Suhas P. Wani
K.V. Raju
Tapas Bhattacharyya *Editors*

Scaling-up Solutions for Farmers

Technology, Partnerships and Convergence

Springer

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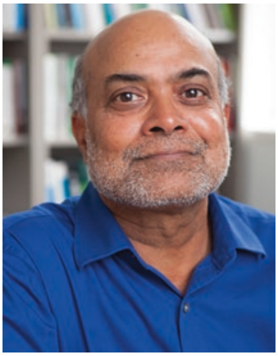
Foreword



Meeting the sustainable development goals (SDGs) 1, 2 and 3 by 2030 for achieving poverty elimination, zero hunger and good health and human well-being is the greatest challenge faced by the global development community. With the increasing population, changing food habits due to increased incomes, impact of climate change and the recent COVID-19 pandemic, the challenge of achieving the SDGs has become even more daunting. Smallholder farms face an unduly larger share of the aforementioned risks and threats to agriculture and food security. Enhancing productivity growth and promoting sustainable intensification of small farms could contribute directly to the achievement of the SDGs. Scientific knowledge and technologies targeted towards small farm systems are available but have not been adopted widely due to poor extension and "last mile delivery" problems.

This book, *Scaling-up Solutions for the Farmers: Technologies, Partnerships and Convergence*, is a very timely publication that addresses the issues of delivery of new knowledge and technologies to smallholder farmers across the globe. Neglecting scaling-up of improved interventions by researchers resulted in the Death Valley of Impacts. In one of its articles in 2020, *Nature Food* reported that researchers worked in isolation without involving smallholder farmers and provided compartmental solutions resulting in low adoption and low impacts on poverty and food security. The CGIAR's numerous efforts in multi-disciplinary on-farm research are an exception and have often resulted in positive impacts for small farm households. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) adopted the tagline "Science with a Human face" and later "Science of Discovery to Science of Delivery", indicating the farmer-focused vision of the institute. A multidisciplinary watershed team from the institute adopted an open-minded and learning-cycle approach to assess low adoption of earlier technologies such as Vertisol by the farmers. This resulted in developing a multi-disciplinary and multi-institutional consortium approach which was piloted by farmers in *Adarsha* Watershed, Kothapally, AP, India. This consortium approach was scaled-up with financial support from several national and international donors in China, India, Philippines, Thailand and Vietnam. A similar consortium approach is now being initiated in South East Africa.

The chapters in this book are based on the learnings during scaling-up initiatives implemented by CGIAR institutes such as ICRISAT, IRRI, ICARDA, CIP and ICAR. The chapters cover holistically all the aspects of scaling-up technology based solutions for farmers through building partnerships, achieving convergence of schemes and departments to achieve sustainable impact on rural lives and livelihoods.

The editors have made a laudable effort in presenting an outstanding set of case studies of successful conduct of farm-based research for enhancing last mile delivery. The way-forward suggestions, based on the long experience of the consortium partners in different scaling-up initiatives, will definitely help scientists, students, development workers, policymakers and development investors alike. I appreciate the timely efforts of the editors and chapter authors who have put together this book and for sharing their learnings for the benefit of all the stakeholders involved in meeting the SDGs.

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Tata-Cornell Institute (TCI), New Delhi, India

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Patancheru, Telangana, India

Foreword

I must first pay a special tribute to the coordinating editors, Dr. Suhas Wani, Dr. K.V. Raju, and Dr. Tapas Bhattacharya, for taking the initiative to produce this book, ***Scaling-up Solutions for Farmers: Technology, Partnerships, Convergence for Farmers.*** They have brought together leading institutions and renowned experts to collaborate on writing this very authoritative book.

In some ways, the title says it all, in terms of what is necessary for smallholder farmers in the drier regions of the world to create opportunities of improved social and economic livelihoods. For indeed that is a key goal of farmers in the tropical developing world – how to secure prosperity for their future generations. For many decades, in fact since the Green Revolution, scientific institutions and universities have been bringing new technologies and improved farming practices to the cultivators of the land. Indeed, new crop varieties, fertilizer technologies, crop protection breakthroughs, and improved water management systems have all contributed to the betterment of the food system in Asia, Africa, and Latin America.

However, agriculture is now facing new challenges in terms of environmental degradation, loss of biodiversity, depletion of soil nutrients and loss of organic matter, and climate change, as well as the effects of the COVID-19 pandemic. All these factors bring one word to mind – ***resilience***. It is therefore commendable that the authors of chapters have sought to underline the necessity of addressing crop diversity, soil quality, drought-resistant farming, conservation agriculture, and sustainable intensification with urgency going forward.

Of course, technologies will not succeed if farmers do not attain new skills, such as digital farming, and utilize value chains and the social-institutional infrastructure led not just by government but also by community-based organizations. Governments can provide the enabling environment in which farmers' organizations are empowered to attain highest levels of self-sufficiency, so as to take advantage of value chains, for example.

A highlight of this book is its focus on ***scaling-up***. The coordinating editors quite appropriately recognize that the outputs from the labs, field trials, experimental farms, and on-farm demonstration sites will only have impact if scaled up to meet the needs of thousands of farmers, collectively. This is a brave and daunting proposition, but one that is necessary if we are to witness the next high level of productivity gains, innovation, environmental sustainability, and socio-economic benefits in the farming sector.

I commend this book to practitioners, researchers, university students, agribusiness leaders, thought leaders, and government decision makers.

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Montreal, Canada

Chandra A. Madramootoo

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and President Honoraire, ICID
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Foreword

This is a timely book addressing the challenges of scaling-up research products to benefit millions of farmers across the developing countries in Asia. The experience and learnings of many partners – International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), International Rice Research Institute (IRRI), International Center for Agriculture Research in the Dry Areas (ICARDA), International Potato Centre (CIP), Food and Agriculture Organization (FAO), Tamil Nadu Agricultural University, and ICAR-Indian Institute of Soil and Water Conservation – have been distilled into this book.

Increasing distress for the 500 million smallholder farmers globally is largely due to large yield gaps between the current farmers' yield and the achievable potential under a given environment. This situation arises primarily due to piecemeal solutions provided to the farmers as the emphasis was on increasing the productivity and not the profitability, increasing cost of inputs, low price realization for farm produce, and poor extension services for the farmers.

The CERES 2030 team had undertaken a meta-analysis based on more than 100,000 published papers/reports and highlighted that the main reasons poverty was not reducing across the globe was that scientists, except those associated with CGIAR network, do not work with smallholder farmers; farmers receive piecemeal solutions and lack access to markets.

ICRISAT focuses on the livelihoods of smallholder farmers through a value-chain approach giving primacy to market-oriented development. With a large footprint across many states in India and also neighbouring countries of China, Thailand and Vietnam, ICRISAT has partnered with national and international institutions, farmers' organizations, and the private sector to reach millions of farmers with science- and evidence-based approaches to improve profitability and ensure the sustainability of dryland farming.

Meeting the Sustainable Development Goals (SDGs) of No Poverty, Zero Hunger, and Good Health and Well-Being is a challenging task with increasing land degradation, reduced per capita land and water availability, changing food habits due to rising incomes, and the impacts of climate change. The lessons learnt over the years have been put together in this book to benefit researchers, policymakers, development investors, extension workers and students across the developing world. I congratulate the editors for bringing out this timely publication.

Jacqueline Hughes

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Preface

The greatest global challenge for humanity in the twenty-first century is to achieve food, nutrition and income security for an ever-growing population. More than 690 million people globally were still hungry in 2019, accounting for 8.9% of the world population – up by 10 million people in 1 year and by nearly 60 million in 5 years, a number which underscores the huge challenge for achieving the Zero Hunger target by 2030. Climate change is looming large and is threatening the smallholder farmer due to increased rainfall variability, occurrence of dry spells, and fluctuating temperatures, further affecting the existing poor crop yields. Large yield gaps between current farmers' yield and achievable potential yield are due to the Death Valley of Impacts as farmers lack updated knowledge. Most researchers worked in isolation without involving smallholder farmers and provided supply driven compartmental solutions which are not adopted by smallholder farmers. With all these challenges things around and occurrence of epidemic COVID-19 which has driven food crises as the pandemic's knock-on effects aggravated pre-existing drivers of hunger as per the new report by the UN's FAO and World Food program (WFP) which has identified 27 countries heading towards food crises. Achieving sustainable development goals (SDGs) addressing hunger, malnutrition and poverty is a great challenge.

To minimise distress for small farmholder farmers, scaling-up holistic solutions for farmers through improved science delivery by adopting partnerships, convergence and collective action and ensuring economic gain for the smallholder farmer, which are innovative, science-based, scalable and efficient through collectivisation, is the way forward. Value addition and ensuring market linkages for the farm produce along with reduced cost of cultivation using new science tools, knowledge and technologies developed by the researchers are all the more necessary. The use of appropriate knowledge delivery systems to reach 500 million smallholder farmers is a must to cross the Death Valley of Impacts.

This book, *Scaling-up Solutions for Farmers: Technologies, Partnerships and Convergence*, is based on the learnings obtained by a number of CGIAR centres in Asia and ICAR and various State Agricultural Universities (SAUs) in India. The learnings as well as the strategies adopted by the teams are boundary neutral and scalable in any part of the developing world. Recent meta-analysis undertaken by the CERES 2030 team based on more than100,000 published papers and reports stated that the researchers in CGIAR, ICAR and SAUs are working together to bring all-round happiness and prosperity to the smallholder farmer. This book will serve the needs of all stakeholders who are involved in improving livelihoods of smallholder farmers globally.

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Chapter 1
Death Valley of Impacts in Agriculture: Why and How to Cross It with Scaling-Up Strategy?

Suhas P. Wani

Abstract Achieving zero hunger, alleviating poverty, improving nutrition and wellbeing of growing population in Asia and Africa are the main challenges during the twenty-first century with increasing land degradation, decreasing per capita availability of land and water and impacts of the climate change. In spite of available game changing technologies small farm-holders in Asia are having large yield gaps mainly due to science of discovery without science of delivery. Lack of integrated approach, compartmentalization of solutions, poor delivery systems have resulted in low adoption of improved sustainable technologies. Business as usual won't help the farmers and there is an urgent need to transform agriculture as a business in India by adopting 4 ISECs (Innovative-integrated- scalable& sustainable environment-friendly& economically remunerative consortium-collective action) approach. Learnings from the number of scaling-up initiatives benefitting >10 million famers are documented which will enable to cross the "*Death Valley* of impacts" and benefit the small farm-holders in Asia and Africa ensuring food, nutrition and income security through climate resilient sustainable agriculture. The chapter describes in detail the reasons for existence of "*Death Valley*" of impacts, how it can be crossed and what needs to be done and explained all the three principles based on the several scaling-up initiatives undertaken benefitting millions of farmers in Asia. The results of meta-analysis undertaken by the CERES 2030 team also described as confirmatory statements for the learnings from scaling-up initiatives.

Keywords Impacts · Scaling-up · Integrated solutions · Demand-driven research · Partnerships · Consortium · Convergence · Collective action · Capacity building

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1.1 Challenges of Agriculture Development in Developing Countries

1.1.1 Need for Increased Food Production to Meet the Food Demand for Growing Population

The greatest challenge in the twenty-first century for the humankind is to have food (SDG 2- Zero hunger) and nutrition security (SDG 3- good health and well-being) along with income security (SDG 1- Poverty reduction) as more than 690 million people globally were still hungry in 2019, accounting 8.9% of the world population-up by 10 million people in 1 year and by nearly 60 million in 5 years, a number which underscores the huge challenge for achieving the Zero Hunger target by 2030 (FAO, IFAD, UNICEF, WFP and WHO 2020). New report by the UN's FAO and World Food program (WFP) has identified 27 countries heading for Covid 19-driven food crises as the pandemic's knock-on effects aggravated pre-existing drivers of hunger (FAO-WFP 2020). It is anticipated that globally total food demand in year 2050 will be approximately 11,200 million tons out of which 9300 million tons food will be required for developing countries (Rockström et al. 2007; Hanjra and Qureshi 2010). Agriculture is of prime importance for the world's food systems, a complex adaptive system, that include many actors, interacting institutions, social, environmental, biological, institutional, political, governance, and demographic considerations as it has special significance for achieving the stated sustainable development goals. In addition, agriculture is at the nexus of three of the greatest challenges of the twenty-first century – sustaining food and nutrition security, adaptation and mitigation of climate change, and sustainable use of critical resources such as water, energy and land. Agriculture is also acquiring renewed importance for gainful employment due to failure of manufacturing sector to pull labour out of agriculture and to keep pace with the growth in workforce in countries like India (Chand 2019). Ensuring global food security for the ever-growing population, which will reach over nine billion by 2050 and reducing poverty is a challenging task in the current setting of climate change impacts, as agricultural production is estimated to rise by approximately 50% from 2013 to 2050 considering the revised estimates by the United Nations for population growth and the increase in agricultural production by 15% between 2005/06 and 2012 (FAO 2017).

1.1.2 Growing Per Capita Incomes in Emerging Economies and Changing Food Habits

With the growing incomes in emerging economies such as Brazil, Russia, India, China, and South Africa (BRICS) imply additional pressure on global food production due to changing food habits. The World Economic Forum estimated that in

India by 2030, 51% of population adding 350 million individuals will be in upper middle and high income and high consuming category as compared to 24% in 2020. With Increasing urbanization, shrinking farm size, development in education and migration to cities in search of better livelihoods is increasing food demand. For example, in India with the growing population as well as increasing incomes more people are taking animal-based food and shrinking the number of vegetarian diet people (Table 1.1). Such a situation puts more pressure to have sustainable food systems with scarce water and land resources. In addition, harvest and post-harvest loss of major agricultural produce in 2018 was estimated at Rs. 92,651 crores ($ 13 billion) (Ministry of Food Processing) per year largely due to storage, logistic, and financing infrastructure inadequacies in India. Prevention of these losses could feed 50 million people per year. About 30–45% of the loss is due to food wastage – a crime indeed. One of the five pillars of Zero Hunger Challenges is "Zero loss or waste of food", seeking change in the mind-set of people to adopt "Save and Grow" (FAO 2011).

1.1.3 Land and Water Scarcity for Food Production

Water is an elixir of life which is one of the five eternal elements (namely, earth, water, fire, air, and ether) which are also known in ancient Indian literature as "*pancha maha bhuta*". Without water life would be impossible as it is an essential part of world's eco-system. Historically, many of the early great civilizations the so-called cradle of civilization like Mesopotamia, was situated between the major rivers Tigris and Euphrates; the ancient society of Egyptians depended entirely on Nile; the Indus Valley civilization in India flourished along the once famous *Sarasvati* river. Water has always a pervasive influence on the cultural and the religious life of Indian people. The great bath of *Mohenjo-Daro* is a great testimony to this fact. The bath is considered by scholars as the "earliest public water tank of the ancient world" (Singh et al. 2020).

Table 1.1 Increasing population, water footprint and freshwater demand: Indian scenario

Year	2010	2025	2050
Population in India (Million)	1150	1394	1750
Vegetarian percentage population	60	50	40
Vegetarian Population (Million)	690	697	700
Non-Vegetarian Population (Million)	460	697	1050
Daily water foot print for Vegetarian diet, Liter/day	4500		
Daily water foot print for Non-Vegetarian diet, Liter/day	15,000		
Annual Water requirement for Vegetarian diet (BCM)	1133	1145	1150
Annual Water requirement for Non-Vegetarian diet (BCM)	2519	3816	5749
Total water requirement (BCM)	3562	4961	6899

Source: Derived from Central Water Commission, Source: Wani (2020a, b)

Increased food production has to come from the available, finite and limited water and land resources that are declining in quality and quantity (Wani et al. 2011a, b).Water's importance for life on planet earth is well known and is the most precious naturally occurring resource is known in Indian civilization since ancient times. The Vedic texts which are more than 3000 years old contain valuable references to water and the 'hydrologic cycle'. As mentioned earlier, the most important concepts, on which the modern science of Hydrology is founded, are mentioned in *Rig Veda* in various verses in the form of hymns and prayers addressed to various deities and divinities such as *Indra* (firmament), Agni (fire), *Maruts* (wind) and so on (Singh et al. 2020).

Water a finite natural resource keeps circulating through the hydrological cycle of evaporation, transpiration, and precipitation mainly driven by various climatic and land management factors (Falkenmark 1997). Total water on earth is 1385.5 million km^3 (Shiklomanov 1993) out of which 97.3% is salt water in oceans. Fresh water constitutes only 2.7% of total global water resource and is the lifeline of the biosphere where forest, woodlands, wetlands, grasslands and croplands are the major biomes (Postel et al. 1996; Rockström et al. 1999). Rockström et al. (1999) reported that about 35% of annual precipitation (110,305 km^3) received on earth surface returns back to ocean as surface run off (38,230 km^3) and the remaining 65% converted into water vapor flow. Moreover, major terrestrial biomes *i.e*., forest, woodlands, wetlands, grasslands and croplands together consume almost 98% of global green water (soil moisture) flow and generate essential ecosystem services. Fresh water availability for producing balanced food diet is estimated around 3000 Kcal/person per day under present conditions concomitant and with increasing population pressure is an important concern. At present some 11% (1.5 billion ha) of the globe's land surface (13.4 billion ha) is used in crop production (arable land and land under permanent crops). There is also a perception, at least in some quarters, that there is no more, or very little, land to bring under cultivation and it could be true in Asia and east Africa, however, the FAO stated that potential exists in sub-Saharan Africa and Latin America but infrastructure for cultivating these lands is a limitation (FAO 2016).

Model pathways that limit global warming to 1.5 °C with no or limited overshoot project a 4 million km^2 reduction to a 2.5 million km^2 increase of non-pasture agricultural land for food and feed crops and a 0.5–11 million km^2 reduction of pasture land, to be converted into a 0–6 million km^2 increase of agricultural land for energy crops and a 2 million km^2 reduction to 9.5 million km^2 increase in forests by 2050 relative to 2010. Such large transitions pose profound challenges for sustainable management of the various demands on land for human settlements, food, livestock feed, fibre, bioenergy, carbon storage, biodiversity and other ecosystem services (high confidence). Mitigation options limiting the demand for land include sustainable intensification of land-use practices, ecosystem restoration and changes towards less resource-intensive diets. The implementation of land-based mitigation options would require overcoming socio-economic, institutional, technological, financing and environmental barriers that differ across regions (IPCC 2018).

In India, agriculture is a primary sector providing livelihood for 58% population, however, it contributes only 17–18% to national gross domestic product (GDP). India has the largest arable agricultural land (142 m ha) in the world followed by USA and China. Enabling food security for 1.3 billion people with 291.95 million tonnes food grain production in 2019–2020 which is higher by 6.64 million tonnes than the record production of 285.21 million tonnes in 2018–2019 is a remarkable achievement (Department of Agriculture, Cooperation and Farmers Welfare) from 126 million ha under food grain cultivation. India's agriculture is unique in terms of 145 million land holdings (86% of them small and marginal farmers with <2 ha land holding) in the country with an average farm size of 0.97 ha per house-holds with 20 agro-climatic zones with 46 of the 60 soil types in the world varying from arid to humid tropics, hot arid deserts, and a varying rainfall as high as 11,873 mm at Mawsynram, Meghalaya, to as low as 166 mm at Jaisalmer in Rajasthan, has huge untapped potential to become powerhouse of growth to achieve food, nutrition and income security for the 1.3 billion plus population as well as for the world (Wani and Singh 2019; Singh and Wani 2020). However, growing population in India is putting severe pressure on water resources which are decreasing year over years along with associated increase in demand from different sectors (Table 1.2) In 2019, India's food security position globally was 72nd as compared to 3rd position for the United States of America, and 35th position for China. Affordability, quality and safety, and availability are the key factors considered for comparing the food security levels among the countries (Global Food Security Index 2020).

Drier climate and water scarcity in India led to numerous innovations in water management. Since Indus valley civilization, irrigation systems, different types of wells, water storage systems and low-cost sustainable water harvesting techniques were developed throughout the region. The reservoir built in 3000 BC at Girnar and

Table 1.2 Water resources availability and demand in India

Water resources availability	2010	2025	2050
Estimated annual precipitation (including snowfall) (km^3)	4000		
Average annual potential in rivers (km^3)	1869		
Estimated utilizable water (km^3)	1123		
Surface water (km^3)	690		
Groundwater (km^3)	433		
Existing surface storage (km^3)	214	412	412
Population (Million)	1150	1394	1750
Per Capita water availability (m^3)	977	806	685
Water demand in different sector (Km^3)			
Domestic	43	62	111
Irrigation	557	611	807
Industry	37	67	81
Energy	19	33	70
Total	656	773	1069

Source: Central Water Commission, Adapted from Wani (2020a, b) the ancient step wells in Western India are examples of some of the schemes. Water technologies such as manually operated cooling device "*Variyantra*" (revolving water spray for cooling the air) is given in the century's old writings "*Arthasastra*" of Kautilya (400 BC). The *Arthasastra* and *Astadhyayi* of Panini (700 BC) give reference to rain gauges (Singh et al. 2020). India has also implemented the biggest integrated watershed management program for rainwater harvesting silently revolutionising the rain-fed agriculture in the country (Wani et al. 2008, 2011a, b; Wani and Raju 2018). The concept of safe operating space for humanity suggested consideration of nine biophysical processes linked to the earth system to remain in the current stable state (Rockström et al. 2009a, b).

1.1.4 Climate Change and Vulnerability of Small Farm-Holders in India

Climate change phenomenon is an imminent based on the IPCC (Intergovernmental Panel on Climate Change) assessment reports and evidences of cases occurring around the globe. Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC 2007, 2018). Constant increase in greenhouse gases concentrations, since preindustrial times, has led to positive radiative forcing of the climate, tending to warm the surface. The fourth assessment report of IPCC confirmed the rise in atmospheric temperature by 0.74 °C over the last 100 years due to global warming and projected a temperature increase of 1.8–4 °C by 2100, global latitudes, especially in seasonal dry and tropical regions of the world (IPCC 2007). Populations at disproportionately higher risk of adverse consequences with global warming of 1.5 °C and beyond include disadvantaged and vulnerable populations, some indigenous peoples, and local communities dependent on agricultural or coastal livelihoods. Regions at disproportionately higher risk include dryland regions, small island developing states, and Least Developed Countries, poverty and disadvantage are expected to increase in some populations as global warming increases (IPCC 2018).

The IPCC in its 5th Assessment Report noted that future yields of rice, wheat, maize, and soybean will likely decrease significantly, by at least 25% in tropical and temperate regions. Aggarwal (2008) reported that in north India, irrigated wheat yields are decreased as the temperatures increase and a 2 °C increase resulted in a 17% decrease in grain yield and with the further increase in temperature the decrease in yield was very high. The highest decrease in chick pea grain yield per degree rise in seasonal *rabi* temperature was observed in Haryana (3.01 q ha^{-1}), followed by Punjab (1.81 q ha^{-1}), Rajasthan (1.27 q ha^{-1}) and Uttar Pradesh (0.53 q ha^{-1}) (Kalra et al. 2008). It was further indicated that due to climate change, there is reduction in crop yield of 10–40% at the present yield level by the turn of the century. Changes in patterns and magnitudes of precipitation are also likely to affect rain-fed crop productivity and influence the availability of water resources for irrigation. So, the effect of climate change scenario of different periods can be positive or negative depending upon the magnitude of change in atmospheric CO_2 and temperature. Using an emissions scenario that represents ecologically friendly economic growth Avnery et al. (2011) estimated that ozone-induced global yield reductions by the year 2030 would be 10.6% for wheat, 4.3% for maize, and 12.1% for soybean. Temperature is an important factor in ozone generation.

Climate change is real and already at our doorstep, its implications are going to be borne by the poorest of the poor. Climate change will have large effect on water globally which will vary regionally. This is due to spatially variable changes in precipitation, increased rate of glacier melt and retreat affecting river water flows, greater evaporation due to increase in temperature and higher water demand. These changes are likely to affect all aspects of agricultural water management including irrigation availability, soil moisture, evapotranspiration and run-off (Boomiraj et al. 2010). Rao et al. 2013 have studied the changes in agro-eco regions in India due to climate change. They reported increased semi-arid areas by 8.45 M ha in Madhya Pradesh, Bihar, Uttar Pradesh, Karnataka and Punjab resulting in over all 3.45 m ha addition to SAT (Fig. 1.1). Dryness and wetness are increasing in different parts of the country in the place of moderate climates existing earlier in these regions. Number of rainy days during the season are decreased and rainfall intensities increased resulting in frequent occurrence of dry spells during the crop growth period (Rao et al. 2013).

The rain-fed agriculture which have economies largely based on weather-sensitive agricultural productions systems, are particularly vulnerable to climate

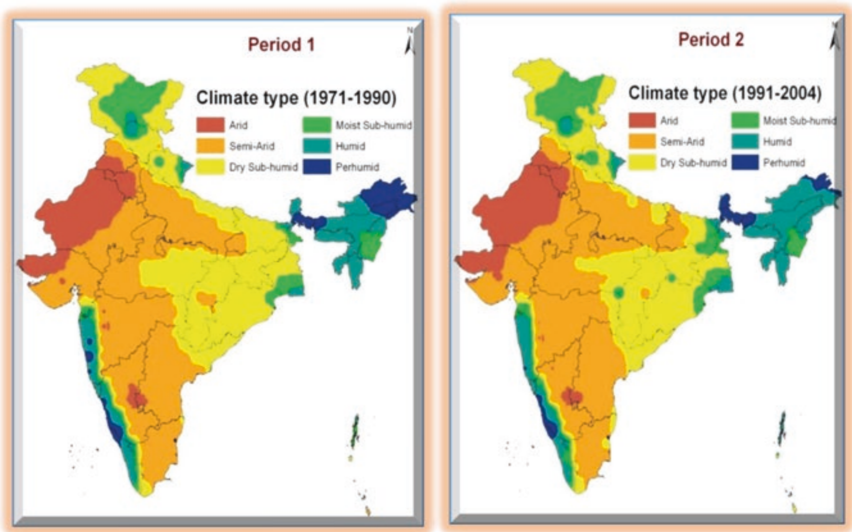

Fig. 1.1 Changes in agro-climatic regions in India due to climate change during 1971–1990 and 1991–2004. (Source: Authors)

change. This vulnerability has been demonstrated by the devastating effects of recent flooding and the various prolonged droughts during the twentieth century. Thus for many poor countries that are highly vulnerable to effects of climate change, understanding farmers' responses to climatic variation is crucial in designing appropriate coping strategies to climate change (Wani et al. 2010). If climatic change is accompanied by an increase in climate variability, many agricultural producers will experience definite hardships and increased risk due to reduced water availability and increased demand for irrigation.

1.1.5 Low Productivity and Existing Large Yield Gaps

Currently, farmers' crop productivity is low particularly in Asia, Africa, WANA and Latin America with large yield gaps for the crops grown worldwide (difference between achievable potential and actual yield) varies from 0.5 to 5 t ha^{-1} as per the agro-ecological zone and the available technologies used by the farmers (Anderson et al. 2016; FAO and DWFI 2015). Yield gap analyses carried out for Comprehensive Assessment for major rain-fed crops in semi-arid regions in Asia and Africa and rain-fed wheat in WANA, revealed large yield gaps with farmers' yields being a factor 2 to 4 times lower than achievable yields for major rain-fed crops (Agarwal 2000; Aggarwal 2008; Rockström et al. 2007; Singh et al. 2009; Bhatia et al. 2008; Wani et al. 2011a, b). In India current farmers' yields are lower by two to fivefolds than the achievable crop yields (Rockstrorm and Falkanmark 2000; Wani et al. 2003b, d; Rockström et al. 2010) with average yields in rain-fed areas hovering around 1–1.5 t ha^{-1} Fig. 1.2.

Huge yield gaps for rice (5.47 q ha^{-1}), maize (12.77 q ha^{-1}), oil seeds and field peas were reported in India (Beigh et al. 2015). In many countries in West Asia, farmers' yields are threefold lower than achievable yields, while in some Asian countries the figure is closer to twofold (Fig. 1.3). Across the top wheat producing countries of the world, there are differences in the progress for increasing yield. In France and Germany, the yield increase is near 100 kg ha^{-1} year^{-1}, while in Australia, it is 15 kg ha^{-1} year^{-1}, which can be attributed to a large difference in the variation in the climate between these two regions. Evaluating smaller-scale yields, e.g., developing county, reveals that weather within the growing season is the dominant factor affecting yield gaps (Lobell et al. 2009). Technological advances have increased the attainable yields at a greater level than the yield trends, indicating that to close the yield gap, wheat producers will have to adopt practices at the local scale that will allow the technology improvements to be realized. These are local decisions made by individual producers; however, efforts to demonstrate how soil and agronomic practices that increase productivity could reduce the yield variation among years will pay dividends in closing the yield gap in wheat.

Historic trends present a growing yield gap between farmers' practices and farming systems that benefit from management advances (Wani et al. 2003d, 2009, 2011a, b). Rosegrant et al. (2002) noted that in the last four decades, 30% of the

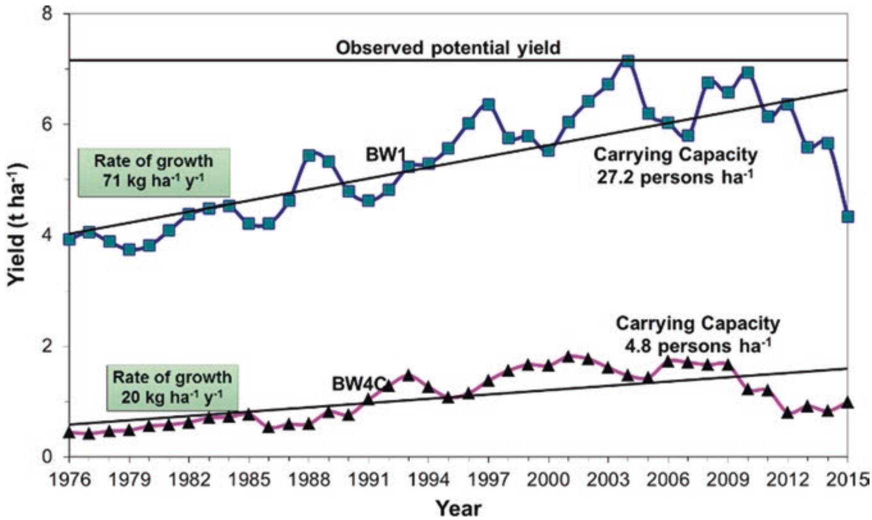

Fig. 1.2 Crop productivity of improved and traditional farmer's practice plots from long-term experiment at Heritage Watersheds at *ICRISAT* since *1976*. (Source: ICRISAT 2017)

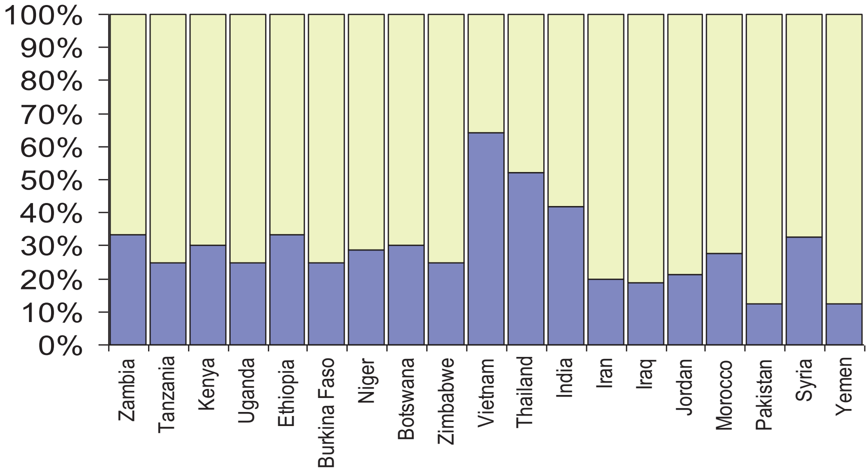

Fig. 1.3 Examples of observed yield gap (for major grains) between farmers' yields and achievable yields (100% denotes achievable yield level, and column actual observed yield levels). (Source: Rockström et al. 2007 cited by Wani and Rockström 2011)

overall grain production growth is due to expansion of agricultural areas and the remaining 70% growth originated from intensification through yield increases per unit land area with large regional variation as well as between irrigated and rain-fed areas. During last four decades in sub-Saharan Africa, with 99% rain-fed production of main cereals such as maize, millet, and sorghum, the cultivated cereal area has doubled since 1960 while the yield per unit land has nearly been stagnant for these staple crops. In South Asia, farmers shifted away from more drought tolerant low-yielding crops such as sorghum and millet, whilst wheat and maize have approximately doubled in area since 1961 (FAOSTAT 2010). Main reason for large yield gaps in most countries are lack of suitable management practices and weather (Aggarwal 2008; Rockström et al. 2007; Singh et al. 2009; Bhatia et al. 2008; Lobell et al. 2009; Wani et al. 2011a, b). Large yield gaps along with lack of holistic approach to target system-level productivity, value-chains, and market linkages added to the plight of small farm-holders in the country (Wani et al. 2018). With the impacts of climate change these yield gaps could widen further, unless technological innovations are taken at the doorstep of farmers urgently (Wani and Raju 2018).

1.2 Why *Death Valley* of Impacts?

In spite of a large number of game-changing technologies, there are large yield gaps in farmers' fields across the world and more so in developing countries in Asia and Africa (mainly due to lack of awareness and access to the technologies (Rockström and Falkanmark 2000; Wani et al. 2003b, c; Lobell et al. 2009; Rockström et al. 2010; Anderson et al. 2016; FAO and DWFI 2015). Most of the technologies rarely moved beyond proof of concept/pilot stage and failed to reach millions of farmers' fields for a significant impact largely due to existence of "*Death Valley* of impact" (Fig. 1.4) largely due to lack of synergy amongst the actors and deficiencies in technology delivery systems as compartmental approach is adopted by the scientists and rarely farmers' requirements are considered while providing the solutions (Wani and Raju 2016, 2020).

These findings of low impacts of technologies particularly on ending hunger are confirmed by CERES 2030 Team (Nature 2020; Laborde et al. 2020, Bizikova et al.

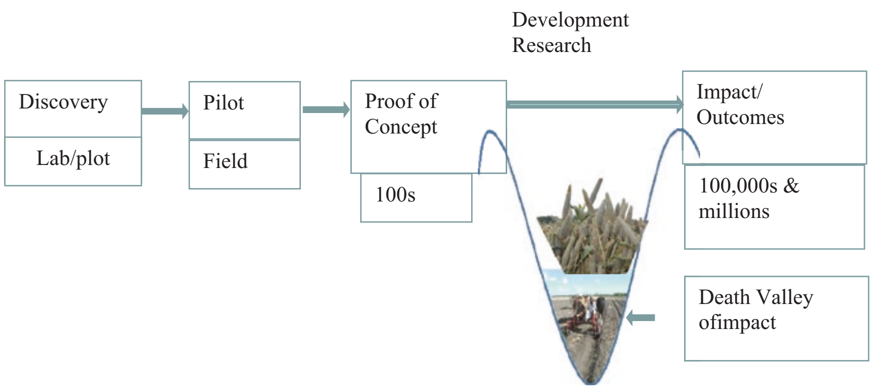

Fig. 1.4 Death Valley of impacts: Pictorial representation of the life cycle of technology/product. (Source: Wani and Raju 2016)

2020) based on its 3-year effort to review more than 100,000 articles published by researchers, think tanks, non-governmental organizations, many UN agencies and the World Bank as follows:

- It’s clear from the review that, despite being involved in making and tracking SDG policies, such organizations (NGOs, World Bank, many UN agencies, Think Tanks), indicated above are not producing nearly as much relevant research as needed.
- Smallholders need new technologies, but they also need research on the effectiveness of existing interventions. One of the papers detailing the CERES 2030 team’s findings includes the striking statement that “most of the included studies only involved researchers without any participation from farmers” (Stather et al. 2020).
- So why aren’t more researchers answering more practical questions about ending hunger that are relevant to smallholder farmers? Many of the key reasons can be traced to the changing priorities of international agricultural-research funding where during last four decades more than half funding is from agribusinesses (Pardey et al. 2016).
- Applied research involving working with smallholder farmers and their families doesn’t immediately boost an academic career. Many researchers – most notably those attached to the CGIAR network of agricultural research centres around the world – do work with smallholder farmers. But in larger, research-intensive universities, small is becoming less desirable. Increasingly, university research-strategy teams want their academics to bid for larger grants – especially if a national research-evaluation system gives more credit to research income.
- Publishers also bear some responsibility. The subject matter for smallholder-farming research might not be considered sufficiently original, globally relevant or world-leading for journal publication.
- National agricultural research systems (NARSs), too, need to listen, because they are the major funding source for researchers in universities. There’s a place for collaborating with big businesses, but achieving the SDG to end hunger will require an order of magnitude more research engagement with smallholders and their families.
- Small farm-holders’ incomes increase when they belong to cooperatives, self-help groups and other organizations that can connect them to markets, shared transport or shared spaces where produce can be stored. Farmers also prosper when they can sell their produce informally to small- and medium-sized firms (Bizikova et al. 2020). That seems to be because such companies share information with farmers and provide sources of credit.

1.2.1 How to Cross **Death Valley** *of Impacts to Transform Livelihoods of Farmers?*

For achieving the impacts by crossing the *Death Valley* of impacts as stated above science must change its focus (Nature Food 2020) and scientists as well as research managers, extension staff, policy makers, donor agencies, publishers of the research journals and farmers must change their mind set (Wani and Raju 2018, 2020). Change of Mind-set of people through awareness building and community participation which is driven by the tangible benefits for the society through their demand-based solutions rather than the supply driven solutions. Agriculture and staying in rural areas is considered as no choice option which need to be changed through development of rural areas with provision of urban facilities in rural areas (PURA) like initiatives. Good example of a national initiative "*Swach Bharat*" with community participation, building public-private-people centric- partnerships (PPPP) as well as qualitative and quantitative monitoring evaluation and learning (MEL) made 98% rural areas open defecation free. *Change of people's mind-set and seeking their participation is a challenge which has to be pursued vigorously and rigorously.*

Several authors (Wani et al. 2011a, b; Wani and Raju 2018; Raju and Wani 2020) suggested the need to go beyond the compartmental approach for achieving a significant impact on ground. The results till to date clearly suggest that business as usual does not serve the purpose of achieving large impacts on ground from the new technologies/products and there is an urgent need for a new paradigm of holistic and integrated approach through innovative partnerships, delivery mechanisms/strategies, policies, institutional arrangements and new technology-based knowledge delivery systems. Transforming our small farm-holders (*Annadatas*- food providers*)* in to climate resilient farmers we need to adopt urgently a new paradigm involving a consortium approach through building partnerships amongst knowledge generating institutions (researchers), Knowledge transforming agencies (government departments, civil society organizations and development investors), private and corporate companies, service providers (Wani et al. 2003b), for adopting inclusive market-oriented development (IMOD) approach as a business rather than just for subsistence (Wani et al. 2011a, b). Important lessons learnt from earlier watershed-based research were listed elsewhere (Wani et al. 2003a, 2011a, b; Wani and Raju 2018, 2020) as mentioned in the following:

- Researchers generally worked with progressive farmers and as a result equity for benefits to small holders and landless was compromised.
- Researchers adopted contractual mode of participation which resulted in low and passive community participation, lack of tangible economic benefits for small far-holders resulting in low community participation (5–10%) as farmers having access to groundwater were only deriving benefits from the interventions.
- Emphasis was on establishing/demonstrating pilots and not Scaling-up as it was supposed to happen through automatically with dissemination process (trickle-down effect).

- Evaluation was undertaken as a postmortem activity and not as a concurrent learning process.
- Scientists were working independently for pilots and as result technical support for most development projects implemented by NGOs/government departments was lacking to address the issues holistically.

Based on these learning the earlier consortium model was developed with following salient constituents (Wani et al. 2003a, 2011a, b; Wani and Raju 2018, 2020):

- Strengthening science of delivery along with science of discovery to benefit farmers through new knowledge-based technologies/products.
- Demand driven approach ensuring tangible private economic benefits to small farm-holders along with eco-system services benefits, landless families, youths and women through income-generating activities was adopted for selecting the watershed and the farmers collectively identified and prioritized the problems for possible technical interventions.
- Consortium approach involving needed research (national, international and local), development institutions along with government departments need to be adopted from the beginning.
- Participatory planning, promoting collective action along with capacity building for implementation along with concurrent participatory monitoring, evaluation and learning (MEL) of watershed research and development with the involvement of all stakeholders.
- New science and technology tools such as remote sensing (RS), geographical information system (GIS), digital terrain modelling (DTM), soil health mapping including soil depth, integrated nutrient management (INM) and crop simulation models with amalgamation of validated conventional/traditional knowledge of the community along with new knowledge dissemination methods.
- Linking successful on-station watersheds and on-farm watersheds for strategic research enabled the farmers as well as researchers to think differently to solve their problems. The "*Islanding Approach*" within the watershed which served as site of learning within the village itself and also to build the confidence of farmers by undertaking research.
- In place of mere soil and water conservation (compartmental approach) a holistic system approach for livelihood improvement to benefit all the community members who were deprived off the project benefits in earlier programs.
- Increased individuals' participation by emphasising on *in-situ* conservation of rainwater and translating benefits of increased soil water availability through integrated genetic and natural resource management (IGNRM) approach enhancing use efficiency.
- For technical development and inputs on individual/private land users to pay 50% (with incentive) and for community-based interventions largely government pays with 10–30% contributions from beneficiaries.
- For scaling-up and technology dissemination use of bench mark sites as training/learning sites for partners, farmers and for sensitizing the policy makers with an intention to develop scaling-up model for the successful pilot.

1.2.2 To End Hunger, Science Must Change Its Focus

An international research consortium Ceres 2030 undertook meta-analysis by reviewing more than 100,000 articles published and found that although policy makers need research on ways to end hunger but most research has had the wrong priorities confirming our findings of existing *Death Valley* of impacts as mentioned above (Wani et al. 2002, 2003e).Two-thirds of hungry people live in rural areas. One of the paper from Ceres 2030 team's findings (Stathers et al. 2020) includes the striking statement that "most of the included studies only involved researchers without any participation from farmers" as recorded above that watershed researchers adopted contractual mode of on-farm research without actively involving small farm-holders (Wani et al. 2003a, 2011a, b, 2020; Wani 2020a, b). The team was able to identify ten practical interventions that can help donors to tackle hunger, but these were drawn from only a tiny fraction of the literature. The Ceres 2030 team members found that the overwhelming majority of agricultural-research publications they assessed were unable to provide solutions, particularly to the challenges faced by smallholder farmers and their families (Nature 2020). Other studies found that these farmers' incomes increase when they belong to cooperatives, self-help groups (SHGs) and other organizations that can connect them to markets, shared transport or shared spaces where produce can be stored (Bizikova et al. 2020).

