of impact assessment.
- Design data collection and analysis.
- Field-test instruments and make adjustments if necessary.
- Collect the information.
- Analyze the information.
- Present the results and recommendations.

Methods involved:

- Before and after method
- Adopted and non-adopted (with and without method)
- Combined methods

Economic impact of NRM technologies

The economic analysis of natural resources management technologies involves evaluating the costs, benefits, and overall efficiency of various strategies and technologies used to manage and conserve natural resources. This type of analysis helps decision-makers, policymakers and businesses make informed choices about resource management. Here are some methodologies and key aspects of economic analysis in this context:

1. Cost-Benefit Analysis (CBA): Cost-benefit analysis is a fundamental method used to assess the economic feasibility of natural resource management technologies. It involves comparing the total costs of implementing a technology or strategy with the total benefits it generates. Costs include investments, operational expenses, and maintenance, while benefits encompass monetary and non-monetary gains such as increased resource yields, reduced environmental degradation, and enhanced ecosystem services.
2. Net Present Value (NPV) Analysis: NPV is a financial technique that calculates the present value of future costs and benefits, allowing for a time-based comparison of alternative resource management technologies. This analysis considers the time value of money, and the chosen technology is considered viable if the NPV is positive.
3. Cost-Effectiveness Analysis (CEA): CEA focuses on comparing different resource management technologies in terms of their cost per unit of desired output or impact. It is particularly useful when there are multiple technologies that can achieve similar objectives, and the goal is to identify the most cost-effective option.
4. Sensitivity Analysis: This technique assesses the impact of uncertainty in key parameters and assumptions on the economic viability of resource management technologies. By varying variables like resource prices, discount rates, and technology performance, sensitivity analysis helps evaluate the robustness of economic assessments.
5. Economic Surplus Methods (ESM)
6. Econometrics
7. Meta–analysis
8. Spatial analysis through GIS and remote sensing

Cost-Effectiveness Analysis (CEA) is a quantitative method used to compare different interventions, projects, or strategies with the goal of identifying which one provides the most value in achieving a specific outcome, typically in a cost-minimizing manner. Here's an overview of the analysis of cost-effectiveness methods:

1. **Identification of alternatives**: Start by identifying the various alternatives or interventions that can achieve the desired outcome. These can be different technologies, programs, policies, or strategies.
2. **Outcome measurement**: Define the outcome or outcomes that you want to assess. These outcomes should be measurable and relevant to the decision at hand. For example, in healthcare, this might be improvements in patient health; in environmental policy, it might be reductions in carbon emissions.
3. **Cost estimation**: Calculate the costs associated with each alternative. Costs should include not only direct financial expenditures but also indirect costs, such as operational and maintenance expenses.
4. **Effectiveness measurement**: Measure the effectiveness of each alternative in achieving the defined outcome. The effectiveness measure can be expressed in various units, such as Quality-Adjusted Life Years (QALYs) in healthcare or tons of CO2 reduced in environmental policy.
5. **Calculation of Cost-Effectiveness Ratio (CER)**: Calculate the cost-effectiveness ratio for each alternative by dividing the cost by the effectiveness measure. The CER shows the cost required to achieve a unit of the desired outcome. The formula is: CER = Cost / Effectiveness.
6. **Incremental analysis**: Determine the incremental cost-effectiveness ratio (ICER) by comparing two alternatives. The ICER shows the additional cost required to achieve an additional unit of the desired outcome when switching from one alternative to another. The formula is: ICER = (Cost2 - Cost1) / (Effectiveness2 - Effectiveness1).
7. **Sensitivity analysis**: Assess the robustness of the results by performing sensitivity analysis. This involves varying key input parameters, such as costs or effectiveness, to understand how sensitive the results are to these changes

Financial analysis: Net Present Value (NPV)

Creating a Net Present Value (NPV) calculation in an Excel spreadsheet involves projecting cash flows, discounting those cash flows to their present value, and then summing them to calculate the NPV. Here's a step-by-step example of how to set up an NPV calculation in Excel:

Step 1: Set up your Excel sheet

Open Excel worksheet and create the following column headers in cells A1, B1 and C1:

- Column A: "Year" (representing the time period)

- Column B: "Cash Flow" (representing the cash flow for each year)
- Column C: "Discount Rate" (representing the discount rate for each year)

Step 2: Enter your data

In Column A, starting from cell A2, list the years corresponding to your cash flows. For example, if you have a 5-year investment, you might list years 0, 1, 2, 3, and 4.