1.2.3 Small Is Less Desirable

Of some 570 million farms in the world, more than 475 million (83%) are smaller than 2 hectares. Rural poverty and food insecurity go hand in hand, and yet the Ceres 2030 researchers observed that more than 95% studies – were not relevant to the needs of smallholders and their families (Nature 2020). India's agriculture is unique in terms of 145 million land holdings (86% of them small and marginal farmers with <2 ha land holding) in the country with an average farm size of 0.97 ha per household (Wani 2020a, b). At the same time, as mentioned above, researchers always preferred to work with farmer leaders with larger farms who can take risk and also serve as opinion makers in the village. It was also reported by the Ceres team that applied research involving working with smallholder farmers and their families doesn't immediately boost an academic career. Many researchers – most notably those attached to the CGIAR network of agricultural research centres around the world – do work with smallholders. But in larger, research-intensive universities, small is becoming less desirable. Increasingly, university research-strategy teams want their academics to bid for larger grants – especially if a national research-evaluation system rewards those who bring in more research income. Publishers also bear some responsibility. Ceres 2030's co-director, Jaron Porciello, a data scientist at Cornell University in Ithaca, New York, told Nature that "smallholder-farming research might not be considered sufficiently original, globally relevant or world-leading for journal publication". This lack of a sympathetic landing point in journals is something that all publishers must consider in the light of the Ceres 2030 team's findings (Nature 2020).

1.2.4 Lack of Extension Support to Small Farm-Holders

As per the national sample survey data, 51% of farmers in India do not get any knowledge support (extension support) and only 11% farmers get support from the government machinery while remaining 38% farmers get support from peers, media and private agencies (NSSO 2013; GoI 2013). The situation cannot be different in other developing countries in Asia, Africa and Latin America. The Ceres 2030 researchers found that major constraint for adoption of new approaches/technologies/products was lack of technical advice, input and ideas, collectively known as extension services for the small farm-holders. The small farm-holders are more likely to adopt new approaches – specifically, planting climate-resilient crops – when they are supported by technical advice, input and ideas (Nature 2020). As reported above, weak science of delivery is the main constraint for benefitting small farm-holders from new technologies/products.

For *Bhoochetana* innovative extension mechanism was developed through an innovative institutional arrangement to rejuvenate the extension system in the state of Karnataka, India as well as to empower farmers through *Ryatu samparka kendras* (RSKs). This initiative also helped to create a new institutional arrangement such as creation of the '*Bhoochetana* cell' in the state to deal with agricultural extension services and input delivery. Since the inception of the initiative, farmer facilitators (FFs) and lead farmers (LF) were the new extension agents who effectively disseminated the knowledge to the community by serving as a link between the extension staff and farmers, which made huge impacts on the state's agricultural scenario. After realizing the importance of FFs in the extension system, this concept was adopted by other departments of the Government of Karnataka such as the Departments of Horticulture and Sericulture to implement other schemes such as *Suvarna Bhoomi Yojane* in the state (Raju et al. 2013a, b; Krishnappa et al. 2016). In all scaling-up projects results of farmer participatory experiments were shared with the farmers by the farmers as well as staff from the "islanding approach" by conducting Field Days (Fig. 1.5)

Fig. 1.5 Dissemination of results from the farmer participatory trials in the presence of policy makers in Karnataka, India. (Source: Authors)

1.2.5 Rapport Building with Community Through Knowledge-Based Entry Point Activity (EPA)

Introducing any development program to the community has always been recognized as an important activity. This is done through what are called 'entry point activities' (EPA) in the parlance of watershed literature. It involves building the rapport with the community, strengthening and sustaining it throughout the program and beyond. To build a rapport between the project implementing agency (PIA) and the villagers before initiating the programs, an EPA is envisaged. The entry point intervention/activity is identified through participatory rural appraisal (PRA). An EPA, such as providing drinking water and sanitation to the community, conducting health awareness camps, construction of community halls, class rooms, repairing or construction of culverts, approach roads, promotion of kitchen gardens, etc., are carried out. Support to group income activities such as fish farming in village tanks and providing power threshers with the community contribution are some other rapport building measures that are practiced (Fernandes 2000). In an innovative farmer participatory consortium model for watershed management by ICRISAT-led consortium, one of the important components was no subsidy for interventions on private farmlands and need-based interventions as demanded by farmers instead of supply-driven interventions padded with free inputs (Wani et al. 2003a). An important lesson learned during that time was that undertaking community level EPA such as drinking water schemes, building roads and community halls, identified as priorities during PRAs, do not provide enough incentive to motivate people to participate in the long-term conservation activities that provide no immediate benefit (World Bank and FAO 2001). On the contrary, such direct money-based (subsidy-based) EPA undertaken by the projects to build rapport, are misinterpreted by the community that project will invest financial resources for all the interventions and that the project has financial resources to work with the community. Following the principle of no free inputs for the individual farmer it was decided not to have money-based EPA in the watersheds to build the rapport with the community, in the Asian Development Bank (ADB) supported project started in 1999 for evaluating a new consortium approach (Wani et al. 2003a).

Selection of the appropriate knowledge-based EPA for building rapport with the community is very critical to ensure equity and tangible benefits to all community members with high B:C ratio. While selecting appropriate EPA, important points to be considered are:

- It should be knowledge-based and should not involve direct cash payment through the project in the village.
- Activity should have high success probability (>80–90%) and be based on strategic research results.
- It should involve participatory research and development (PR&D) approach.
- It should be simple for farmers to undertake participatory evaluation.
- Most importantly, it should be applicable for majority of the farmers.
- Should have a reliable and cost-effective approach/method to assess the constraint.

There is much need to innovate new methods to share knowledge with primary stakeholders as traditional methods of extension are failing miserably in most of the developing countries in Asia and Africa. For building rapport with the community, good PRA and knowledge about local natural resources can be used to identify knowledge-based EPA. Knowledge-based EPA was found far superior than traditional subsidy or cash-based EPA for enabling community participation of higher order i.e. cooperative and collegiate rather than contractual mode of community participation. Lead farmers and PIAs served as good trainers and contributed significantly in up-scaling strategy. Field days during the season where lead farmers explained the results to their peers, media personnel and policy makers proved very effective tool for up-scaling community watersheds in the SAT and benefited large number of families. This new approach of extension based for enhanced awareness of primary stakeholders by sharing knowledge proved more effective than cash-based EPA.

Considering all the above-stated points and based on the participatory rural appraisal (PRA), stress-tolerant and high-yielding pigeon pea cultivar was introduced in Adarsha watershed, Kothapally, India. Poor soil health was identified as the EPA for the Andhra Pradesh Rural Livelihoods Program (APRLP) nucleus watersheds and also in *Bhoochetana* initiatives in Karnataka, Andhra, Odisha and also several CSR initiatives.

1.2.6 Holistic Integrated Approach Is Must to Transform Livelihoods of Small Farm-Holders

Business as usual cannot address the complex agrarian rural economy, and livelihood systems which have not shown desired impacts on improving rural economy in India. With the impacts of climate change existing yield gaps could widen further, unless technological innovations are taken at the doorstep of farmers urgently. Most researchers adopted compartmental solutions when farmers' livelihoods are complex as family income sources for small farm-holders comprised of crops, livestock and service sectors. The primary sector including agriculture, horticulture, livestock, fisheries, etc. need to play a key role in improving food and nutrition security in India. Although, India has transformed itself from dependency("sheep to mouth" situation in 1960s) on imports to self-sufficiency, still the challenge is to remove the farmers' distress in the country. Current farmers' field yields are lower by two to fivefolds than the achievable potential. Further, complexities are observed as farmers' income from crops vary from 24.28% in West Bengal to 66.98% (Telangana State) across the states with an average proportion of 48% at national level. Similarly, large proportion of rural farmer's family income is from other sources such as employment etc. Large (40.18%) share is from other sources at national level varying from 23.45% (Madhya Pradesh) to 65.46% in Kerala. Third major source of income for the farmers is from livestock which contributed 11.87% at national level varying from 4.84% (Kerala) to 26.41% in Odisha (GOI 2013; NSSO 2013). As a result, there is wide divide in per capita per year (Rs 40,925 rural vs Rs 98,435 urban per capita) income of rural and urban Indian households which is less than half of the urban counterpart Table 1.3 (NSSO 2013; Financial Express 2019). Agriculture sector is a primary sector providing livelihood for 58% population but it's contribution to the national gross domestic product (GDP) value is 16.5% in 2019–2020 and farmers in India are in distress. Several development researchers have indicated since long the need for integrated holistic solutions for small farm-holders to achieve impacts (Fan et al. 2000; FAO 2006; Wani et al. 2003a, 2006a, 2008; Wani and Raju 2020). We need a paradigm shift from compartmental to integrated-holistic approach through building partnerships integrating markets and should be knowledge driven transformation.

1.2.7 Allied Sectors Also Must Be Developed

As reported in above Sect. 1.2.6 farmers' livelihoods are complex and depend on multiple sources of income (Table 1.3). For improving livelihoods of small farm-holders along with crop production and its marketing other allied sectors which vary from region to region contributing to farm family income also must be developed. Secondary agriculture is of primary importance for transforming rural areas for *Atmanirbhar* (self-sufficient/reliant) India. Considering Indian population's

Table 1.3 Different sources of farmer's family income in different states of India (Derived from GoI 2013; NSSO 2013)

State	Av. farmer's income (Rs/mo)	Av. cropping income (Rs/ mo)	Av. income livestock (Rs/mo)	Share of cropping income (%)	Share of livestock income (%)	Share of income of other sources (%)
Punjab	18,059	10,862	1658	60.15	9.18	30.67
Haryana	14,434	7867	2645	54.50	18.32	27.17
Kerala	11,888	3531	575	29.70	4.84	65.46
Karnataka	8832	4930	600	55.82	6.79	37.39
Gujrat	7926	2933	1930	37.00	24.35	38.64
Maharashtra	7386	3856	539	52.21	7.30	40.50
Rajasthan	7350	3138	967	42.69	13.16	44.15
Tamil Nadu	6980	1917	1100	27.46	15.76	56.78
Assam	6695	4211	799	62.90	11.93	25.17
All India	6426	3081	763	47.95	11.87	40.18
Telangana	6311	4227	374	66.98	5.93	27.10
Madhya Pradesh	6210	4016	732	64.67	11.79	23.54
Andhra Pradesh	5979	2022	1075	33.82	17.98	48.20
Chhattisgarh	5177	3347		64.65	0.00	35.35
Odisha	4976	1407	1314	28.28	26.41	45.32
Uttar Pradesh	4923	2855	543	57.99	11.03	30.98
Jharkhand	4721	1451	1193	30.74	25.27	43.99
West Bengal	3980	979	225	24.60	5.65	69.75
Bihar	3558	1715	279	48.20	7.84	43.96

dependence on agriculture, combined with sophisticated, labour substituting technologies, leaves little scope for non-farm sectors to absorb surplus human resource (Dalwai 2020). Diversification of livelihoods to provide around the year employment to rural people through microenterprises such as livestock rearing, bee keeping, composting, biogas production, raising nurseries, kitchen gardens, operating decentralised rural wastewater treatment using constructed wet lands, in addition to processing of farm produce can be strengthened through FPOs generating rural employment for men, women as well as youths (Wani et al. 2003a, 2011a, b; Wani and Raju 2018, 2020). Raju et al. (2016) suggested following key strategies for formation and enhancement of the performance of the FPOs in Andhra Pradesh.

- Policy support for promotion and sustainability of FPOs thru linking financial institutions
- Exploring the opportunities for CSR funding with due credit for their contribution
- Convergence of different departmental schemes for assured fund flow and proper allocation

- Monitoring by third party agencies for maintaining transparency, accountability and public information system.
- Linking to corporate as a business proposition thru public private partnership
- Skill development of rural youths to work as facilitators for strengthening FPOs
- Use of ICT tools/products for enhancing business efficiency of FPOs
- Ecological/sustainable farming – as a service/choice to members of FPOs

Strategic framework as depicted in Fig. 1.6 was proposed in *Rythu Kosam* project in Andhra Pradesh.

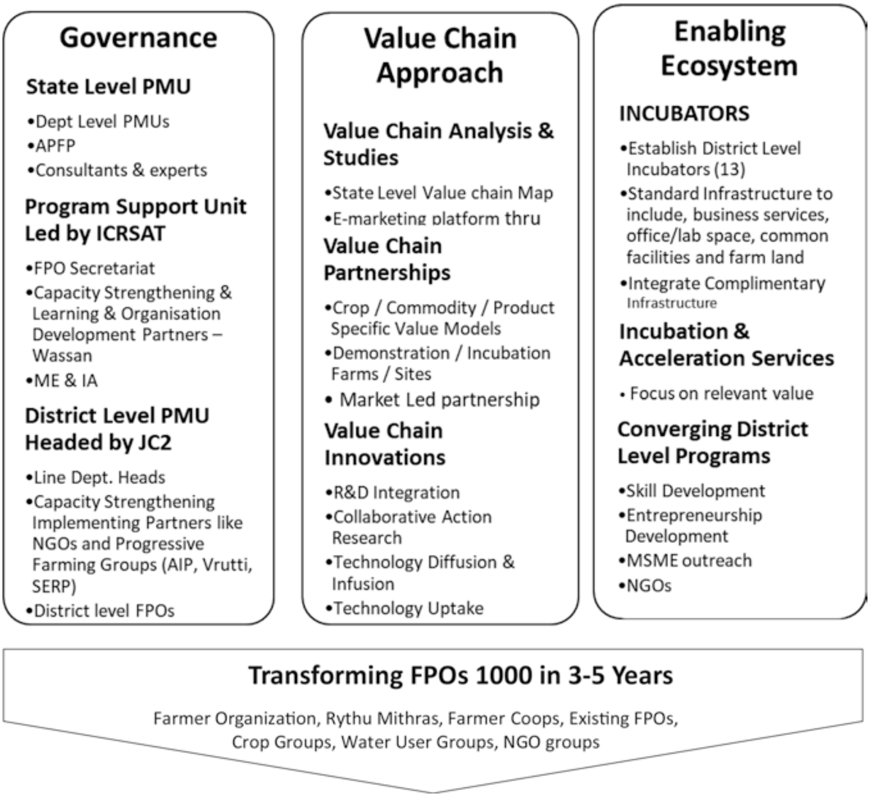

Fig. 1.6 Strategic framework for FPOs reorganization targeting 1000 FPOs covering 1 million farmers. (Source: Derived from 70th Round National Sample Survey on Situation Assessment of Agricultural Households (Singh and Wani 2020)

1.2.8 Building Public-Private-People Centric Partnerships (PPPP)

Promote Public-Private –People Centric Partnerships (4Ps) for implementation of holistic and integrated value-chain approach for transforming rural areas, urgent need is to build the partnerships with public-private corporates which are people-centric. The main advantages of the consortium approach include synergy and creativeness in the tackling natural resource of challenges for which solutions are rarely found with a single discipline expertise. The capital of partnership/collaboration is far larger than the financial capital and consortium promotes the co-creation of innovations (Fig. 1.7).

Considering the long value-chain and number of intermediaries involved in the value-chain the MSMEs need to be promoted in rural areas through farmer producer organizations (FPOs) to overcome the problem of fragmented agriculture and large number of small and marginal farmers for adopting value-chain approach as well as generating rural employment. Farmer Producer Organisations (FPOs) rightly pursued by government of India need to be empowered by creating an eco-system ensuring finance as well as professional experts to strengthen value-chain and marketing in the country. "*One District One Product*" (*ODOP*) through empowered FPOs can ensure right price for the farmers and consumers as well as create rural employment. Although, thousands of FPOs are registered (10,000 more to be formed in 5 years as per 2019 budget), very few of them are really performing. We need to move from target-based formation of FPOs to performance-based functional FPOs. Government can support appointing professionals initially on priority to develop and run the FPOs as business model identified in the clusters to do processing, packaging, and marketing/e-marketing as well as providing credit and empowerment through training and capacity building through a support organisation (Raju et al. 2017). The FPOs take-up sell of current farm produce particularly

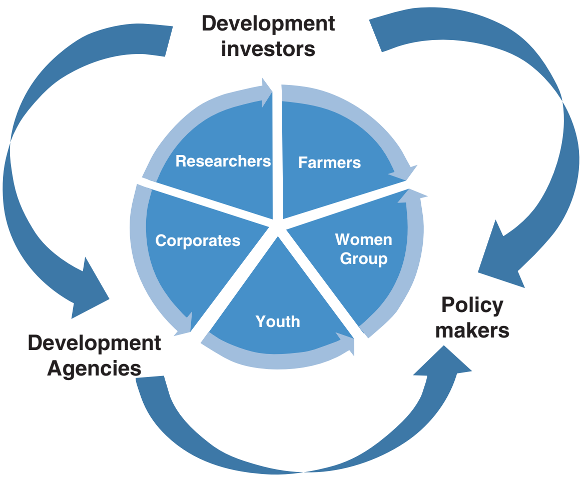

Fig. 1.7 Process of innovating hybrid solutions through consortium. (Source: Wani 2020a, b)

the perishable items like fruits and vegetables directly to the consumers with or without Agricultural Produce Marketing Committee (APMC). During COVID-19 pandemic with falling prices of fruits and vegetables (Economic Times 2020) number of state governments facilitated harvesting, transportation and direct delivery at homes of fruits and vegetables which benefitted farmers as well as consumers. The empowered FPOs can become direct suppliers of vegetables, fruits, fish, chicken, and other agricultural products including processed cereals and pulses to on-line marketing channels like Big Basket, Big Haat, Groafers, Flipcart, Amazon, Reliance and others in addition to direct consumers in vicinity. The empowered FPOs can also help in procuring quality inputs at reasonable price directly from the producers and also become procurement centres for farm produce and money can be directly transferred in farmers' bank accounts by the government. The FPOs can also operate machine hiring centres (MHCs) to benefit the farmers. However, to achieve this in short time strong coordination across the relevant departments at state and district levels is must. Such entrepreneurial activities through FPOs in rural areas will benefit the rural people for employment, shorten the value-chain, eliminate intermediaries and benefit the farmers and help in transforming rural economy along with recent reforms by the government in essential commodities act, APMC act to enable farmers to sell the produce at farm itself, strengthening FPOs, contract farming laws, etc. will benefit the rural transformation (Wani 2020a, b; Wani and Singh 2019)

1.2.9 Science of Delivery Must Be Strengthened

For transforming rural economy in India, science of delivery need to be strengthened to deliver holistic solutions to the farmers as farmers' livelihoods are multifarious. A holistic and integrated consortium approach for developing rain-fed areas sustainably through watershed development is recommended (Wani et al. 2003a, 2006a, 2008; Joshi et al. 2008) and was adopted by several national and international development programs. Our main problem is we know a lot about what to do? but very little about how to do it? Strong need across the country is felt for rejuvenating extension systems with innovations and use of new technologies such as information technology (IT), internet of things (IoT) and deep penetration of mobiles (97–98%) in rural areas to keep pace with the current challenges and aspirations of the farmers as well as to ensure reach of extension system to small farmholders. Integrated holistic approach with 4 ICEs was proposed by Wani et al. 2003a and later revised to 4 ISECs (Wani 2020a).

Innovate	**S**ustainable	**C**onsortium	**E**conomic gain
Inclusive	**S**ocially acceptable	**C**ollective	**E**quity
Intensive	**S**calable	**C**apacity Building	**E**fficiency
Integrated	**S**ynergistic	**C**onvergence	**E**nvironment protection

Consortium approach involves number of stakeholders/partners and it's a multidisciplinary and multi-sectoral approach providing end to end solutions to the farmers. Participatory integrated watershed management by adopting consortium approach is one of the tested, sustainable, scalable and eco-friendly options (Wani et al. 2003a, 2006b). The innovative approach is briefly described as 4 ICEs (Wani et al. 2003a, 2008; Wani 2016), (later revised to 4 ISECs) (Wani 2020a, b). As indicated earlier sensitization of all the actors involved in integrated rural development to help small farmers as their responsibility must happen to help the small farmholders. Amongst the researchers as well as academicians on-farm research or working with small farm-holders is not favourably considered largely due to wrong performance assessment indicators as well as bias of scientific journal publishers as highlighted by Nature Food (2020). The era of ultra-specialization working in compartments is over as it has not benefitted small farm-holders and integrated holistic solutions through building partnerships with various actors is very much needed (Wani 2003; Wani et al. 2011a, b).

The process of consortium formation and participatory approach from the beginning till scaling-up is depicted in Fig. 1.8 which is very much impact oriented on ground but a cumbersome and time taking process revolving around building partnerships to provide demand driven integrated solutions to the farmers. This involves lot of soft science which is a basic element for effective science of delivery for impact along with the science of discovery (Wani and Rockström 2011; Wani et al. 2011a, b; Wani and Raju 2020)

1.2.10 Big Data and Need to Harmonize Quality Data

To transform rural areas and their economy, to start with planning, the number of villages (rural areas) in India is anywhere between 649,481 according to Census, 2011 to 1,000,000 (MGNREGA) according to various government department databases as well as the definition. The Ministry of drinking water and sanitation indicates 608,662 number in their Integrated Information Management System (IIMS). The *Swach Bharat Abhiyan* (*Gramin*) report by the same ministry indicates 605,805 villages. In India, even the number of villages vary as per different arms of the government from 600,000 to 1000,000 which indicates the status of poor data management calling for drastic reforms. This is just an example indicating urgent need to harmonise data sets at national level as each institution, department, scheme has worked in compartments and adopted varying definitions as per convenience.

India is complex with 29 states and 9 union territories, 687 districts and more than 600,000 villages (Fig. 1.9). First and foremost, need is to understand the extent and then their problems which need to be solved through transformation in India. India's rural areas with its 142 million ha arable land cultivated by 145 million farm households, with 46 of the 60 soil types in the world, along with 15 agro-climatic zones and 100 agro-eco-sub-regions (AESRs) varying from arid to humid tropics, hot arid deserts, and a varying rainfall as high as 11,873 mm at Mawsynram,

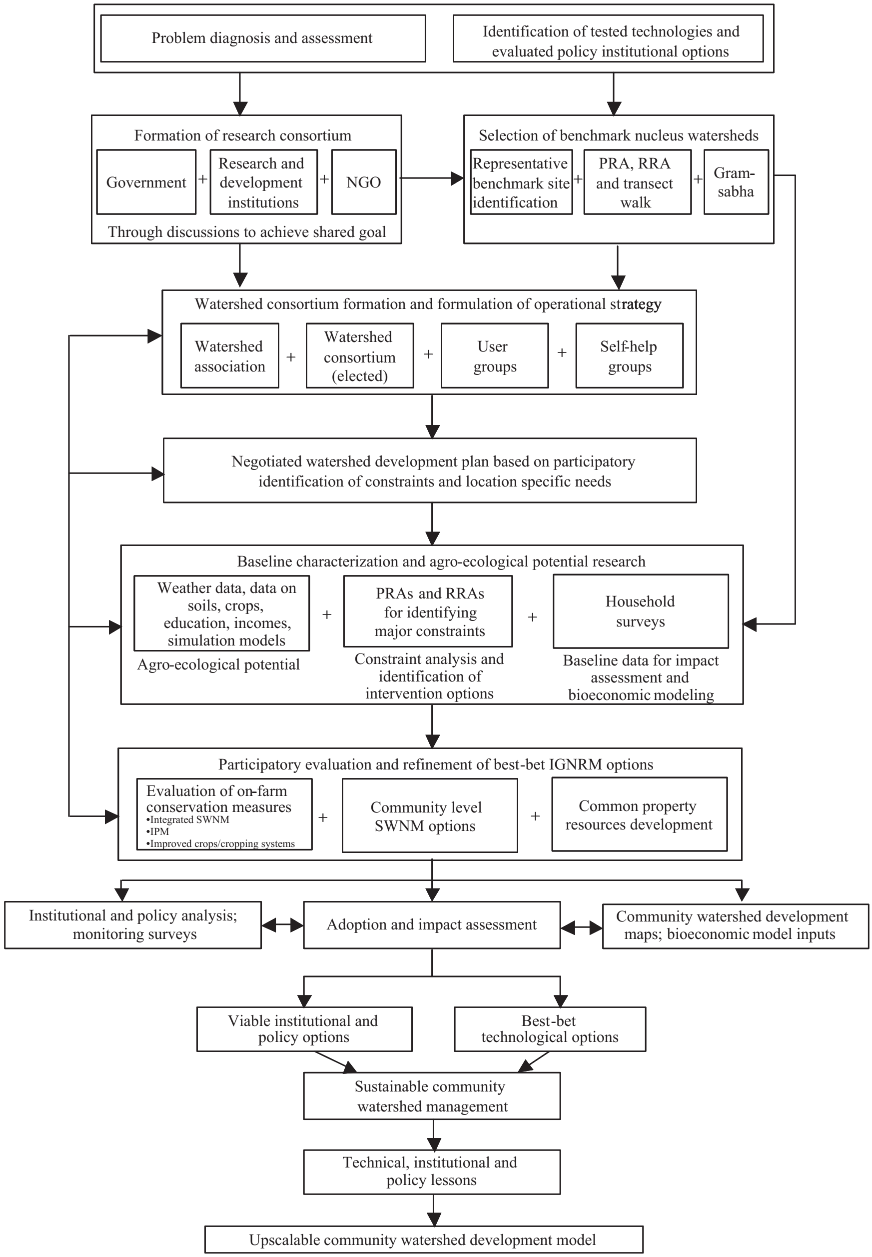

Fig. 1.8 Process of participatory consortium approach through community watersheds. (Source: Wani et al. 2002, 2003a, c)

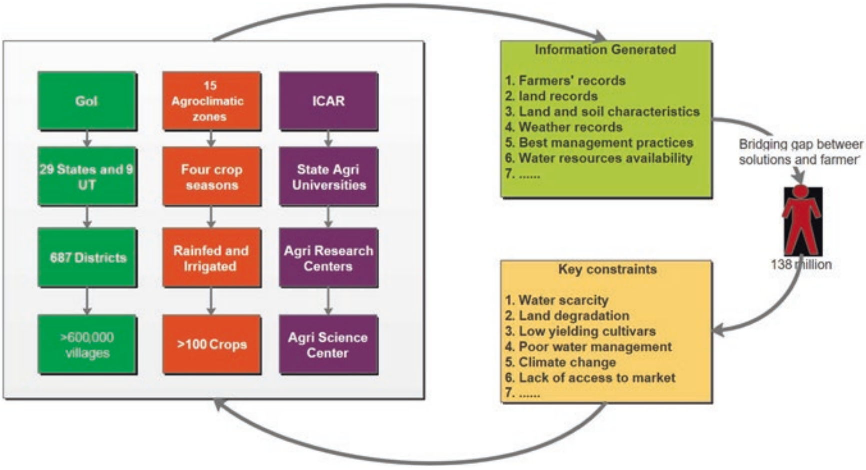

Fig. 1.9 Challenges in diverse India for data collection and harmonization at national level. (Source: Authors)

Meghalaya, to as low as 166 mm at Jaisalmer in Rajasthan is unique. More than 100 crops are grown during three to four seasons in different regions (Fig. 1.9). Such vast canvas of agriculture for production, soils, weather, AESRs, water availability, water quality, market linkages, financial institutions, producers, processors, consumers, infrastructure, extension services, research findings (Table 1.4) and so on is a daunting challenge for data collection, sanitization, harmonization and security. To check the quality of data before getting on the unified platform for the country/state/district, *taluka/block/mandal* and village level is a daunting challenge but very essential.

New technologies such as remote sensing, geo-tagging of farms, simulation modelling, sensors, geographical information system (GIS), internet of things (IoT), IT tools can be effectively harnessed for harmonization of data. Government of India has aptly demonstrated to the world that for a country of 1.3 billion population system like *Áadhar* as well as *Jan Dhan* accounts, Direct benefit transfer (DBT), Goods and service tax (GST) with e-*chalans*, e-NAM (electronic national agricultural market), etc. could be implemented qualitatively in shortest possible time. For rural transformation such will and grit by the government is the need of the hour. In addition to quality of data accessibility and availability for use is a big challenge. Country's data wealth is locked in to the lockers of concerned data holders and are not made easily available to users even to the other government department in a timely manner. In the era of IT we talk of big data, machine learning (ML), artificial intelligence (AI) but all this can be applied and meaningfully used provided we have quality data available. The silos which are created with water tight boundaries *need to be blasted* through urgent reforms to enable the country to harness the power of IT revolution. As we understand 90% of land records are digitised by several states. Fortunately, India is in forefront of IT revolution and this opportunity must not be

Table 1.4 Sample list of datasets required for the agriculture sector

Data	Description	Source
Maps	Cadastral maps: This database includes information such as land parcel number, reference management unit, reference micro-watershed, owner of the land parcel (farmer), area, etc. Satellite imagery: high resolution (spatial and temporal) satellite images, digital elevation models, Soil maps: physical, chemical and biological properties, morphological and geological characteristics. Land maps: Slope, slope length, erosion, drainage, runoff, groundwater depth, flooding, surface fragment, rock-our crops, land use/land cover etc.	National remote sensing centres /state remote sensing application centres (NRSC &SRSAC). Public domain data from international scape agencies Survey of India National Bureau of Soil Survey and Land Use Planning (NBSS&LUP)
Hydrological data	Surface runoff, infiltration, evaporation, evapotranspiration, groundwater recharge, water tanks, quantities available in dams/tanks, sediment load, base flow, water quality, aquifer information, irrigation related data etc.	Water resource department, Jal Shakati Ministry Sourcing data from IoT devices
Drainage data	Rivers/streams (entire drainage), All water bodies both perennial and ephemeral (with names of major bodies), Canals, both perennial and ephemeral, Springs/ seepages.	NRSC/SRSACs, Water resource department
Crop coverage	This database includes information such as reference land parcel number, reference management unit, reference micro-watershed, farmer data, areasown, sowing date, harvest date, etc.	National/state remote sensing center. Department of Agriculture, Cooperation and Farmers Welfare (DOAC&FW)
Farmer data	This database includes information such as farmer name, village, taluk, district, contact number, adhaar number, etc.	DOAC&FW
Market Information	Suppliers of agricultural inputs as well as buyers of agricultural produce, daily price information, insurance companies	Marketing Department and DOAC&FW
Package of practices for different crops	Suitability of crops for different regions, improved cultivars, seeds availability, fertiliser companies, pesticide product companies, package of practices (INM,IPM,ICM) etc.	DOAC&FW, State DOA, SAUs, national and international research institutes

lost because of compartmentalization and holding of data which is government's proprietary right. The Ministry of Statistics and Project Implementation need to be strengthened and work along with IT Ministry to collect, sanitize, organise, and develop protocols for data security, sharing and use. Current government reforms are in this direction for example Ministry of Agriculture is named as DOAC&FW, Ministry of *Jal Shakti* is newly formed by converging water related activities of different ministries.

*1.2.11 Data Driven IT-Based Market-Driven Farming (***Fork to Farm** *Approach)*

At present farmers produce what they like/prefer to produce (*farm to fork*) approach and then seek the market. There is an urgent need to adopt "*fork to farm*" approach and produce what market needs. The AER-based farming considering vast scope to diversify the agricultural production in the country need to be harnessed using power of big data, AI, ML, RS, modelling, GIS etc. to guide the farmers based on the market, weather as well as associated infrastructure for processing. Approach of "*One district one product"* (ODOP) proposed by the government of India (GoI) need to be adopted at state level. There are hundreds of platforms providing compartmental solutions to the farmers at present. However, not much impact on ground as farmers need holistic solutions for their complex problems. There is an urgent need to have a reliable, dynamic and integrated platform for authentic solutions for the farmers. Considering the large number (145 million) of farm-holders, 15 AERs, 100 AESRs and around 100 crops plus several allied sector activities undertaken by the farmers the big data management is a great challenge but country has shown the grit to achieve this scale of implementation effectively as mentioned for *Aadhar*, GST, E-NAM, digital payments, land records, and so on in Sects. 1.2.10 and 1.2.12.

ICRISAT in collaboration with Microsoft and Government of Andhra Pradesh in 2016 a 'Sowing App' was unveiled for farmers in Andhra Pradesh, India. ICRISAT adopted Microsoft Cortana Intelligence Suite including Machine Learning (ML) and Power BI or Business Intelligence, to empower farmers and government officials with technology, and promote digital farming practices in the state. Equipped with a Personalized Village Advisory Dashboard, this App aids farmers achieve optimal harvests by helping them make critical decisions such as when to prepare the field, when to sow groundnut where seed costs are substantial (ICRISAT 2016; Business Standard 2016). The same App also guided the farmers to sow any of the selected crops and harvest increased crop yields. This is done with the help of an interface between artificial intelligence, weather forecasting models and extensive weather and agricultural data including rainfall over the last three decades for the region. In a recent blog, Jean –Philippe Courtois, President at Microsoft Global Sales opined that Artificial Intelligence can be part of the solution for the farmers (FAO 2019). The AI Sowing App draws from more than 30 years of climate data, combined with real-time weather information, and then uses sophisticated forecasting models powered by Azure AI to determine the optimal time to plant, the ideal sowing depth, how much farm manure to apply, and more. In the pilot's first year (2016), 175 groundnut farmers in Kurnool district, Andhra Pradesh, India participated. Most farmers in the region planted in early June, as dictated by custom and tradition. Farmers who used the AI Sowing App delayed planting by 3 weeks. For those who waited, the results were dramatic—on average they harvested 30% more groundnut per hectare than farmers who planted at the beginning of June.

Using water balance model and data related with soils, sowing date and weather, Garg et al. 2016 using data from micro-watershed at ICRISAT campus developed and validated a simple and farmer-friendly decision support system (Water Impact Calculator-WIC) at three pilot sites on farmers' fields in Rajasthan, Gujarat and Telangana in India for enhancing water use efficiency in agriculture by advising the farmers through SMS when to irrigate their crops and how much water should be added. Field studies were conducted under two land-form treatments (broad bed and furrow (BBF) and flat fields); and irrigation water was applied following two different methods (drip and flood). The data collected at micro-watershed at the ICRISAT and three other sites showed that WIC could be used under wide range of soil and rainfall conditions. WIC simulated soil moisture was comparable with the observed moisture data, which forms the basis of irrigation scheduling. For simplifying the quantity of water to be added farmers were advised based on their pump capacity and water discharge for how much time the pump should run for irrigating one-acre crop. The WIC-based water balance at these experimental sites showed that number and amount of irrigation could be reduced by 30–40% using WIC-based irrigation scheduling without compromising the crop yield (Table 1.5). The WIC could be a potential tool for water resources planning and efficient management at the field and watershed scale in the SAT (Garg et al. 2016).

1.2.12 Enabling Policies and Institutions Are Must

For success of any initiative/program enabling policies at macro-and micro- level as well as enabling institutions and proper implementation, monitoring evaluation and learning are very much needed. The best example of Watershed management in India clearly demonstrated that the watersheds which started as drought prone area program (DPAP) by the central government in close integration with the state governments evolved through common guidelines by the government of India. Through evolving watershed guidelines this program transformed from soil conservation, rainwater harvesting to water harvesting, efficient water use and soil conservation to livelihood improvement through number of revisions in watershed guidelines (Fig. 1.10) (Wani et al. 2005, 2006b, 2008, 2011a, b).

Table 1.5 Need-based irrigation scheduling using water impact calculator saved water

	Calendar-based system		WIC-based system	
Water balance parameters	Drip	Furrow	Drip	Flood
Irrigation applied (mm)	260	380	190	250
Av. Initial soil moisture (mm)	80	80	80	80
Consumptive water use (mm)	255	265	255	265
Deep Percolation (mm)	35	125	5	45
Soil moisture at end (mm)	50	70	10	20
Wheat Yield (tons/ha)	3.4	3.4	3.4	3.5
Water Use Eff. (Kg/ha/mm)	13	9	18	14

Data from farmers' participatory field trials conducted in Rajasthan (Derived from Garg et al. 2016)

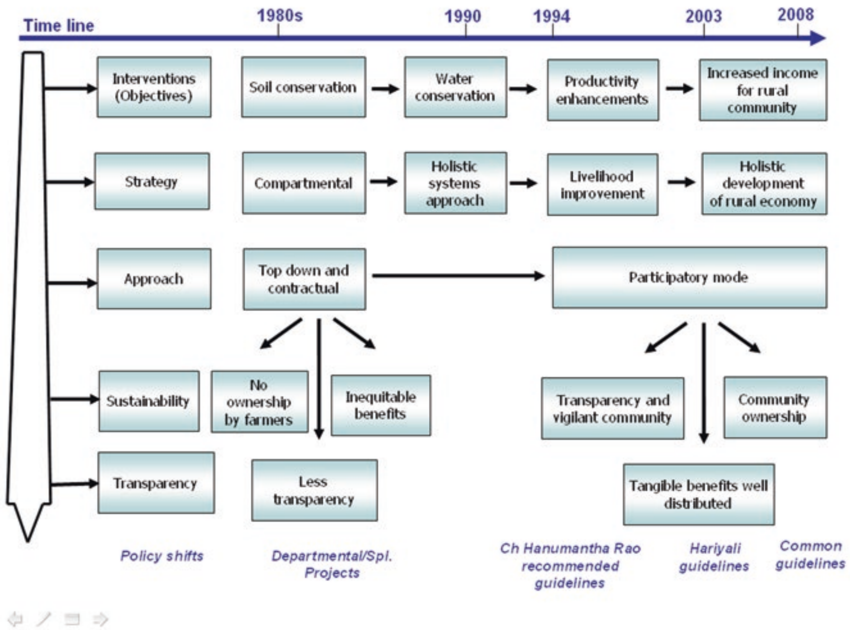

Fig. 1.10 Evolutionary journey of watersheds approach in India through enabling policies. (Source: Authors)

Similar was the case for many successful scaling-up programs such as *Bhoochetana and Bhoo Samrudhi* in Karnataka*, Rythu Kosam* in Andhra Pradesh and several corporate social responsibility (CSR) projects (Wani et al. 2012, 2013; Raju et al. 2013a, b, 2017; Wani 2016; Wani and Raju 2018). The government of India is actively pursuing the transformation of agriculture and basket of new reforms promote value-chain development as well as marketing at national and international levels. New reforms such as creation of Gramin Agricultural Markets (GrAMs) as aggregation platforms, opening up of three market channels viz. APMCs, intra and interstate direct trade under The Farmers Produce' Trade and commerce (promotion and Facilitation) law, 2020, Agricultural Export Promotion Policy 2018 focussing on volumes, standards & quality and cluster approach to production, liberalisation of control orders under The Essential Commodities Act,1955, contracts in respect of farming and services through Farmers (Empowerment and Protection) Agreement on Price Assurance and Farm Services law, 2020, promotion of 10,000 FPOs. Under *Atmanirbhar* Bharat that targets investment of 1.65 lakh crore in the farm sector, agri. logistics will get a boost across all sectors (Wani 2020a, b; Singh and Wani 2020). For rural transformation proper implementation is very critical and must. Awareness building amongst the public and making it a public movement through active participation, DBT, implementation through online process, removing intermediaries who generate corruption. Such enabling policies and associated institutions would help the scaling-up of integrated holistic solutions for the farmers and transform the rural sector.

1.3 Scaling-Up Strategy for Impacts

The scaling-up strategy was developed by our pursuit with low impact of economically remunerative technologies developed by scientists for unlocking the potential of rain-fed agriculture in spite of on-farm demonstrations in different regions in India (Wani et al. 2003a, 2011a, b; Wani and Raju 2020). Basically we started with why low adoption of technologies? how adoption can be improved? and what need to be done for increasing adoption of technologies? (Wani et al. 2003a). Chaffey (2020) described this approach of why, how and what as the Sinek's Golden Circle theory. We started our process with understanding the reasons for low adoption of technologies by closely interacting with the farmers with whom on-farm demonstrations were conducted at different locations. Basically, we adopted the learning Cycle approach (NASA 2012) of engaging with the farmers who were involved in on-farm demonstrations, exploring the various reasons for low-adoption, explaining to a multidisciplinary team of scientists involved in assessing the reasons for low-adoption and then reflecting the learnings and planning new strategy with a multidisciplinary team. Based on the success of new strategy in model watershed it was extended to four satellite watersheds and evaluated for reflecting and incorporating changes (Wani et al. 2003a; Wani and Raju 2020). The process of scaling-up was mainly based on the strong capacity building through participatory research for providing holistic solutions through partnerships adopting the consortium approach. The detailed process is depicted in the Fig. 1.11.

1.3.1 Capacity Building Is Critical

Our unique proposition to the farmers was that we will help them through knowledge-based interventions for increasing their crop yields and incomes by working with them but they themselves have to do on-farm experimentation, evaluation and adoption and no free inputs will be provided (Wani et al. 2003a). All the partners were involved in capacity building also along with planning, implementation and evaluation by sharing the credit equally for all the success. The comprehensive assessment of watershed programs in India undertaken by ICRISAT-led consortium (Wani et al. 2008; Joshi et al. 2008) for the government of India resulted in New Watershed Guidelines in 2008 by the government of India making watershed programs as livelihood improvement program and converging all watershed programs under Ministry of Rural Development (MoRD), Government of India. The scaling-up journey started in 1999 with establishment of the model watershed based on the multidisciplinary on-farm watershed experiment results (linking on-station research

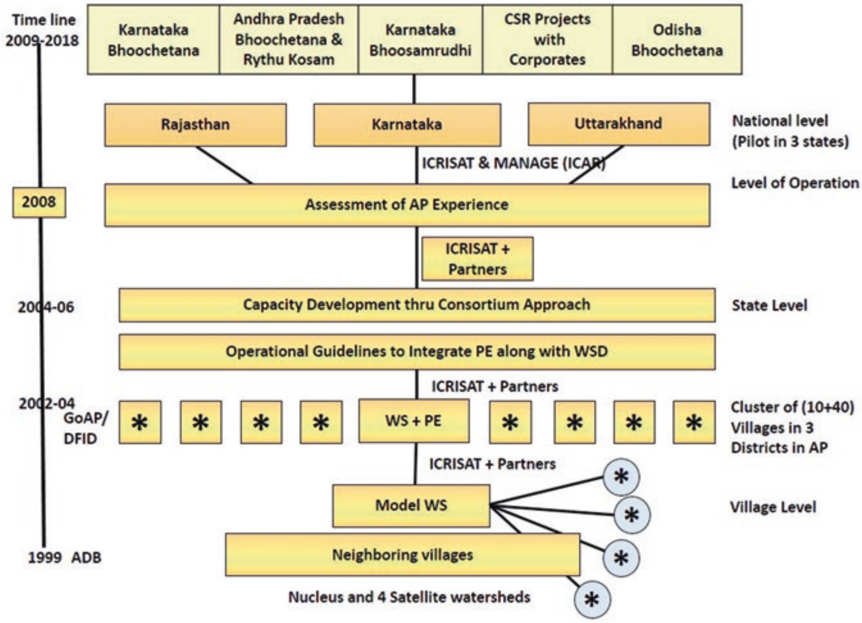

Fig. 1.11 Scaling-up process through strong capacity building strategy from the benchmark/model site with satellite sites. (Source: Authors)

to on-farm research), moving from multidisciplinary strategy to multi-institutional partnerships (consortium approach) for providing holistic solutions to the farmers through farmer participatory approach from the beginning itself. As reported (Wani et al. 2003a; Wani and Raju 2020) tangible benefits in terms of increased crop productivity and incomes resulted in demand to the government department for similar support to surrounding villages. This was the first sign of demand driven scaling-up through knowledge-based solutions as depicted in Fig. 1.11 by selecting four satellite watersheds for one model watershed. During further scaling-up initiative supported by Government of Andhra Pradesh through DFID project using CB as a strategy for each of 10 nucleus watershed 40 satellite watersheds were selected (Fig. 1.11) and livelihood approach was adopted and scaled-up.

Further for scaling-up at national level, GIZ supported initiative ICRISAT and MANAGE- ICAR undertook CB in three pilot states of Rajasthan, Uttarakhand and Karnataka (Fig. 1.11) and later scaled-up in several states with the support from government of India, state governments of Karnataka, Andhra Pradesh, Telangana, Odisha, number of corporates through corporate social responsibility by adopting consortium approach for providing holistic solutions including market linkages (Wani et al. 2011a, b; Wani and Raju 2018, 2020; Raju and Wani 2016; Raju et al. 2013a, b). During several scaling-up initiatives we observed that many institutions knew what they are doing, some of them knew how they are doing but very few institutions/organisations knew why they do what they do? (Chaffey 2020). For successful scaling-up strong and passionate leadership is must with clear understanding why we wish to do particular thing such as in our case we were sure that low productivity, large yield gap and low family incomes of small farm-holders must be addressed and improved through knowledge-based solutions. How it can be done? Was addressed through building partnerships with identified institutions and individuals for their expertise by adopting consortium approach. Once why and how was discussed and finalised by all the stakeholders then what can be done was identified easily along with the farmers (Wani et al. 2003a, 2011a, b; Wani and Raju 2018, 2020).

For example, during the second phase of *Bhoochetana* project (4 years) period, 165 training courses were conducted at the district level with 15,820 participants; 540 trainings at taluk level to train 42,273 trainees; and 17,382 cluster village level trainings to train 980,827 farmers, including women (ICRISAT 2018).

1.3.2 Identifying Key Partners/Players and Bringing Them Together in Consortium

For *Bhoochetana (BC)* the mission project was converted in to a state mission during the second phase of the project to cover all (rain-fed and irrigated) systems in the state and all agriculture related departments and divisions in each department were brought together to achieve convergence. An innovative partnership between the Government of Karnataka and ICRISAT has been built on a strong foundation laid during the *Sujala*-ICRISAT initiative aided by the World Bank in 2005, for enhancing the impact by translating strategic research into research for development and impact which innovated new paths of development. It was a holistic and end to end approach for scaling-up development; refined and scaled-up by the ICRISAT's watershed consortium team by adopting research for development and Inclusive Market Oriented Development (IMOD) approach. The *Sujala*-ICRISAT initiative consortium demonstrated the power of science-led development to benefit a large number of small farmers through productivity enhancement, increasing profitability and sustainability in the micro-watersheds. The yields of crops increased by 33–58% through the implementation of soil-test based balanced nutrient management, the use of improved cultivars, seed treatment, soil and water conservation measures and the use of improved machinery, translated the strategic knowledge into farmer-friendly information resulting in large-scale adoption in the target districts (ICRISAT 2009). Based on this experience during 2009, the DoA, Government of Karnataka requested ICRISAT to provide technical support through a mission mode approach for increasing productivity of crops in rain-fed areas which was christened *Bhoochetana* (Rejuvenating soils) for unlocking the potential of rain-fed systems in the state. This clearly demonstrated that once the on-ground impacts are seen the policy makers chase such agencies as it's a win-win-win proposition for them to benefitting the policy makers for demonstrating their work benefitting the farmers, the farmers get the benefits and the institute undertaking the initiative also benefits through uptake/higher adoption of new technologies/products.

For *Bhoochetana* the consortium comprised of Karnataka's State Department of Agriculture as implementing agency, with its Commissioner and Director as nodal officers to implement the project. The other partners included:

- Watershed Development Department; its Commissioner was the focal person to coordinate activities.
- Four State Agricultural Universities of Agricultural Sciences (SAUs) (Bengaluru, Raichur, Dharwad and Shivamogga) in the state; their Vice-Chancellors were State Coordination Committee (SCC) members supporting technical help from university scientists.
- Karnataka State Natural Disaster Management Cell (KSNDMC)
- Karnataka State Seed Corporation (KSSC)
- Department of Economics & Statistics (DoES)
- *Krishi Vigyan Kendras* (KVKs) in the state
- Community-based Organizations (CBOs)
- Watershed Committees (WCs), user groups (UGs) and watershed associations (WAs)
- International Crops Research Institute for the Semi-Arid Tropics, (ICRISAT) as leader of the consortium to facilitate improved technologies to all stakeholders and participating farmers through technical support.
- Private companies/corporates (for supplying inputs such as seeds, fertilisers and micro-nutrients) making it available at cluster of villages level.

Bhoo samrudhi (BS) (Prosperity through land) was a flagship initiative of Government of Karnataka based on the success of *Bhoochetana* mission project for establishing learning sites of scaling-up integrated and participatory research for development to benefit small and marginal farmers across four districts of Tumkur, Chikkamagalur, Raichur and Bijapur.

The consortium approach was adopted in BS to harness the synergies of international and national research institutes as consortium partners:

- International Crops Research Institute for the semi-Arid Tropics (ICRISAT).
- International Water Management Institute (IWMI)
- International Livestock Research Institute (ILRI)
- International Rice Research Institute (IRRI)
- The International Maize and Wheat Improvement Center, known by its Spanish acronym (CIMMYT)
- International Food Policy Research Institute (IFPRI)
- International Center for Agricultural Research in the Dry Areas (ICARDA)
- Asian Vegetable Research and Development Center (AVRDC)
- National institute, Indian Institute of Horticulture Research (IIHR)
- Four state agricultural universities (Bengaluru, Dharwad, Raichur, Shimoga)
- State horticulture university (Bagalkote)
- State university of Animal Husbandry & Fisheries (Bidar)

- Government line-departments (DoA, WDD, DoAH, DoH, DoWR, DRD & PR, KSSC, KSNDMC).
- Private inputs supplying companies

This indicated that for each project the consortium partners need to be identified, consortium formed through formal agreements. Through conduct of several workshops all partners need to be brought on the same platform to understand standard operating processes such as why we are in the consortium? how we will function as a team? and what we need to do to achieve the objectives/mission? etc. For every scaling-up project this process is must.

For a challenging project like AP Primary Sector Mission (*Rythu Kosam*) Agricultural Transformation in Andhra Pradesh: Equitable, Scientific, Prosperous and Climate Smart Agriculture for Primary Sector to achieve double digit growth year on year the process was complex. In addition to the identified government line departments (Agriculture, Animal Husbandry, Horticulture, Fisheries, Marketing, Watershed and Planning Department, etc.) partners were several in addition to private companies, state agriculture universities, research institutions, and the NGOs. The consortium formation was a challenging task to bring different line departments on one platform and traditionally each department protected its territories. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) formed a consortium (as shown in Fig. 1.12) consisting of all relevant departments of the state government, knowledge institutions, both public and private universities, state and national level research organizations and other relevant organizations. This consortium approach enabled development of primary sector strategy to enhance productivity, profitability through value addition to the farmer community of Andhra Pradesh (ICRISAT 2016).

ICRISAT team conducted several workshops organised by the nodal DoA and capacity building programs with all the line departments, private companies, entrepreneurs, progressive farmers, state university scientists and researchers to make consortium of different sectors and to harness their technical and financial capacities for developing the primary sector. For 13 districts in all 18 NGO partners were selected for on-ground support for the pilot sites. Number of agencies such as NABARD Consultancy Services (NABCONS) as well as private companies were identified for inclusion in the consortium (ICRISAT 2016).

1.3.3 Strategy and Plan Preparation

For any large project such as *Bhoochetana* or *Bhoo Samrudhi* clarity on its strategy is very crucial. The project adopted mission approach through convergence of various government programs and schemes implemented by a consortium consisting of different line departments of Government of Karnataka along with academic institutions like University of Agricultural Sciences located in Bengaluru, Dharwad, and Raichur and the international institutions working in the area of dryland agriculture

Fig. 1.12 A schematic diagram of consortium approach adopted in *Rythu kosam* primary sector development initiative in Andhra Pradesh. (Source: Authors)

worldwide. For better planning, execution and monitoring, Government of Karnataka constituted a high-powered Steering Committee (SC) chaired by the Additional Chief Secretary and Development Commissioner. The committee reviewed the performance of the project every fortnight. It also played a crucial role in ensuring policy decisions quickly making this project successful in the state. Detailed planning of the process as well as fixing the responsibilities played important role in the success of *Bhoochetana* mission project. The conceptualization of *Bhoochetana* started with organizing a brainstorming session in 2009 by inviting major stakeholders, including policy makers, SAUs, line departments and ICRISAT. During the deliberation, the good performing technologies were very much appreciated and it was decided to demonstrate the innovative technologies through a programme with technical assistance from ICRISAT. The strategy was prepared and discussed with high-level policy makers and technocrats. The programme was launched within a short time and implementation started with soil-test-based fertilizer recommendation as an entry point activity in six districts in the 2009 *kharif* (rainy season). The modalities of input procurement, supply and storage were worked out and crop sampling, nutrient analysis and capacity building programmes were organized to understand the process of implementation. The programme was based on the concept of generating funds using state resources as well as central resources. The proposal was developed based on this concept and funds were organised by converging schemes like *Rashtriya Krishi Vikas Yojana* (RKVY) and other programmes. It is an innovative approach to converge with all the ongoing programmes to address the larger issues in a scientific manner. To implement this ambitious programme, the state government made provision for 25% of the total programme cost to come from the state budget and the remaining 75% to come from central funding. The budget was created using funds of different schemes such as the Integrated Scheme of Oilseeds, Pulses, Oil palm and Maize (ISOPOM), the National Food Security Mission (NFSM) and the Accelerated Pulse Production Programme (A3P), and additional funds required were met under the integrated agricultural extension system (IAES) and *Rashtriya Krishi Vikas Yianna* (RKVY).

For better monitoring, a three-tier decentralized system was adopted; namely, State Level Coordination Committee (SLCC), District Level Coordination Committee (DLCC) and Taluk Level Coordination Committee (TLCC). These committees met regularly, reviewed the progress and addressed the issues/concerns appropriately. Every Wednesday, a video conference was organized at the state level to review the programme, and higher authorities attended this conference regularly and took swift decisions to facilitate the programme (Fig. 1.13).

Bhoochetana was implemented strategically in different phases over a period to make essential gains in the struggle for improved agricultural productivity, rural incomes and nutrition. The scaling-up process in this particular project (*Bhoochetana*) adopted a multi-level 'refinement strategy' to increase the effectiveness of technologies and reach a greater number of farmers. It is part of a broader process of innovation and learning. With effective monitoring and evaluation processes, the knowledge acquired from the initial year was used to scale-up the model to create larger impacts in the entire state. The process occurred in an iterative and interactive cycle, as the experience from scaling-up feeds back into new ideas and learning. The process adopted in *Bhoochetana* involves harnessing the potential of good partnership,

Fig. 1.13 Regular video conferencing with all the 30 districts officials for review of the *Bhoochetana* mission program in Karnataka. (Source: Authors)

political will, administrative support, science-backed capacity building, and regular and effective monitoring mechanisms (Fig. 1.14). This initiative also adopted innovative ideas of support services such as extension services to reach more farmers to create awareness about improved agricultural methods. It is a systematic approach followed to maximize the impact on the ground in Karnataka. This clearly brings out that *Bhoochetana* is a holistic approach adopted with the support from all stakeholders for benefiting the state as a whole and smallholders in particular.

The most important factors of the strategy are soil-test based nutrient management with a major thrust on micronutrients application, supply, and distribution of inputs at 50% incentive at *hobli* and cluster of villages level, services of farm facilitators (FFs) and lead farmers for sharing of technology and disseminating knowledge, enabling policies to fill the gaps in a timely manner, wide publicity through

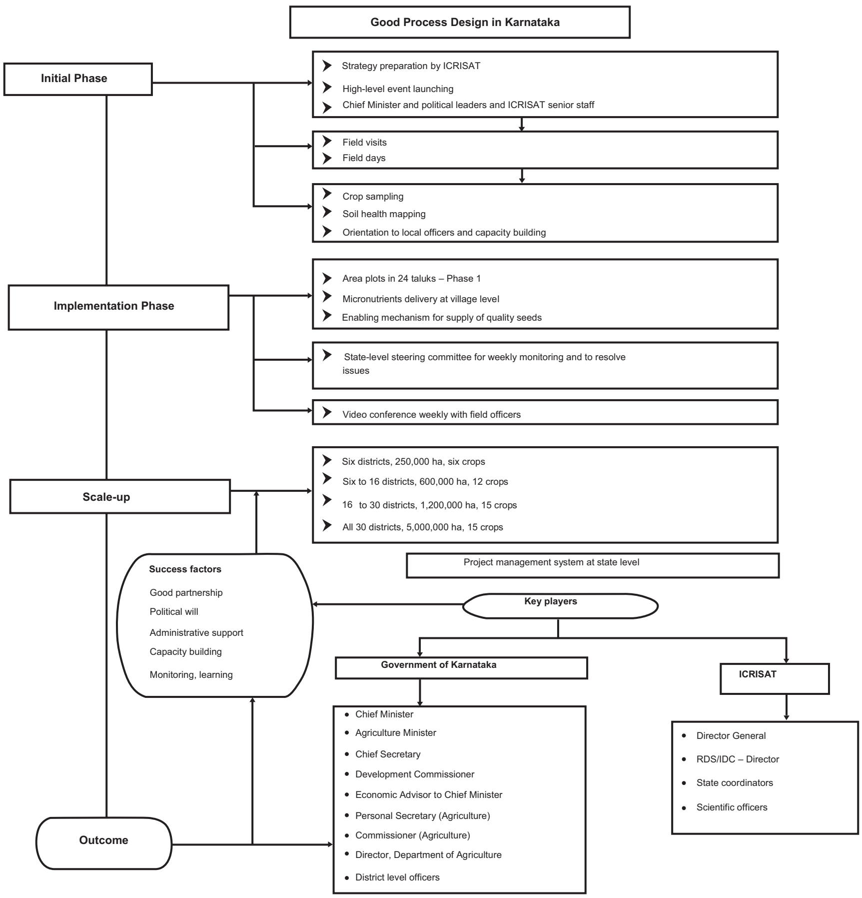

Fig. 1.14 Process of conceptualization, implementation and scaling up of *Bhoochetana* in Karnataka. (Source: Authors)

wall writings, posters, village meetings, and mass media, and effective project monitoring and feedback.

The salient strategy points included:

- The Mission adopted the principle of four Cs, i.e., Consortium, Convergence, Capacity building, and Collective action. The consortium of development agencies such as line departments of the state government and FF along with knowledge- generating institutions for improving the livelihoods of the rural poor in dryland area was formed.
- Convergence of all schemes of DoA into *Bhoochetana*.
- Creation of *Bhoochetana* cell at DoA headquarter to deal with implementation, planning, and monitoring the activities.
- Demand driven approach – farmers to register and pay 50% of the cost on inputs (no free inputs).
- Develop capacity of DoA staff to adopt science-led development in the state and build the strong cadre of farm facilitators (FFs) through capacity building with the help of master trainers from State Agricultural Universities (SAUs).
- Address the Mission goal through four Es, i.e., Efficiency, Economic gain, Equity, and Environmental protection, which are the important pillars of sustainable and inclusive development in the country.
- Ensure timely supply, availability, and access to the necessary vital inputs such as knowledge-based soil nutrient management options, acquire micronutrients, availability of good quality seed and other best practices, necessary financial incentive to undertake best-bet options for increasing agricultural productivity through *Raithu Samparka Kendras* (RSKs) a local level institution for supplying inputs and knowledge to farmers by the DoA.
- Adopt improved best-bet management practices (BBMPs) on large scale and share knowledge through trained FFs and lead farmers.
- Map soil nutrient deficiencies in the 30 districts which will be the starting point for scaling-up the soil analysis based integrated nutrient management practices for sustainable growth in dryland areas of Karnataka (Fig. 1.15)
- Demonstrate and popularize other best-bet management practices (BBMPs) such as rainwater management, pest management options, and organic matter improvement practices to support the long-term sustainability and enhanced productivity.
- Establish village seed banks for crop cultivars by training the farmers to ensure timely supply of quality seeds at reasonable prices for the farmers.
- Well planned time-bound targets for covering productivity enhancement in 30 districts, soil sampling and nutrient analysis mapping, and capacity building of stakeholders during the project period.
- Crop cutting experiments for estimating crop yields were undertaken by a joint team of officials from DoA and DES and Scientists from University of Agricultural Sciences (UAS) along with ICRISAT Technicians and a uniform crop sampling procedure was adopted across all the districts.

Fig. 1.15 Dr. L Shantha Kumari Sunder IAS, Additional Chief Secretary and Development Commissioner visited ICRISAT and nurtured seedling of Bhoochetana. (Photo Source: Authors)

- Identify all farmers who are registered/took the inputs from RSKs and applied in their designated fields and sown selected major crop. This was ascertained through RSK bills and FFs who facilitated the farmers in the village to register/get the inputs. At taluk level, Assistant Director of Agriculture (ADA) or Agricultural Officer (AO) ensured in preparing the total list of those identified farmers along with ICRISAT Research Technician and FFs or lead farmers in the villages.
- Pool up the list of farmers at district level to facilitate further monitoring and evaluations.
- At taluk level, ICRISAT staff/AO/ADA made at least two field visits in the cropping season to randomly select farmers' fields having crops at the end of vegetative phase and flowering or maturity phase.
- In these phases, field photos showing crop growth differences in individual farmer's fields were obtained as a record for verification.

At the time of crop harvest, the office of Joint Director of Agriculture (JDA) prepared farmers' list for crop sampling randomly selecting farmers' fields which also had farmers' management treatment in the same farmer's field (Raju et al. 2013a, b).

For the large mission project *Rythu Kosam* in Andhra Pradesh strategy plan for the program implementation was prepared by ICRISAT through deliberations organized by the nodal Department of Agriculture with all concerned Principal Secretaries, Commissioners, Directors and other senior officers from the State Agricultural Universities, research institutions and fruitful discussions with the Special Chief Secretary, Planning Department led to the development of a strategy plan. The first and foremost strategy adopted was science-led development approach by bringing the scientific developments of state, national and international expertise and experiences to benefit the sector, state and the farmers. In order to achieve the efficiency, the principle of synergy of primary sector actors through integration approach was proposed by discarding the traditional sectoral/compartmental approach as in the holistic and integrated approach as shown in Fig. 1.16. Each department was asked to fix their targets and requirement of funds and government ensured availability of funds through convergence. The sites of learning – pilot sites – were established to operationalize the holistic approach in all the districts of AP in partnership and along with the DoA officials in the district. Another major change was made in the strategy is to bring in the participation of stakeholders by giving up the top down hierarchical strategy. Overall, the entire primary sector mission pilot sites covered 267 villages (both agril., horticulture, livestock and fishery) under 38 *mandals* in 13 districts of the state. Approximately 0.192 million farmer households were directly targeted for mission interventions across 13 pilot sites. A total population of 0.685 million was covered initially during 2015–2016 cropping season. About 0.142 million ha of cropped area (including agril. and horticultural crops) was covered across 13 pilot sites corresponding to 13 districts in the state. Nearly 0.99 million population of livestock animals was also covered for wide range interventions in under selected *mandals* in the mission pilot sites. Roughly 8892 ha of fishery area (including both prawns and fish cultivation) was also covered under mission interventions. In nut shell, the cumulative pilot site area represented about 1.75% of the total cropped area in the state. Approximately about 1.4% of the total state's population also being covered in these pilot sites.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) as a leader formed a consortium (as shown in Fig. 1.12) consisting of all relevant departments of the state government, knowledge institutions, both public and private universities, state and national level research organizations and other relevant organizations (ICRISAT 2016). Through adoption of innovative strategy of 4 ICEs as indicated below the primary sector's transformation through scientific development to increase production, productivity as well as profitability for the farmers as well as the state through sustainable intensification was strategized to achieve double digit growth in primary sector gross domestic product (GDP). During the 3 years of project duration double digit growth in primary sector GDP was recorded. Like

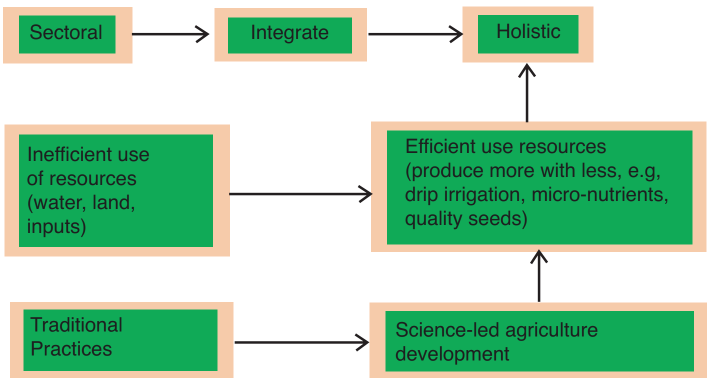

Fig. 1.16 A schematic diagram of holistic approach adopted in *Rythu kosam*. (Source: Authors)

Bhoochetana mission project in *Rythu kosam* project also Chief Secretary and Hon. Chief Minister of Andhra Pradesh used to review the process, progress and difficulties in achieving the targets fixed by the concerned departments every 3 months by devoting full day for review involving all the concerned ministers and departmental officials along with ICRISAT team leader.

For developing rain-fed areas which occupy 75% of arable land in the Philippines as part a collaborative effort between ICRISAT with DA-BAR, Local Government Units (LGUs) and State Universities and Colleges (SUCs), the *Yamang Lupa* program was launched to adopt the *Bhoochetana* principles and approaches in strategic rain-fed areas. ICRISAT organized training and exposure visits for the program management group to understand the nuances of *Bhoochetana* program in Karnataka State and ICRISAT's research for development programs in the drylands. Training on integrated crops and natural resources management was organized for young and potential researchers-cum-leaders of the country to lead promising innovative strategies for boosting agricultural productivity while managing the natural resources effectively and efficiently for the smallholder farmers. A training-workshop on soil sampling, analysis and mapping was conducted with the support of DA-BSWM. Six scientific visits were organized by ICRISAT and top executives and officials of the Consortium Partners involved in the program took part in them for deeper appreciation of the *Bhoochetana* principles and understanding on the *Yamang Lupa* program as well as to benchmark good planning and M&E practices promoted by ICRISAT. At the end of the exposure trips and visits, work plans for 2014–2015 of the three pilot regions were developed based on their learnings in India, concept of the *Yamang Lupa* program and experiences in the Philippines.

Through ICRISAT's experiences and guidance, the Steering Committee (SC) and program management group (PMG) was set up both at the national and regional levels prior to the implementation of the program. To build awareness in the community, amongst farmers and government officials working in DA and policymakers, ICRISAT supported the conduct of the program launching in pilot regions through the initiatives and cooperation of the regional technical working group. The management group finalized the first year work and financial plans of the program and the program's implementing guidelines and policies during the Steering Committee meeting. The group also agreed to provide necessary guidance to those regions or provinces that will initiate the implementation of the program through the Local Government Units (LGUs). ICRISAT team provided on-ground guidance and participated in conduct of the Steering Committee meeting. ICRISAT developed a flow chart (Fig. 1.17) on program management and process documentation and program implementation eligibility with local government units (LGUs) (ICRISAT 2014). This approach has been considered by the management group as a guide in dealing with interested LGUs to implement the program both in the municipal and provincial levels.

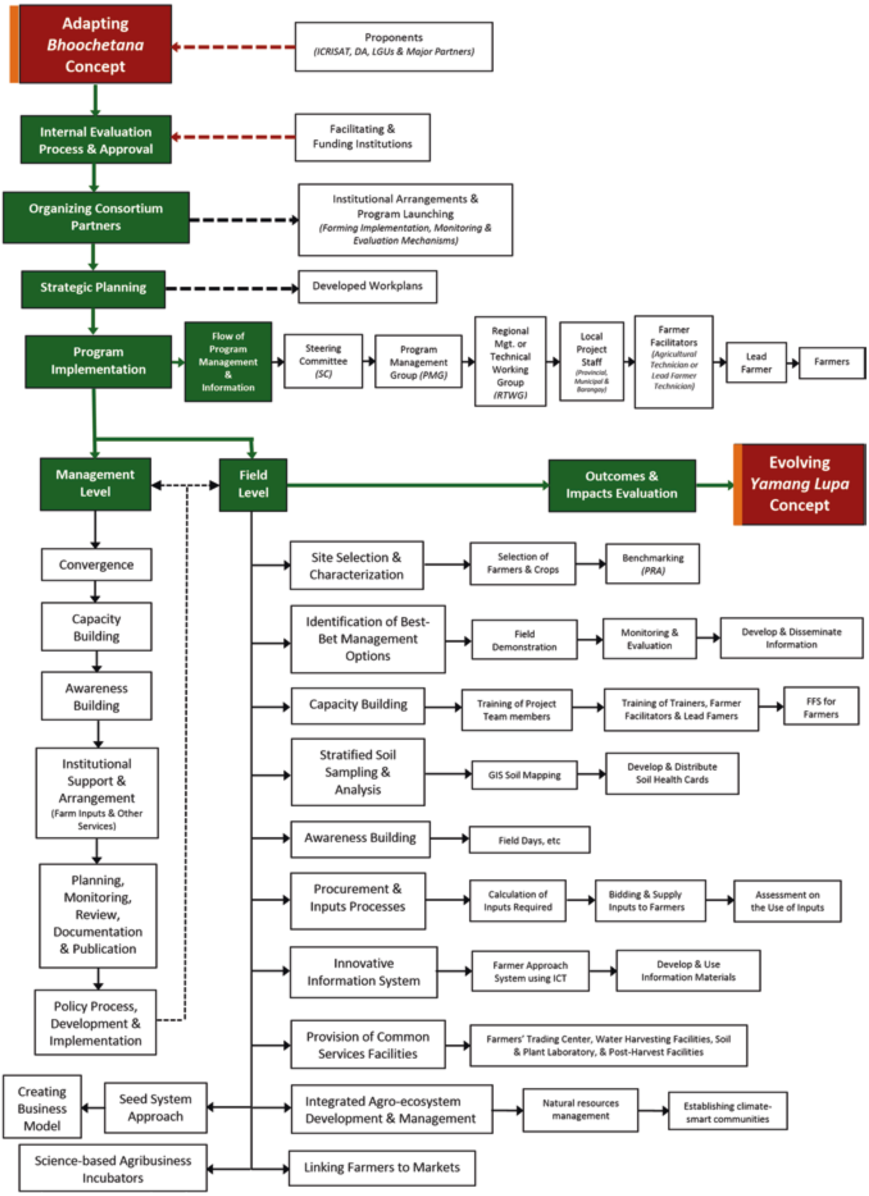

Fig. 1.17 Flow chart depicting *Yamang Lupa* program management and process documentation and program implementation with local government units (LGUs). (Source: Authors)

1.3.4 Creating Visibility and Sharing Success Stories Is Critical

Creating visibility through close interactions with farmers, researchers, extension staff, policy makers and development investors from the beginning plays very critical role for scaling-up. For example, through our *Bhoochetana* about 5 million farmers benefitted through increased crop yields and incomes with total benefit working around US $ 453 million in 7 years. *Bhoochetana* was launched by the Hon. Chief Minister of Karnataka (Fig. 1.18) which created awareness amongst the farmers as well as passed on the message about the importance of the project to all the stakeholders.

For enhancing awareness about the mission project in each of the 30 districts number of awareness building events by the district officials were conducted (Fig. 1.19). The *Bhoochetana* initiative's synergistic and participatory approach was showcased in many national and international fora (e.g. the World Water Forum held in France in 2012 and CGIAR's Fund Council Meeting in New Delhi on 26th April, 2013) on "Partnering for Impact" Reforms in the CGIAR have spawned new ways of thinking about agricultural research for development, innovative ways of doing science and broader partnerships to reduce rural poverty, improve food security, enhance nutrition and health, and sustainably manage natural resources. A step in this direction was the Government of Karnataka (GoK)-CGIAR's *Bhoochetana* initiative for improving rural livelihoods through innovative scaling-up of science-led participatory research for development. One of the four program initiatives selected for presentation to the Fund Council, it drew appreciation for its innovation and scaling-up of benefits of strategic research for development. A panel

Fig. 1.18 *Bhoochetana Project* launching at Haveri by Hon'ble Chief Minister, Government of Karnataka

Fig. 1.19 *Bhoochetana Ratha* for awareness building in Shimoga (L) and Brochure on Bhoochetana in Ramanagar (R)

comprising GoK's senior representative, former economic advisor to GoK and ICRISAT's Asst. research program director and *Bhoochetana* project leader elaborated the novelty of the initiative, its Inclusive Market-Oriented Development (IMOD) approach and how impacts could be achieved by: (1) adopting a consortium mode for building partnerships; (2) convergence of schemes for a holistic approach; (3) capacity building to empower stakeholders; and (4) collective action for sustainability. A case was made for strengthening the GoK-CGIAR partnership through a coordination committee, independent monitoring and impact assessment and by providing matching grants from the Consortium. Commenting on the presentation, Dr. Frank Rijsberman, CEO, CGIAR Consortium said, "*Bhoochetana* is a very good success story and one needs to listen carefully to understand its nuances as it has contributed to system level outcomes." "This is one of the best examples to convince that more investments in strategic research benefit development," said Dr. Juergen Voegle, World Bank, Fund Council. "The 26 impact and cost benefit ratios are very good and the way the case has been presented logically is very convincing," he added.

Under the GoK-CGIAR initiative led by ICRISAT, seven members of the CGIAR Consortium (ICRISAT, IWMI, ILRI, IRRI, CIMMYT, ICARDA, IFPRI, ICRAF and AVRDC) have joined hands to provide technical support in establishing four benchmark sites in Karnataka, the success of the *Bhoochetana* programme changed the mind-set of different stakeholders, including policy makers, in approaching the problem through science-led solutions at the CGIAR Fund Council Meeting.

The policy makers understood the need for developing such programmes to benefit the state of Karnataka in general and smallholders in particular. In 2012, the state had initiated the discussion on bringing the international expertise to provide solutions to agriculture and allied sectors with the aim of addressing the problem through a systems approach with the help of SAUs, KVKs and line departments. As a result, in 2013, a programme called '*Bhoosamrudhi*' (land prosperity) was launched to address problems holistically covering agriculture, horticulture, animal husbandry and other allied sectors, together with the technical support from the eight international research institutions along with SAUs led by ICRISAT. Initially, this initiative was implemented in 2013 in four districts representing four revenue divisions covering an area of 320,000 ha and extended to another four districts in 2015 covering an area of 320,000 ha.

Following *Bhoochetana* and *Bhoosamrudhi* in Karnataka, a unique model was developed in Andhra Pradesh to increase the state's gross domestic product to the level of double-digit growth with overall development of the primary sector. The Government of Andhra Pradesh has launched the Primary Sector Mission (later named as *Rythu Kosam*) in all the 13 districts by converging agriculture, horticulture, livestock, fisheries, marketing and rural development with the technical support from a ICRISAT-led consortium (Fig. 1.20). In addition to convergence at the state level, another innovative mechanism was formulated for convergence by entrusting the Primary Sector Strategy implementation responsibility to the Joint Collector at district level along with allocation of resources with accountability to deliver double-digit growth by implementing the identified growth engines in

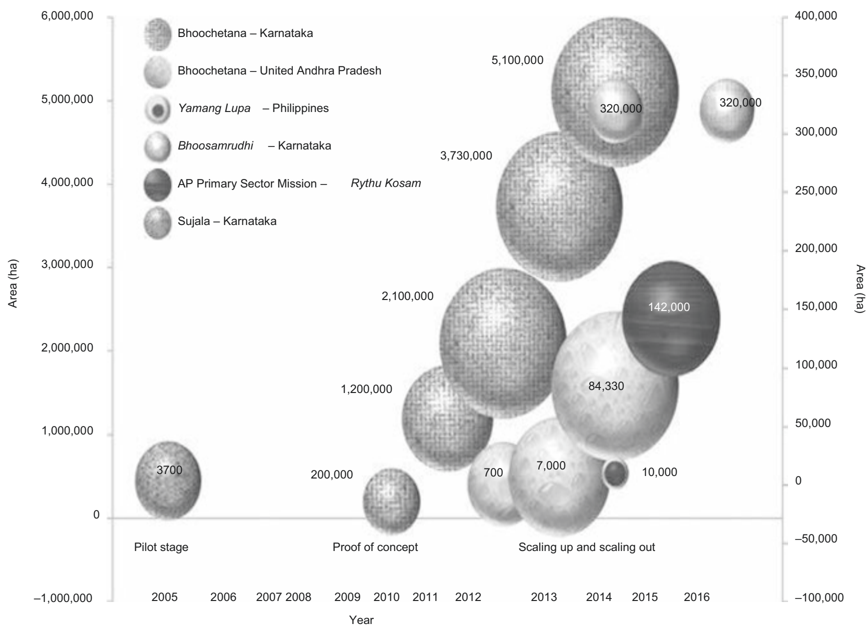

Fig. 1.20 An example of scaling-up and scaling-out of *Bhoochetana* approach In India and the Philippines (ICRISAT 2014)·

different sectors. It is an innovative approach to break the existing silos and achieve convergence for attaining efficiency and impacts at ground level. As in Karnataka, Andhra Pradesh too extended higher level policy support to implement the programme in all 13 districts. The major objective was to establish sites of learning with an area of 10,000 ha in each district to demonstrate innovative technologies to improve the productivity and income.

In addition to presentations of the strategy as well as results in terms of impacts at national and international for a, creating visibility through electronic media, print media played very important role in enhancing awareness about the Consortium approach for providing integrated holistic solution for improving livelihoods of millions of small farm-holders. For example, for *Bhoochetana* program in state of Karnataka in India several articles were written by the correspondents of national as well as international media as listed below.

- Article on BBC In Pictures: Natural ways of increasing Indian yields. http://www.bbc.co.uk/news/world-asia-india-20261745
- Philippines The Bhoochetana Awakening. The drylands grow the poor rich
- The Guardian Global Development section in UK. "India farmers think big but grow micro to enrich their soil" http://www.guardian.co.uk/global-development/povertymatters/2013/mar/13/india-farmers-grow-micro-enrich-soil 71
- World Water Week Article on Worms, Water & Bollywood An Indian agricultural research institution has developed a series of simple technologies that has the potential to dramatically increase the productivity of small farms across the developing world. Alina Paul reports
- Article on Climate Conversations – *Bhoochetana* helps farmers tackle drought
- Article on Portfolio by Mark Tran Agriculture in Karnataka is enjoying a spurt in productivity as farmers rejuvenate the soil using micronutrients, reports
- Link for coverage of ABP MAJHA, MCCS, Maharashtra on Bhoochetana http://youtu.be/oIm – kxqb1Vs http://youtu.be/5uJsk4Dybls http://www.youtube.com/watch?v=oIm -kxqb1Vs http://www.youtube.com/watch?v=5uJsk4Dybls

For *Yamang Lupa* program in the Philippines to enhance the awareness among policy makers about harnessing the potential of rain-fed agriculture exposure visits were organised to *Bhoochetana* fields in Karnataka and interactions with the policy makers in Karnataks (Fig. 1.21) were organised. In partnership with DA-BAR, DA-BSWM and implementing groups, ICRISAT team developed a poster, brochure and flyers with details of the program. They have been translated into the local dialect by the implementing groups headed by DA concerned offices & SUCs and distributed by the LGUs concerned.

Several publications such as bulletins in English as well as local languages, flyers, research articles, books were written by the consortium team members for disseminating the details about the scaling-up initiatives. Interactions with policy makers at state as well as at national levels and also with the international and national development investors (donors) helped a lot in scaling-up as well as policy changes through writing strategy papers for national government of India as well as Chinese Academy of Agricultural Sciences (CAAS), China, Department of

Fig. 1.21 Publicity materials developed for *Yamang Lupa* Program in The Philippines

Agriculture and Department of Soils, Government of The Philippines, Royal Department of Agriculture and Department of Land Resources Development, Thailand, Vietnam Agricultural Sciences Institute (VASI), Vietnam helped scaling-up in these countries.

1.4 Lessons and Way Forward

Considering the demand for increasing food production largely due to population growth which is expected to cross 9 billion by 2025 along with changing food habits with growing incomes in the developing economies such as BRICS with scarce and finite land and water resources is the challenge in the twenty-first century. In addition, the impacts of climate change are already at our doorstep which are causing more stress on water and land resources due to reduced number of rainy days, increased intensity of rains, increasing temperature resulting in more water demand for the crops and reducing crop yields largely in developing tropical countries.

- Although, several game changing technologies/products are developed by the researchers through science of discovery, farmers in Asia, Africa are harvesting two to fivefolds lower yields than the achievable potential yields. Such low adoption of improved technologies/products by the farmers are mainly due to poor extension services which are depriving the small farm-holders the benefits of research.
- It is learnt from several case studies including the meta-analysis undertaken by the CERES 2030 team that main reason for low impacts on farmers' fields are largely due to poor extension services, scientists do not address the concerns of the small farm-holders and large number of small farm-holders cannot access the markets, knowledge as well as cannot become the part of value-chain.
- Most scientists have adopted compartmental approach and adopted supply driven research rather than demand driven research strategy.
- The agrifood systems are complex, involve number of stakeholders, interactions amongst the socioeconomic factors, biophysical and biochemical interactions. Moreover, farmers' livelihoods are dependent on multiple sources of income such as crops, livestock, service and micro-enterprises.
- Under such challenging situation business as usual cannot achieve the impact and new paradigm through strengthening science of delivery along with science of discovery is must for providing integrated and holistic solutions to the farmers.
- For providing holistic solutions partnerships amongst different players must be built by adopting 4 ISECs approach.
- Forming effective consortium as well as achieving the convergence amongst different areas/schemes/approaches cannot be achieved without capacity building and adopting collective action by the small farm-holders through mechanisms such as SHGs, FGs, FPOs, farmers' cooperatives etc.
- Also innovations, integration, inclusivity and impact on field must be the central thread of partnerships in the consortium for achieving efficiency, achieving economic gain, addressing equity and most importantly protecting environment.
- The new paradigm/approach must be sustainable, scalable, socially acceptable and synergistic.

These learnings are based on large number of scaling-up initiative benefitting more than 10 million farmers in Asia and the proposed model for scaling-up is well tested across different agro-ecoregions.

Acknowledgement This chapter is based on work as well as interactions of team of scientists working in IDC, ICRISAT as well as partner institutions, number of state government departments, Department of Agriculture, Cooperation and Farmers Welfare (DOAC&FW), Government of India, number of corporates who supported CSR initiatives, policy makers, administrators and officials at ICRISAT are gratefully acknowledged for their valuable inputs.

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Chapter 2
Scaling-up Agro-Technologies Using Agro-Eco Sub-Regions in the Target States

Tapas Bhattacharyya, Suhas P. Wani, and P. Tiwary

Abstract Agro Eco Regions/Sub-regions (AERs/AESRs) are near homogeneous area similar with respect to (a) broad soil groups, (b) overhead climate and (c) length of moisture availability period in relation to crop production. Efforts of zoning world soils /lands at global level has been tropicalized for minimizing the inadequacies of the concept and to suit the requirement of the Indian subcontinent using the revised length of growing period (LGP) with special reference to dryland agriculture. To address these inadequacies for developing agro-ecological zones/regions, LGP was taken as an index of crop production, since it considers soil-water balance as a direct function of moisture availability in a landform instead of the total annual rainfall. The map boundaries, depicting 20 (twenty) AERs in India were delineated by superimposing bio-climate and LGP on soil-scape. The LGP classes were further grouped into different feasible cropping systems in an agro-environment to delineate 60 (sixty) AESRs. For land use planning agro ecology concept has been considered as a vehicle for technology transfer to address the issues of agricultural land use planning, climate change, soil water availability and the livelihood of the farming community.

Keywords Agro-eco region · Dryland agriculture · Agricultural land use planning · LGP · Climate change

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2.1 Importance of Understanding Agro-Ecologies for Agricultural Planning

Agricultural land use planning involves systematic and iterative processes to develop an appropriate and sustainable environment for acceptable utilization of land resources. These processes involve the physical, socio-economic, institutional and legal potentials and the constraints with respect to an optimal and sustainable use of land resources. In addition, it also empowers people to make informed decisions about how to allocate those resources for reaping maximum benefit. On the basis of an inventory of land resources, land management options are formulated keeping in view the biophysical limitations and potentials of resources to develop the agro-ecological zones/sub-regions (Bhattacharyya 2021a).

FAO (1978–1981) defined Agro Eco zone (AEZ) as a near homogeneous area similar with respect to (a) broad soil groups, (b) overhead climate and (c) length of moisture availability period in relation to crop production. The efforts of FAO were to concentrate on creation of broad crop feasibility zone based on FAO/UNESCO Global Soil and Terrain Map on 1:5 m scale by superimposition of climate and moisture availability period. The major drawback of AEZ of FAO so created is its limited utility for crop planning at regional sub-levels for Asia, Africa, Europe and Latin America.

2.2 Criteria for Delineating Agro-Ecological Zones (AEZs) and Agro-Ecological Regions (AERs) in India

2.2.1 Agro-Ecological Zones (AEZs) in India

AEZ provides a standardized framework for the characterization of climate, soil, and terrain conditions relevant to agricultural production. In this context, the concepts of "length of growing period" and of latitudinal thermal climates was applied in mapping activities focussing on zoning at various scales, from the subnational to the global level. Second, AEZ matching procedures are used to identify crop-specific limitations of prevailing climate, soil, and terrain resources, under assumed levels of inputs and management conditions. This part of the AEZ methodology provides estimates of maximum potential and agronomically attainable crop yields for basic land resources units. Third, AEZ provides the frame for various applications. The previous two sets of activities developed large database. The information contained in these data sets form the basis for a number of AEZ applications, such as quantification of land productivity, extents of land with rain-fed or irrigated cultivation potential, estimation of the land's population supporting capacity, and multi-criteria optimization of the use and development of land resources.

The AEZ methodology uses a land resources inventory to assess, for specified management conditions and levels of inputs, all feasible agricultural land-use options and to quantify anticipated production of cropping activities relevant in the specific agro-ecological context. The characterization of land resources includes components of climate, soils, and landform. The recent availability of global digital databases of climatic parameters, topography, soil and terrain, and land cover have allowed for revisions and improvements in calculation procedures. Also permitted the expansion of assessments of AEZ crop suitability and land productivity potentials to temperate and boreal environments. This effectively enables global coverage for assessments of agricultural potentials. The AEZ methodologies and procedures have been extended and newly implemented to make use of these digital geographical databases, and to cope with the specific characteristics of seasonal temperate and boreal climates.

The concept of agro-ecological zone (AEZ) for improving the rainwater use efficiency, conservation of natural resource and practice of sustainable agriculture under rain-fed situation is essential. In this endeavour, the highest priority is given to assess land resources and their components such as soil, water and climate to create an integrated system to apply the best of scientific technology and knowledge for agricultural development. The main purpose for delineating AEZ was to create a near homogenous soil climatic region that is compatible for (i) potential genetic expression in terms of growth of a particular group of crops and cultivars and their sustenance, and (ii) the AEZ-based dissemination of agro-technology to reduce the recurring costs.

2.2.2 Agro-Ecological Regions (AERs) in India

To address the inadequacies for developing agro-ecological zones/regions, length of growing period (LGP) was taken as an index of crop production, since it considers soil-water balance as a direct function of moisture availability in a landform instead of the total annual rainfall. The map boundaries, depicting 20 AERs in India were delineated by superimposing bio-climate and LGP on soil-scape. The LGP classes were further grouped into different feasible cropping systems in an agro-environment.