In Column B, starting from cell B2, enter the cash flows for each year. These can be positive (inflows) or negative (outflows). For this example, let's say you have an initial investment of -$10,000 (an outflow) at year 0 and then annual inflows of $3,000 each year for years 1 through 4.

In cell B7, calculate the Net Present Value using the following formula: **=NPV (C2, B3:B7)** Here, **C2** refers to the discount rate in cell C2, and **B3:B7** refers to the range of cash flows from year 1 to year 4.

Step 3: Enter the discount rate

In cell C2, enter the discount rate. The discount rate is typically the cost of capital or the minimum required rate of return for your investment. For this example, let's assume the discount rate is 10%. You can enter "0.10" in cell C2.

Step 4: Calculate NPV

After entering the formula in cell B7 and the discount rate in cell C2, you should see the NPV result, which represents the present value of your cash flows. In this example, it should be calculated as follows:

NPV = -$10,000 / (1 + 0.10)^0 + $3,000 / (1 + 0.10)^1 + $3,000 / (1 + 0.10)^2 + $3,000 / (1 + 0.10)^3 + $3,000 / (1 + 0.10)^4

NPV = -$10,000 + $2,727.27 + $2,479.34 + $2,254.85 + $2,049.86

NPV = $1,512.32

So, the NPV of this investment is $1,512.32.

Economic surplus approach to impact assessment

Economic surplus indicates the difference between the monetary values of the units produced and consumed at the equilibrium price and quantity. Mathematically, economic surplus represents the summation of total consumer surplus and total producer surplus (ES=CS+PS). The triangle PeD represents the total consumer surplus which is the difference between the willingness to pay of the consumer for a product/service without forgoing it and when he actually pays in exchange of getting the product/service (Figure 16.1)

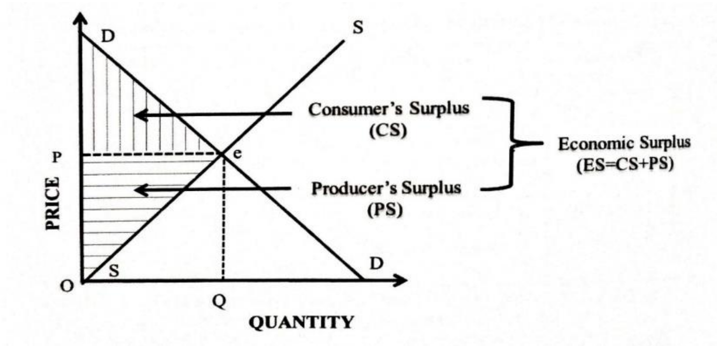

Figure 16.1: Concept of economic surplus

Similarly, the triangle OeP represents the total producer surplus which is the difference between what a producer receives after selling the product/service in the market and his willingness to sell the same product/service at a particular price. However, the triangle OeD represents the total economic surplus accrued to the society due to the product/service which is equivalent to area of the triangle PeD and OeP. However, the three different surpluses (producer surplus, consumer surplus and economic surplus) are sensitive to any changes in demand or supply elasticity. The economic surplus approach to impact assessment is rooted in the microeconomics of supply and demand. Consumer demand can be described by a downward sloping demand curve. Across all consumers, the area beneath the demand curve, D, and above the equilibrium price, p*, measures the total value of consumer surplus. Producer supply can be described by an upward sloping curve. The aggregate benefits described by the area above the supply curve, S, and below the equilibrium price, p*, measure the total producer surplus. Together, consumer surplus and producer surplus sum up to economic surplus. The economic impact of a new production technology can be estimated as the change in economic surplus that results from a shift in the supply curve. Most N R M technologies present several special characteristics that require a different approach to conceptualizing and measuring economic surplus.

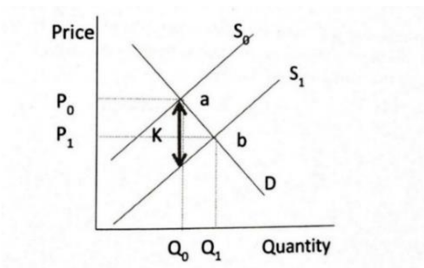

Figure 16.2: Impact of research on closed economy with a parallel supply shift

Economic surplus can be calculated using following formula.