FAO (1976, 1978) developed the concept of agro-ecological zones with strong emphasis on comparable agro-climatic parameters to delineate agriculturally potential areas suitable for particular genotype so that optimum production potential of the genotypes is achieved. With an urge to optimize land use for increased agricultural production on a sustainable basis, agro-ecologically comparable resource region was delineated for generating and transferring agro-technology to meet the country's ever-increasing food, fodder and fibre needs. Through several approximations using the parameters, such as, bio-climate, length of growing period, physiography and soils, the scheme outlined in Table 2.1, an agro-ecological region map of the country has been prepared and published (Sehgal et al. 1992). The climatic data of more than 1700 meteorological stations were used for preparing water balances which formed the base for the generalised climatic map and for preparing the Length of Growing Period (LGP) map. Therefore, in the present study, nine states, *viz.* Karnataka, Andhra Pradesh and Telangana, Odisha, Madhya Pradesh and Chhattisgarh, Madhya Pradesh, Bihar and Jharkhand, and Maharashtra have been identified as target states for delineating agro-ecologically based potential areas for agro-technology transfer. Mostly the drier areas of these states are selected except a few exceptions.

Table 2.1 Various levels of exercises to develop agro-ecological zones in India

S.No	Level	Criteria Used			
		Soil	Physiography	Bioclimate	Length of Growing Period
1.	Agroecological Regions of India (AER) (20 AER) (for resource planning at national level)	Soil great group association (1:7 m scale)	Broad (15 nos)	After Thornthwaite & Mather, 1955 water balance using Penman PET and climatic divisions are arid, semiarid, subhumid, humid, per humid	*<90 days; 90-150; 150-210; >210 and Normal LGP (annual) value
2.	Agroecological subregions of India (60 AESR) (for resource planning at regional level)	Soil sub group association (1:1 m scale)	Sub division of major physiography	arid — typic arid, hyper arid Semiarid — semiarid dry, semiarid moist Sub humid — dry, moist Humid perhumid	LGP value starting from <60 days and 30 days interval to >330 days and probability of occurrence of LGP (annual) at 50 percent level
3.	Agroecological zones at state level (for resource planning at state level)	Soil family association at (1:250,000 scale)	Landform	Bioclimate computation based on subdivision level rainfall data and PET based on pan evaporation data	LGP isolines at 15/30 days interval depending on the climate and LGP probability analysis on monthly basis
4.	Agroecological unit at district level (for resource planning at district level)	Soil series association (50,-000 scale)	Geomorphic unit	Bioclimate classification based on rainfall and pan evaporation data at block level	LGP isoline based on weekly or 10 days interval and LGP probability analysis at growth phases
5.	Agroecological unit at watershed level	Soil phase level 1:5,000 scale)	Details of geomorphic units	Effective rainfall at unit level and pan evaporation data at watershed level	LGP based on actual AWC of soil unit and LGP probability analysis at growth phases

*<90 days : *feasible for single short duration crop*
90-150 days : *suitable for one medium duration crop or single short duration crop plus relay crop*
150-210 days : *feasible for one long duration crop or two single short duration crop*
>210 days : *feasible for double cropping*

2.3 Ecoregions and Soils (Karnataka, Andhra Pradesh and Telangana, Odisha, Madhya Pradesh and Chhattisgarh, {Madhya Pradesh}, Bihar and Jharkhand {Bihar}, Maharashtra)

Soil data and its utility in land use planning and more so for agriculture have been discussed in many forums. For an effective and acceptable planning, the unit of land parcel for agro-technology transfer has also been discussed. For land use planning agro-ecology concept has been considered as a vehicle for technology transfer. Ideally, agro-ecology takes care of soil and land information while delineating different units. Therefore, information on soils need a special attention to sharpen the concept of agro-ecology.

2.3.1 Soils of Karnataka

Karnataka state covers an area of 19.1 million hectare and accounts for 5.8% of the total geographical area (TGA) of India. The state represents three major physiographic regions viz. south Deccan Plateau, the Western Ghats and the West Coast Plains with different climate, geology, and vegetation which influence a variety of soils in this state. It has a 350 km coast line which forms the western boundary. The important geological formations are Achaean group, Proterozoic, Mesozoic and Cainozoic rocks. The Achaeans are the oldest formation and covers 60% area of the state. The chief rocks are gneisses, granites, and charnockites. The climate varies from arid to semiarid in the plateau region, sub humid to humid tropical in the Ghats region and humid tropical monsoonic type in the west coast plains. The mean annual rainfall in main three regions of the state varies from a minimum of 350 mm to 5000 mm (Fig. 2.1). The mean annual temperature ranges from 20.3 °C to 27.6 °C, with the summer temperature ranging from 35 to 42 °C and winter temperature 13–23 °C. The soil moisture regime is ustic in most part of the state except Bellary, Raichur and Bijapur districts where it is dry and moisture regime is Aridic (Soil Survey Staff 2014). In west coast plains, aquic moisture regime is found in local patches. The soil temperature regime is isohyperthermic.

Based on physiography, soils, bio-climate and length of growing period (LGP), the state is divided into seven agro ecological sub regions (AESRs) (Sehgal et al. 1996). More soils and climatic information helped to revise the LGP and revise the AESRs (Mandal et al. 2014). Out of seven, nearly 80% areas in the state is under dry climate covering AESRs, 1, 2, 3, 4 and 5 (Fig. 2.2). Ecologically five types of forests are identified in this state. These are, dense evergreen, semi evergreen, moist deciduous, dry deciduous and miscellaneous.

Soils of Karnataka have been traditionally classified into soil groups namely red, laterite, black and alluvial soils. Other important soils are brown forest soils (Mollisols). The soil formation in South Deccan Plateau is influenced by parent material, topography, and climate resulting in the formation of Alfisols, Inceptisols, Entisols, Aridisols and Vertisols. In the Western Ghats Alfisols, Ultisols and Mollisols are formed by the influence of climate, vegetation and relief. Topography and parent material influence the Eastern Ghats to form Entisols and Inceptisols while in the East Coast by climate and topography forming Ultisols and Entisols. The soils belong to 7 orders, 12 suborders 27 greatgroups 47 subgroups and 96 families (Bhattacharyya et al. 2009). Alfisols are the dominant soils (28%: Fig. 2.3)

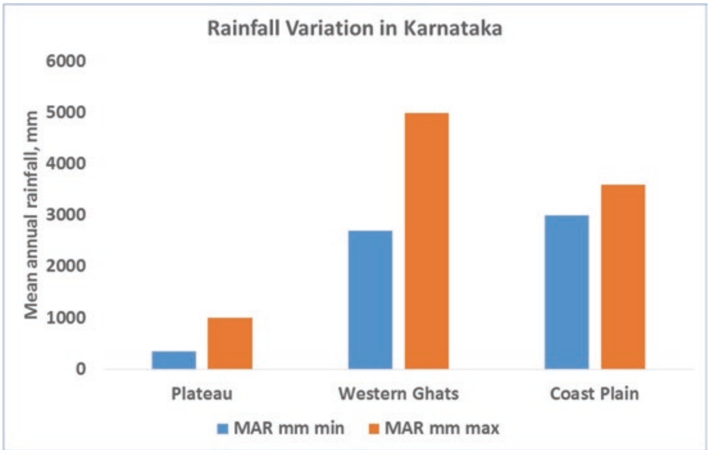

Fig. 2.1 Rainfall variations in Karnataka (min: Minimum rainfall; max: maximum rainfall)

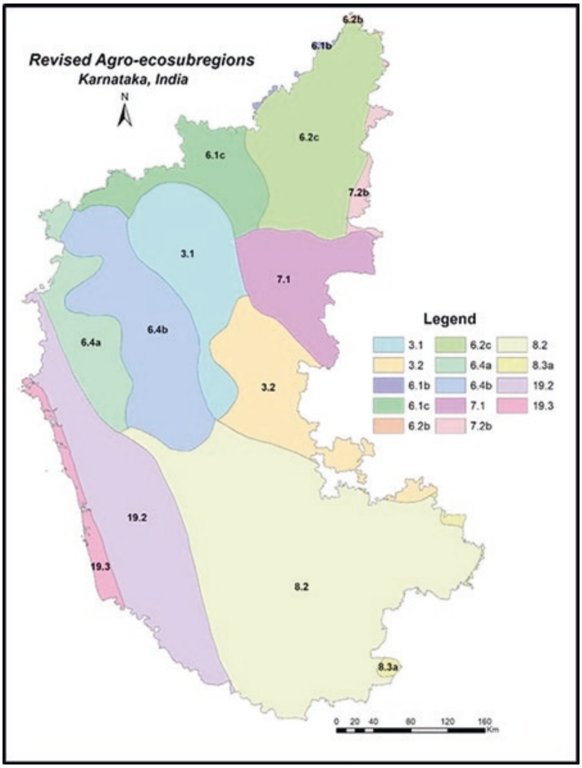

Fig. 2.2 Agro-eco sub-regions (AESRs) in Karnataka, India

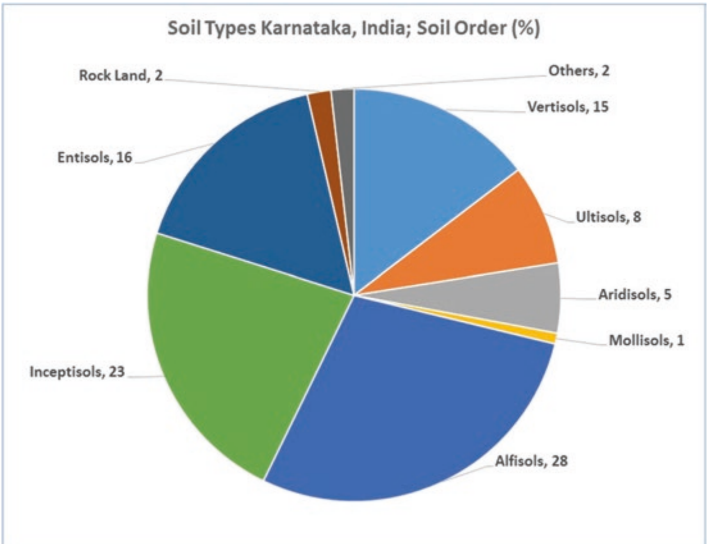

Fig. 2.3 Soil types of Karnataka, distribution of soil orders in percent

followed by Inceptisols, Entisols and Vertisols. About 2% of the total area is covered by others including rocky lands. Land use of Karnataka is governed by topography, climate, soils and food habits of people. About 53% of the state area is under cultivation (Fig. 2.4) of which 30% area is under irrigation (Anonymous 2008–2009). A representative soil of this state and its different parameters are shown in Tables 2.2 and 2.3.

2.3.2 Soils of Andhra Pradesh and Telangana

Andhra Pradesh state, located in the south eastern part of the subcontinent has an area of 162.97 lakh hectare. It is bounded by the Indian states of Tamil Nadu to the south, Karnataka to the southwest and west, Telangana to the northwest and north, and Odisha to the northeast. Andhra Pradesh has a long coastline of around 974 km. Telangana state is surrounded by Maharashtra and Chhattisgarh in the North, Karnataka in the West and Andhra Pradesh in the South and East directions and covers an area of 114.84 lakh ha. Details of land use of Telangana and Andhra Pradesh states are shown in Tables 2.4 and 2.5.

Both the states are museum of various geological formations including Achaean, Precambrian, Palaeozoic, Carboniferous, Triassic, Cretaceous, Mesozoic, Tertiary,

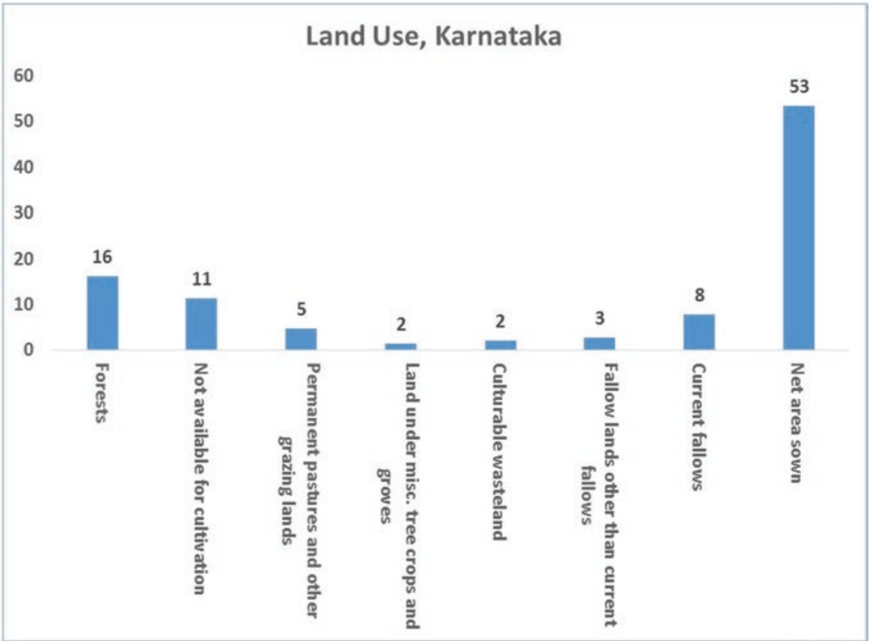

Fig. 2.4 Land use of Karnataka. (Source: Anonymous (2008–2009))

Table 2.2 Morphological properties of representative soils in the selected states

Horizon	Depth cm	Matrix colour Moist	Texture	Structure	Nodules (conca/conir/conmn) (%)	Effervescence[a] (dil HCl)	Other features	Cracks[b]
Karnataka: Achmatti: 600 m above MSL: MAR 660 mm: Very fine, smectitic, isohyperthermic Sodic Haplusterts								
Ap1	0–4	10YR 3/1	Clay	Granular	2	Strong	–	10–15 mm wide
Ap2	4–22	10YR 3/1	Clay	Sub-angular blocky and granular	5	Strong	–	10–15 mm wide
Bss1	22–54	10YR 3/1	Clay	Angular blocky	–	Strong	Intersecting slickensides	10–15 mm wide
Bss2	54–87	10YR 3/1	Clay	Angular blocky	–	Strong	Intersecting slickensides	10–15 mm wide
BCk1	87–152	10YR 4/2	Clay	Angular blocky	7	Violent	Intersecting slickensides	less than 10 mm wide
BCk2	152–170	10YR 3/1	Clay	Angular blocky	10	Violent	Slickensides	less than 10 mm wide
Andhra Pradesh: Kurnool: 254 m above MSL: MAR 740 mm: Fine, smectitic (calcareous), isohyperthermic Vertic Haplustepts								
Ap	0–18	10YR 3/2	Clay	Sub-angular blocky	–	Violent		–
Bw1	18–50	10YR 3/3	Clay	Sub-angular blocky	–	Violent	Pressure faces	–
Bss1	50–79	10YR 3/3	Clay	Sub-angular blocky	–	Violent	Non-intersecting slickensides	–
Bss2	79–109	10YR 3/3	Clay	Sub-angular blocky	–	Violent	Non-intersecting slickensides	–
Bss3	109–151	10YR 3/4	Clay	Sub-angular blocky	–	Violent	Non-intersecting slickensides	–
Telangana: Kasireddipalli: 540 m above MSL: MAR 760 mm: Fine, smectitic, isohyperthermic Typic Haplusterts								
Ap	0–8	10YR 3/2	Clay	Sub-angular blocky	Many lime nodules	Slight	–	
Bw	8–18	10YR 3/2	Clay	Sub-angular blocky	Many lime nodules	Slight	Pressure faces;	
Bss1	18–32	10YR 3.5/2	Clay	Angular blocky	Many lime nodules	Slight	Well-developed slickensides	
Bss2	32–44	10YR 3/2	Clay	Angular blocky	Many lime nodules	Strong	Well-developed slickensides	

Bss3	44–65	10YR 3/2	Clay	Angular blocky	Many lime nodules	Strong	Well-developed slickensides	
Bss4	65–87	10YR 3.5/2	Clay	Angular blocky	Many lime nodules	Strong	Well-developed slickensides	
Bss5	87–115+	10YR 4.5/4	Clay	Sub-angular blocky	Many lime nodules	Violent	Well-developed slickensides	
Odisha: Sunugarh: 18 m above MSL: MAR 1520 mm: Fine, mixed, hyperthermic Aquic Ustochrepts								
Ap	0–16	10YR 4/3	Silty clay	Massive	–	–	Prominent Mottles	20 mm wide cracks
BA	16–33	10YR 4/3	Clay	Angular blocky	–	–	Mottles	10–20 mm wide cracks
Bw1	33–58	10YR 4/2	Clay	Angular blocky	–	–	Mottles	10 mm wide cracks up to 41 cm depth
Bw2	58–81	10YR 5/2	Clay	Angular blocky	–	–	Mottles	
BC	81–150	10YR 5/1	Clay	Angular blocky	–	–	Mottles	
Bihar: Hirapatti: 60 m above MSL: MAR 1257 mm: Fine-loamy, mixed, hyperthermic family of Fluventic Haplustepts								
Ap	0–18	2.5Y 5/2 M	Silt loam	Massive		Slight		
Bw1	18–35	10YR 6/2	Silt loam	Sub-angular blocky	Iron manganese concretions	Slight		
Bw2	35–58	10YR 6/3	Silt loam	Sub-angular blocky	Iron and manganese concretions	Slight		
Bw3	58–71	10YR 6/3	Silt loam	Sub-angular blocky		slight		
Bw4	71–103	10YR 6/3	Silt loam	Sub-angular blocky		Slight		
BC	103–150	10YR 6/4	Silt loam	Massive		Slight		
Jharkhand: Pusaro: 125–500 m above MSL: MAR 1090 mm: Fine-loamy, mixed, hyperthermic Typic Paleustalfs								
A	0–9	5YR 4/6	Loam	Massive	Iron-manganese concretions	–		–
AB	9–30	5YR 4/4	Loam	Sub-angular blocky	Iron-manganese concretions	–		–

(continued)

Table 2.2 (continued)

Horizon	Depth cm	Matrix colour Moist	Texture	Structure	Nodules (conca/conir/conmn) (%)	Effervescence[a] (dil HCl)	Other features	Cracks[b]
BA	30–48	5YR 4/6	Clay loam	Sub-angular blocky	Iron-manganese concretions	–		–
Bt1	48–73	5YR 5/6	Clay loam	Sub-angular blocky	Iron-manganese concretions	–	Thick clay cutans	–
Bt2	73–91	5YR 5/6	Clay loam	Sub-angular blocky	Iron-manganese concretions	–	Thick clay cutans	–
Bt3	91–114	5YR 4/6	Clay loam	Sub-angular blocky	Iron-manganese concretions	–	Thick clay cutans	–
Bt4	114–141	5YR 4/6	Clay loam	Sub-angular blocky	Iron-manganese concretions	–	Thick clay cutans	–
BC	141–186	5YR 5.5/6	Clay	Angular blocky	Iron-manganese concretions	–	Thick clay cutans	–
Madhya Pradesh, Arsia: 190 m above MSL: MAR 960 mm: Fine, smectitic, hyperthermic Typic Haplusterts								
Ap	0–20	7.5YR 3/2	Clay	Granular		Slight		20–30 mm wide cracks
B	20–73	7.5YR 3/2	Clay	Sub-angular blocky		Slight	Shiny pressure faces	20–25 mm wide cracks
2Bss	73–101	7.5YR 3/2	Clay loam	Angular blocky		Strong	Wedge-shaped peds with shiny pressure faces	10–20 mm wide cracks
2BC	101–118	7.5YR 5/4	Clay loam	Sub-angular blocky	5% lime nodules	Strong		
Chhattisgarh, Chaugel: 500–600 m above MSL: MAR 1400 mm: Fine-loamy, mixed, isohyperthermic Plinthustalfs								
A	0–11	10YR 4/3	Sandy clay loam	Sub-angular blocky	–	–	–	–
Bw1	11–34	10YR 5/6	Sandy clay loam	Sub-angular blocky	–	–	Thin clay cutans	–

Bw2	34–49	10YR 5/6	Sandy clay loam	Sub-angular blocky	–	–	Thin clay cutans	–
Bw3	49–71	10YR 5/6	Sandy clay loam	Sub-angular blocky	–	–	Thin clay cutans	–
Btc1	71–104	10YR 5/4	Sandy clay	Sub-angular blocky	–	–	Thin clay cutans	–
Btc2	104–143	10YR 6/6	Sandy clay	Sub-angular blocky	–	–	Thin clay cutans	–
BC1	143–159	10YR 6/6	Sandy clay loam	Sub-angular blocky	–	–	Thin clay cutans	–
BC2	159–172	10YR 6/6	Sandy clay loam	Sub-angular blocky	–	–	Thin clay cutans	–
Maharashtra: Linga: 300–320 m above MSL: MAR 1125 mm: Very fine, smectitic, hyperthermic Udic Haplusterts								
Ap	0–16	10YR 3/2	Clay	Sub-angular blocky		Slight		
Bss1	16–47	10YR 3/2	Clay	Angular blocky	Lime nodules	Strong	Intersecting slickensides	
Bss2	47–84	10YR 3/2	Clay	Angular blocky	Lime nodules	Strong	Intersecting slickensides	
Bss3	84–117	10YR 3/2	Clay	Angular blocky	Lime nodules	Strong	Intersecting slickensides	
BC	117–140	2.5Y 4/2	Clay	Angular blocky	Lime nodules	Violent	Intersecting slickensides	

[a]Matrix effervescence observed in 42–150 cm
[b]Cracks ~ 0.5 mm wide up to 20 cm

Table 2.3 Physical and chemical properties of representative soils in the selected states

Horizon	Depth cm	Sand %	Silt %	Clay %	Coarse fragments > 2 mm % of whole soil	Organic carbon (%)	Carbonate as $CaCO_3$ < 2 mm (%)	pH (1:2.5) H_2O	CEC NaOAc pH 8.2 cmol (p+)kg^{-1}	Exchangeable sodium (%)	Base saturation NaOAc (%)
Karnataka: Achmatti: 600 m above MSL: MAR 660 mm: Very fine, smectitic, isohyperthermic Sodic Haplusterts											
Ap1	0–4	23.5	21.9	54.6	12	1.25	16.2	8.3	59.4	4	109
Ap2	4–22	22.3	19.1	58.6	12	1.21	13.6	8.6	60.5	7	111
Bss1	22–54	13.2	18.8	68.0	5	1.27	12.8	8.7	71.5	14	111
Bss2	54–87	9.8	20.7	69.5	8	0.78	15.2	8.8	67.4	17	110
BCk1	87–152	9.8	20.1	70.1	13	0.71	15.0	8.9	66.1	20	114
BCk2	152–170	10.0	19.7	70.3	9	0.48	13.7	8.4	66.7	27	127
Andhra Pradesh: Kurnool: 254 m above MSL: MAR 740 mm: Fine, smectitic (calcareous), isohyperthermic, Vertic Haplustepts											
Ap	0–18	32.1	26.2	41.7	–	0.78	16	9.1	–	23	–
Bw1	18–50	17.3	28.0	54.7	–	0.37	20	9.8	–	37	–
Bss1	50–79	14.1	27.0	58.9	–	0.32	18	9.6	–	33	–
Bss2	79–109	12.2	28.2	59.6	–	0.16	17	9.6	–	33	–
Bss3	109–151	11.6	26.3	62.1	–	0.23	16	9.5	–	31	–
Telangana: Kasireddipalli: 540 m above MSL: MAR 760 mm: Fine, smectitic, isohyperthermic, Typic Haplusterts											
Ap	0–8	23.3	29.6	47.1	–	0.65	4.37	8.0	42.6	3	108
Bw	8–18	22.6	25.6	51.8	–	0.58	4.21	8.1	49.2	2	98
Bss1	18–32	21.2	25.9	52.9	–	0.42	4.14	8.2	50.4	2	106
Bss2	32–44	20.4	25.0	54.6	–	0.34	4.88	8.2	48.7	2	110
Bss3	44–65	17.0	24.4	58.6	–	0.3	4.25	8.1	57.4	2	94
Bss4	65–87	14.3	24.9	60.8	–	0.27	4.14	8.2	54.7	2	95
Bss5	87–115+	13.0	22.4	64.6	–	0.15	6.09	8.1	54.7	3	95
Odisha: Sunugarh: 18 m above MSL: MAR 1520 mm: Fine, mixed, hyperthermic Aquic Ustochrepts											
Ap	0–16	6.4	43.1	50.5		0.60	nd	6.2	30.8	8	70
BA	16–33	6.0	37.5	56.5		0.31	nd	6.4	30.8	8	68

Bw1	33–58	5.4	37.1	57.5		0.30	nd	6.5	31.5	8	62
Bw2	58–81	6.0	37.5	56.5		0.35	nd	6.6	31.5	8	66
BC	81–150	6.8	39.7	53.5		0.27	nd	6.7	30.8	8	71
Bihar: Hirapatti: 60 m above MSL: MAR 1257 mm: Fine-loamy, mixed, hyperthermic family of Fluventic Haplustepts											
Ap	0–18	9.2	70.9	19.9		1.14	3.8	7.9	9.0		94
Bw1	18–35	2.4	77.5	20.1		0.40	3.7	8.0	7.5		97
Bw2	35–58	0.8	75.3	23.9		0.51	4.0	8.0	9.6		97
Bw3	58–71	0.6	78.0	21.4		0.42	3.5	8.0	8.8		96
Bw4	71–103	12.8	62.2	25.0		0.42	3.1	7.7	10.3		92
BC	103–150	30.2	54.5	15.3		0.32	2.9	7.3	6.9		85
Jharkhand: Pusaro: 125–500 m above MSL: MAR 1090 mm: Fine-loamy, mixed, hyperthermic Typic Paleustalfs											
A	0–9	51.6	28.5	19.9	Tr	0.26		4.3	8.5	2	55
AB	9–30	43.7	29.7	26.6	Tr	0.23		5.0	8.8	1	70
BA	30–48	40.2	28.0	31.8	3	0.13		5.7	9.1	1	76
Bt1	48–73	40.8	26.7	32.5	3	0.10		5.9	9.6	2	90
Bt2	73–91	40.4	25.9	33.7	2	0.10		5.6	10.4	1	86
Bt3	91–114	42.1	24.0	33.9	5	0.08		5.7	11.4	1	82
Bt4	114–141	36.7	25.7	37.6	2	0.07		5.6	13.3	1	80
BC	141–186	33.6	25.8	40.6	2	0.05		5.5	14.3	2	82
Chhattisgarh, Chaugel: 500–600 m above MSL: MAR 1400 mm: Fine-loamy, mixed, isohyperthermic Plinthustalfs											
A	0–11	62.6	8.1	29.3	4	0.70		5.4	10.5	–	66
Bw1	11–34	60.3	11.6	28.1	2	0.60		5.0	13.6	–	51
Bw2	34–49	61.6	10.3	28.1	26	0.44		4.9	14.2	–	49
Bw3	49–71	59.8	9.3	30.9	8	0.38		4.9	17.7	–	36
Btc1	71–104	47.1	10.5	42.4	31	0.41		4.8	19.8	–	48
Btc2	104–143	47.1	11.3	41.6	7	0.28		5.1	23.3	–	43
BC1	143–159	51.4	14.3	34.3	37	0.16		5.3	16.2	–	57

(continued)

Table 2.3 (continued)

Horizon	Depth cm	Sand %	Silt %	Clay %	Coarse fragments > 2 mm % of whole soil	Organic carbon (%)	Carbonate as $CaCO_3$ < 2 mm (%)	pH (1:2.5) H_2O	CEC NaOAc pH 8.2 cmol (p+)kg^{-1}	Exchangeable sodium (%)	Base saturation NaOAc (%)
BC2	159–172	56.7	8.4	34.9	38	0.17		5.4	13.9	–	60
Madhya Pradesh, Arsia: 190 m above MSL: MAR 960 mm: Fine, smectitic, hyperthermic Typic Haplusterts											
Ap	0–20	20.3	30.4	49.3	13	0.27	2.0	7.5	45.2	6	96
B	20–73	20.4	29.5	50.1	13	0.17	1.0	7.4	46.2	10	93
2Bss	73–101	31.1	36.4	32.5	13	0.15	12.5	7.6	30.6	8	95
2BC	101–118	34.2	34.4	31.4	13	0.15	11.5	7.8	30.0	8	98
Maharashtra: Linga: 300–320 m above MSL: MAR 1125 mm: Very fine, smectitic, hyperthermic Udic Haplusterts											
Ap	0–16	4.8	20.6	74.6	2	0.51	1.9	8.3	59.3	8	8
Bss1	16–47	5.5	20.0	74.5	3	0.47	4.0	8.1	56.0	8	8
Bss2	47–84	9.7	16.5	73.8	4	0.42	5.6	8.1	64.2	7	7
Bss3	84–117	10.3	15.1	74.6	4	0.49	6.5	8.1	69.4	7	7
BC	117–140	10.1	19.0	70.9	8	0.27	8.5	8.1	65.1	6	6

Table 2.4 Land use and other details of Telangana sate, India

Sl No	Particulars	Lakh[a] ha	
1.	Total geographical area	114.84	
2.	Forest	27.43	23.9
3.	Barren and uncultivable land	6.15	5.4
4.	Land put to non-agri. uses		
5.	Water logged area	0.06	0.1
6.	Social forestry	0.07	0.1
7.	Land under still water	2.46	2.1
8.	Others	6.36	5.5
9.	Total Land put to Non-Agriculture Use (TLPNAU)	8.95	7.8
10.	Culturable waste	1.78	1.5
11.	Permanent pastures and other grazing lands	3.01	2.6
12.	Land under misc. tree crops, groves not included in net area sown	1.14	1.0
13.	Other fallow lands	7.17	6.2
14.	Current fallow lands	9.6	8.4
15.	Gross area sown	62.88	54.8
16.	Net area sown (including fish culture)	49.61	43.2
17.	Area sown more than once	13.27	11.6
18.	No. of farm holdings (Lakh Nos)	55.54	
19.	Average farm holding size (Ha)	1.12	
20.	Average annual rainfall (in mm)	906.8	
21.	Net irrigated area	17.74	15.4
22.	Gross irrigated area	31.64	27.6
	Cropping intensity (%)	127	
	Irrigation intensity (%)	138	

Source: Anonymous (2013–2014)
[a]10 lakh =1 million

Table 2.5 Land use in Andhra Pradesh, India

Sl No.	Particulars	*Lakh ha*[b]	*% of TGA*
1.	TGA	162.97	
2.	Forest	36.88	23
3.	Barren and uncultivable land	13.45	8
4.	Land put to non-agri. uses	20.55	13
5.	Culturable waste	4.14	3
6.	Permanent pastures and other grazing lands	2.09	1
7.	Land under misc. (Tree crops, groves)	1.55	1
8.	Other fallow lands	9.4	6
9.	Current fallow lands	14.43	9
10.	Net area sown[a]	60.48	37

[a]Net Area Sown under (i) Crops is 58.94 lakh ha (ii) Fish Ponds 1.54 lakh ha. (Source: Anonymous 2015–2016)
[b]10 lakhs = 1 million

Miocene, Pliocene, Pleistocene and Recent. The states represent a transition from tropical to subtropical monsoonic climate of semi-arid to arid in Telangana and humid to sub humid in the coastal regions. The average annual rainfall varies from 690 to 860 mm. The red soils are most common in both the states (Fig. 2.5) and most of these soils are categorised either as Alfisols and Inceptisols.

2.3.3 *Soils of Odisha*

The state of Odisha is surrounded by West Bengal, and Jharkhand to the north, Andhra Pradesh in the south, Chhattisgarh to the west and Bay of Bengal in the east. Odisha has a coastline of 485 km along the Bay of Bengal. The state covers an area

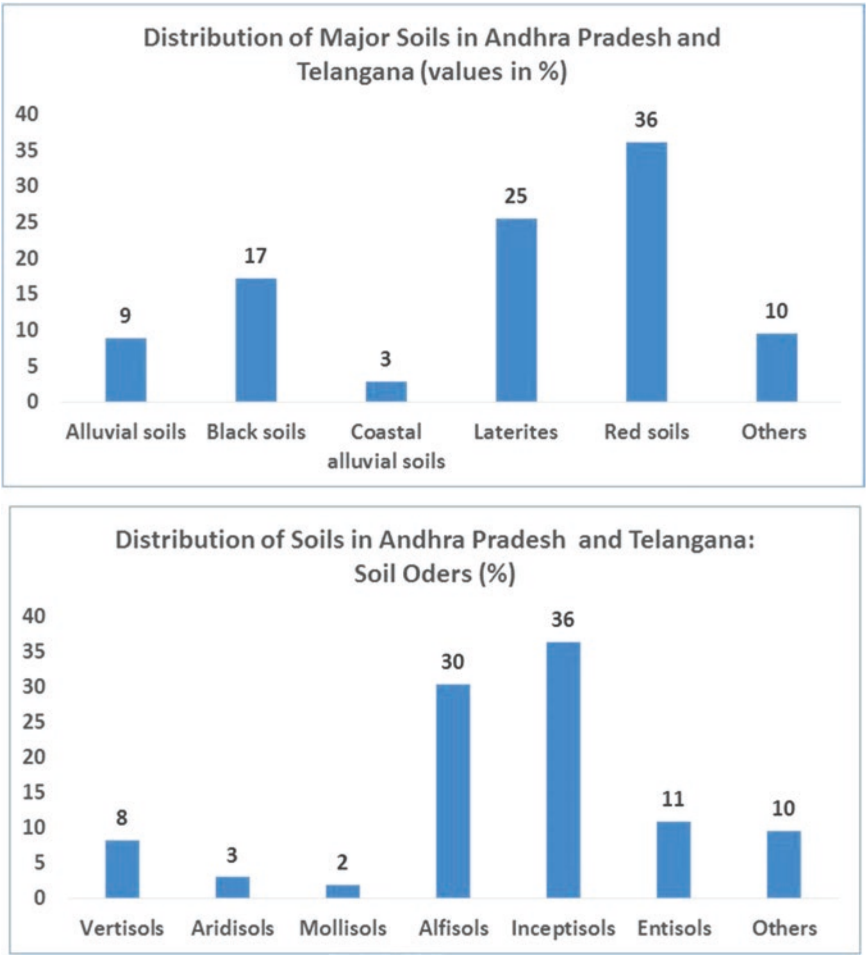

Fig. 2.5 Soils in Andhra Pradesh and Telangana in India

of 15.57 million hectares. Based on stratigraphy, tectonic history and relief features along with erosional processes, the state presents four broad physical regions (i) northern plateau, (ii) central table land, (iii) Eastern Ghats, and (iv) east coast plains. The present day landforms are the result of several cycles of denudation, sedimentation and igneous activities. The geological sequences responsible for the present topography are the Achaean to Pleistocene and Recent age. A group of lime stones, sandstones, and slates occurring in the bed of northern hilly regions belongs to Miocene age. Larger deposits of laterite are of the Pleistocene origin. The Deltaic sediments of the Mahanadi, Brahmini, and other rivers cover the Balasore, Cuttack and Puri districts of the coastal tract. The changing pattern of rainfall in the state causes both drought and flood. The state receives south west monsoon from June to September. The average annual rainfall is 1481 mm. The rainfall variation (Fig. 2.6), potential evapo-transpiration (PE), actual evapo-transpiration (AE) and soil data help estimating the length of growing period (LGP) to group the state into 6 agro-ecological sub regions (11.0,12.1,12.2,12.3,18.4, and 18.5) (Sehgal et al. 1992). The mean minimum temperature is ~12 °C and maximum of about 42 °C. The soils of this state belong to 4 orders, 9 suborders, 15 greatgroups, 35 sub-groups and 93 families (Bhattacharyya et al. 2009). Figures 2.7 and 2.8 show the distribution of different soils in Odisha. The major soils in the state are alluvial, black, coastal alluvial, laterites, red and hills. The land use of the state is shown in Fig. 2.9.

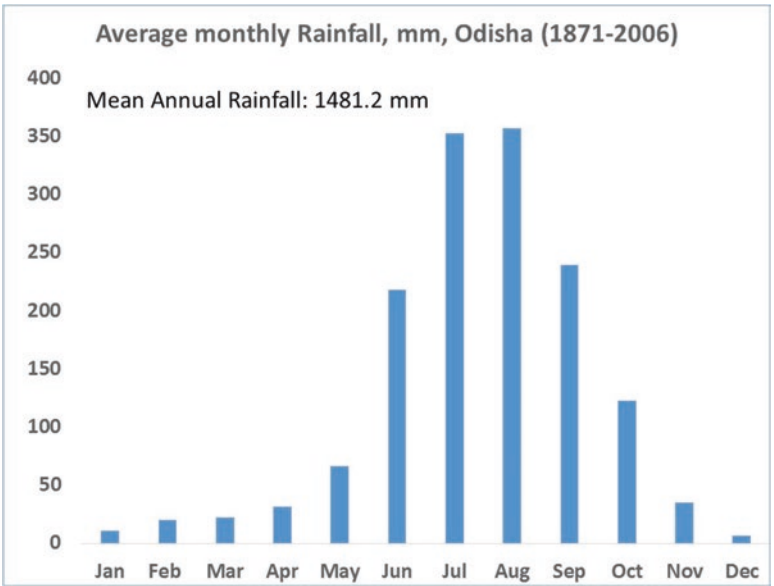

Fig. 2.6 Rainfall distributions in Odisha. (Source: Patra et al. 2012)

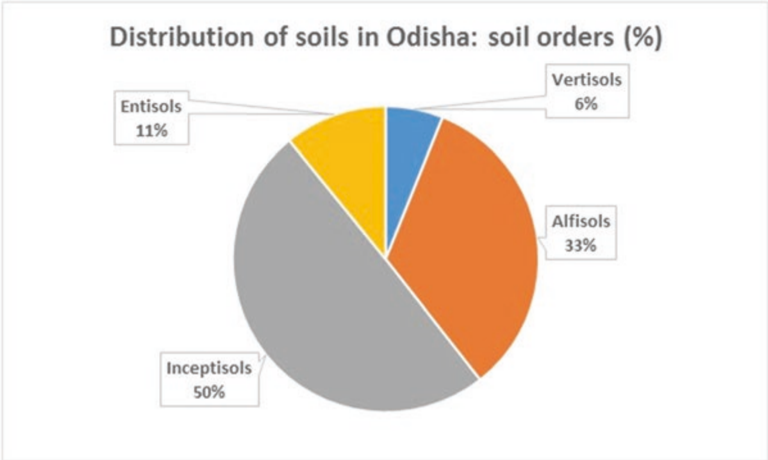

Fig. 2.7 Distribution of soil orders in Odisha

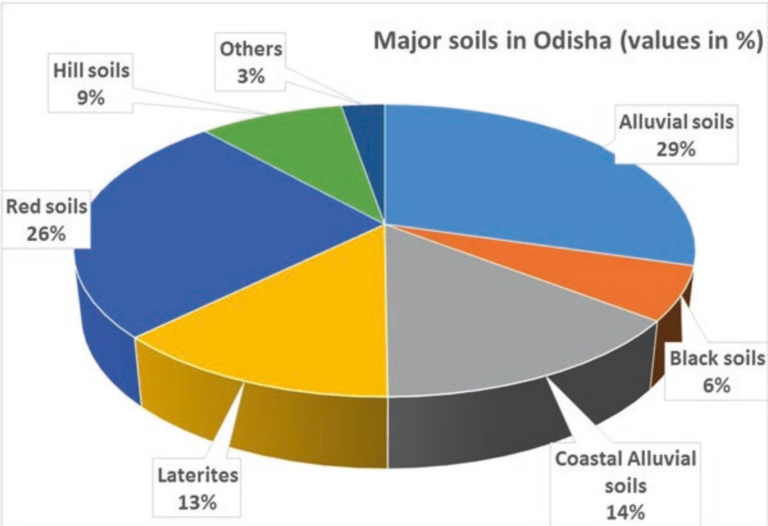

Fig. 2.8 Distribution of major soils in Odisha (others include rock outcrops and water bodies)

2.3.4 Soils of Bihar and Jharkhand

Bihar is situated in eastern part of India and is a part of the Indo-Gangetic Plains, India. It is contiguous with Uttar Pradesh to its west, Nepal to the north, the northern part of West Bengal to the east, and with Jharkhand to the south. The land use of Bihar is shown in Fig. 2.10. Jharkhand is situated in eastern part of India. The state shares its border with the states of Bihar to the north, Uttar Pradesh to the north

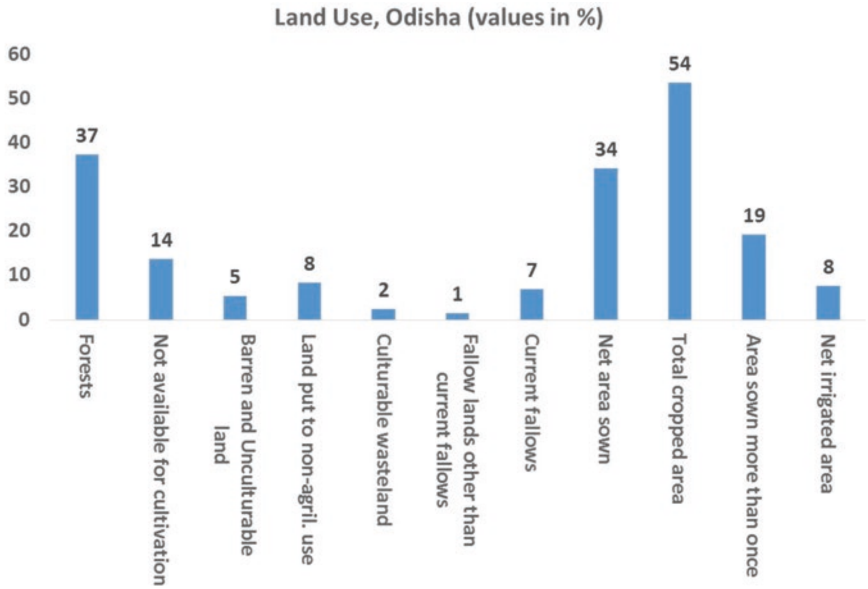

Fig. 2.9 Land use, Odisha. (Source: Dash et al. 2017)

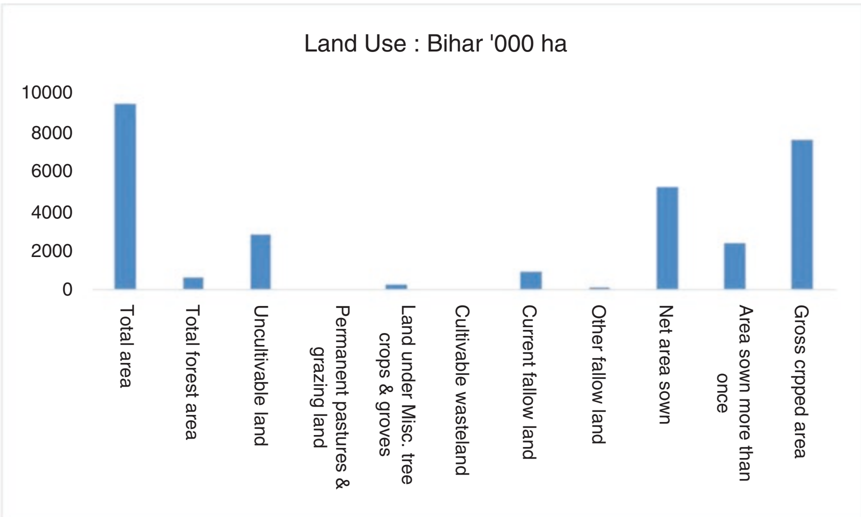

Fig. 2.10 Land use, Bihar. (Source: Anonymous 2015–2016)

west, Chhattisgarh to the west, Odisha to the south and West Bengal to the east. The land use of Jharkhand is shown in Fig. 2.11. The soils of Bihar and Jharkhand belong to 4 orders, 9 suborders, 19 greatgroups, 40 subgroups and 79 families (Bhattacharyya et al. 2009). Figures 2.12 and 2.13 show the distribution of different soils in these states. The major soils in the state are alluvial, black, and red.

2.3.5 Soils of Madhya Pradesh and Chhattisgarh

Madhya Pradesh (MP) is situated in central India and is a part of the peninsular plateau of India. It is bordered in the northeast by Uttar Pradesh, to its southeast by Chhattisgarh, to its south by Maharashtra, Gujarat to the west, and to its northwest lies Rajasthan. The Narmada Son valley defines its topography. Madhya Pradesh is positioned in the heart of India and spans an area of 30.8252 million ha. The land use of Madhya Pradesh is shown in Fig. 2.14.

Chhattisgarh is bounded by southern Jharkhand and Odisha in the east, Madhya Pradesh and Maharashtra in the west, Uttar Pradesh and western Jharkhand in the north and Andhra Pradesh in the south. Out of the geographical area of 13.79 million hectares, gross cropped area is about 35% of the total geographical area. *Kharif* (rainy season) is the main cropping season. Rice is the predominant crop of the state. Other important crops are maize, wheat, niger, groundnut and pulses. The state has one of the biggest collections of rice germplasm. Horticulture crops are grown in an

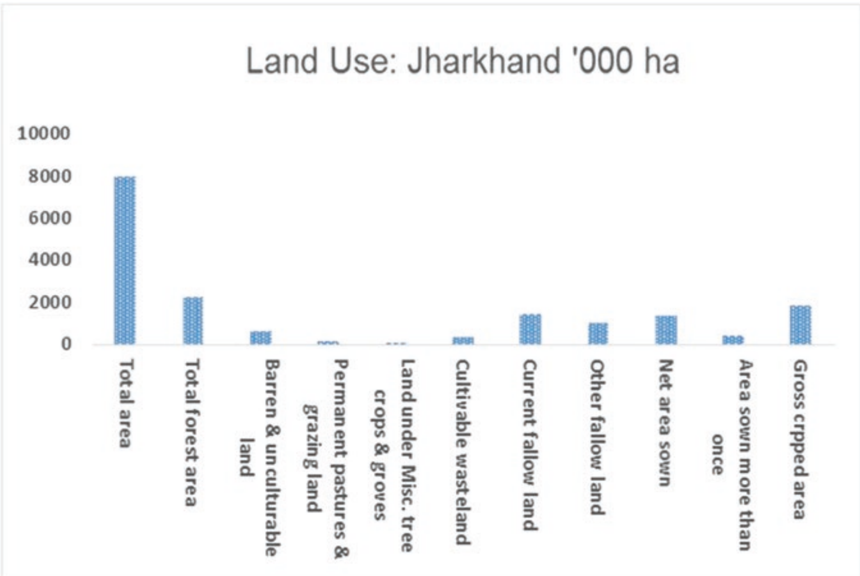

Fig. 2.11 Land use, Jharkhand. (Source: Anonymous 2015–2016)

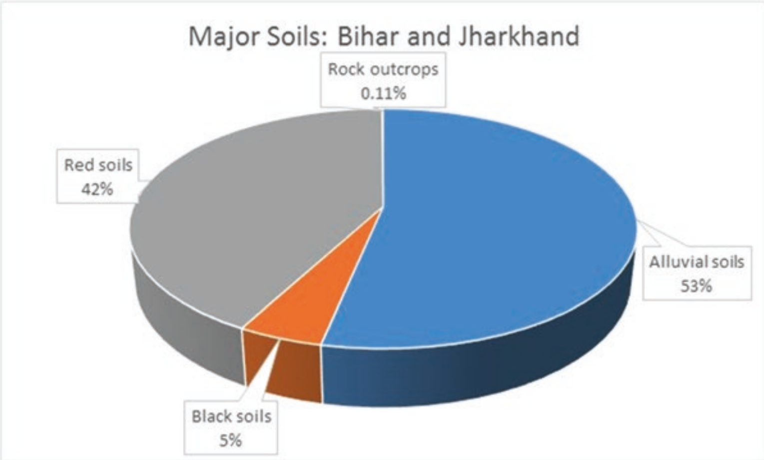

Fig. 2.12 Distribution of major soils in Madhya Pradesh and Chhattisgarh (others include rock outcrops and water bodies)

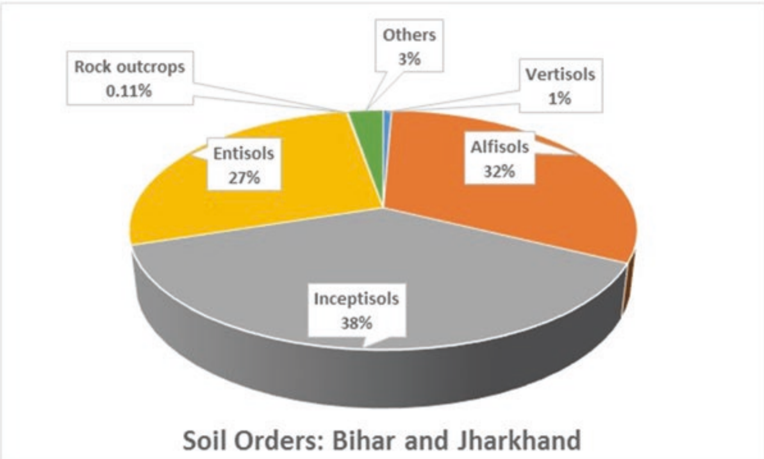

Fig. 2.13 Distribution of soil orders in Bihar and Jharkhand

area of about 540 thousand hectares. The state has 18.09 lakh hectare irrigated area. The land use of Chhattisgarh is shown in Fig. 2.15.

The soils of Madhya Pradesh and Chhattisgarh belong to 5 orders, 8 suborders, 11 greatgroups, 26 subgroups and 176 families (Bhattacharyya et al. 2009). Figures 2.16 and 2.17 show the distribution of different soils in these states. The major soils in the state are alluvial, black, and red.

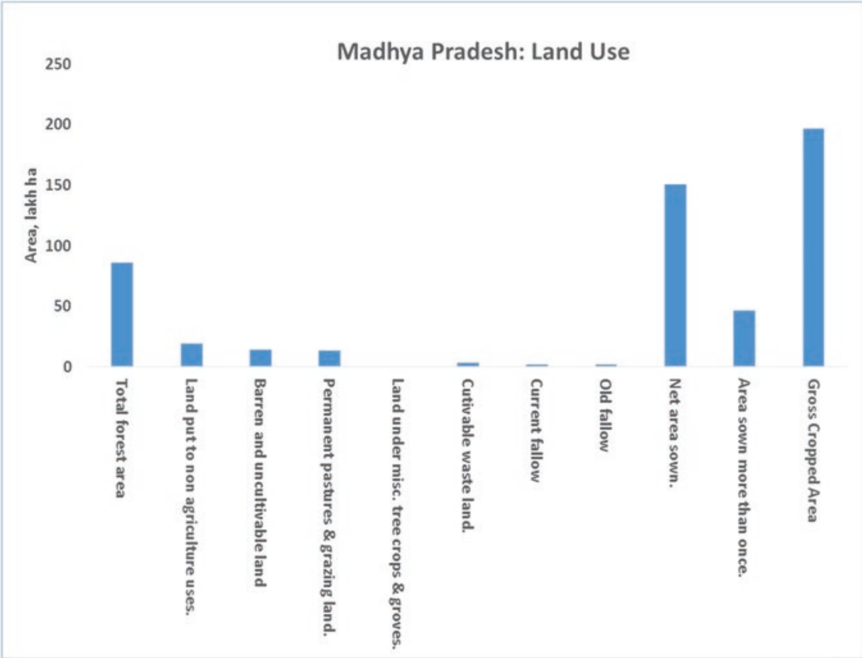

Fig. 2.14 Land use, Madhya Pradesh. (Source: Anonymous 2015–2016)

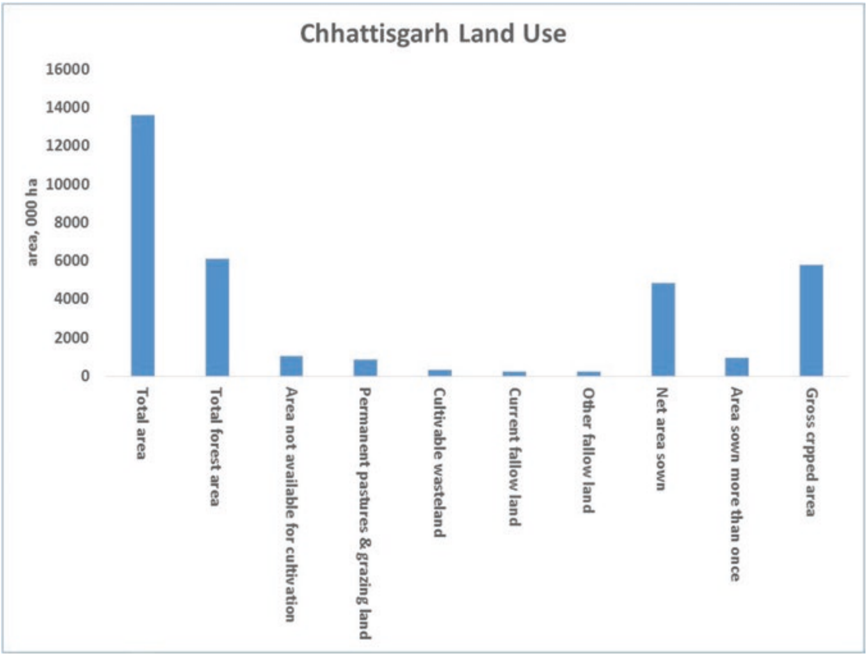

Fig. 2.15 Land use, Chhattisgarh. (Source: Anonymous 2015–2016)

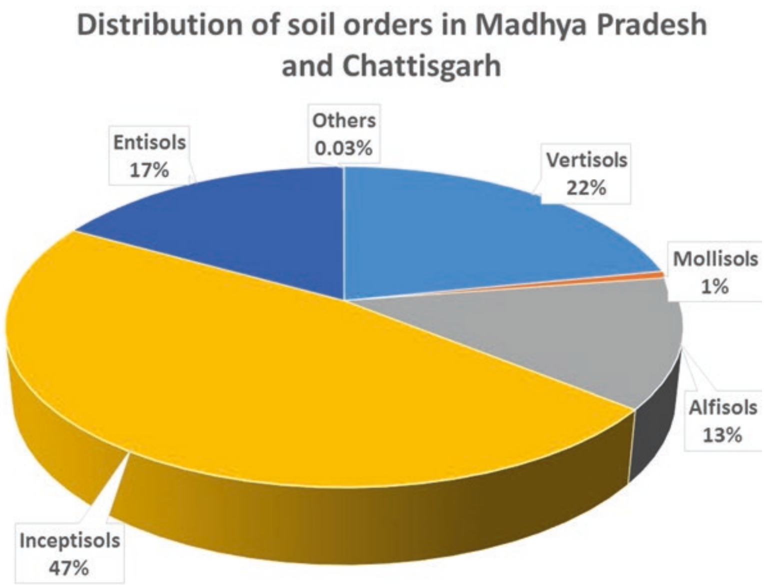

Fig. 2.16 Distribution of soil orders in Madhya Pradesh and Chhattisgarh

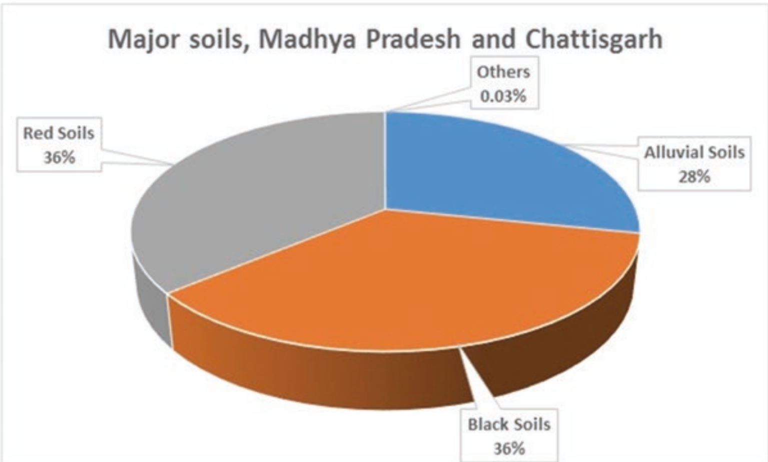

Fig. 2.17 Distribution of major soils in Madhya Pradesh and Chhattisgarh (others include rock outcrops and water bodies)

2.3.6 Soils of Maharashtra

Maharashtra is a state in the western peninsular region of India occupying a substantial portion of the Deccan Plateau. Maharashtra is bordered by the Arabian Sea to the west, the Indian states of Karnataka and Goa to the south, Telangana to the southeast and Chhattisgarh to the east, Gujarat and Madhya Pradesh to the north, and the Indian union territory of Dadra and Nagar Haveli and Daman and Diu to the northwest. The land use of Maharashtra is shown in Fig. 2.18

The soils of Maharashtra belong to 5 orders, 7 suborders, 8 great groups, 18 subgroups and 95 families (Bhattacharyya et al. 2009). Figures 2.19 and 2.20 show the distribution of different soils in these states. The major soils in the state are alluvial, black, and red.

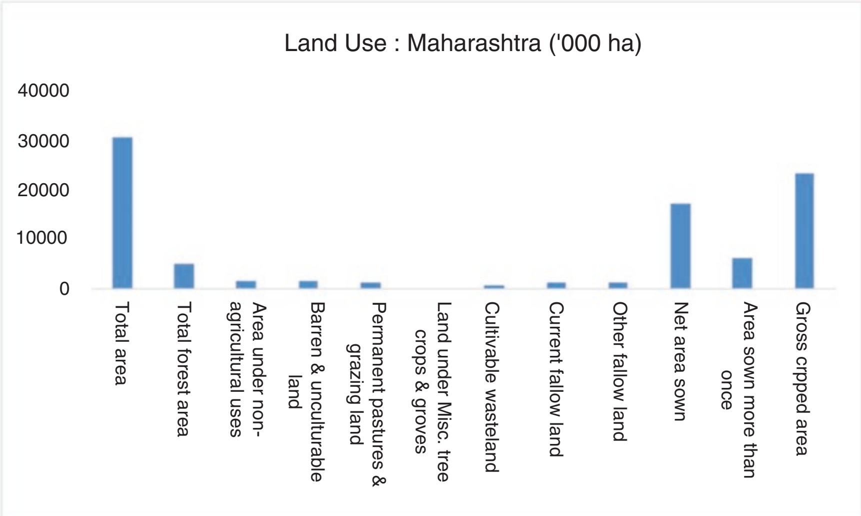

Fig. 2.18 Land use, Maharashtra. (Source: Anonymous 2015–2016)

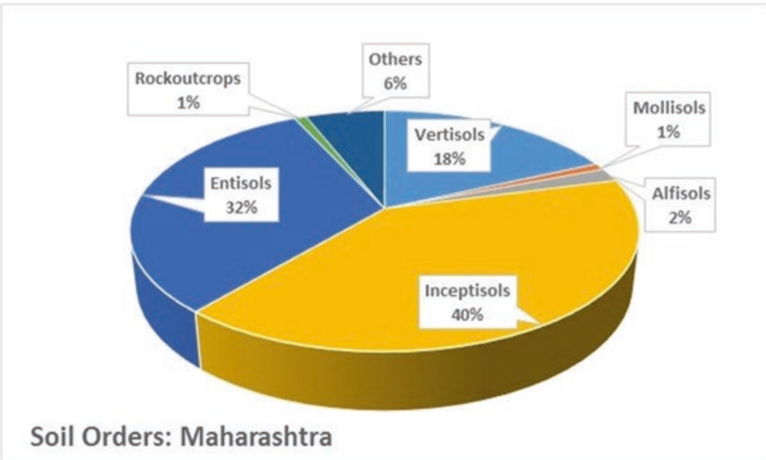

Fig. 2.19 Distribution of soil orders in Maharashtra

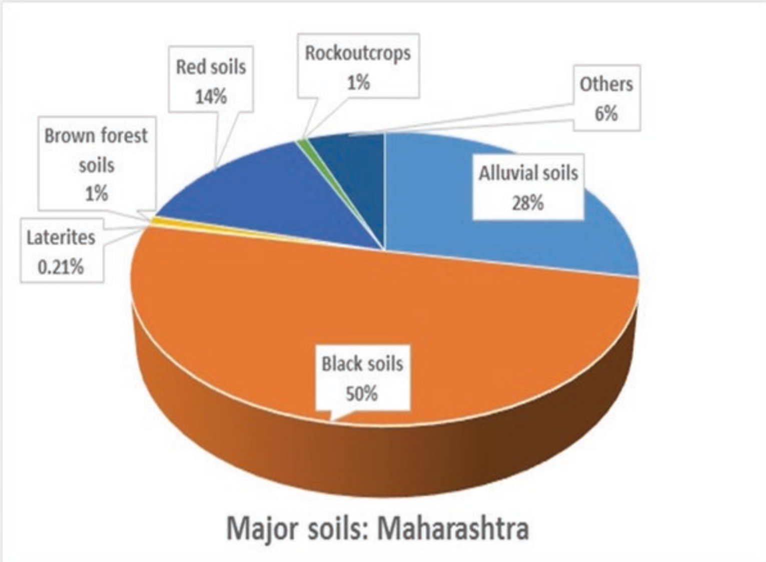

Fig. 2.20 Distribution of major soils in Maharashtra

2.4 Moisture Regimes and the Target Regions

2.4.1 Soil Moisture Regime

The term "soil moisture regime" refers to the presence or absence either of groundwater or of water held at a tension of less than 1500 kPa in the soil at different times of the year. Water held at a tension of 1500 kPa or more is not available to keep most mesophytic plants alive. Soil is considered moist when it is at moisture tension of < 1500 kPa (15 bar) and dry when the tension is ≥ 1500 kPa in the soil moisture control section (SMCS) (Figs. 2.21 and 2.22). The limits of SMCS are determined by the soil depth. Soil moisture regime is controlled by the soil parameters, most important of which, is soil texture. The textural class (Fig. 2.22) in terms of clay content and its quality fix the limit of soil moisture available for plants and trees.

Under natural conditions soils experience two different types of soil moisture regimes namely (i) saturated, and (ii) unsaturated. A soil may be continuously moist in some or all horizons either throughout the year or for some part of the year. It may be either moist in winter or dry in summer or the reverse. In the Northern Hemisphere, summer refers to June, July, and August and winter refers to December, January, and February (Soil Survey Staff 2014). The soil moisture regimes are defined in terms of the level of groundwater and in terms of the seasonal presence or absence of water held at a tension of less than 1500 kPa. There are five different classes of soil moisture regime viz. aquic, aridic or torric, udic, ustic, and xeric (Soil Survey Staff 2014).

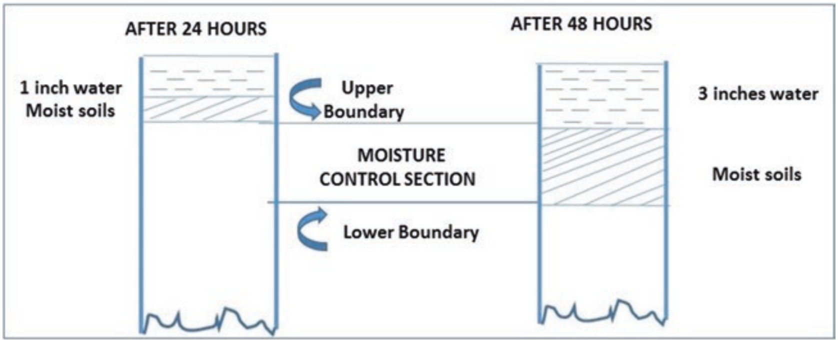

Fig. 2.21 Schematic diagram showing upper and lower boundaries of soil moisture control section (SMCS)

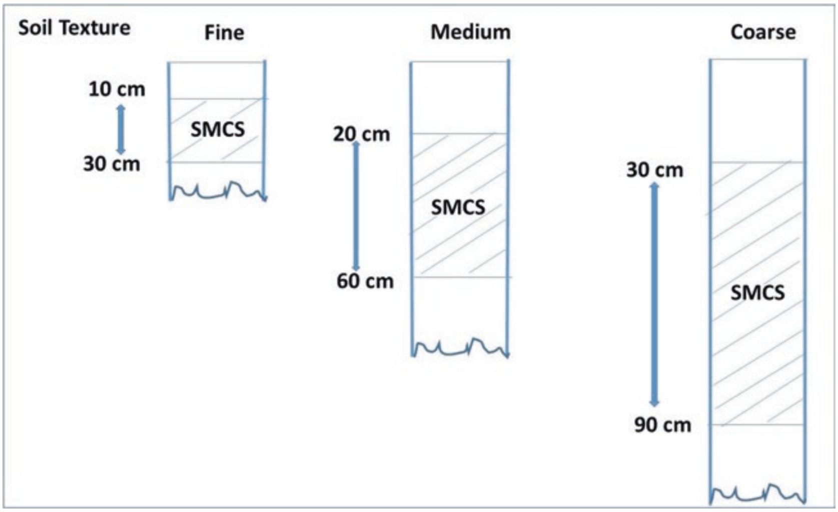

Fig. 2.22 Schematic diagram showing variation in soil moisture control section (SMCS) in different soil textures (Fine: fine silty to clayey), medium (fine loamy to coarse loamy) and coarse (sandy)

2.4.2 Soil Moisture Regimes in the Target Regions

The target states are Karnataka, Andhra Pradesh, Telangana, Odisha, Madhya Pradesh, Chhattisgarh, Madhya Pradesh, Bihar, Jharkhand, and Maharashtra. Mostly the drier areas of these states are selected for the present study except a few exceptions. The moisture regimes of these states belong to aquic, udic, ustic and aridic as detailed (Table 2.6; Figs. 2.23, 2.24, 2.25, 2.26, 2.27 and 2.28).

Table 2.6 Classes of soil moisture regime in the target states and their distribution in target states

States	Moisture regimes				
	Aquic	Udic	Ustic	Aridic	Torrid
Karnataka			17795.99	545.86	137.38
Andhra Pradesh and Telangana	122.63		23867.97	810.06	77.89
Odisha	3786.31		11146.13		
Madhya Pradesh & Chhattisgarh	12.9		43659.67		
Bihar & Jharkhand	5749.64	233.06	10916.16		
Maharashtra	108.07		28536.58		

Aquic: Aquic (L. aqua, water) soil moisture regime is a reducing regime in a soil that is virtually free of dissolved oxygen because it is saturated by water
Udic: Udic (L. udus, humid) soil moisture regime is one in which the soil moisture control section is not dry in any part for as long as 90 cumulative days in normal years
Ustic: Ustic (L. ustus, burnt; implying dryness) soil moisture regime is intermediate between the aridic regime and the udic regime
Aridic and torric (L. aridus, dry, and L. torridus, hot and dry): In the aridic (torric) soil moisture regime, the moisture control section is, in normal years: Moist in some or all parts for less than 90 consecutive days when the soil temperature at a depth of 50 cm below the soil surface is above 8 °C (Soil Survey Staff 2014)
Values in ‘000 ha

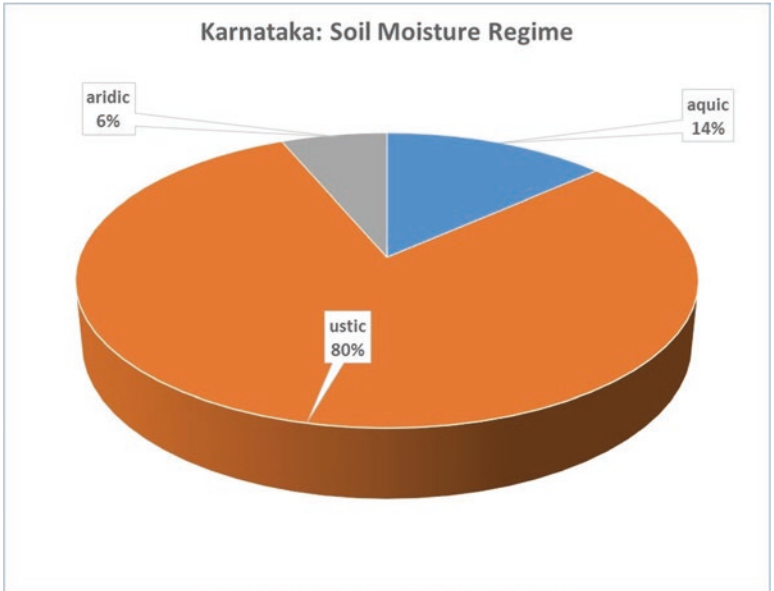

Fig. 2.23 Soil moisture regime in Karnataka

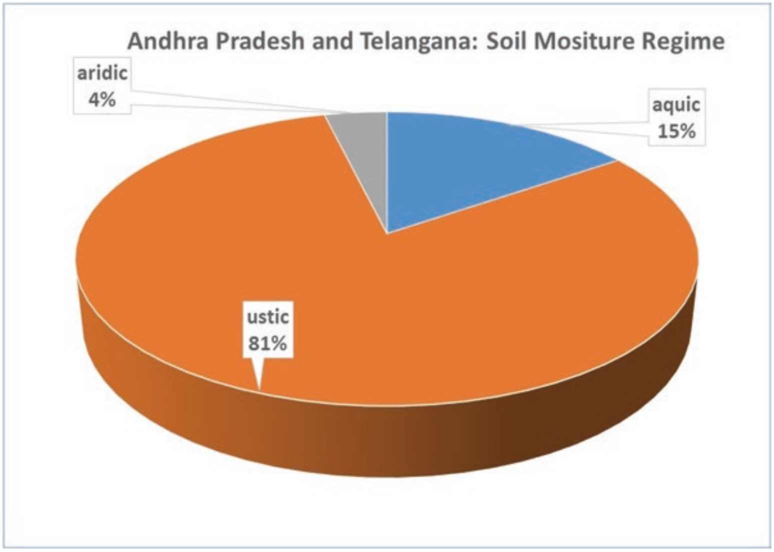

Fig. 2.24 Soil moisture regime in Andhra Pradesh and Telangana

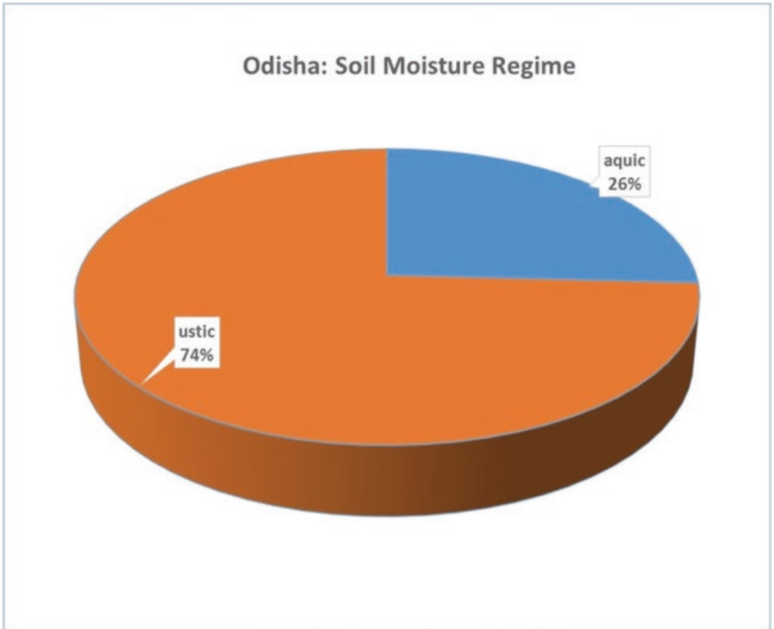

Fig. 2.25 Soil moisture regime in Odisha

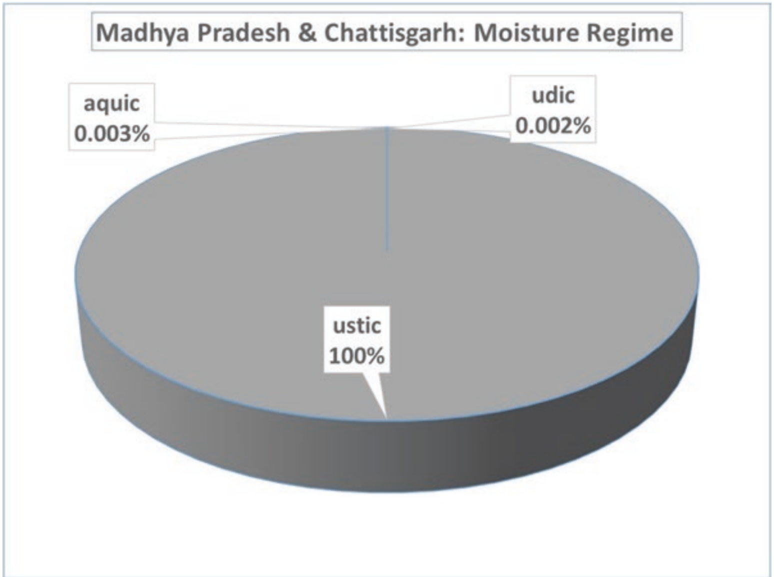

Fig. 2.26 Soil moisture regime in Madhya Pradesh and Chhattisgarh

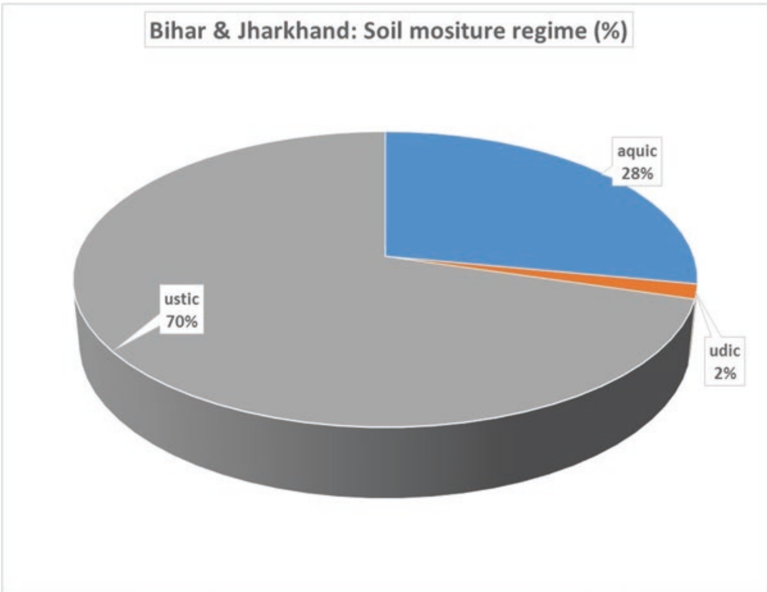

Fig. 2.27 Soil moisture regime in Bihar and Jharkhand

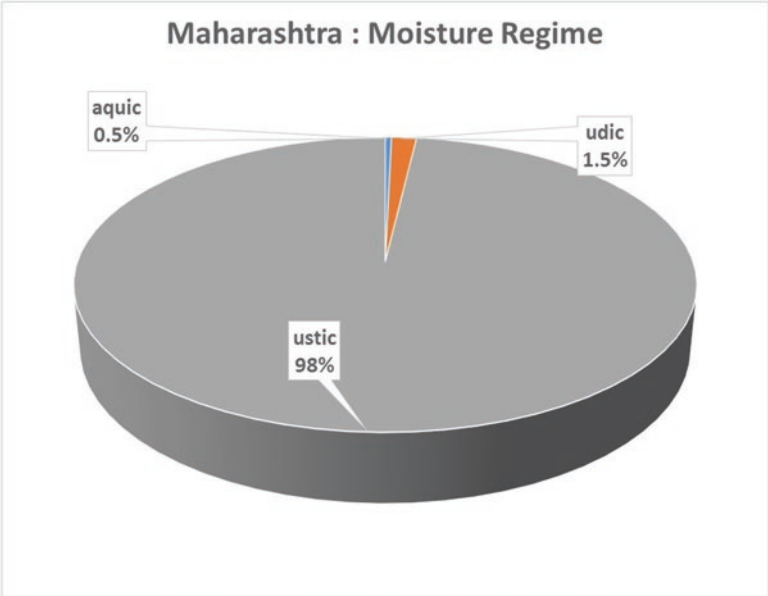

Fig. 2.28 Soil moisture regime in Maharashtra

2.4.3 Length of Growing Period (LGP) in Target Areas and Identification of Major Food Systems

2.4.3.1 Concept of Length of Growing Period (LGP)

The growing period is the period when the moisture in soils is adequate enough to support plant growth. The LGP was earlier estimated following the FAO model (Higgins and Kassam 1981) (Fig. 2.29). The growing period starts when precipitation (P) exceeds 0.5 PET and ends with the utilization of assumed quantum of stored soil moisture (100 mm) after P falls below PET. This is conditioned again by threshold temperature of 5 °C.

Concept of the length of growing period (LGP) (Sehgal et al. 1992) was mooted to address inadequacies in the above mentioned protocols for agro-ecological zones/regions. The LGP is an index of crop production because it takes care soil-water balance, which is a direct function of moisture availability in a landform rather than total rainfall. The 20 Agro-Ecological Regions (AERs) were delineated by the NBSS&LUP by superimposing bio-climate and LGP on soil-scape. The LGP classes were clubbed apparently related to cropping in an agro-environment (Mandal et al. 1999). While developing AER, only 5 LGP classes were considered showing due importance to crop durations, such as short (<90 days), medium (90–150 days), long (150–180 days), relay cropping (180–210 days) and double cropping (>210 days). Realising the importance of narrower LGP interval of 30 days for diverse crop suitability and also the need to further subdivide the bio-climate and

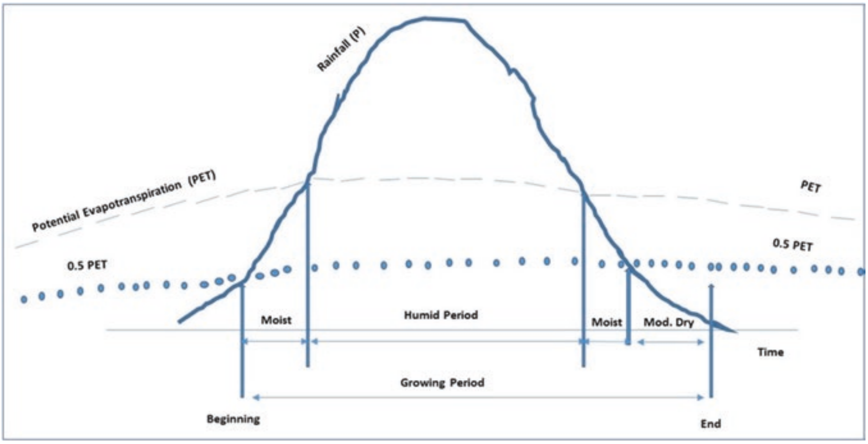

Fig. 2.29 Schematic diagram showing estimation of Length of growing period (LGP)

some important soil quality parameters like depth and available water capacity (AWC), NBSS&LUP divided 20 AERs into 60 Agro-ecological sub regions (AESRs) (Velayutham et al. 1999). Usefulness of 60 AESRs has been demonstrated in estimating soil carbon and available potassium stocks of the IGP and black soil regions and also in prioritizing areas for carbon sequestration (Bhattacharyya et al. 2007, 2008) and potassium management in different crop and cropping systems. In spite of this, refinement of AESR boundaries to match the new soil information of states (SRM at 1:2,50,000 scale) and moisture availability after cessation of rainfall, a function of the amount of rainwater that enters in the soil profile and their quantum of availability depending on nature of soil minerals and exchangeable Na^{+}, Mg^{2+} ions together in sub-soils. This has been a concern for raising *rabi* crops in SAT environment. However, to address this issue there is a need to gather antecedent soil moisture after the cessation of rains when rainfall (P) falls short of 0.5 potential evapotranspiration (PE). In the absence of such essential data the present AESR boundaries vis-a-vis crop performance exhibits scenarios a little away from reality under adverse soil condition. The information on different soil modifiers (gypsum, zeolite, palygorskite, lubenite; Bhattacharyya 2021b) must also be included in fine tuning the LGP computation. The 20 agro-ecological map of India published in 1992 by NBSS and LUP, was the outcome of superimposition of broad physiography, soils and bio-climate.

Later these 60 AESRs were revisited keeping in mind the shortfall of FAO's assumed quantum of stored soil moisture (100 mm) after P falls below PET (Mandal et al. 2014) to 84 AESRs, a few of which fall in the target states (Fig. 2.30). The AESR maps of the target states (Fig. 2.31) and details of LGP, crops, and their water requirements are shown in Tables 2.7, 2.8, and 2.9.

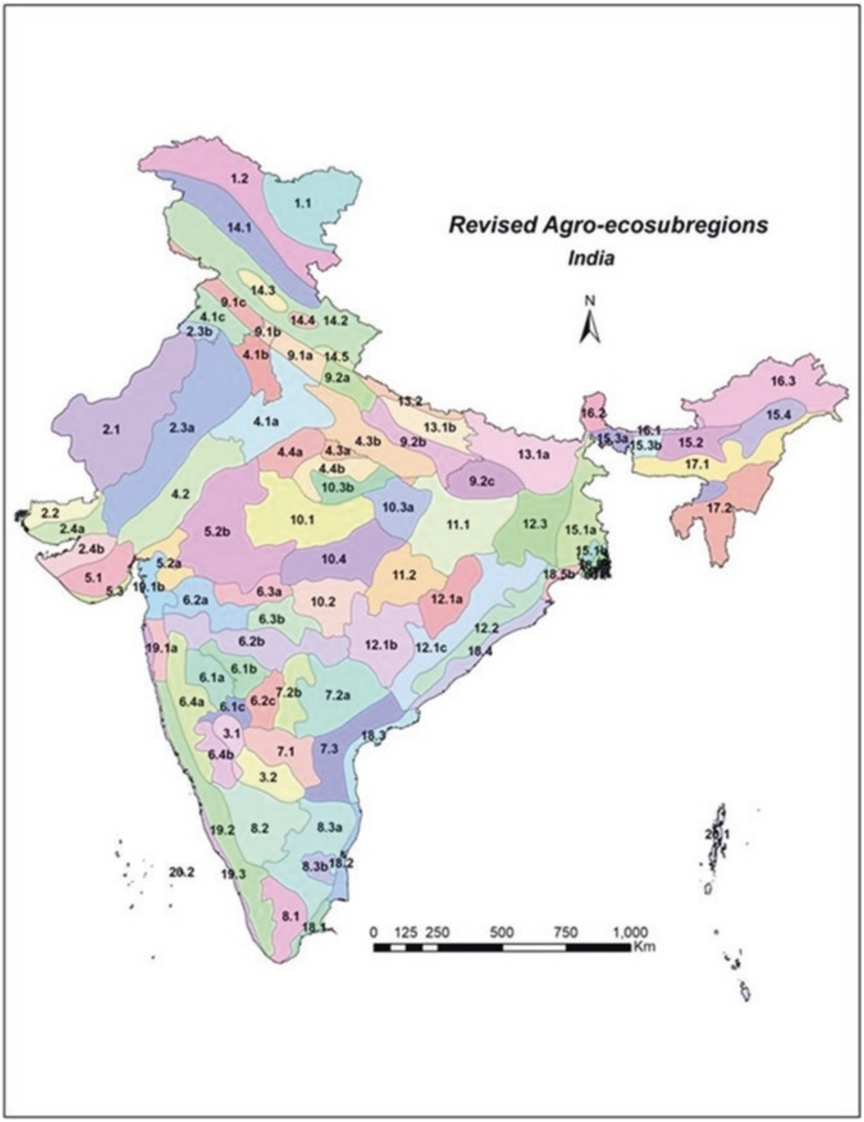

Fig. 2.30 Revised agro-eco sub-region (AESR) map of India

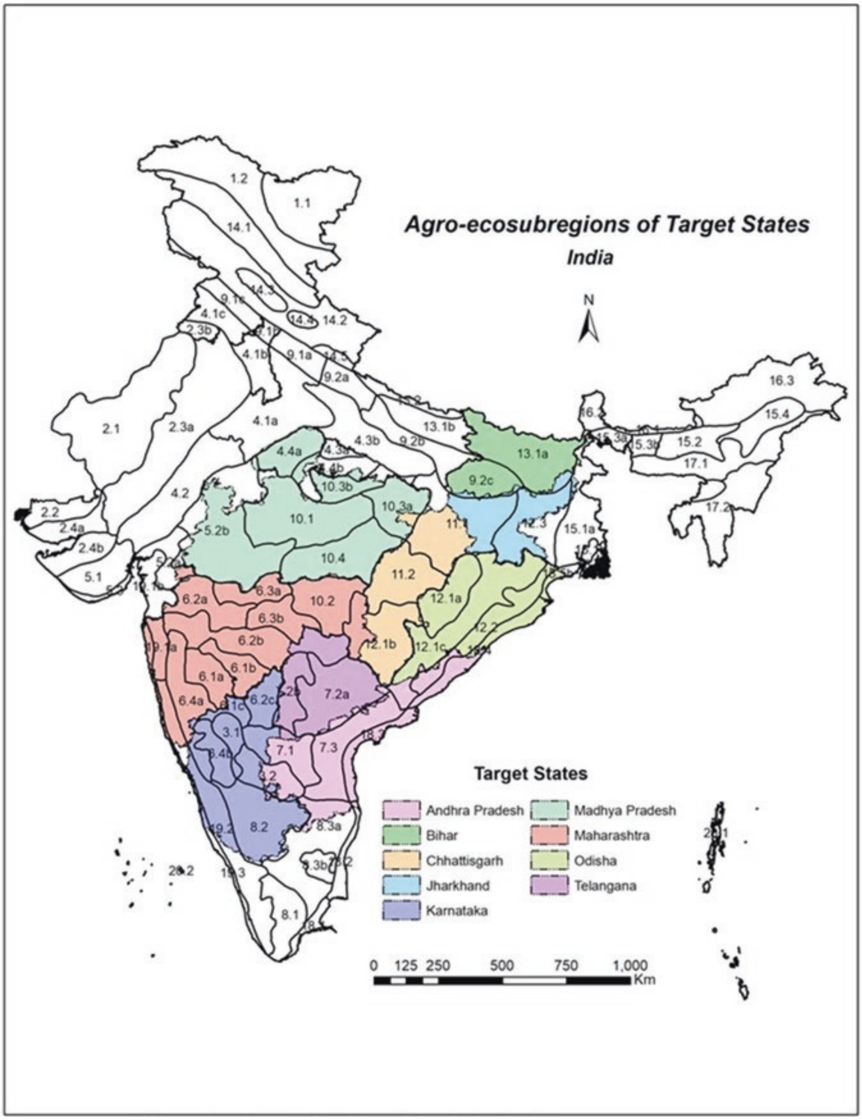

Fig. 2.31 Revised agro-eco sub-region (AESR) of the nine target states

Table 2.7 AESRs, LGP, crops and crop water requirements in target states: Arid and semi-arid ecosystem