$$\Delta CS = P_0 Q_0 Z(1 + 0.5Z\eta$$

$$\Delta PS = P_0 Q_0 (K - Z)(1 + 0.5Z\eta$$

$$\Delta TS = \Delta CS + \Delta PS = P_0 Q_0 K(1 + 0.5Z\eta)$$

Where,

P_0 = Base price of commodity

Q_0 = Base quantity

η = Absolute value of the price elasticity of demand

Z = $K\ \varepsilon/(\ \varepsilon + \eta)$ are the proportionate price reduction in the market, where ε is the elasticity of supply

Kt = Proportionate reduction in cost per ton of production in time

Difference-in-Difference approach (DID)

The major challenge is using a more reliable methodology for better evaluation. Comparative study between the treated and non-treated groups is a technical way while before and after intervention comparison is also another way. Impact evaluations rely on control or comparison groups, as well as other econometric techniques. One tool which control for factors or events called confounders that are correlated with the outcomes but are not caused by the project is the DID estimate. The DID method is one of the recent improvements in development studies and in many economic evaluation studies

Particulars	Treatment Farmers	Control Farmers	Difference Across Groups
After	T1	C1	T1-C1
Before	T0	C0	T0-C0
Difference across time	T1-T0	C1-C0	Double difference (T1-C1) -(T0-C0)

The data are collected for two groups for two periods. And one of the them is the treatment group and other group is the control group. The treated group receives treatment in one period while the control group receives no treatment during both periods. The average gain over time in the control group is extracted from the gain over time in the treated group. This double differencing methods, removes biases arising from permanent differences between those groups, as well as time differences in the treatment group which can be due to time trend.

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17. Statistical Tools for Impact Assessment of Rainfed Technologies

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Impact Assessment (IA) is an assessment of change that can be attributed to a particular intervention, such as a project, program or policy. In contrast to outcome monitoring, which examines whether targets have been achieved, impact assessment involves counterfactual analysis. The 'counterfactual' measures what would have happened to beneficiaries in the absence of the intervention, and impact is estimated by comparing counterfactual outcomes to those observed under the intervention. In other words, they look for the changes in outcome that are directly attributable to a program. Counterfactual analysis enables evaluators to attribute cause and effect between interventions and outcomes.

Impact Assessments (IAs) are formal, evidence-based procedures that assess the economic, social, and environmental effects of a project, program or policy (Adelle and Weiland, 2012). Impact assessments can focus on specific themes, such as social impact assessments and gender impact assessments. Impact assessment helps people answer key questions for evidence-based policy making: what works, what doesn't, where, why and for how much? Impact assessment helps by apprising policy makers about potential economic, social, and environmental ramifications.

Assessment of impact

Estimation methods depend up on evaluation designs adopted. Different designs require different estimation methods to measure changes in outcome from the counterfactual. In experimental and quasi-experimental evaluation, the estimated impact of the intervention is calculated as the difference in mean outcomes between the treatment group (those receiving the intervention) and the control or comparison group (those who don't). This method is also called Randomized Control Trials (RCT). The single difference estimator compares mean outcomes at end-line and is valid where treatment and control groups have the same outcome values at baseline. The difference-in-difference (or double difference) estimator calculates the difference in the change in the outcome over time for treatment and comparison groups, thus utilizing data collected at baseline for both groups and a second round of data collected at end-line, after implementation of the intervention, which may be years later.

Impact evaluations which have to compare average outcomes in the treatment group, irrespective of beneficiary participation (also referred to as 'compliance' or 'adherence'), to outcomes in the comparison group are referred to as intention-to-treat (ITT) analyses. Impact Evaluations which compare outcomes among beneficiaries who comply or adhere to the intervention in the treatment group to outcomes in the control group are referred to as treatment-on-the-treated (TOT) analyses. ITT therefore provides a lower-bound estimate of impact, but is arguably of greater policy relevance than TOT in the analysis of voluntary programs.

Inferential statistics

Inferential statistics comprises the use of statistic (some function of sample values) to make inferences concerning some unknown aspect of a population called parameter. The aim is to draw inferences about a population from a sample.

Sampling distribution

Assume we repeatedly take samples of a given size from the population and calculate the sample mean ($\bar{x}$, the arithmetic mean of the data values) for each sample. Different samples will lead to different sample means. The distribution of these means is the "sampling distribution of the sample mean" (for the given sample size). According to the central limit theorem, if the population is not normal but "sufficiently well behaved", the sampling distribution of the sample mean will still be approximately normal provided the sample size is sufficiently large. Thus, the mean of the sampling distribution of a statistic is equivalent to the expected value of the statistic. For the case where the statistic is the sample mean:

$$\mu_{\bar{x}} = \mu$$

where μ is the mean of the population distribution of that quantity.