AESRs							
Nos	Details	LGP days	States	Districts	Crops	Crop water requirement (m^3/ha)	Area mha
3.1	Deccan Plateau Hot Arid Ecoregion with well drained dominantly black soils	90–120	Karnataka	Bijapur (Part), Dharwad (Part), Raichur (Part), Bellary, Chitradurg (Part), Tumkur	Sorghum	3646	1.56
3.2	Deccan Plateau Hot Arid Ecoregion with well drained, red loamy soils	< 90	Andhra Pradesh	Anantapur	Sorghum, groundnut	3646,4570	3.08
4.3a	Northern Plain and Central Highlands Ecoregion – Ganga-Yamuna Doab, Rohilkhand and Avadh plain, hot, moist semi-arid eco-sub region with dominantly black soils, well drained	120–150	Madhya Pradesh	Gwalior, Morena, Shivpuri, Datia, Bhind	Rice, wheat	8922, 8275	0.02
5.2b	Northern Plain and Central Highlands Ecoregion – Madhya Bharat plateau Western Malwa plateau, Eastern Gujarat plain, Vindhyan and Satpura range and Narmada valley hot, moist semi-arid eco-sub region with black soils, well drained	150–180	Madhya Pradesh	Jhabua, Ratlam, Mandsaur, Ujjain, Indore, Dewas, East Nimar, East Dhar, Rajgarh (Part), Shajapur (Part)	Soybean, wheat	4686, 8275	14.72
6.1a	Deccan Plateau, hot semi-arid Eco-Region – South Western Maharashtra and North Karnataka plateau, hot dry semi-arid eco-sub region with black Soils (Shallow) loamy Skeletal, well drained	150–180	Maharashtra	Ahmadnagar (Part) , Bid, Latur (Western Part), Osmanabad, Solapur, Sangli (Part), Satara (Part), Pune (Part)	Sorghum	3565	2.77
			Karnataka	Bijapur (Part), Raichur			
6.1b	Deccan Plateau, hot semi-arid Eco-Region – South Western Maharashtra and North Karnataka plateau, hot dry semi-arid eco-sub region with black soils (Shallow), well drained	120–150	Maharashtra	Ahmadnagar (Part) , Bid, Latur (Western Part), Osmanabad, Solapur, Sangli (Part), Satara (Part), Pune (Part)	Sorghum	3565	2.38
			Karnataka	Bijapur (Part), Raichur			

6.1c	Deccan Plateau, hot semi-arid Eco-Region – South Western Maharashtra and North Karnataka plateau, hot dry semi-arid eco-sub region with black soils, well drained	150–180	Maharashtra	Ahmadnagar (Part) , Bid, Latur (Western Part), Osmanabad, Solapur, Sangli (Part), Satara (Part), Pune (Part)	Sorghum	3565	0.97
			Karnataka	Bijapur (Part), Raichur			
6.2a	Deccan Plateau, hot semi-arid Eco-Region – Central and western Maharashtra plateau and North Karnataka plateau and North Western Telangana plateau, hot moist semi-arid eco-sub region with Mixed Red and Black Soils	180–210	Maharashtra	Nashik, Dhule, Aurangabad, Jalna, Nanded, Parbhani, Latur, Ahmadnagar (Hilly part), Jalgaon (Part)	Sorghum	3565	3.75
			Karnataka	Bidar, Gulbarga			
			Telangana	Nizamabad, Adilabad			
6.2b	Deccan Plateau, hot semi-arid Eco-Region – Central and western Maharashtra plateau and North Karnataka plateau and North Western Telangana plateau, hot moist semi-arid eco-sub region with Dominantly Black Soils	150–180	Maharashtra	Nashik, Dhule, Aurangabad, Jalna, Nanded, Parbhani, Latur, Ahmadnagar (Hilly part), Jalgaon (Part)	Sorghum	3565	9.56
			Karnataka	Bidar, Gulbarga			
			Telangana	Nizamabad, Adilabad			
6.2c	Deccan Plateau, hot semi-arid Eco-Region – Central and western Maharashtra plateau and North Karnataka plateau and North Western Telangana plateau, hot moist semi-arid eco-sub region with Dominantly Black Soils	180–190	Maharashtra	Nashik, Dhule, Aurangabad, Jalna, Nanded, Parbhani, Latur, Ahmadnagar (Hilly part), Jalgaon (Part)	Sorghum	3565	2.11
			Karnataka	Bidar, Gulbarga			
			Telangana	Nizamabad, Adilabad			
6.3a	Deccan Plateau, hot semi-arid Eco-Region – Eastern Maharashtra plateau, hot moist semi-arid eco-sub region with Dominantly Black Soils, mod well drained	180–210	Maharashtra	Buldhana, Akola, Amravati, Yavatmal, Jalgaon (Part)	Cotton	6888	2.34
6.3b	Deccan Plateau, hot semi-arid Eco-Region – Eastern Maharashtra plateau, hot moist semi-arid eco-sub region with Dominantly Black Soils	180–210	Maharashtra	Buldhana, Akola, Amravati, Yavatmal, Jalgaon (Part)	Cotton	6888	2.73

(continued)

Table 2.7 (continued)

AESRs			States	Districts	Crops	Crop water requirement (m^3/ha)	Area mha
Nos	Details	LGP days					
6.4a	Deccan Plateau, hot semi-arid Eco-Region – North Sahyadris and Western Karnataka plateau, hot dry sub-humid eco-sub region with Red loamy soils well drained	180–210	Maharashtra	Kolhapur (Part), Satara (Part), Sangli, Pune	Sorghum, rice	3565, 8768	4.67
			Karnataka	Belgaum, Dharwad (Part)			
6.4b	Deccan Plateau, hot semi-arid Eco-Region – North Sahyadris and Western Karnataka plateau, hot dry sub-humid eco-sub region with Black Soils (calcareous), imperfectly drained	150–180	Maharashtra	Kolhapur (Part), Satara (Part), Sangli, Pune	Sorghum, rice	3565, 8768	2.08
			Karnataka	Belgaum, Dharwad (Part)			
7.2a	Deccan (Telangana) Plateau and Eastern Ghats, hot arid ecoregion – North Telangana plateau, hot moist, semi-arid eco-sub region with Dominantly Red soils	180–210	Telangana	Karimnagar, Warangal, Ranga Reddy, Mahbubnagar, Nalgonda, Khammam, Sangareddy and Hyderabad	Sorghum	3565	7.19
7.2b	Deccan (Telangana) Plateau and Eastern Ghats, hot arid ecoregion – North Telangana plateau, hot moist, semi-arid eco-sub region Dominantly black soils	180–190	Telangana	Karimnagar, Warangal, Ranga Reddy, Mahbubnagar, Nalgonda, Khammam, Sangareddy and Hyderabad	Sorghum	3565	2.77
7.3	Deccan (Telangana) Plateau and Eastern Ghats, hot arid ecoregion – Eastern Ghat (South) hot, moist, semi-arid, dry sub-humid eco-sub region with Deep well drained calcareous clay soils with occasional flooding, at places Deep well drained clayey soils.	150–180	Andhra Pradesh	West Godavari (part), Krishna (Machhlipatnam), Guntur (Part), Prakasam and Nellore	Rice, sorghum, groundnut	8985, 3672, 4626	3.4
8.2	Eastern Ghats, TN Uplands and Deccan (Karnataka) Plateau, hot, semi-arid Ecoregion – Central Karnataka plateau, hot, moist, semi-arid eco-sub region with Deep well drained clayey soils with mod. to severe erosion, at places imperfectly drained calcareous soils.	150–180	Karnataka	Hassan, Tumkur, Bangalore, Mysore, Mandya, Kolar, Chickmangalur, Shimoga (Part), Chitradurga (Part)	Sorghum, groundnut	3565, 4677	6.5

8.3a	Eastern Ghats, TN Uplands and Deccan (Karnataka) Plateau, hot, semi-arid Ecoregion – Tamil Nadu uplands and plains, hot moist semiarid eco-sub region with Black Soils of Cauvery Delta	180–210	Andhra Pradesh	Chittor	Rice	8985	7.38
8.3b	Eastern Ghats, TN Uplands and Deccan (Karnataka) Plateau, hot, semi-arid Ecoregion – Tamil Nadu uplands and plains, hot moist semiarid eco-sub region with Red loamy Soils	150–180	Andhra Pradesh	Chittor	Rice	8985	1.15

Source: Mandal et al. (2014), Kumari et al. (2017)

Table 2.8 AESRs, LGP, crops and crop water requirements in target states: Sub humid ecosystem

AESRs							
Nos	Details	LGP	States	Districts	Crops	Crop water requirement (m^3/ha)	Area m ha
9.2	Northern, plain hot sub-humid (dry) Ecoregion – Rohilkhand, Avadh and South Bihar plains, hot dry, sub-humid eco-sub region		Bihar	Bhojpur, Rohtas, Jahanabad, Patna, Bihar Sharif, Aurangabad, Gaya, Narwada,	Rice, Wheat	8985, 8136	8.3
10.1	Central Highlands (Malwa, Bundelkhand and Eastern Satpura Range), hot, sub-humid (dry/ moist) eco-region – Malwa plateau, Vindhyan scarpland and Narmada valley, hot dry, sub-humid eco-sub region with Dominantly black soils, well drained	180–210	Madhya Pradesh	Guna, , Raisen, Sagar, Bhopal, Sehore, Shajapur, Hoshangabad, Jabapur, Narsimhapur, Vidisha, Damoh	Soybean, wheat	3646, 8275	9.24
		180–210	Chhattisgarh	Rajgarh	Soybean, wheat	3646, 8275	
10.2	Central Highlands (Malwa, Bundelkhand and Eastern Satpura Range), hot, sub-humid (dry/ moist) eco-region – Satpura and Eastern Maharashtra plateau, hot dry, sub-humid eco-sub region with Dominantly black soils	180–210	Madhya Pradesh	Betul	Cotton, soybean	6888, 5106	4.44
			Maharashtra	Wardha, Nagpur, Chndarpur (Part0	Cotton, soybean	6888, 5106	
10.3a	Central Highlands (Malwa, Bundelkhand and Eastern Satpura Range), hot, sub-humid (dry/ moist) eco-region – Vindhyan scarpland and Baghelkhand plateau, hot dry, sub-humid eco-sub region with Black soils, well drained	180–210	Madhya Pradesh	Tikamgarh, Chhatrpur, Panna, Satna, Rewa, Sidhi, Shahdol	Rice, wheat	8922, 8275	3.83
10.3b	Central Highlands (Malwa, Bundelkhand and Eastern Satpura Range), hot, sub-humid (dry/ moist) eco-region – Vindhyan scarpland and Baghelkhand plateau, hot dry, sub-humid eco-sub region with Red loamy soils	150–180	Madhya Pradesh	Tikamgarh, Chhatrpur, Panna, Satna, Rewa, Sidhi, Shahdol	Rice, wheat	8922, 8275	2.41

10.4	Central Highlands (Malwa, Bundelkhand and Eastern Satpura Range), hot, sub-humid (dry/moist) eco-region –Satpura range and Wainganaga valley, hot moist sub-humid eco-sub region with Deep to very deep, well drained to mod. Well drained clay soils with mod. to slight erosion, at places calcareous and cracking clay soils.	180	Madhya Pradesh	Chhindwara, Seoni, Mandla, Balaghat, Jabalpur (Part)	Rice, wheat	8922, 8275	
			Maharashtra	Bhandara	Rice, wheat	8922, 8275	
11.1	Chhattisgarh/Mahanadi Basin Agro eco-region – Chhattisgarh/Mahanadi basin, hot sub-humid, eco-sub region with Black, Red and yellow Sandy Loam	>210	Jharkhand	Hazaribag, Ranchi (Part), Lohardaga, Gumla, Palmu	Rice, wheat	8985, 8136	9.07
			Chhattisgarh	Bilaspur, Ambikapur, Raigarh, Durg, Rajnandgaon, Raipur, Jagdalpur (Part)	Rice, wheat	8985, 8136	
11.2	Chhattisgarh/Mahanadi Basin Agro eco-region – Chhattisgarh/Mahanadi basin, hot sub-humid, eco-sub region with Black Soils, at places imperfectly to poorly drained	180–210	Jharkhand	Hazaribag, Ranchi (Part), Lohardaga, Gumla, Palmu	Rice, wheat	8985, 8136	5.12
			Chhattisgarh	Bilaspur, Ambikapur, Raigarh, Durg, Rajnandgaon, Raipur, Jagdalpur (Part)	Rice, wheat	8985, 8136	
12.1a	Eastern (Chhotanagpur) Plateau and Eastern Ghats, hot sub-humid ecoregion – Garjat hills, Dandakaranya and Eastern Ghats, hot, moist sub-humid eco-sub region with Dominantly black soils of Mahanadi basin, poorly to imperfectly drained	180–210	Odisha	Koraput, Balangir, Sambalpur, Sundargarh, Dhenkanal, Kalahandi, Mayaurbhanj, Phulbani, Kendujhargarh	Rice, groundnut	8985, 4626	3.91
			Maharashtra	Chandrapur, Gadchiroli	Rice, groundnut	8985, 4626	
12.1b	Eastern (Chhotanagpur) Plateau and Eastern Ghats, hot sub-humid ecoregion – Garjat hills, Dandakaranya and Eastern Ghats, hot, moist sub-humid eco-sub region with Mixed red loamy and black soils	150–180	Odisha	Koraput, Balangir, Sambalpur, Sundargarh, Dhenkanal, Kalahandi, Mayaurbhanj, Phulbani, Kendujhargarh	Rice, groundnut	8985, 4626	6.70
			Maharashtra	Chandrapur, Gadchiroli			

(continued)

Table 2.8 (continued)

AESRs							
Nos	Details	LGP	States	Districts	Crops	Crop water requirement (m^3/ha)	Area m ha
12.1c	Eastern (Chhotanagpur) Plateau and Eastern Ghats, hot sub-humid ecoregion – Garjat hills, Dandakaranya and Eastern Ghats, hot, moist sub-humid eco-sub region with Red, sandy loam soils	>210	Odisha	Koraput, Balangir, Sambalpur, Sundargarh, Dhenkanal, Kalahandi, Mayaurbhanj, Phulbani, Kendujhargarh	Rice, groundnut	8985, 4626	8.71
			Maharashtra	Chandrapur, Gadchiroli			
12.2	Eastern (Chhotanagpur) Plateau and Eastern Ghats, hot sub-humid ecoregion – Eastern Ghats, hot moist sub-humid eco-sub region with Deep, poorly to imperfectly drained loamy to clay soils with occasional to severe flooding. At places mod. deep, well drained loamy soils.	>180	Andhra Pradesh	Vishapatnam (Hilly Parts), Vizianagaram, Srikakulam	Rice, rice	8985, 10791	
			Odisha	Ganjam, Puri, Cuttack, Baleshwar			
12.3	Eastern (Chhotanagpur) Plateau and Eastern Ghats, hot sub-humid ecoregion – Chhotanagpur plateau and Garjat hills, hot dry and moist sub-humid transitional eco-sub region	180–210	Jharkhand	Ranchi, Dhanbad, Giridih, Devghar, Santhal Pargana, Singbhum Sahibganj (Part)	Rice, maize	8985, 4328	5.6
			Odisha	Kendujhargarh (North)			
13.1	Eastern Plain, hot sub-humid (moist) ecoregion – North Bihar and Avadh plains, hot dry moist sub-humid eco subregion	180–210	Bihar	Gopalgang, Bhagalpur, Siwan, Saran, Muzaffarpur, Madhubani, Darbhanga, Begusarai, Samastipur, Saharsa, West Champaran, Purba Champaran, Munger, Katihar, Khagaria, Sitamarhi, Purnia, Munger, Katihar, Vaishali, Patna (Part)	Pulses, Wheat	3809, 8136	9.9
			Jharkhand	Sahebganj	Pulses, Wheat	3809, 8136	9.9

Source: Mandal et al. (2014), Kumari et al. (2017)

Table 2.9 AESRs, LGP, crops and crop water requirements in target states: Coastal ecosystem

AESRs							
Nos	Details	LGP	States	Districts	Crops	Crop water requirement (m^3/ha)	Area mha
18.3	Eastern Coastal Plain, hot sub-humid to semi-arid ecoregion – Andhra Coastal, hot dry sub-humid eco-sub region	150–180	Jharkhand	Sahebganj	Cotton, groundnut, rice	7092, 4626, 10791	2.0
			Andhra Pradesh	Nellore, Prakasam, Guntur, Krishna, West Godavari	Cotton, groundnut, rice	7092, 4626, 10791	
18.4	Eastern Coastal Plain, hot sub-humid to semi-arid ecoregion – Utkal Plain and East Godavari Delta, hot dry sub-humid eco-sub region	180–210	Andhra Pradesh	East Godavari, Vishakhapatnam, Vizianagaram, Srikakulam	Rice, rice	8985, 10791	3.2
			Odisha	Ganjam, Puri (Part), Cuttack	Rice, rice	8985, 10791	
18.5	Eastern Coastal Plain, hot sub-humid to semi-arid ecoregion – Gangetic Delta, hot moist, sub-humid eco-sub region	240–270	Odisha	Baleshwar (Part)	Rice, rice	8985, 10791	1.2
19.1a	Western Ghats and Coastal Plain, hot, humid-perhumid ecoregion – North Sahyadris and Konkan Coast, hot, humid eco-sub region with Red loamy soils, well drained, severe erosion and moderate salinity	180–210	Maharashtra	Raigarh, Thane, Pune (Part)	Rice	8985	1.3
19.1b	Western Ghats and Coastal Plain, hot, humid-perhumid ecoregion – North Sahyadris and Konkan Coast, hot, humid eco-sub region with Calcareous, well drained black soils, slight to moderate salinity	180–210	Maharashtra	Raigarh, Thane, Pune (Part)	Rice	8985	1.87
19.2	Western Ghats and Coastal Plain, hot, humid-perhumid ecoregion – Central and South Sahyadris, hot moist, sub-humid to humid eco-region	210–270	Maharashtra	Ratnagiri, Sindhudurg, Kolhapur (Part)	Rice	8985	6.9
			Karnataka	Uttar Kannad, mangalore, Chikmagalur (Part), Kodagu, Hassan, Shimoga	Rice	8985	
19.3	Western Ghats and Coastal Plain, hot, humid-perhumid ecoregion – Konkan, Karnataka and Kerala Coastal Plain, hot humid to perhumid eco-sub region	240–270	Karnataka	Mangalore, Karwar	Rice	8985	2.0

Source: Mandal et al. (2014), Kumari et al. (2017)

2.4.3.2 Consumptive Water Use Requirements in the Target Areas

The results of Crop Wat model give consumptive water use; however, it does not include water losses during water supply from source to crop field i.e. evaporation, percolation, seepage loses from conveyance channel (Kumari et al. 2017). Water requirements for crop productions are influenced by the various factors viz. area share of different crops, climatic factors (temperature, wind velocity, relative humidity, sunshine and rainfall), crop variety, crop duration and soil structure. Besides these, agronomic practices and plant physiology also affect the water consumption by the crops. Thus, these factors lead to difference in the consumptive water use for the same crop in different regions. Most of the crops growing during the *kharif* season are using more green water (rainfall mediated soil moisture) and supplemented by blue water (artificial irrigation), whereas crops grown in *rabi* (post-rainy) season were catering water requirement from irrigation water and somewhat fulfilled by off season rainfall for their crop cycle (Tables 2.10, 2.11, 2.12). The major crops grown during *kharif* season were rice, maize, *jowar* (sorghum), small millets and wheat, barley in *rabi* season (Kumari et al. 2017).

Table 2.10 AESRs, crops and consumptive water use in target states: Arid and semi-arid ecosystem

		Consumptive water use (m^3/ha)					
		Blue water	Green water	Total water	Blue water	Green water	Total water
AESR Nos.	Crops	*Kharif*			Rabi		
3.1	Sorghum	1125	2521	3646			
3.2	Groundnut	1856	2713	4570			
4.3a	Wheat				7256	1018	8275
5.2b	Wheat				7256	1018	8275
	Cotton	2230	5225	7455			
6.1a	Groundnut	1585	3092	4677			
6.1b, 6.1c	Sorghum	1164	2400	3565			
6.2a, 6.2b, 6.2c	Sorghum	1125	2521	3646			
	Sunflower	5489	1538	7027			
6.3a	Cotton	2230	5225	7455			
6.3b	Sorghum	1125	2521	3646			
6.4a, 6.4b	Rice	3906	4862	8768			
	Sorghum	1164	2400	3565			
7.2a, 7.2b	Rice	3389	5595	8985			
	Sorghum	722	2949	3672			
7.3	Rice	3389	5595	8985			
	Sorghum	722	2949	3672			
	Groundnut	1430	3196	4626			
8.2	Groundnut	1430	3196	4626			
8.3a, 8.3b	Rice	3389	5595	8985			

Source: Mandal et al. (2014), Kumari et al. (2017); blue water (artificial irrigation), green water (rainfall)

Table 2.11 AESRs, Crops and consumptive water use in target states: Sub humid Ecosystem

AESRs Nos	Crops	Consumptive water use (m^3/ha)					
		Blue water	Green water	Total water	Blue water	Green water	Total water
		Kharif			Rabi		
9.2	Rice	3389	5595	8985			
	Wheat				6959	1176	8136
10.1	Soybean	1750	2936	4686			
	Wheat				7256	1018	8275
10.2	Cotton	2230	5225	7455			
	Soybean	1750	2936	4686			
10.3a, 10.3b, 10.4, 11.1, 11.2	Rice	3715	5207	8922			
	Wheat				7256	1018	8275
12.1a, 12.1b, 12.1c, 12.2	Rice	3389	5595	8985			

Source: Mandal et al. (2014), Kumari et al. (2017); blue water (artificial irrigation), green water (rainfall)

Table 2.12 AESRs, LGP, crops and crop water requirements in target states: Coastal ecosystem

AESR Nos	Crops	Consumptive water use (m^3/ha)					
		Blue water	Green water	Total water	Blue water	Green water	Total water
		Kharif			Rabi		
18.3, 18.4, 18.5	Rice	3389	5595	8985			
	Gram				1754	502	2256
19.1a, 19.1b, 19.2, 19.3	Rice	3906	4862	8768			

Source: Mandal et al. (2014), Kumari et al. (2017); blue water (artificial irrigation), green water (rainfall)

2.5 Use of New Science Tools for AESR-Based Agriculture

Land use planning is a systematic and iterative process carried out to create an enabling environment for sustainable development of land resources. It assesses the physical, socio-economic, institutional and legal potentials and the constraints with respect to an optimal and sustainable use of land resources, in addition, it also empowers people to make informed decisions about how to allocate those resources for reaping maximum benefit. Originating from an internationally accepted framework for land evaluation, the Agro-ecological zones/sub-regions methodology enables rational land management options to be formulated on the basis of an inventory of land resources and in the assessment of biophysical limitations and potentials.

Five basic elements which form the AESR framework are,

(i) *land utilization types (LUTs): specific agricultural production systems with defined input and management relationships and crop-specific environmental requirements and adaptability characteristics,*
(ii) *land resource database: georeferenced climate, soil and terrain data combined into a database,*
(iii) *crop yields and LUT requirements matching: procedures for calculating potential yields and for matching environmental requirements of the crop/LUT with the respective environmental characteristics contained in the land resource database, by land unit and grid-cell, and*
(iv) *assessments of crop suitability and production potential of land (models), and applications for agricultural developmental planning.*

Earlier, a generalized LGP value (based on overhead climatic data) of dominant soils of the region was considered, while developing an AESR map in 1994 with 60 delineations. Recent research indicates that the shrink-swell soils do not remain saturated with moisture at field capacity due to poor hydraulic properties caused by sub-soil sodicity characterized by high pH, exchangeable sodium percent and poor to very poor drainage as evidenced by low saturated hydraulic conductivity. To estimate LGP, 100 mm m^{-1} of stored soil moisture was used as standard for the deep soils assuming this amount to be the measure of available water after cessation of rains. Since this measure could be an over estimation the LGP values were modified (Mandal et al. 2014) using new science tools of database management, remote sensing, GIS, soil information system (Bhattacharyya 2021b).

LGP values were revised in the target states with soil data (Please see Tables 2.2 and 2.3). LGP values depend on water retention, bulk density (BD) and saturated hydraulic conductivity (sHC). In many cases pedotransfer functions (PTFs) were used to estimate these soil parameters (Tiwary et al. 2014).

(MC 33, MC 100, MC 1800 = moisture content (%) at −33 k Pa, −100 k Pa, −1800 k Pa; Clay= Clay % in soils; ECP= exchangeable Ca percent; Silt= silt % in soils; OC- organic carbon in soils (%); ESP= exchangeable Na percent; pH = soil reaction values; Ex Ca/Ex Mg = ratio of exchangeable Ca and Mg)

$$MC33 = 22.388 + 0.443 * Clay - 0.149 * ECP$$

$$MC100 = 9.006 + 0.429 * Clay - 0.071 * ECP + 0.102 * silt$$

$$MC1800 = 5.449 + 0.364 * Clay - 0.083 * ECP$$

$$BD = 1.634 - 0.002 * clay - 0.180 - OC + 0.005 * ESP$$

$$sHC = 120.637 - 13.094 * pH - 0.102 * clay + 1.151 * \left(\frac{ExCa}{ExMg} \right)$$

The estimated available water content, saturated hydraulic conductivity, and use of pedo-transfer functions (Tiwary et al. 2014) in assessing the drainage conditions and soil quality helped in computing precise LGP to generate agro-ecological sub regions (AESR) (Fig. 2.32). Since AESR is considered as a tool for agro-technology

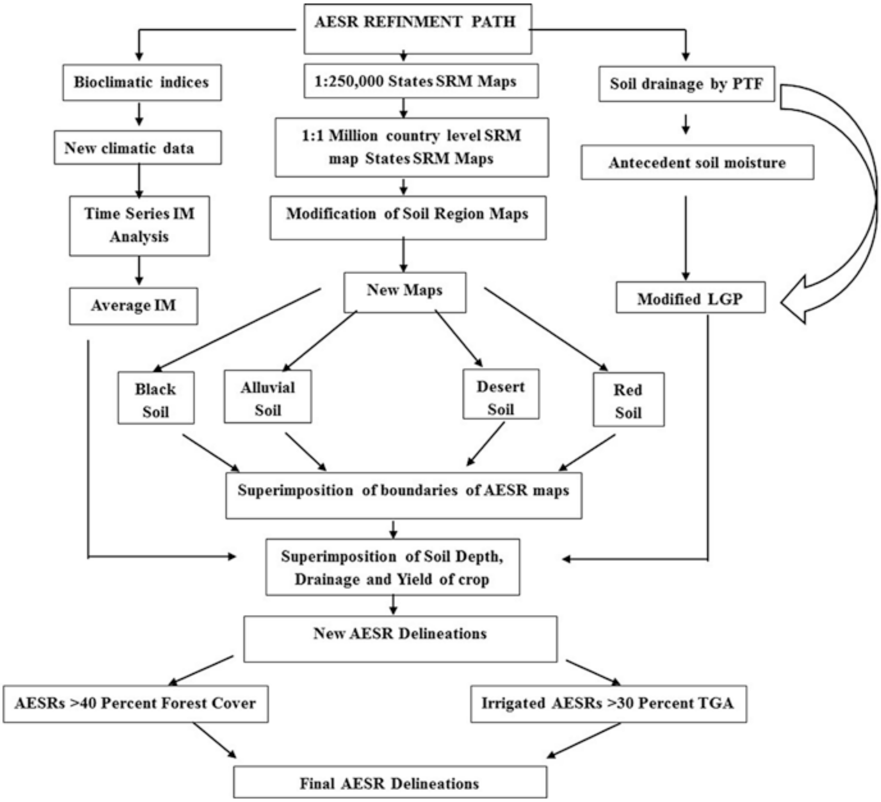

Fig. 2.32 Flowchart to generate agro-ecological sub-regions (AESR) map. (Source: Bhattacharyya et al. 2015)

transfer by scaling up research findings at the farmers' level, an example is shown here for two important crops in the target states.

2.5.1 Usefulness of GeoSIS to Develop Integrated Food Systems Strategy

Modern tools have made the natural resource management lot easier in terms of data access and retrieval. Many such information are detailed elsewhere (Bhattacharyya et al. this volume, this book). A few are discussed here.

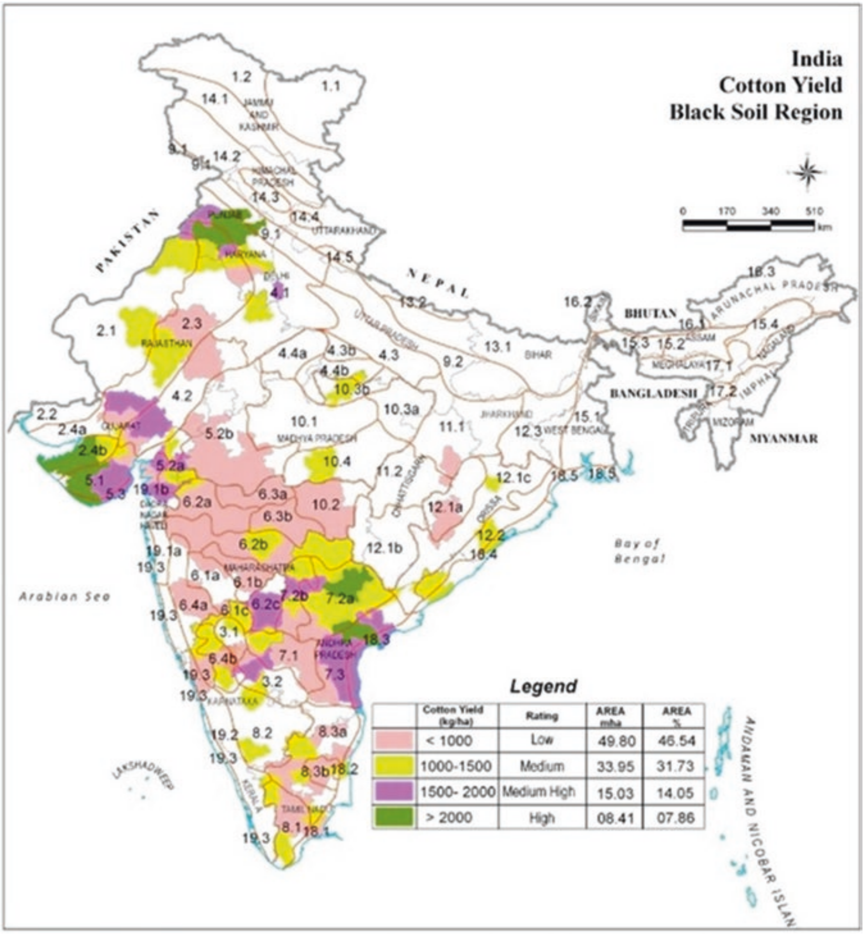

Fig. 2.33 AESR-based cotton crop planning in target states for livelihoods systems in target states. (Source: Bhattacharyya et al. 2015)

2.5.1.1 Cotton-Based Cropping for Livelihoods Systems in Target States

Based on productivity, the cotton growing areas in different AESRs of the BSR are mapped as a part of crop planning. The entire BSR is divided into four different regions such as low, medium, medium high and high indicating <1000, 1000–1500, 1500–2000 and >2000 kg seed cotton ha^{-1} (Fig. 2.33). It is interesting to note that merely 15% area under cotton produce >1500 kg ha^{-1} which is the national average. The distribution of cotton yield in different AESRs in the target states with a few exceptions shows that there is a scope to elevate low to medium cotton yield areas to medium high or high yield categories in 86% area through appropriate site specific management interventions including cultivar selection (Table 2.13; Fig. 2.34). Alternatively, area under cotton from the low productivity areas can be diverted to

Table 2.13 Cotton yield and acreage in different agro-ecological sub regions in the target states

AESR		Cotton area				
Nos.	Area (mha)	Area (mha)	%			
	a	b	(b/a)*100	Districts	Yield level kg ha^{-1}	States
3.1	1.56	0.37	24	Koppal, Gadag	Low	Karnataka
	1.56	0.39	25	Bijapur, Belgaum	Medium	Karnataka
	0.39	0.06	15	Bellary	Medium High	Karnataka
3.2	3.08	0.27	9	Koppal	Low	Karnataka
	3.08	0.31	10	Chitradurga	Medium	Karnataka
5.2b	12.71	6	47	Banswara,Ratlam,Dhar, Jhabua, Barwani, Khargo, Khandwa, Dewas, Bhilwara	Low	Rajastahan, MP
	12.71	0.03	0.03	Nandurbar	Medium	Maharashtra
6.1a	2.77	0.99	36	Ahmadnagar, Satara, Sangli	Low	Maharashtra
	2.77	0.03	1	Bijapur	Medium	Karnataka
6.1b	2.38	2.02	85	Latur, Ahmadnagar, Bid Osmanabad	Low	Maharashtra
	2.38	0.01	0	Gulbarga	Medium High	Karnataka
6.1c	0.97	0.9	93	Bijapur, Kolhapur	Medium	Karnataka, Maharsahtra
	0.97	0.05	5	Gulbarga	Medium High	Karnataka
6.2a	3.75	3.38	90	Dhule, Nashik, Aurangabad, Jalna, Buldhana, Jalgaon	Low	Maharashtra
	3.75	0.3	8	Nandurbar	Medium	Maharashtra
	3.75	0.04	1	Surat	Medium High	Gujarat
6.2b	7.34	4.07	55	Dhule, Nashik, Aurangabad, Jalna, Buldhana, Jalgaon , Ahmadnagar, Bid, Nanded	Low	Maharashtra
	7.34	3.22	44	Parbhani, Hingoli, Adilabad, Karimnagar	Medium	Maharashtra, Telangana
6.2c	2.22	0.15	7	Bijapur, Raichur	Medium	Karnataka
	2.22	1.5	68	Gulbarga, Medak	Medium High	Karnataka
6.3a	2.34	2.33	100	Akola, Jalgaon, Buldhana, Amravati	Low	Maharashtra
	2.73	2.57	94	Washim, Akola, Yavatmal, Buldhana	Low	Maharashtra
	2.73	0.16	6	Parbhani, Hingoli	Medium	Maharashtra
6.4a	4.67	2.44	52	Satara, Sangli, Ahmadnagar, Uttarkahhad	Low	Maharashtra
	4.67	0.42	9	Belgaum	Medium	Karnataka

(continued)

Table 2.13 (continued)

AESR		Cotton area				
Nos.	Area (mha)	Area (mha)	%		Yield level	
	a	b	(b/a)*100	Districts	kg ha^{-1}	States
6.4b	2.08	0.61	29	Dharwad, Gadag	Low	Karnataka
	2.08	1.2	58	Belgaum, Haveri	Medium	Karnataka
	2.08	0.03	1	Bellary	Medium High	Karnataka
7.2a	7.19	0.86	12	Mahbubnagar	Low	Telangana
	7.19	4.13	57	Karimnagar, Khammam, Nalgonda, Hyderabad	Medium	Telangana
	7.19	0.56	8	Medak, Krishna	Medium High	Telangana, AP
	7.19	1.61	22	Warangal, Nalgonda	High	Telangana
7.2b	2.77	0.88	32	Mahbubnagar, Nizamabad	Low	Telangana
	2.77	1.18	43	Nizamabad, Hyderabad	Medium	Telangana
	2.77	0.7	25	Medak, Gulbarga	Medium High	Telangana, Karnataka
7.3	5.58	1.12	20	Kurnool, Kadapa	Low	AP
	5.58	0.16	3	Khammam	Medium	Telangana
	5.58	2.65	47	Ongole, Nellore, Krishna	Medium High	AP
	5.58	0.69	12	Guntur	High	AP
8.2	6.8	0.18	3	Erode	Low	TN
	6.8	1.33	20	Chitrdurga, Mysore, Dharmapuri	Medium	Karnataka, TN
8.3a	7.38	2.29	31	Vellore, Viluppuram, Erode , Salem, Tiruchirappalli	Low	AP, TN
	7.38	1.62	22	Dharmapuri, Namakkal, Coimbatore, Sivaganga	Medium	TN,
8.3b	1.15	0.82	71	Tiruchirappalli, Salem,Perambalu	Low	TN
	1.15	0.14	12	Cuddalore, Dharmapuri	Medium	TN
10.1	9.24	0.13	1	Dewas	Low	MP
	9.24	0.02	0	Chhatarpur	Medium	MP
10.2	4.41	3.57	81	Wardha, Nagpur, Chandrapur, Yavatmal, Amravati	Low	Maharashtra
10.3b	2.41	0.74	31	Chhatarpur	Medium	MP
10.4	6.56	0.08	1	Nagpur, Betul	Low	Maharashtra, MP
	6.56	1.26	19	Chhindwara	Medium	MP
11.1	9.07	0.58	6	Raigarh	Low	Chhattisgarh
	5.12	0.14	3	Raigarh	Low	Chhattisgarh
12.1a	3.91	1.3	33	Balangir, Bhawanipatna, Bargarh	Low	Odisha

(continued)

Table 2.13 (continued)

AESR		Cotton area				
Nos.	Area (mha)	Area (mha)	%		Yield level	
	a	b	(b/a)*100	Districts	kg ha^{-1}	States
12.1c	8.71	0.25	3	Bhawanipatna	Low	Odisha
	8.71	0.56	6	Deogarh, Chhatrapur	Medium	MP, Odisha
12.2	4.19	1.26	30	Chhatrapur, Vishakhapatnam	Medium	AP, Odisha
18.3	1.97	1.32	67	Ongole, Nellore, Krishna	Medium High	AP
	1.97	0.22	11	Gunntur	High	AP
18.4	2.9	0.72	25	Vishakhapatnam	Medium	AP
19.1a	1.38	0.02	1	Nashik	Low	Maharashtra
19.1b	2.02	0.44	22	Bharuch	Low	Gujarat
	2.02	0.01	0	Godhra	Medium	Gujarat
19.2	7.63	0.54	7	Uttar Kannad	Low	Karnataka
	7.63	0.21	3	Coimbatore	Medium	TN
19.3	1.87	0.12	6	Uttar Kannad	Low	Karnataka

Source: Bhattacharyya et al. (2015); MP: Madhya Pradesh; AP: Andhra Pradesh; TN: Tamil Nadu

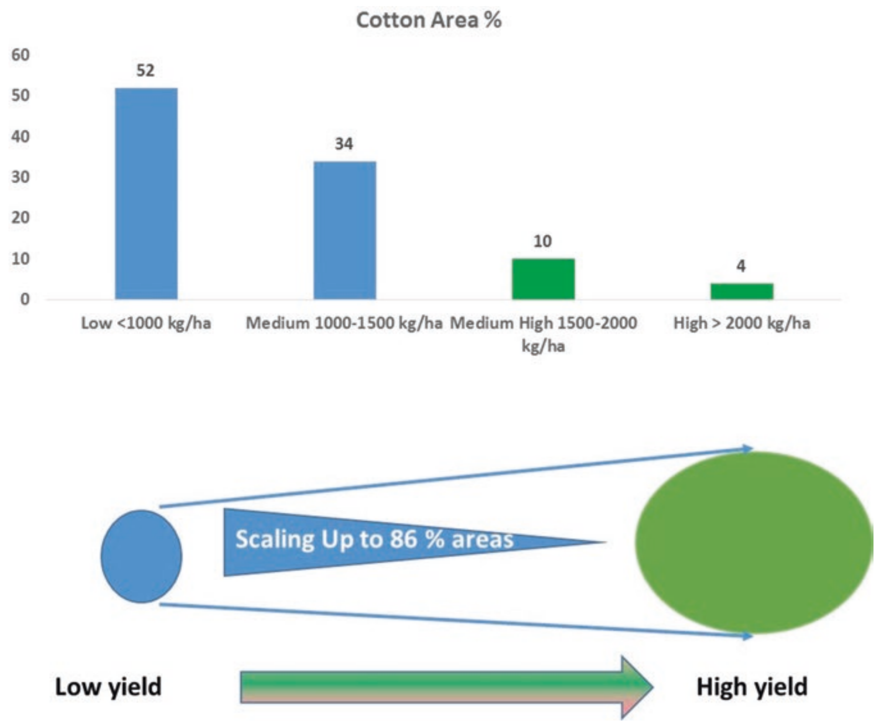

Fig. 2.34 Scaling up potential of cotton yield in target states. (Source: Modified from Bhattacharyya et al. 2015; also see Table 2.13)

more productive crops to ensure food security. Keeping crop variety and other management factors similar, the recently built geo-referenced soil information system (GeoSIS) (Bhattacharyya et al. 2014b) was used to find out exact soil-related constraints (mainly physical properties, such as saturated hydraulic conductivity, sHC), which can be ameliorated to improve the soil quality to plan cotton production in low and medium cotton yield areas for posterity (Bhattacharyya et al. 2015) in the target states.

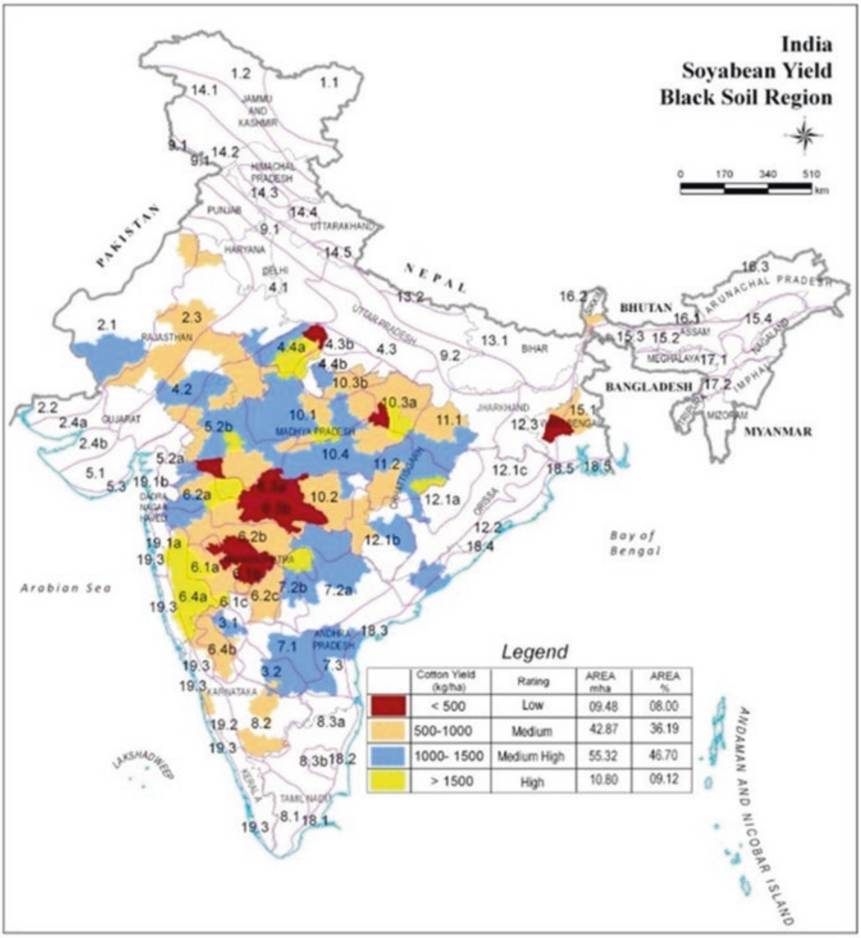

Fig. 2.35 AESR-based soybean crop planning in target states for livelihoods systems in target states. (Source: Bhattacharyya et al. 2015)

Table 2.14 Soybean yield and acreage in different agro-ecological sub regions in the target states (* in this Table is used to calculate % cotton area)

AESR		Cotton area				
Nos.	Area	Area m ha	%		Yield level	
	a	b	b/a*100	Districts	kg ha^{-1}	States
3.1	1.6	0.24	15	Belgaum, Gadag	Medium	Karnataka
3.1	1.6	0.62	40	Bagalkot	Medium High	Karnataka
3.2	3.1	0.15	5	Tumkur	Medium	Karnataka
3.2	3.1	1.65	54	Anantpur	Medium High	Andhra Pradesh
4.3	6	0.01	0.2	Rewa	Medium	Madhya Pradesh
4.3b	1.1	0.02	2	Bind	Medium	Madhya Pradesh
4.4a	3	0.63	21	Bind, Datia, Baran	Medium	Madhya Pradesh, Rajasthan
5.2b	4.7	0.6	13	Barwani	Low	Madhya Pradesh
5.2b	13	6.16	48	Jhabua, Banswara, Khargon, Khandw, Hoshngabad, Mandsaur, Jhalawar, Kota , Bundi, Baran, Dhule	Medium	Rajasthan, Madhya Pradesh, Maharashtra
5.2b	13	5	39	Nimachi, Ratlam, Dhar, Ujjain, Shajapur, Harda, Dewas	Medium High	Madhya Pradesh
6.1a	5.2	0.14	3	Bid, Osmanbad	Low	Maharsahtra
6.1a	2.8	1.68	61	Solapur, Ahmadnagar	Medium	Maharsahtra
6.1b	72	1.73	2	Bid, Osmanabad, Latur	Low	Maharsahtra
6.1b	2.4	0.66	28	Solapur, Ahmadnagar, Bidar	Medium	Maharsahtra, Karnataka
6.1c	1	0.25	26	Belgaum, Gulbarga	Medium	Karnataka
6.1c	1	0.01	1	Bagalkot	Medium High	Karnataka
6.2a	9.7	0.36	4	Buldhana	Low	Maharsahtra
6.2a	3.8	1.84	49	Dhule, Aurangabad, Jalna	Medium	Maharsahtra
6.2a	3.8	1.02	27	Nashik	Medium High	Maharsahtra
6.2b	11	0.79	7	Bid, Latur, Yavatmal	Low	Maharsahtra
6.2b	7.3	3.59	49	Ahmadnagr, Aurangabad, Jalna, Perbhani, Hingoli,Nanded	Medium	Maharsahtra
6.2b	7.3	2.87	39	Adilabad	Medium High	Telangana
6.2c	1.2	0.03	3	Osmanbad, Latur	Low	Maharsahtra
6.2c	2.2	2.02	91	Bidar, Gulbarga	Medium	Karnataka
6.2c	2.2	0.03	1	Hydrabad	Medium High	Telangana

(continued)

Table 2.14 (continued)

AESR		Cotton area		Districts	Yield level kg ha^{-1}	States
Nos.	Area	Area m ha	%			
	a	b	b/a*100			
6.3a	2.3	0.05	2	Khargon, Khandwa	Medium	Madhya Pradesh
6.3a	2.3	0.02	1	Betul, Chhindwada, Seoni, Balaghat	Medium High	Madhya Pradesh
6.3b	85	2.32	3	Amravati, Akola ,Buldhana, Washim, Yavatmal	Low	Maharsahtra
6.3b	2.7	0.39	14	Hingoli, Nanded, Parbhani, Chandrpur	Medium	Maharsahtra
6.3b	2.7	0.02	1	Adilabad	Medium High	Telangana
6.4a	4.7	0.03	1	Nashik	Medium High	Maharsahtra
6.4b	2.1	1.81	87	Belgaum, Dharwad, Haveri	Medium	Karnataka
6.4b	2.1	0.02	1	Bagalkot	Medium High	Karnataka
7.2a	7.2	3.09	43	Karimnagar, Warangal, Sangereddi	Medium High	Telangana
7.2b	2.8	0.16	6	Gulbarga, Nanded	Medium	Karnataka, Maharashtra
7.2b	2.8	0.97	35	Warangal, Sangareddi, Hydrabad	Medium High	Telangana
7.3	5.6	2.5	45	Ongole, Cuddapah	Medium High	Andhra Pradesh
8.2	6.8	1.59	23	Mysore, Tumkur	Medium	Karnataka
8.2	6.8	0.61	9	Chamrajnagar, Anantpur	Medium High	Karnataka, Telangana
8.3a	7.4	0.05	1	Chamrajnagar, Anantpur	Medium High	Karnataka, Telangana
10.1	0.2	0.01	7	Umaria	Low	Madhya Pradesh
10.1	9.2	2.53	27	Baran, Sagar , Hoshangabad, Panna, Katni	Medium	Madhya Pradesh
10.2	16	0.69	4	Amravati, Yavatmal	Low	Maharashtra
10.2	4.4	2.9	66	Wardha, Nagpur, Chandrapur	Medium	Maharashtra
10.3a	7.5	0.29	4	Umaria	Low	Madhya Pradesh
10.3a	3.8	2.26	59	Satna, Rewa , Sidhi	Medium	Madhya Pradesh
10.3b	2.4	1.41	59	Chhatrapur, Panna, Satna, Rewa	Medium	Madhya Pradesh
10.4	3.5	0.23	7	Umaria	Low	Madhya Pradesh
10.4	6.6	1.71	26	Hoshangabad, Mandla, Dindori, Nagpur	Medium	Madhya Pradesh, Maharashtra
11.1	9.1	1.84	20	Ambikapur	Medium	Chhattisgarh
11.2	5.1	1.55	30	Rajnadgaon, Durg	Medium	Chhattisgarh

(continued)

Table 2.14 (continued)

AESR		Cotton area				
Nos.	Area	Area m ha	%			
	a	b	b/a*100	Districts	Yield level kg ha^{-1}	States
12.1b	6.7	1.7	25	Gadchiroli, Durg	Medium	Maharashtra, Chhattisgarh
19.2	7.6	0.3	4	Udupi, Belgaum	Medium	Karnataka
19.3	1.9	0.11	6	Udupi	Medium	Karnataka
10.1	9.2	6.02	65	Guna, Vidisha, Rajgarh, Bhopal, Sahajanpur, Sehore, Raisen, Dewas, Damoh, Jabalpur	Medium High	Madhya Pradesh
10.2	4.4	0.43	10	Bhandara	Medium High	Maharashtra
10.3a	3.8	0.38	10	Bainkuthpur, Bilaspur	Medium High	Chhattisgarh
10.3b	2.4	0.56	23	Tikamgarh, Damoh	Medium High	Madhya Pradesh
10.4	6.6	4.33	66	Betul, Chhindwada, Seony, Balaghat	Medium High	Madhya Pradesh
11.1	9.1	2.38	26	Baikunthpur, Korba, Raigarh, Jashpurnagar	Medium High	Chhattisgarh
11.2	5.1	2.88	56	Kawaradha, Bilaspur, Jangir, Raipur	Medium High	Chhattisgarh
12.1b	6.7	1.84	27	Jagdalpur, Raipur	Medium High	Chhattisgarh
12.1c	8.7	0.17	2	Vishakhapantam	Medium High	Andhra Pradesh
12.2	4.2	0.7	17	Vishakhapantam	Medium High	Andhra Pradesh
18.3	2	0.46	23	Ongole	Medium High	Andhra Pradesh
18.4	2.9	0.4	14	Vishakhapantam	Medium High	Andhra Pradesh
19.1a	1.4	0.02	1	Nashik	Medium High	Maharashtra
4.4a	3	1.2	40	Shivpuri, Gwalior	High	Madhya Pradesh
4.4b	2.8	0.37	13	Shivpuri, Gwalior	High	Madhya Pradesh
5.2b	13	0.44	3	Indore, Jalgaon	High	Madhya Pradesh, Maharashtra
6.1a	2.8	0.92	33	Pune, Satara, Sangli	High	Maharashtra
6.2a	3.8	0.45	12	Jalgaon	High	Maharashtra
6.3a	2.3	0.77	33	Jalgaon	High	Maharashtra
6.4a	4.7	3.28	70	Sangli, Kolhapur	High	Maharashtra
7.2a	7.2	0.06	1	Nizaamabad	High	Telangana
7.2b	2.8	0.76	27	Nizaamabad	High	Telangana
10.1	10	0.63	6	Shivpuri	High	Madhya Pradesh

(continued)

Table 2.14 (continued)

AESR		Cotton area		Districts	Yield level kg ha^{-1}	States
Nos.	Area	Area m ha	%			
	a	b	b/a*100			
10.3a	3.8	0.85	22	Shadol	High	Madhya Pradesh
10.4	6.6	0.26	4	Shadol, Narsimhpur	High	Madhya Pradesh
11.2	5.1	0.49	10	Mahasamund	High	Chhattisgarh
12.1a	3.9	0.03	1	Mahasamund	High	Chhattisgarh
12.1b	6.7	1.91	28	Dantewara	High	Chhattisgarh
19.1a	8.7	0.01	0.1	Pune	High	Maharashtra
19.2	1.4	0.11	8	Kolhapur	High	Maharashtra

Source: Bhattacharyya et al. (2015)

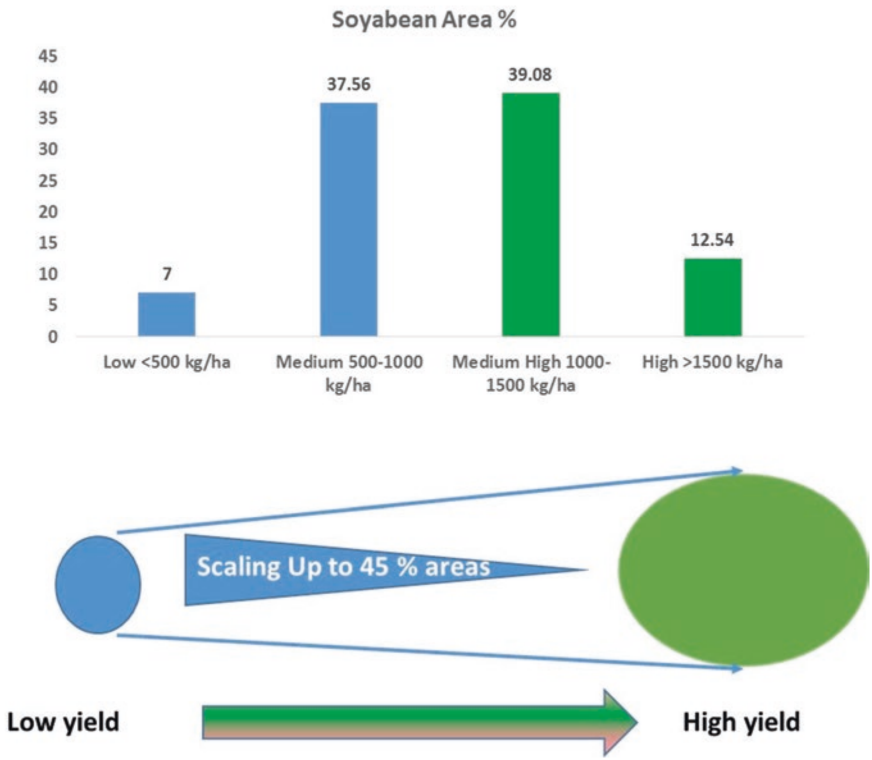

Fig. 2.36 Scaling up potential of soybean yield in target states. (Source: Modified from Bhattacharyya et al. 2015; also see Table 2.13)

2.5.1.2 Soybean- Based Cropping for Livelihoods Systems in Target States

Figure 2.35 shows soybean growing areas in the black soil region. District level soybean yield data were used to divide the BSR into four regions such as low, medium, medium high and high representing areas yielding < 500, 500–1000, 1000–1500 and >1500 kg ha^{-1} soybean. It may be noted that only 7% area is falling under low category, and ~ 52% areas fall under medium high to high yield category (Fig. 2.35). AESRs in the target states with a few exceptions shows that there is a scope to elevate low to medium soybean yield areas to medium high or high yield categories in 45% area through appropriate site specific management interventions including cultivar selection (Table 2.14; Fig. 2.36). The GeoSIS provides soil parameters in terms of their physical, chemical and biological properties to develop a theme map on soybean and its distribution cutting across different AESRs. Exact AESR and the locations of the districts are shown in Table 2.14 to identify areas under low and medium soybean yield.

2.6 Impacts of Climate Change

2.6.1 Impacts of Climate Change in Soils of the Target Regions

There has been a great interest in mitigating climate change due to global warming by sequestering and storing carbon in soil and through its influence on soil quality and agricultural productivity (Bhattacharyya et al. 2014a). Soils provide important ecosystem services at both local and global levels and are the mainstay for crop production. Soils act both as sources and sinks for carbon (Bhattacharyya et al. 2008). Among others, the most important impact of warming on soils is on soil carbon and its influence on different soil parameters as discussed in this section. Soils represent the largest terrestrial stock of C. The first 30 cm of soil holds 1500 Pg C in the world (Batjes 1996)) and 11.4 Pg C in India (Bhattacharyya et al. 2017b).

Table 2.15 Changes in carbon stock over years in soils (0–150 cm depth) of the target states

Soils	SOC stock (Tg/lakh ha)		SOC change over 1980 (%)	SIC stock (Tg/lakh ha)		SIC change over 1980 (%)
	1980	2005		1980	2005	
Asra	6.3	13.6	116	2	2	0
Semla	15.8	13.3	−16	74	46	−37
Vijaypura	7..7	7.7	0	0	0	0
Kaukantla	4.7	10.2	118	0	12.5	100
Kheri	5.6	10.5	87	8.3	9.7	17
Linga	9.7	12.9	34	15.4	21.7	40

Source: Bhattacharyya et al. (2007) (1 Tg= 10^{12} g)

Changes in terrestrial C stocks can be of both regional and global significance and may contribute significant amounts of CO_2 emissions and therefore be linked to climate change. Decline in soil organic carbon (SOC) has major implications for the maintenance of soil health. Carbon stock in the soil depends largely on the areal extent besides other factors such as carbon content, depth and bulk density (BD) of the soil. Even with a relatively small amount of SOC (0.2–0.3%), the arid and semi-arid tracts showed high SOC stock (Bhattacharyya et al. 2000) due to large areal extent of these two bioclimatic systems. To avoid such illusion, here the carbon stock changes have been expressed per unit area (Table 2.15) to interpret the influence of soil and/or a management parameters for sequestration of both organic and inorganic carbon in the soil (Bhattacharyya et al. 2000, 2006). The SOC tend to attain quasi-equilibrium (QE) values with varying duration of 500–1000 years in a forest system 30–50 years in agricultural systems after forest cutting, 5–15 years in agricultural systems after forest cutting in red soils of Odisha, India, and 20–50 years under different agricultural systems with cotton for 20 years, with cotton and pigeon pea for 50 years and horticultural system (citrus) for 30 years (Naitam and Bhattacharyya 2004). Our observations in two time periods (viz. 1980 and 2005) capture the changes in carbon stock over the last 25 years. Judging by the time required to reach the QE stage for the agricultural system, it may be presumed that the soils under study had reached the QE stage after 25 years.

Soil information system (Bhattacharyya 2021b; Bhattacharyya et al. 2021, this volume) helped estimating changes in soil quality parameters in terms of soil organic carbon (SOC), soil inorganic carbon (SIC), bulk density (BD) and saturated hydraulic conductivity (sHC). It is realized that a few selected dynamic properties of soil such as SOC, SIC, BD and sHC change depending on the land use system and time. There is an increasing concern about the declining soil productivity and impoverishment of soil nutrients caused by intensive agriculture. Two-time series datasets for 1980 and 2005 developed earlier were used to assess changes in the levels of carbon in soils of the target states (Bhattacharyya et al. 2007) (Table 2.16). Soil carbon stock depends largely on the areal extent besides other factors such as carbon content, depth and BD of the soil. Even with a small amount of SOC (0.2–0.3%), the arid and semi-arid tracts show high SOC stock due to large area of these two bioclimatic systems (Bhattacharyya et al. 2006). To avoid such illusion, we express the changes in carbon stock per unit area (Table 2.16), to interpret the influence of soil and/or management parameter for sequestration of both SOC and SIC in the soil (Bhattacharyya et al. 2007). In the target states, a marginal decrease in arid and 80% increase in semi-arid bioclimatic system is reported (Bhattacharyya et al. 2014c). It is interesting to note that when we compare SOC stock in 2005 and 2010 at seven BM spots, we find, most of them show a tendency towards quasi equilibrium of SOC, with few exceptions. It has been earlier reported that in agriculture systems the SOC values tend to attain QE over a period of 30–50 years (Naitam and Bhattacharyya 2004). Table 2.15 shows changes in BD and sHC in soils of the target states. Compared to 2005, BD shows a lower value in most of the soils. Changes of BD and sHC affect soil drainage (Table 2.16). Decrease in sHC values indicates that these soils are gradually becoming less porous and require immediate attention.

Table 2.16 Changes (%) in soil parameters over time in soils of the target states

MAR mm	Soils	SOC stock			SOC change*	SIC stock			SIC change	BD (Mg m^{-3})			BD change**	sHC (cm h^{-1})			sHC change**
		1980	2005	2010		1980	2005	2010		1980	2005	2010		1980	2005	2010	
<550	Sokhda	11.2	9.2	9.2	−17	23.6	61.0	53.1	125	1.4	1.8	1.5	−13	0.001	2.58	2.39	−7
1000	Teligi	7.4	15.2	13.1	80	21.0	29.6	28.5	35	1.4	1.4	1.7	22	0.001	0.55	0.07	−87

*Over 1980; ** at 2010 over 2005; ***Very high ESP values produce (–ve) values of sHC when PTFs are used; so we presented a value of 0.001; Teligi soils (Sodic Haplusterts) are found in semi-arid dry bioclimate (632 mm mean annual rainfall, MAR); Sokhda soils (Leptic Haplusterts) are found in arid bioclimate (533 mm MAR)

Source: Bhattacharyya et al. (2014b)

2.6.2 Climate Change and Land Degradation Neutrality in the Target Region

The United Nations Convention to Combat Desertification (UNCCD) is spearheading the issues of land/soil degradation to arrest the precious natural resources becoming unfertile at the global level (Cowie et al. 2018; IPBES 2018). Such steps will render land resources to be protected and restored for promoting sustainable use of terrestrial ecosystems including forests. The main objective is to help reversing land/soil degradation and to combat climate change. Since major soil (and landscape) forming factor is climate, the issues of climate change always involve soils/lands so far its effect on terrestrial ecosystem is concerned. Since landmass is finite, there is an ever-increasing competition to control land resources in terms of their services for the living organisms bringing tremendous pressure on the carrying capacity of land. There are many reasons for land area being dwindled of which degradation of both natural and anthropogenic are important. It seems, therefore, logical to save our motherland and focus on land degradation neutrality (LDN). LDN will help to provide necessary ecosystem functions and services of the land resources and enhance food security. It will also assist to keep the land resources stable and may also improve its quality within specified temporal and spatial scales and ecosystems. Since land and/or soil degradation has the potential to cause social problems leading to poverty and malnutrition, the implementation of LDN requires involvement of multi-stakeholders with adequate support of the national and regional governments (Bhattacharyya 2020). LDN could be achieved by balancing degradation for which major requirement is the information on soil and land for better horticulture, quality of irrigation water (Bhattacharyya et al. 2016b, 2017a; Bhattacharyya 2020).

Black soils (Vertisols and their intergrades) occupy 84.8 million hectares in India (Bhattacharyya et al. 2020). The soils in the target states are mostly found in arid and semi-arid conditions. An example is the soils in ICRISAT Farm, Telangana. It is established that due to aridity in the atmosphere, soil pedo environment dries up to begin the formation of pedogenic carbonates (PC) which triggers subsoil sodicity resulting in chemical degradation of soil (Bhattacharyya et al. 2016b). These soils manifest poor physical properties such as high bulk density (~1.8 kg m^{-3}), and poor drainage (sHC<1 cm hr^{-1}). In many cases such situation renders land as barren. The crops/trees grown on these landscapes have low available water, poor aeration, poor root proliferation and produce low yield (Bhattacharyya et al. 2016a). Interestingly in spite of hostile pedo environment, these soils in the semi-arid tropics, are showing resilience (Bhattacharyya et al. 2016b) otherwise, such soils could have been infertile and perhaps irreparable. The national agricultural research system (NARS) has been doing an excellent job for last many years (Bhattacharyya et al. 2016a). This was shown with SAT soils to understand the fate of soils and landscape with and without management interventions.

Changes in the level of soil carbonate mineral since 1975 till 2030, is predicted. In case present land use options are continued (BAU), the carbonates would increase

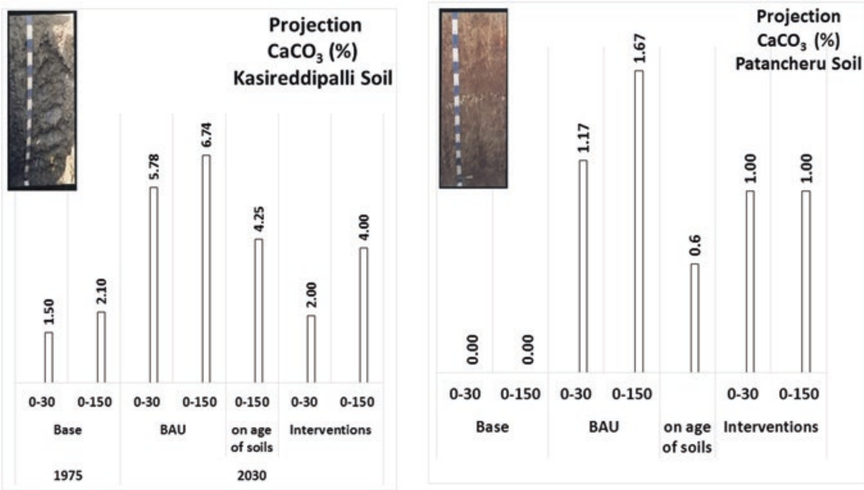

Fig. 2.37 Temporal changes of carbonate mineral in two different soils under BAU (business as usual) and with management interventions. (Source: Bhattacharyya 2020)

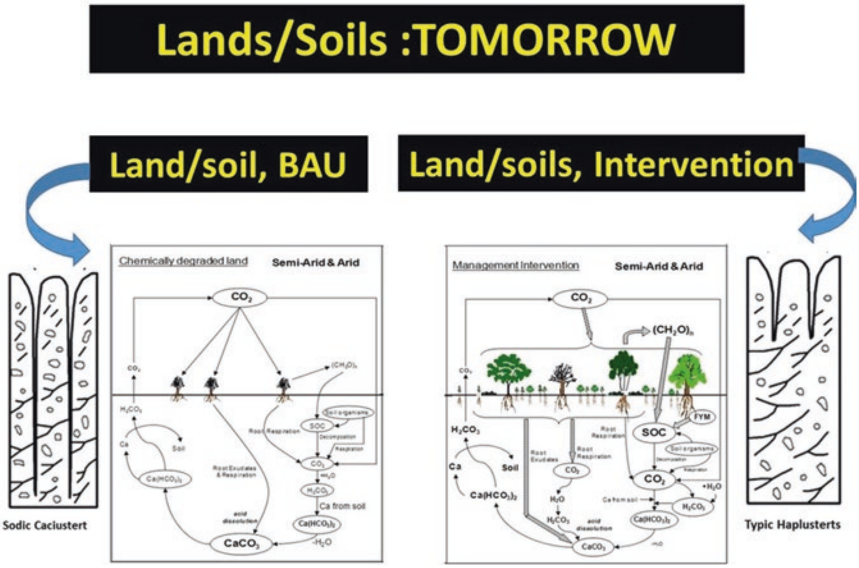

Fig. 2.38 Present and future look of soils and landscape with changes of time and land use changes in business as usual (BAU) and management intervention. (Source: Bhattacharyya 2020)

from 2 to 7% in black soils, and, for (non-calcareous) red soils, to 2%. However, if interventions are adopted, the content of carbonate minerals would reduce appreciably (Fig. 2.37) (Bhattacharyya 2020; Bhattacharyya et al. 2016a). Usually, carbonate minerals, start forming pedogenically, in the sub surface. If these are allowed to form, at the existing rates, with the present land use options these minerals will engulf the entire soil profile from the surface beyond the root zone depth. With poor drainage, very high bulk density, these SAT soils, may look like hard rock in future. The land dominated by such soils will look barren, without much vegetations left on it, as shown on the left side of Fig. 2.38 (Bhattacharyya et al. 2016a). Fortunately, these soils have tremendous resilience, and, therefore, if management interventions are adopted, the same soils will be mellowed, and the land surface will have lush green vegetation as shown on the right side of Fig. 2.38 (Bhattacharyya et al. 2016b).

2.7 Lessons Learnt and Way Forward

India is a large country with nearly 160 million ha area waiting for immediate attention in terms of better food production, resource management and scaling up research achievements to the farm level. It is a challenge. Things have been done which took shape in the target states, yet more is required. Through up-scaling techniques using partnership approach with line departments, government organizations and NGOs, such areas can be brought back to sustainable agriculture. Resilience of soils of SAT suggests that initially degraded soils could be made the vibrant crop production areas to feed the population for another couple of centuries. The

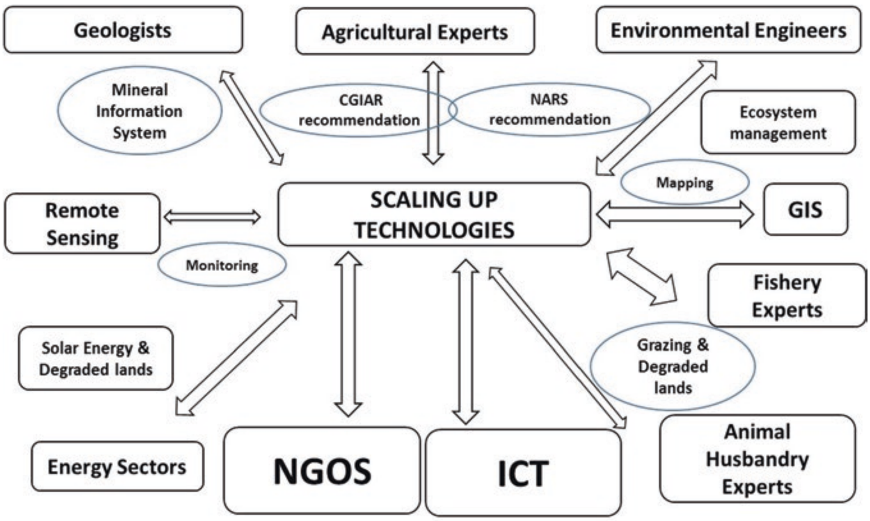

Fig. 2.39 Schematic diagram showing a tentative policy to achieve scaling up technologies

degradation in dry arid areas with desert and coastal sand dunes has been amply demonstrated.

Many soil scientists and natural resource managers are hesitant to talk on LDN, even if their research is devoted to land degradation neutrality. Future research should focus involving multi-disciplinary experts to fulfil the target of scaling up various technologies gathered by SAUs, ICAR, CGIAR and many other organizations directly or indirectly working in these sectors with active participation of non-governmental organizations (NGOs) with an acceptable policy (Fig. 2.39). The contribution of various experts is paramount not only from ecological point of view but also bringing some areas under agriculture and other allied activities. This will result in not only vertical but also horizontal expansion of areas under agriculture, animal husbandry, fisheries and other non-agricultural sectors. Bringing waste land to harness non-conventional source of energy can be doubly beneficial. Firstly, it will help using alternate source of energy to reduce carbon footprints, and secondly, shall enable farmers to utilise the generated energy for operating various agricultural implements.

As mentioned, the nine (9) target states cover nearly 151.9 million ha out of the total 84 revised AESRs (Fig. 2.30) in India. The Figs. 2.40 and 2.41 show the relative proportion of these AESRs occupying the state areas. Forty-eight (48) AESRs in the target states have 11 different categories of LGP starting from < 90 to 240–270 days (Figs. 2.40 and 2.41). Out of these eleven categories (Table 2.17), the LGP showing < 120 days (4 months), 120–150 days (4–5 months), and 150–180 days

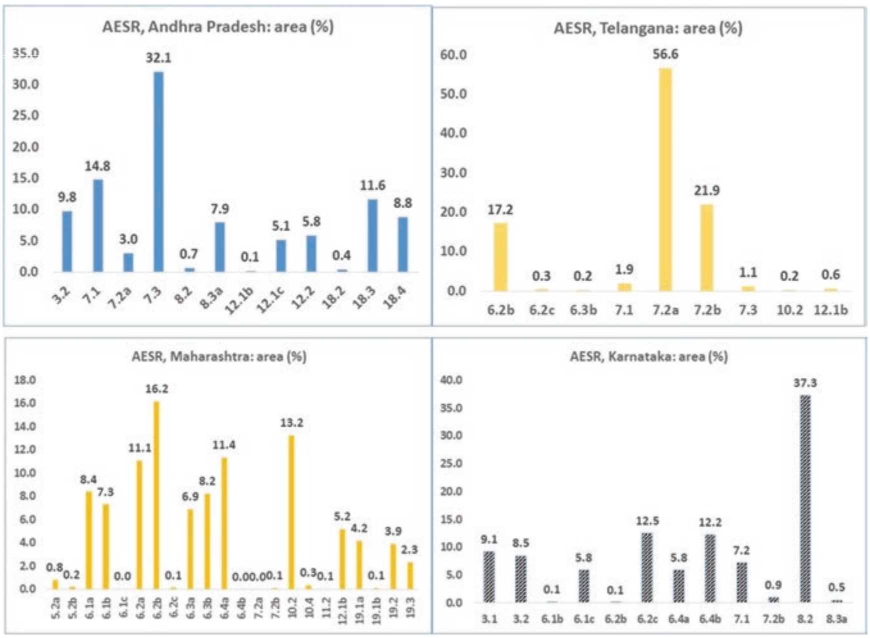

Fig. 2.40 Agro-eco sub-regions (AESRs) in four target states and their relative proportions

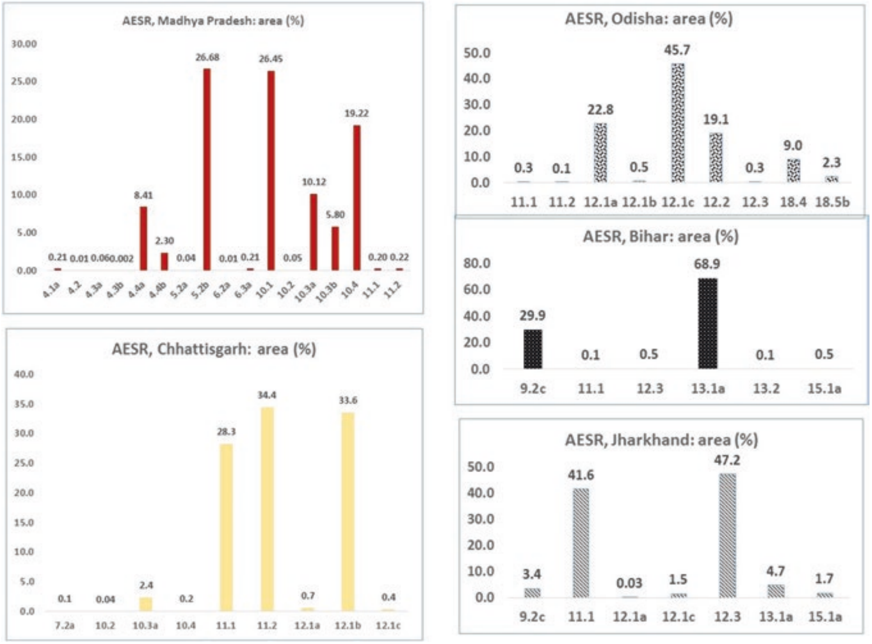

Fig. 2.41 Agro-eco sub-regions (AESRs) in five target states and their relative proportions

Table 2.17 Areas showing length of growing periods (LGP) of different AESRs in the target states (values in million hectare) (areas with bold digits need attention)

	Length of growing periods (LGP) days										
States	<90	90–120	120–150	150–180	180	180+	180–190	180–210	210+	210–270	240–270
	Priority 1		**Priority 2**	**Priority 3**							
Andhra Pradesh	1.59			9.69		0.94		4.05	0.02		
Telangana				2.26			2.49	6.37	0.06		
Maharashtra			2.50	7.61	0.11		0.07	16.96	1.59	1.21	0.71
Madhya Pradesh		0.07	2.62	10.01	5.92			12.13	0.06		
Chhattisgarh					0.02			5.14	8.37		
Karnataka	1.38	1.49		8.24			2.20	3.03			
Bihar				2.81				6.54	0.01	0.05	
Jharkhand				0.27				4.26	3.32	0.13	
Odisha				3.55		2.97		8.59	0.13		0.35
Total	**2.97**	**1.56**	**5.12**	**44.46**	**6.05**						

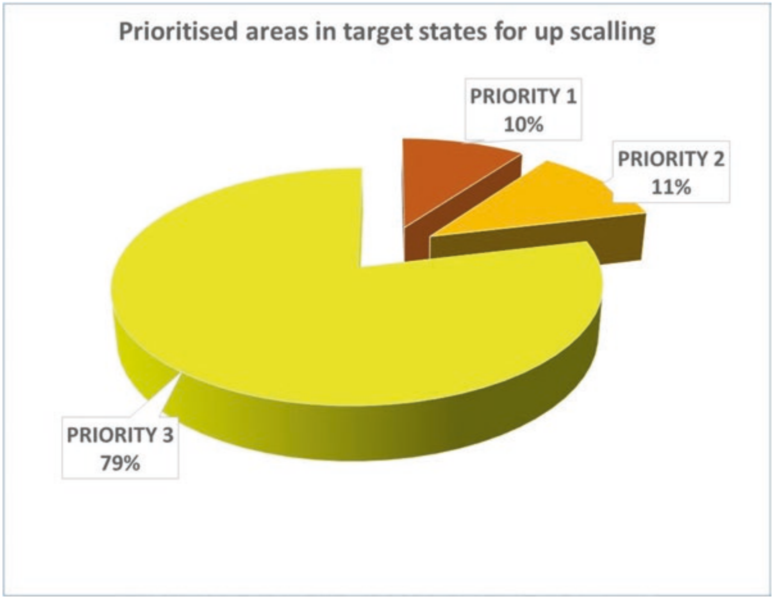

Fig. 2.42 The prioritised areas of the target states for up scaling (Also see Table 2.17)

(5–6 months) are grouped as Priority 1, 2 and 3 in terms of receiving attention from the administrators. Earlier 158.9 million ha areas were prioritised in India mostly from drier AESRs for organic C sequestration (Bhattacharyya et al. 2008) and Conservation Agriculture (Bhattacharyya et al. 2014c). The present study suggests the way forward for the planners in 10%, 11% and 79% of the AESRs providing 4 months to 6 months growing period as the top priority in the nine target states to better the livelihood of the farming community (Fig. 2.42).

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Chapter 3
Empowerment of Stakeholders for Scaling-Up: Digital Technologies for Agricultural Extension

Tapas Bhattacharyya, Suhas P. Wani, and P. Tiwary

Abstract In most of the developing countries in Asia and Africa large yield gaps are existing between the current farmers' yields and potential achievable yields. The necessity of meeting the farmers' requirement to scale up research results is paramount for adequate food production. This requires empowerment of farmers by answering queries of farmers appropriately through different extension channels including state and central machineries. These are the backbone of the agricultural technology development to empower farmers as the major stakeholders and hence requires attention. Lack of awareness among farmers about good agricultural management practices compel them to follow the traditional practices. All agricultural education and research, ultimately aims at increased productivity and economic well-being of farmers. This is possible only when there is a minimum gap between laboratories and land. This gap is bridged by agricultural extension. But human capacity, the content of the information, processes of delivery and technology determine effectiveness of extension services. Non-availability of sufficient extension personnel is a major constraint. To overcome these shortcomings, e-Extension (eE) is the alternative. It is important to rejuvenate the agricultural extension system (AES) with innovative information communication technology (ICT) models for knowledge generation and dissemination. Latest digital technologies are discussed in this chapter on ICT to empower farmers to scale up for reaching the required target of food production with special reference to Indian scenario.

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There is an urgent need to transform neglected knowledge delivery systems by strengthening the science of delivery which has been neglected by the researchers/development worker/policy makers alike. Availability of new technologies such as information technology (IT), internet of things (IoT), audio and video using cell phones, geographical information system (GIS), simulation modelling, remote sensing (RS) open up new vistas for effective knowledge delivery for achieving the impacts on ground. This will help to cross the *"Death Valley of Impacts"* for achieving the zero hunger goal by adopting innovative approaches/tools and partnerships.

Keywords Empowering stakeholders · Bridging yield-gaps · Science of delivery · ICT-enabled extension · Farmers' empowerment

3.1 Stakeholders, e-Extension (eE) and Empowerment

3.1.1 Stakeholders

A stakeholder is an individual or group with an interest in the success of an organization in fulfilling its mission—delivering intended results and maintaining the viability of its products, services and outcomes over time. The key constituencies in the realm of delivering outcomes suggest what members of each group have at stake. Some "stakes," of course, are held by more than one constituent group in the list of stakeholders (Table 3.1). Stakeholders are identified as any individuals or

Table 3.1 Key agricultural constituent groups and their stake in Project Success

Constituent Groups	Stake
Farmers	Good produce, good return, better social status, children education, social security, crop security, on-time supervision by the experts in case
Researchers	Replication of research results in field, Professional Excellency, Recognition
Extension Workers	Regular Research updating and back-up from researchers, Farmers' success, Help from Government machinery
NGOs	Regular research back up from research Institutions and state agricultural Universities, Constant link with the field workers and the farmers
Government Organisations	Supply of funds, Monitoring, Buying agricultural produce and/or easing quick purchase of produce, transport, basic infrastructural facilities for storage of produce.
Agricultural Universities	Research, Extension Education, Farmers' rallies, Publications in local vernaculars, Use of ICT, TV, other media for extension of research findings
Sponsors	Supply of funds, Monitoring
Business community	Keeping an watch over product, on-field pick up agricultural produce, quick and hassle-free payment to farmers
Taxpayers	Getting a good return on their tax investment
Citizens	Getting a good return on their tax investment, Good consumable products, reasonable at price

groups which can affect organization or project performance or which are affected by the achievement of the organization's or project's objectives as evidenced by a range of categories of stakeholders (Table 3.2). Identifying right stakeholders for scaling-up is a challenging task as several sectors are involved and are interlinked in delivering the desired impact. For example, for a large scaling-up mission program like *Bhoochetana* in Karnataka (Fig. 3.1) or *Rythu kosam* in Andhra Pradesh a consortium was formed amongst the knowledge- generating and -transforming institutions as well as private corporates for inputs supply and market linkages.

Table 3.2 Different types of stakeholders

Stakeholders	Sources
Government, political groups, shareholders, financial community, activist groups, consumers, consumer advocacy groups, unions, employees, trade associations, competitors and suppliers.	Freeman (1984)
Shareholders, customers, voters, general public, financial community, lawmakers, communities, the press, higher education, employees and their families, labour unions, company distributors and other companies including competitors.	Droge et al. (1990)
Customers, community, stockholders, government, employees.	Lerner and Fryxell (1994)
Buyers (intermediate customers: distributors and retailers; and ultimate customers), Suppliers (goods and service suppliers), Lateral stakeholders (competitors, government and non-profit organizations), Internal stakeholders: functional departments, employees and business units.	Morgan and Hunt (1994)
Client, project leader's organization, outsourced services, invisible team members	Briner et al. (1996)
Environmental stakeholders: customers, owners, community; Process stakeholders: employees, suppliers.	Atkinson et al. (1997)
Internal stakeholders (departments, divisions and functional units), External stakeholders (customers, shareholders, distributors, suppliers, employees, local community, the mass media, and the environment), Distal stakeholders (competitors, government agencies, labour unions, auditors, and industry leaders)	Sirgy (2002)
Owners, governments, customers or clients, employees, communities, society, suppliers.	Bao (2004)
Shareholders, customers, employees and other stakeholders including suppliers, and communities.	Fitzroy and Hulbert (2005)
upstream stakeholders (paying customers and end users; N downstream stakeholders—suppliers and subcontractors), external stakeholders (general community and independent concerned parties), invisible stakeholders (delivering project benefit with their vital support for project success), and project stakeholder group (project sponsors and delivery team).	Li (2007) and Walker and Nogeste (2008)
Citizens of India, Individual government employees, Various employee associations, NGOs, Sixth Central Pay Commission, NIC	(GoI 2020)

Revised from Rowlinson and Cheung (2008)

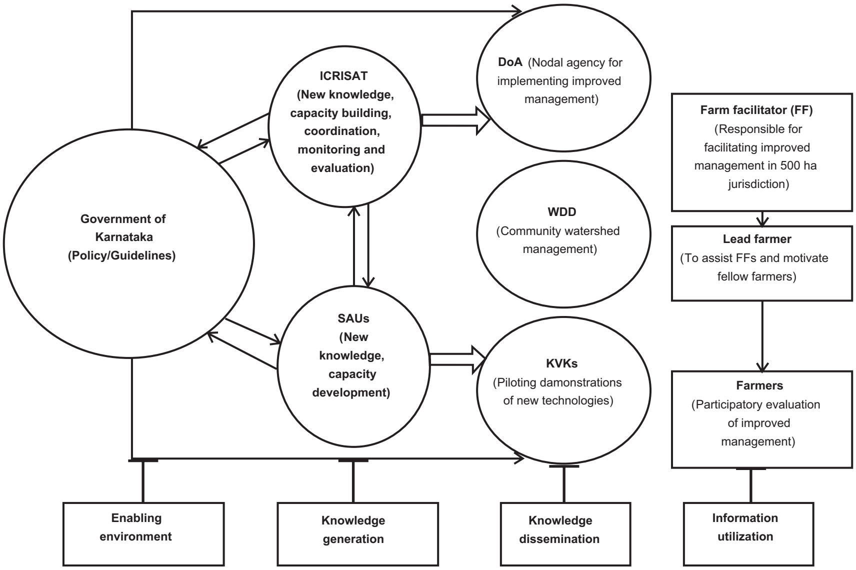

Fig. 3.1 Consortium of partners in the *Bhoochetana* programme in Karnataka. DoA, Department of Agriculture; FF, farm facilitators; KVKs, *Krishi Vigyan Kendras*; SAUs, state agricultural universities; WDD, Watershed Development Department. (Source: Anantha et al. 2016)

3.1.2 e-Extension (eE) and State Agricultural Universities in India

A discussion paper of the International Food Policy Research Institute (IFPRI) opened with a question: are farmers' information needs being met? (Glendenning et al. 2010). In fact, our agricultural extension system has several parallel channels of information to farmers. State Agricultural Universities (SAUs) are one of them. These are important because they are backbone of the agricultural technology development. They are also expected to perform an effective role in extension of these technologies. The question is how do they do it?