The standard deviation of the sampling distribution of the statistic is referred to as the standard error of that quantity. For the case where the statistic is the sample mean, the standard error is:

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$$

where σ is the standard deviation of the population distribution of that quantity and n is the size of the sample (number of items).

Null Hypothesis: It is a statement about population parameters, which is tested for possible rejection under the assumption that it is true.

Alternative Hypothesis: This is complementary to null hypothesis. When a null hypothesis is formed, it is always in contrast to an implicit *alternative hypothesis*, which is accepted if the observed data values are sufficiently improbable under the null hypothesis. If one wants to test null hypothesis that yield effect of Rainfed Technology-I is same as that of II then alternative hypothesis could be:

i) two tailed test i.e. $\mu_1 \neq \mu_2$.

ii) left tailed test i.e. $\mu_1 < \mu_2$.

iii) right tailed test i.e. $\mu_1 > \mu_2$.

Level of Significance: It is the percentage chance that null hypothesis is rejected though it is true. If the null hypothesis is true, the significance level is the probability that it will be rejected in error. This chance of committing error arises due to fluctuations in sampling. Popular levels of significance are 5%, and 1%.

Example

	Truth	
Verdict	***True***	***False***
True	No Error	Type II Error
False	Type I Error	No Error

5% Level of Significance: It means there is 5% chance that we reject null-hypothesis though it is true.

1% Level of Significance: There is 1% chance that we reject the null hypothesis, though it is true.

Testing of hypothesis - small sample tests

The aim of this section is to draw inferences about a population from a small sample.

4.1 Two Sample t-Test

Let μ_1, μ_2 are the mean outcomes in treatment group and control group populations and $\overline{x_1}$ and $\overline{x_2}$ are mean outcomes of random samples of sizes n_1 and n_2 drawn independently from the populations of treatment group and control group.

Assumptions:

i) Population from which samples are drawn is normal.

ii) The samples are drawn independently and at random.

iii) Population standard deviations (S.D.s) are equal

Constraints:

i) Common population S.D. is not known

Null Hypothesis: $H_0 : \mu_1 = \mu_2$

Outcome in treatment group is equal to outcome in control group.

Test statistic:

$$t = \frac{(\overline{x}_1 - \overline{x}_2) - (\mu_1 - \mu_2)}{s_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}},$$

follows t distribution with $(n_1 + n_2 - 2)$ degree of freedom.

Where, S_p is Pooled S.D.

$$s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2},$$

$$s_1^2 = \frac{1}{(n_1 - 1)}\sum_{i=1}^{n_1}\left(x_{1i} - \overline{x}_1\right)^2$$

s_2^2 may be computed using a similar formula.

Conclusion: If calculated t is greater than t table value for $(n_1 + n_2 - 2)$df at required level of significance, the null hypothesis is rejected. It is concluded that there is significant difference between two means with respect to character under consideration. Otherwise null hypothesis is accepted.

Example: Let us see whether there is any difference in yield of maize crop with ridge & furrow planting compared to flatbed planting. A sample of 10 maize farmers were drawn at random from each planting method. The yields (in t/ha) obtained by the sampled farmers are as under.

Ridge & furrow	3.6	3.7	3.3	4.5	4.4	3.9	2.9	3.2	3.5	4.1
Flatbed	2.2	2.6	1.8	3.4	2.8	2.3	3.6	1.7	2.7	2.9

The difference in yield between 2 planting methods may be attributed to ridge & furrow planting. Make a statement about the significance of the difference.

Solution:

i) sample sizes are $n_1 = 10$, $n_2 = 10$

ii) $H_0 : \mu_1 = \mu_2$

$H_1 : \mu_1 \neq \mu 2$

iii) Test Statistic

$\overline{x}_1 = 3.71$, $\overline{x}_2 = 2.6$

$s_1^2 = 0.387$ $s_2^2 = 0.27$ $S_p = 0.57$

$$t = \frac{(3.71-2.6)-0}{0.57\sqrt{\frac{1}{10}+\frac{1}{10}}} = 4.33$$

Conclusion: t (Cal) = 4.33 is greater than t (table) value i.e. 2.88 at 1% level of significance. Hence null hypothesis is rejected and concluded that the difference is statistically significant.

It can be inferred that ridge & furrow planting had positive impact over flatbed planting.

4.2 Paired t-Test

When to use paired t-test:

The sample sizes should be equal and the two samples are not independent (sample observations are paired together). For example, difference in performance of a group of farmers before and after training may be tested using this test. Let μ_1, μ_2 are the performances before and after training. A random sample of size n is drawn from the group of farmers who undergone training. Let x_{i1} and x_{i2} are the pair of observations pertaining performance before and after training respectively on ith (i=1, 2, ...n) sampled farmer.

Assumptions:

i) Population from which samples are drawn is normal.

ii) The paired sample is drawn at random.

iii) Population S.D.s are equal

Constraints:

i) Sizes of the samples are equal

ii) Common population S.D. is not known

Null Hypothesis: H_0 : $\mu_1 = \mu_2$

There is no difference in performance before and after training

Test statistic: $t = \frac{\overline{d}}{\sqrt{\frac{S_d^2}{n}}}$ follows t distribution with $(n-1)$ degree of freedom.

where, $\overline{d} = \frac{1}{n}\sum_{i=1}^{n} d_i$ and $d_i = x_{i1} - x_{i2}$

$$S_d^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(d_i - \bar{d}\right)^2$$

Conclusion: If calculated t is greater than t table value for (n-1) df at required level of significance, the null hypothesis is rejected. Otherwise, null hypothesis is accepted.

Example: A 5 days capacity building programme on rainfed technologies was organized at ICAR-CRIDA to 40 farmers. A random sample of 15 farmers were drawn before start of the programme. Their knowledge level was tested before and after the programme. The marks obtained with Max marks as 60 are given below.

Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
After programme	52	46	49	58	41	38	44	35	36	43	31	55	46	47	50
Before Programme	12	18	14	9	8	15	11	14	10	8	12	5	13	4	8

Test whether the programme was effective?

Solution:

H_0: The programme is not effective

H_1: The programme is effective

Computation of Test Statistic: $\bar{d}$ = 34 and S_d^2 = 91.57

$$t = \frac{34}{\sqrt{\frac{91.57}{15}}} = 13.76$$

Conclusion: t (tab) value for 14 degree of freedom at 5% level of significance is 2.14. Here we find that t (cal) is > t (tab). Hence, null hypothesis is rejected at 5% level of significance and it is concluded that the programme is effective.

Testing for impact of a programme on adoption of a rainfed technology

Proportion: The proportion of individuals having a particular characteristic is the number of individuals possessing the characteristic divided by total number of individuals. Suppose we create a variable that equals 1 if the individual has the characteristic and 0 if not. The proportion of individuals with the characteristic is the mean of this variable because the sum of these 0s and 1s is the number of individuals with the characteristic.

Test of significance for difference of proportions

Testing of the Null Hypothesis H_0: $P_1 = P_2$ (the population proportions are equal) against Alternative Hypothesis H1: $P_1 \neq P_2$ (the population proportions are not equal).

The test is performed by calculating z statistic and comparing its value to the percentiles of the standard normal distribution to obtain the observed significance level. If this probability value is sufficiently small, the null hypothesis is rejected.

$$Z = \frac{(\hat{P}_1 - \hat{P}_2) - 0}{\sqrt{\hat{P}(1-\hat{P})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \text{ follows N (0,1)}$$

Where $\hat{P}_1$ and $\hat{P}_2$ are the estimated proportions computed from samples of size n_1 and n_2, respectively.

$\hat{P}$ is the proportion of individuals having the characteristic when the two samples are pooled together.

$$\hat{P} = \frac{n_1\hat{P}_1 + n_2\hat{P}_2}{n_1 + n_2}$$

Example: A KVK claims that adoption of a rainfed technology is more in the village adopted by them compared to neighbouring village. Independent random samples of size 40 has been drawn from each village. The estimated proportions (on the basis of samples) are 0.7 and 0.4 for the KVK adopted village and neighbouring village respectively. Please verify the claim of the KVK?

Solution:

H0: $P_1 = P_2$

H1: $P_1 \neq P_2$

$$\hat{P} = \frac{(40 * 0.7 + 40 * 0.4)}{40 + 40} = 0.55$$

$$Z = \frac{0.7 - 0.4}{\sqrt{0.55 * (1 - 0.55)\left(\frac{1}{40} + \frac{1}{40}\right)}} = 2.70$$

Conclusion

Calculated Z (2.70) falls in the rejection region, as Z table value is 1.96 at 5% level of significance. Therefore, null hypothesis is rejected and the claim of KVK is admitted. It is further concluded that adoption of the rainfed technology is more in the village adopted by the KVK compared to neighbouring village.

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