The SAUs ideally develop technologies and generate content. They provide extension education service through training of trainers. The scientific and technical staff of SAUs is mandated with extension. But it is just one of the mandates along with research and education which consume more of their time. The SAUs do provide limited extension through Agricultural Technology Information Centres which attract visitors. They also provide wider extension through Krishi Vigyan Kendras (KVKs) which depend on SAUs for technology and on ICAR for actual delivery through various channels (Adhiguru et al. 2009) (Fig. 3.2). All agricultural education and research, ultimately aims at increased productivity and economic well-being of farmers. This is possible only when there is a minimum gap between lab and land. This gap is bridged by agricultural extension. But human capacity, content of the information, processes of delivery and technology determine effectiveness of

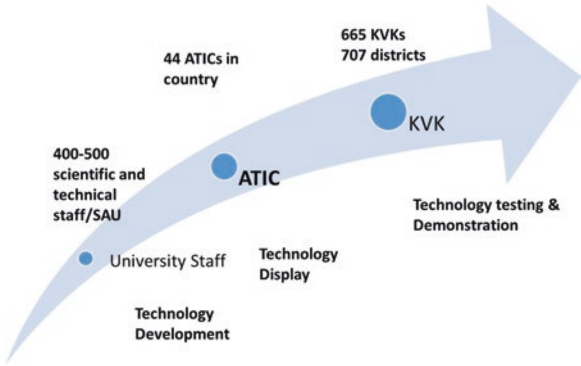

Fig. 3.2 Agricultural Extension in India: Role of SAUs (The dimension of the circle indicates relative contribution to agricultural extension). (Bhattacharyya et al. 2018a)

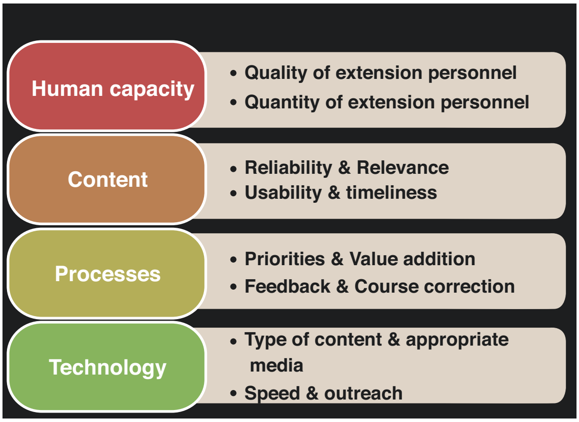

Fig. 3.3 Agricultural Extension in India: Effective extension. Lack of personnel and outdated technology are major constraints. (Bhattacharyya et al. 2018a)

extension services (Glendenning et al. 2010). Some of the parameters of these factors are keeping the effectiveness of agricultural extension perhaps at a low (Fig. 3.3).

Non-availability of sufficient extension personnel is a major constraint. The state agricultural universities (SAUs) do not have adequate extension personnel to reach out to the wider farming community. And as detailed earlier, they are burdened with other duties. On the other hand, the state agriculture department (a line department) catering to the same area as the jurisdiction of a SAU may have a relatively large number of extension personnel. For example, in Konkan region of Maharashtra, the extension workers in the agriculture department are nearly 100 times more than the university extension workers. Moreover, the state department has a wider presence than any SAU. Indeed, even the agriculture departments are under severe staff crunch in most Indian states (Sajesh and Suresh 2016). Another constraint is the limited reach of traditional extension approaches. Only about 40% of our farmers gain access to any kind of extension services either public or private. To overcome these shortcomings, e-Extension (eE) is the alternative as shown in Fig. 3.4 (Anonymous 2016; Ghimire et al. 2014; Anonymous 2009).

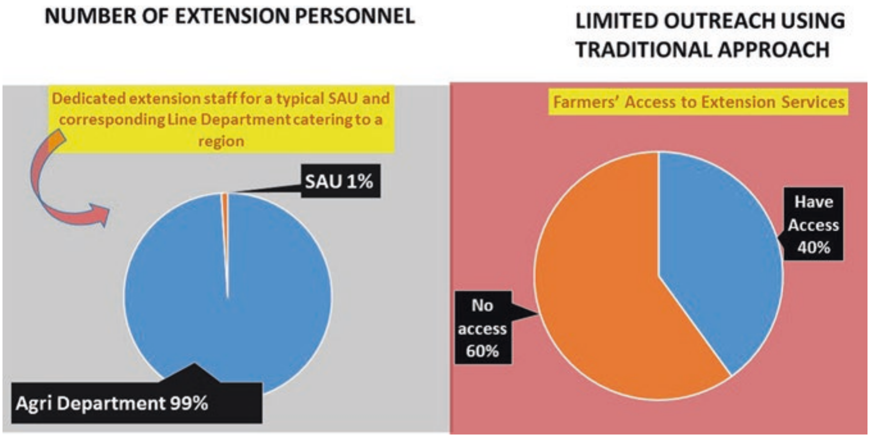

Fig. 3.4 Forces pushing for e- Extension in India. Lack of dedicated extension staff with SAUs and farmers' lack of access to extension services rendered through traditional means have made it imperative to go for e-Extension. The staff data is sourced for Konkan region from DBSKKV, Dapoli and Department of Agriculture, Government of Maharashtra. Data for access to extension services from Anon. 2016. (Bhattacharyya et al. 2018a)

3.1.3 Empowerment

Empowerment means authority or power given to someone to do something or is the process of becoming stronger and more confident, especially in controlling one's life and claiming one's rights. In this context farmers' empowerment means farmers are enabled to do improved farming with increased productivity and profitability in the current context. Empowerment comes through acquiring knowledge about new things but at the same time effective empowerment can be achieved only through convergence as without policy support farmers cannot achieve the goal of income enhancement even if they produce more as market pulls down the prices. Even productivity cannot be increased only through sharing the knowledge with the farmers as without needed availability of quality inputs at right time with right price productivity cannot be increased. Also farmers need to adopt *"fork to farm"* approach based on the market demand rather than *"farm to fork" where* farmers produce what they like and then find market. In brief, empowerment goes far beyond the context of traditional capacity building/development. In this chapter, we discuss the holistic empowerment of the farmers for achieving the goal of zero hunger through achieving food security and also wellbeing through increased family incomes.

In this regard the first step for empowering farmers is acquiring education by the farmers. Education is the process of facilitating learning, or the acquisition of knowledge, skills, values, beliefs or habits. Education methods include teaching, training, storytelling, discussion, directed research and demonstrations particularly participatory demonstrations. Education can take place in formal or informal settings and in the context of extension for the farmers using new technologies also, the informal settings become important.

Thus, the concept of empowerment is addressed in this paper in order that the process of project management can be put into an appropriate, and contemporary context. Various authors have shown that a stakeholder management approach to governance entails long-term social exchange between parties, mutual trust, interpersonal attachment, commitment to specific partners, altruism and cooperative problem solving (Stoney and Winstanley 2001; Carter 2006). Now onwards, empowerment in this chapter is discussed as holistic empowerment of stakeholders for achieving the desired impact on ground.

3.2 Awareness Creation-Formal and Informal Methods for Skill Building, Knowledge, and Practices Through e-Extension (eE)

Overall reach of extension media has been reported to be 35-40 per cent farm household (Anon. 2016). Major farmers who adopted technology mediated by extension services reported the methodology and other details of innovations useful. The important extension media were progressive farmers, mass media, SAUs and KVKs. However, the pattern of access differed. The mass media was accessed routinely to provide general information. On the contrary, the SAUs and KVKs provide design, crop and even farm- specific advisory. With the use of internet and e-services, progressive farmers, SAUs, KVKs and extension workers can be empowered to reach the maximum number of farmers.

The eE is envisaged to operate mainly through web portals, social media and mobile apps and therefore has several benefits over the traditional extension approaches. The methodologies are portable, cost-effective and can reach to the larger section of people in real time. Most of these technologies are interactive with stakeholders connecting online or offline and permit quick feedback (Saravanan and Bhattacharjee 2015; Saravanan et al. 2015). The major benefit of e-Extension is that it has the capacity to integrate various farms and extension media such as texts, pictures, videos and animations. The eE provides opportunities for improving weak and vulnerable sections of society including women and unemployed youth. There is a scope to foster public-private and farmers-experts partnerships through eE. Resources including finance and insurance can also be mobilized greatly through this technique. The eE stands on four inter-connected bonds *viz* e-learning, e-extension, e-farming and e-trading (Fig. 3.5).

FAO suggested 15 points' strategy to modernize extension systems at lower levels (Table 3.3). Other than many, the point which flags performing extension services with less number of staff appears as the common scenario in most of the SAUs. Outsourcing is an important option. It also insists to make use of information technology tools and media, but with educated human back-stopping which is all

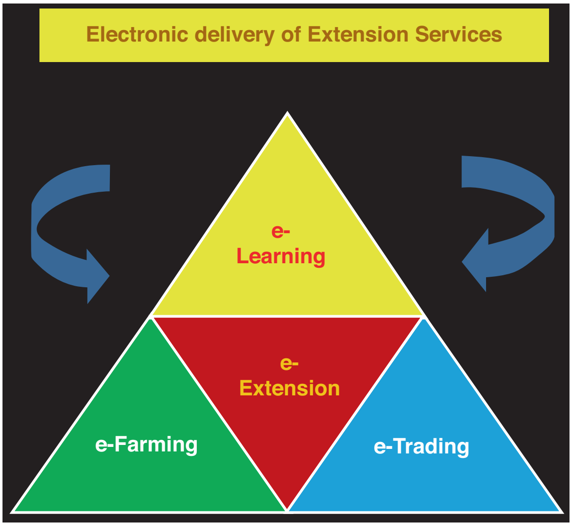

Fig. 3.5 The inter-connected bonds of e-Extension. (Source: Saravanan and Bhattacharjee 2015; Saravanan et al. 2015)

about e-extension. Treating extension finance and extension delivery would be two separate functions (FAO 2005).

The history of information and communication technology (ICT) for extension in agriculture dates back to the use of radio and much before that by just personal communication (Fig. 3.6), as an example in Sweden during 1800s. These channels help mostly in one-way dissemination of topical and general information. Farmers need farm and season-specific information. Attempts to make radio and television more interactive have proved successful. As per the national sample survey office (NSSO) report (Anonymous 2016), these media are routinely accessed by the farmers. But it is the IT revolution, which has really brought mobile and internet in the hands of the farmers (Rajkumar et al. 2016). The potential of IT found to be harnessed by government and different organizations for the best results (Kaegi 2015). Several initiatives have been taken up by the government departments for advancing e-E. The M-Kisan portal provides SMS based advisory as a value-added services. Service apps include *Kisan Suvidha*, *Gujarat Sarkar Khedut Mitra* (Gujarat), *Shetkari Masik* (Government of Maharashtra). Many of these can now be installed on smart phones and the relevant advisory information can be obtained by the farmers (Fig. 3.7). Even the Tata Chemicals supported *Kasturi* initiative which relies on in-person exposure of women agripreneurs travelling countrywide to various SAUs on a special train also relies on continuous digital learning (www.mykasturi.org).

The Indian Council of Agricultural Research (ICAR) has initiated several schemes for enhancing extension of agricultural technology. To increase electronic communication, the ICAR has facilitated development of network of *Krishi Vigyan Kendras* (KVKs) as stakeholders. To involve the farmers more proactively in dissemination of experiments and success stories, ICAR has also initiated farmers' blogs. It has launched mobile apps like Rice Expert which has a support system for

Table 3.3 Methods of e-Extension

Sl. No.	Particulars	Details
1.	Existing extension organization	Assessment
		Farmers' needs
		Strengthening and/or restructuring
2.	Decentralize extension	Capacity-building of the staff and
		Orientation of officials
3.	Technical mandate of extension	Broadening
		Development of rural human resources
4.	National policy	Formulation
		political and financial commitment
5.	Status of extension profession	long overdue
		Consider other agricultural disciplines
6.	Pre-service education in agricultural extension	Modernization
		Development of national extension system
7.	Pluralism	Involve public, private, and civil society institutions
8.	Privatization	Complete privatization
		Social and economic feasiblilty analysis
9.	Information technology (IT)	Development and application of IT tools
		IT Training extension workers
10.	Site-specific extension methodologies	Development of original, location-specific, participatory, gender-sensitive and inexpensive methodologies
		Apply modern techniques
11.	Orientation	Major food security
		Global developments
		Rural livelihoods
12.	Empowering farmers	Organizing legal associations
		Forming strong farmers' lobby
13.	Bottom-up approach	Encouraging grassroots extension
		Involvement of farmers for conservation of natural resources and environment protection
		Demand-driven extension
14.	Poor manpower	Outsourcing
		IT and media
		Merging overlapping staff positions
		Delivery responsibilities
		Contractual short-term staff
		Progressive farmers as facilitators
		Move bulk of extension staff from central level to sub-district level and village level
		Treating extension financing and extension delivery as two separate functions
		Avoiding individual farmer contact: Group extension approach
15.	Operational linkages	Effective organic relation between extension, research and other relevant institutions

Adapted from FAO (2005). Also see Bhattacharyya et al. (2018a)

Fig. 3.6 Evolution of e-Extension. (Source: Anonymous 2016)

Fig. 3.7 Selected initiatives of agricultural e-Extension in India. (Source: Various web portals)

Fig. 3.8 Indian and ICAR initiatives of e-Extension. (Source: ICAR website and several brochures)

the farmers through electronic interface (Fig. 3.8). It is in this connection, the collaboration between Indian Farmers' Fertilizer Cooperative (IFFCO), Bharati Airtel and Star Global Resources Ltd. needs to be mentioned. It provides value-added services through the network of Airtel. They involved village co-operative societies as mediators. Information-driven apps are available on web portal and on smart phones. Real-time, predictive, weather and market information are also available. Many Non-Government Organizations (NGOs) have examples in Digital Green. It is a platform which acts as repository of locally produced videos. The NGOs use this information to disseminate knowledge to the farmers using extension channels, their integrated approach has been reported to be effective (Gandhi et al. 2009). Some SAUs have taken up e-Extension in a mission mode. Tamil Nadu Agricultural University is an example. Their content is streamlined and made available on a web portal. Group specific expert concept is also made available through mobile apps. This programme of digital media is one of the important tools to literate and provide information to the farmers about modern agricultural research and technology and to empower them in future days (Soni Kumari 2016). In addition to the government, private agricultural companies are also providing innovative solutions for agricultural extension (Fig. 3.9).

- awareness among farmers about available tools for getting the information;
- a one-stop application for all agriculture-related activities;
- regular updates of information;
- voice messages with a toll-free number;
- video documentation;
- a consortium of government agencies and agricultural research-and-development agencies for content generation and dissemination;
- weather-based agro-advisory information;
- fertilizer recommendation(s);
- mobile data collection;
- insect and pest monitoring and control measures;
- a two-way communication option; and
- market information sellers of agri inputs and buyers of farm produce.

Fig. 3.9 Key constituents of an ICT assisted delivery system/AES. (Source: Patil et al. 2016)

3.3 Other e-Extension Approaches

An innovative agricultural extension system (AES) is necessary to ensure deep penetration of available agricultural technologies into the farming community. Introduction of farm facilitators (FFs) and lead farmers in the AES has provided the local point of information dissemination at the village level. FFs are not agricultural graduates and information acquired by them during training sessions is adequate to address basic issues, such as the use of soil-test-based nutrient management promotion of improved crop cultivars, generic pests and diseases, and other field operations. However, this information may not be sufficient to address real- time issues, such as crop planning based on weather, correcting the nutrient deficiency during the crop growing period and identifying pests and diseases. Thus, there is a need to create a convenient channel for information exchange between FFs and the developmental organizations and the research agencies.

Creative and effective ways of disseminating the information have been explored during the *Bhoochetana* programme to improve the adoption rate among the farming community. For example, information related to soil fertility status has been disseminated among the farmers through writing the information on the walls of schools or houses and through soil health cards. These ways are far more effective than dissemination through group meetings. Use of media, posters, leaflets, and other written documents in the local vernacular are effective. This system is aimed at strengthening the local extension agent by providing a channel for information dissemination and to monitor the real-time agriculture status on the ground.

Digital technologies have been used in the AES such as television/radio programmes, call centres, satellite programmes and a short message service (SMS) - based advisory system. The cellular telecommunication has good penetration in urban as well as rural areas of India. Thus cellular technology has become a very useful tool for marketing through mobile marketing, the service providers can directly communicate with the consumers; the main objective is to develop close and stronger interactions with the consumer and provide customized services. AESs are already adapting mobile communication technology to change the livelihood of farmers through up scaling farming technologies (Patil et al. 2016).

3.3.1 Digital Technology

The other e-Extension techniques were piloted with Samsung Galaxy Tablet (Tab) 2. However, a tablet with a similar specification including a 17.8 cm (7 inch) touch screen. 3G and Wi-Fi connectivity, a voice-calling facility, a primary and secondary camera with a good resolution, global positioning system (GPS), Bluetooth, expandable memory and 1 GB RAM, is also suitable for a tablet-based extension system. The ruggedness of this tablet will be useful in farmers' fields.

Krishi Gyan Sagar (KGS), a tablet-based extension system, was developed by ICRISAT in collaboration with others (Patil et al. 2016). It is a generic framework for a digital extension system that can be deployed in any part of the world. The KGS is designed to help in sharing knowledge of front laboratory to farmers as well as information collection from farmers to laboratory. The web app is dovetailed in the KGS as the website for visualizing the data gathered by the farm facilitators (FF) using the KGS app (Fig. 3.10).

3.3.2 Adopting ICT Tools for e-Extension: Road to Precision Farming

The e-Extension has the potential to transform traditional farming into precision farming. Most developed countries rely on precision farming for increased productivity and profitability. Precision farming has economic, social and environmental benefits as is the case in Israel. Precision farming requires adoption of advanced technology. In most of the cases, technology is available, but its rate of adoption is slow. The e-Extension can play a crucial role to enhance the adoption rate of technology. In Israel, for example the number of extension personnel is just in 100s. But

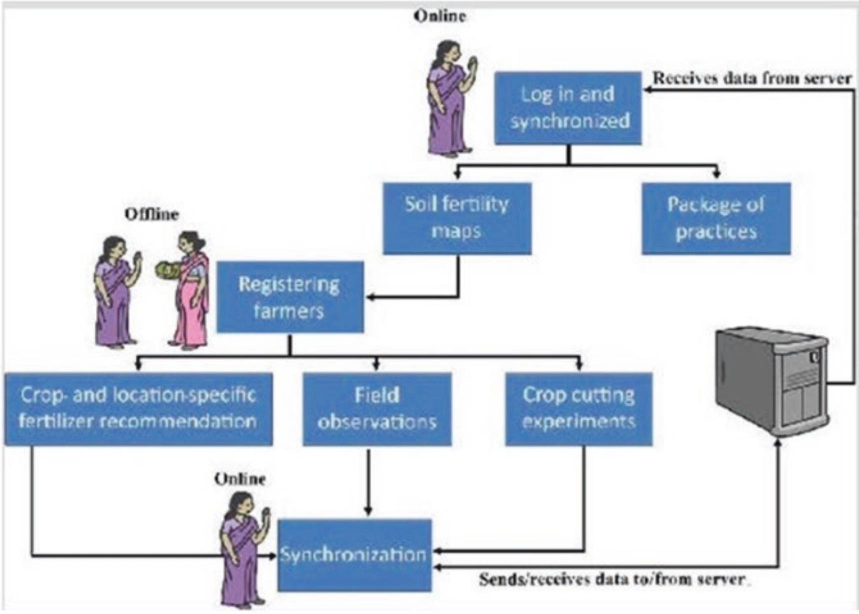

Fig. 3.10 Field Operation of the Krishi Gyan Sagar (KGS). (Patil et al. 2016)

they have ensured very high rate of technology adoption. The e-Devices and softwares ensure data logs from sensors and through feed-back. Management and analysis of these logs lead to improved technology which further enhance access to technology, inputs and advisory to improve the rate of adoption (Fig. 3.11) (Bhattacharyya et al. 2018a).

3.3.3 e-Extension: Opportunity for State Agricultural Universities

The SAUs are poised to take advantage of advanced technology for e-Extension. The limited and over-burdened manpower can be shifted to social media platform for productive interaction with farmers' groups. The newly-evolved Students-READY (Rural Entrepreneurship Awareness Development Yojana) Programme under the Vth Deans' Committee syllabus offers a unique opportunity to involve students as extension intermediaries (Bhattacharyya et al. 2018b). Information and communication technology is also an integral part of agricultural education. A wide range of mobile apps are available for recording data, monitoring crops and environment (Antle et al. 2017). Similarly, smartphone capabilities enable video making and better photography with Geo-tagged information. Social media is already being used to supplement the formal class-room, laboratory or field learning informally.

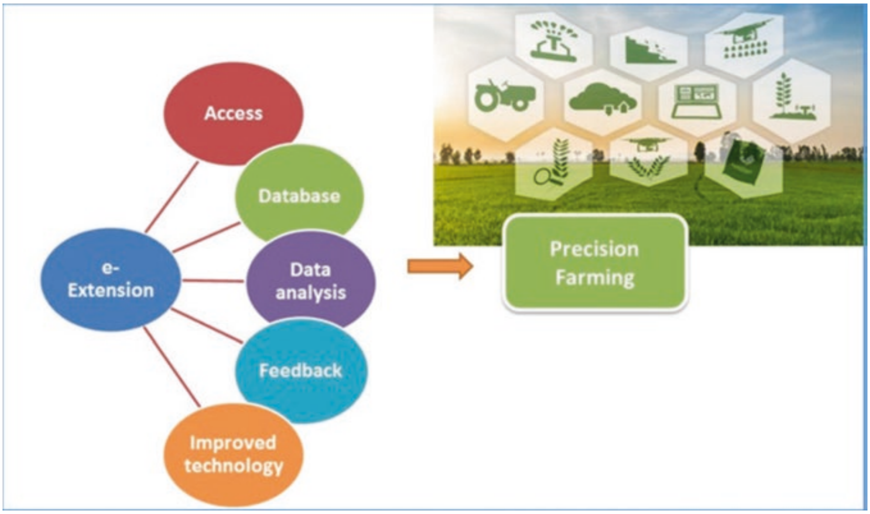

Fig. 3.11 e-Extension: Road to precision farming. (Bhattacharyya et al. 2018a)

SAUs can develop local diagnostic and responsive apps and reach an unprecedented number of farmers through their students. Therefore, SAUs should decide that they need not lag behind in providing extension services due to lack of manpower. Moderated social media can be successfully used for protective farming and at every stage of the value chain. The e-Extension further reduces the time lag between need and application of farming technology. It also helps in cost reduction and waste reduction. It empowers farmers by opting as a part of decision support system. The e-Extension can be harnessed to improve traceability of farm products which is a crucial parameter in the era of food certification. All these benefits together can contribute immensely to doubling farmers' income (DFI) (Bhattacharyya et al. 2018c).

3.3.4 Krishi Vani

ICRISAT in collaboration with IKSL and Bharti Airtel initiated the *Krishi Vani* platform which is a mobile phone/phablet-based application. This initiative has been piloted in 171 villages in Telangana and Karnataka benefiting 40,000 farmers (ICRISAT 2014). Through this application generic advisories are delivered to groups of farmers in a location through the mobile phone enabled by Green SIM. IKSL has pioneered the voice-message-based agro-advisory system. To subscribe to *Krishi Vani*, the user has to buy Green SIM card specially configured for receiving voice messages and other agro-advisory services. Every day, four free voice messages are delivered to the subscribers. The contents of voice messages are advised by subject matter specialists and cover diverse areas such as soil management, crop management, dairy and animal husbandry management, horticulture and vegetable management, plant protection, market rates, weather forecast information, human and cattle health, employment opportunities and government schemes. The android KGS app is a field tool for information dissemination and data collection, whereas the web app is the website for visualizing the data gathered by the FF using the KGS app (Fig. 3.10). Both android app and web app have a common database server. The web address for this application is www.krishigyansagar.com; however, this application was not accessible to all users. The web app contained all the information available on the android app. The important features of this app were *user registration and report generation tools.*

3.4 Empowerment of Stakeholders

Stakeholder management involves the project team in a process of enabling stakeholders to identify, negotiate and achieve their objectives, such as social, environmental or economic, through active participation in the project process (Brammer and Millington 2004; Pajunen 2006). This involvement inevitably necessitates some degree of empowerment of the stakeholders to facilitate their engagement. Thus, the concept of empowerment is addressed in this paper in order that the process of project management can be put into an appropriate, and contemporary context. Various authors have shown that a stakeholder management approach to governance entails long-term social exchange between parties, mutual trust, interpersonal attachment, commitment to specific partners, altruism and cooperative problem solving (Stoney and Winstanley 2001; Carter 2006).

Relationship management influences empowerment and overall performance to accrue benefits as shown schematically in the model (Fig. 3.12) with special reference to India and Indian farmers. An input- conversion output paradigm is used in terms of several incentives to the Indian farmers by the Governments (Anonymous 2020) which determine the effectiveness of the empowerment through various stimuli for the ultimate benefits of the Society in particular and for the Nation, at large. This scheme might be a model understanding to empower Indian farmers and may be sharpened with new concepts and case studies in days to come.

Initiatives of the Government of India and Indian National Agricultural Research & Education System (INAERS) for empowering Indian farmers include Digital India Programme which is set to transform India into digital empowered society and knowledge economy (Fig. 3.13). This programme of digital media is one of the important tools to literate and provide information to the farmers about modern agricultural research and technology and to empower them in future days (Soni Kumari 2016).

As discussed in Chap. 1 of this book, large yield gaps between current farmers' yields and the achievable potential achievable yield exists for all the crops and across the countries in the developing world. In India, one of the main reasons identified for large yield gaps and low adoption of improved technologies/products is

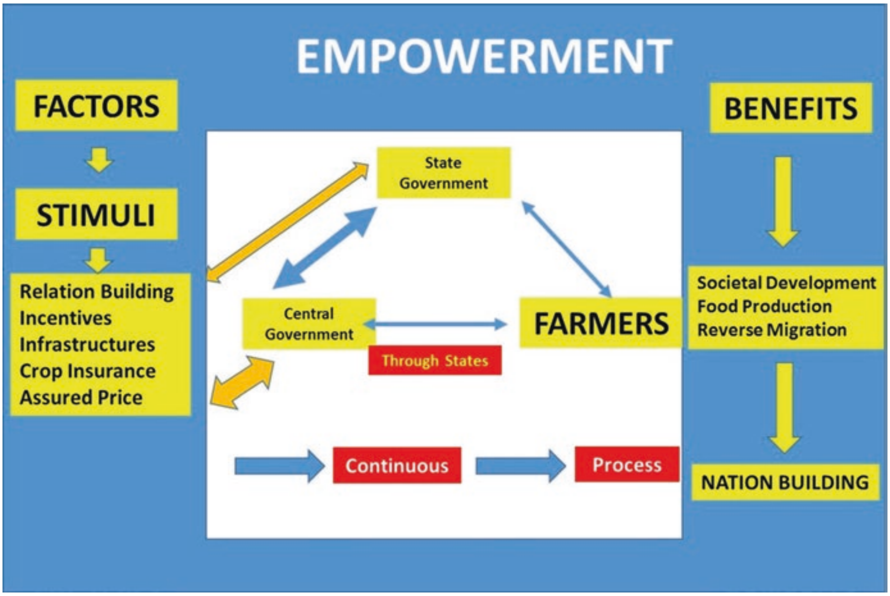

Fig. 3.12 Schematic Diagram showing Empowerment Model for Indian Farmers as a continuous Process. (Conceptualized from Goria et al. 2018)

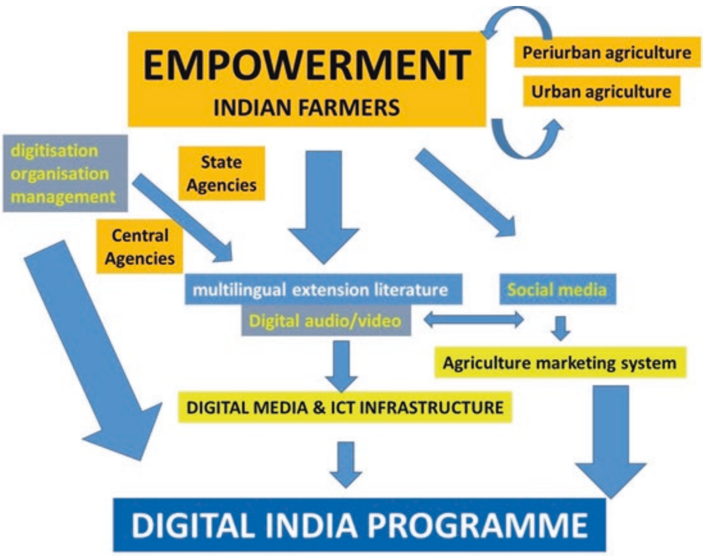

Fig. 3.13 Digital India Programme and Empowerment of Indian Farmers

poor extension support for the farmers. As per the national sample survey data, 51% farmers in India do not get any knowledge support (extension support) and only 11% farmers get support from the government machinery while remaining 30% farmers get support from peers, media and private agencies (NSSO 2013; GoI 2013). The situation cannot be different in other developing countries in Asia, Africa and Latin America. Recent meta-analysis undertaken by the Ceres 2030 team of scientists analysed 100,000 research papers published and recorded that ending hunger is not achieved largely due to wrong priorities of the researchers and not working with the farmers confirming findings of existing *Death Valley* of impacts (Wani 2020, 2021; Wani and Singh 2019; Wani et al. 2002, 2003; Nature Food 2020). The Ceres 2030 researchers found that major constraint for adoption of new approaches/technologies/products was lack of technical advice, input and ideas, collectively known as extension services for the small farm-holders. The small farm-holders are more likely to adopt new approaches specifically, planting climate-resilient crops when they are supported by technical advice, input and ideas (Nature Food 2020). Recent review of current status of trends and the way forward of extension system in India by (Gulati et al. 2018) observed that only 0.54% of gross domestic product from agriculture (GDPA) was spent on total research and extension education with a considerable variation amongst the states. They also noted that eastern states which are also poorest amongst few with high dependency on agriculture and low agricultural productivity are also the states with lowest spending on agricultural R & E indicating a strong linkage between extension and agricultural productivity. The declining rate of extension personnel in the agriculture sector in Karnataka contributed to low level adoption of science-led innovations thereby adversely affecting agricultural growth in the state (Government of Karnataka 2006). Low technology in the agriculture sector has hindered the production of high-value products that generates employment and income (Government of Karnataka 2011).

Based on earlier learning the consortium model was developed with salient constituents highlighting the need for strengthening the science of delivery using new science tools, building partnerships with different stakeholders by forming consortium, undertaking participatory demand driven research. Innovative capacity building approaches such as *"islanding approach"* within the watershed which served as site of learning within the village itself and also to build the confidence of farmers by undertaking research (Wani et al. 2003; Wani and Raju 2018, 2020). Linking successful on-station watersheds and on-farm watersheds for strategic research enabled the farmers as well as researchers to think differently to solve their problems. Other studies found that these farmers' incomes increase when they belong to cooperatives, self-help groups (SHGs) and other organizations that can connect them to markets, shared transport or shared spaces where produce can be stored (Bizikova et al. 2020) through learning from peer group members.

Using this framework focus of empowerment/capacity building varies with the goal of the development initiative. For example, in scaling-up initiative such as *Bhoochetana* the focus was on developing capacity at the bottom two levels of the framework (i) the organization, and (ii) the individual/farmer. Due consideration was, however, given to targeted initiatives (in a range of areas) at the other two levels (i.e. environmental and sectoral levels).

3.4.1 Model Case Studies

Empowerment is a concept linked to power. Information and Communication Technologies (ICT) have been found to bring many positive benefits and have helped farmers in many countries. Various model case studies are in place to empower the farmers viz. e-*Choupal* project in India that delivers farming information to farmers' mobile phones (Radhakrishna 2011), business project in Indonesian villages that brings farmers' mobiles in the social network (Vaswani 2012), and interactive community-based information network (Rural and Agricultural Development Communication Network; RADCON) in Egypt to link and support rural farmers (UNICEF 2011; Ginige and Richards 2012).

An Australian model involving mobile-based information system for empowering farmers was reported (Ginige and Richards 2012) (Fig. 3.14). The model details the goals, processes and activities of empowerment with its ultimate outcome for farmers. It helps to identify possible goals of the farmers and their families to have (i) a secure job, (ii) financial security, (iii) access to information for decision making, iv) perceive alternative solutions, (v) developed modern and sustainable agricultural skills, (vi) access education for themselves and their near and dear ones, (vii) feel safe as any other citizen of any Nation,, and (viii) create disaster recovery plan (Ginige and Richards 2012).

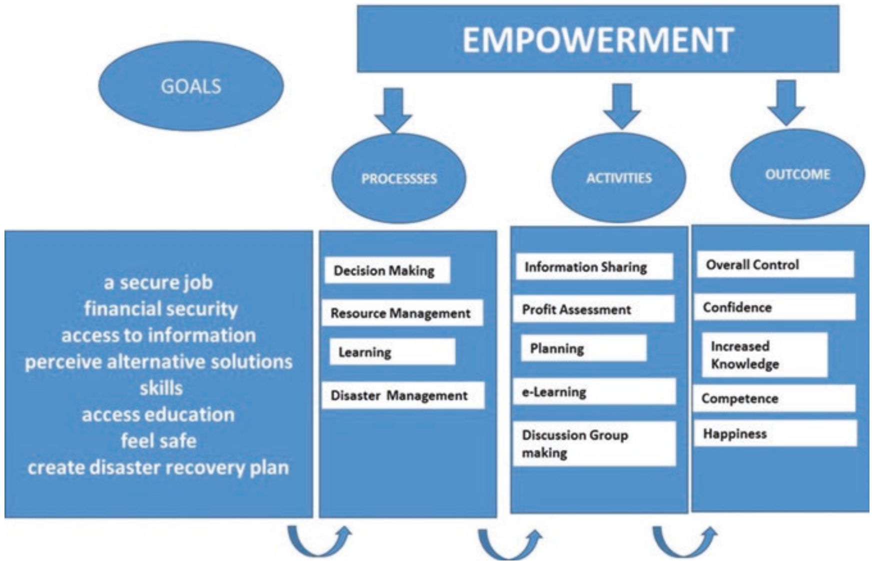

Fig. 3.14 An Australian model involving mobile based information system for empowering farmers. (Adapted from Ginige and Richards 2012)

3.4.1.1 *Bhoochetana* in Karnataka

This case study is based on the reports and publications based on the results recorded in *Bhoochetana* initiative during 2009-2016 (Wani et al. 2012, 2013; Patil et al. 2016; ICRISAT 2018). ICRISAT along with the Government of Karnataka implemented a unique scaling-up *Bhoochetana* mission program through institutional reforms for the *Bhoochetana* programme, which was operationalized through a structure composed of state- and grass-root-level institutions (Raju et al. 2013). At state level *Bhoochetana* cell for transparent monitoring and to facilitate input delivery and the educated practicing farmers as farm facilitators (FFs) (para-extension workers) from the farming community, formed the village-level institutional mechanism for scaling-up the *Bhoochetana* model. The innovativeness of *Bhoochetana* includes convergence of central and state-supported programmes/schemes to increase financial efficiency. The innovativeness of this project includes identification of soil nutrient deficiency status and taluk-wise (block level) (Wani 2008) nutrient recommendations based on nutrient status supported by making available the necessary inputs at 50% subsidy. For timely and readily available inputs, these were delivered in advance to each cluster of villages as well as to the *Raithu Samparka Kendras* (RSKs) at every *hobli*. These inputs (seeds, seed treatment chemicals, gypsum, micronutrients and biofertilizers) were supplied as a package.

Bhoochetana in Karnataka was unique scaling-up initiative technically supported by ICRISAT which was:

- Demand driven by the GoK as well as by the farmers and impact oriented.
- Science-based innovative strategy ensuring tangible economic benefits for small and marginal farm-holders (inclusivity).
- Convergence of state and central government schemes in the DoA and associated departments like Watershed Development Department (WDD) to benefit farmers.
- Integrated and holistic consortium approach to provide integrated solutions including ensuring availability of needed inputs at village level.
- Built partnerships between knowledge-generating institutions and knowledge delivery institutions in the state.
- Transformed AES using IT tools and honorary Farm Facilitators.
- Empowered stakeholders through suitable CB and training workshops.
- Soil health assessment (Wani 2008) was used as knowledge-based entry point activity (EPA) to build rapport with the farmers. Mapped soil nutrient deficiencies in all the 30 districts which was the starting point for scaling-up the soil analysis-based integrated nutrient management practices for sustainable growth in dryland areas of Karnataka.
- Farmers had to pay 50% cost for inputs upfront and register to participate in the program.
- Collective action through *Rythu samaparka kendras (*RSKs) and FFs.
- Participatory approach for DoA staff to fix targets for each season at district-*taluk* and *hobli* level and proper funding through convergence and budgetary provisions.

- Sound strategy development based on the constraints identified and needs assessment.
- Enabling policies and institutions by identifying and empowering policy makers.
- Result-based, open and transparent monitoring and evaluation system from the beginning.
- Creation of *Bhoochetana* cell at DoA headquarter to deal with implementation, planning, and monitoring the activities.
- Adopted improved best-bet management practices (BBMPs) on large scale and shared knowledge through trained FFs and lead farmers.
- Crop cutting experiments were conducted in partnership with staff of Department of Statistics & Economics, DoA staff, farmers, SAU staff to ensure that benefits observed are recorded transparently and results are integrated in annual economic survey for calculating gross domestic product (GDP) for the state.

3.4.1.2 Impact of *Bhoochetana* in Karnataka

An innovative holistic and integrated mission approach adopted in *Bhoochetana* in Karnataka benefitted the farmers through increased crop productivity and profits as well as the state government through increased GDP for the state through increased agricultural growth rate year on year since 2009 which was stagnant around 1% since 2001–2008. In addition to financial benefits for the farmers and the state government social and environmental benefits were also recorded due to *Bhoochetana* implementation in the state.

At the state level, the improved crop yield contributed to enhanced net income and additional value of the product. Net profits have been arrived at by subtracting the cost of micronutrients. At the state level, by the end of the seventh year since inception of the project in 2009, the net profit accrued from the programme was about Rs. 24497million Indian rupees equivalent to US $ 497 million from all the 30 districts (Table 3.4). The result of crop cutting experiments revealed that the state has potential in bridging the large yield gap by adopting holistic science-led crop management interventions with farmers' participation.

The project started with six districts in the state during first year covering 0.2 million ha and during second year additional 10 districts were included in the project. From third year onward, all 30 districts were covered. During seven years 7.4 million ha area was covered benefitting more than 4.75 million farmers with increased productivity by 20–66% over their traditional practice.

Table 3.4 Economic benefits accrued from *Bhoochetana* project during 2009–2015

Year	2009	2010	2011	2012	2013	2014	2015	Total
Net income (Rs. in Million)	114.9	2048.1	5994.5	4518	6951.5	487	1464.8	24,497
Net income (Million US$)[a]	2.52	45.72	112.48	82.44	110.35	77.3	22.53	453.34

[a]US $ conversions are done using the prevalent exchange rate during the time. Net income was calculated based on the minimum support price (MSP) provided by the government and cost of cultivation based on the inputs used in improved management

Benefits varied with crops and seasons as the rainfall differed from year to year as well as amongst the districts. In *Bhoochetana*, the overall benefit: cost (B:C) ratio (which was calculated by taking into account additional cost and additional income) of the cropping system in Karnataka was above 5:1. This suggests that the integrated approach, including soil-test-based fertilizer application, improved varieties of seed and integrated pest management measures, has the potential of producing a higher B:C ratio as compared with any single management approach (Anantha et al. 2016). Improved management practice in *Bhoochetana* enhanced the net income by ₹8000–10,000/ha under maize and nearly ₹3000–5000/ha under millet and sorghum production. Among pulses, pigeon pea was more remunerative as net income obtained from this crop varied from ₹20,000–25,000/ha at moderate rainfall of 800 mm. Improved management practice enhanced the net income further to ₹8000–10,000/ha. On the other hand, groundnut was very sensitive with application of micro and secondary nutrients. Net income for groundnut cultivation increased by ₹5000–15,000/ha with improved practices (IP) as compared with farmers' practices (FP) (Garg et al. 2016).

As planned annual growth rate in agriculture sector was >5 percent during the project period, every $ invested returned $ 3 to 14 to the farmers. Field observations and agronomic records also showed that crops were found to be more tolerant to various pests and diseases and yielded more compared with farmers' management practices. The beneficial impact of the *Bhoochetana* programme is observed in not only wet and normal years but also in dry years. The programme has proven that improved management systems were vital in building the resilience of the farming systems in spite of normal or below normal rainfall in the state. Increased crop yields and net income by about 30% has contributed to the household budget in rural areas as the benefit:cost (B:C) ratio ranges from 2 to 20 for different cropping systems and regions (Garg et al. 2016).

Bhoochetana became people's program rather than the government program in spite of changes of the government three times during the project. It happened due to public demand, ownership from the grass root level, and institutionalization of the program in the overall agricultural system of the state.

Apart from yield and economic benefits, social benefits of the programme were recorded as the yield and economic benefits have immensely contributed to improving the social status of the participating farmers. A stratified sampled household survey in eight districts representing four revenue divisions of the state revealed simple social benefit measures such as increased investment on assets formation, gender equity and enhanced knowledge (Anantha et al. 2016). About 40% of farm households reinvested the additional income obtained from *Bhoochetana* on agriculture and agriculture-related infrastructure. A proportion (13%) of households also invested in white goods (luxury goods). It is important to note that about 10% of the households have invested income obtained from Bhoochetana on loan repayment, house infrastructure and education.

Bhoochetana, a knowledge driven holistic process-based mission project, was intended to increase crop productivity and also enhanced stakeholders' knowledge regarding agricultural operations. The periodic training or capacity building programmes empowered the farmers as the knowledge dissemination process initiated by ICRISAT through master trainers from the University of Agricultural Sciences (UAS) and the Department of Agriculture (DoA), Karnataka had a most positive impact on farmers, as more than 50% of the households acknowledged improved knowledge on major aspects of agricultural development in the state. Secondly, the knowledge about soil health status, micronutrient application and seed varieties, which are critical components of agricultural development, improved significantly. More than 85% of rural households reported that their knowledge enhanced on these critical components. Besides, nearly 80% of households learnt new methods to control pests and diseases to enhance their crop yield in rain-fed agriculture (Anantha et al. 2016). More than 70% of farmers made collective decisions regarding harvesting, threshing, seed selection and storage.

3.5 Key Challenges (Limitations of Technology, Suitability, Adoption and Approvals from Agencies and Government)

The use of e-Extension technology in AES is changing as per the requirements. Changes in dissemination pathways were driven by innovation in technology and its adaptation. The major constraints faced during implementation of the digital extension system are as follows:

- information communication tools are themselves dependent on other technologies: for example, lack of appropriate infrastructural facilities, and internet speed,
- connectivity in remote villages restricts users' ability to update the android application,
- tablet and other AES tools may be relatively expensive and is not designed to be weather resistant.

3.6 Lessons Learnt and a Way Forward

Agriculture is the mainstay of Indian nation. Farming is a difficult profession and is becoming more so in the face of sever climate and socio-economic challenges. It is in this juncture farmers need to be motivated to till their lands for their own prosperity and the survival of all.

The state agricultural universities (SAUs) are mandated to impart agricultural education, to conduct research, to disseminate latest happenings in agriculture and allied field activities to the farming communities in the rural area and also to their children through education imparted by various schools, diploma colleges, and agricultural colleges at different levels (under-graduate, post-graduate, doctoral and post-doctoral). In other words, education in SAUs is closely interlinked with research and extension education. And logically these three components cannot be separated. Humanity plays a great role in raising the standard of agriculture. Individual motivation as a leader is above all funds and facilities. This motivation may come from a team of bright scientists, professors and extension experts and with the support of the farming community to do more (Bhattacharyya et al. 2018b).

Modern-day farming is heavily dependent on technologies which are born through research which are transferred to farmers through extension education and to the Gennext through agricultural education. The state agricultural universities (SAUs) should, therefore, be the hub of all such activities and should continuously be fed through other institutions related to agriculture (Fig. 3.15). Agriculture is an important ball game and should be handled with professionals only. The suggestive model might help the planners and administrators for way forward.

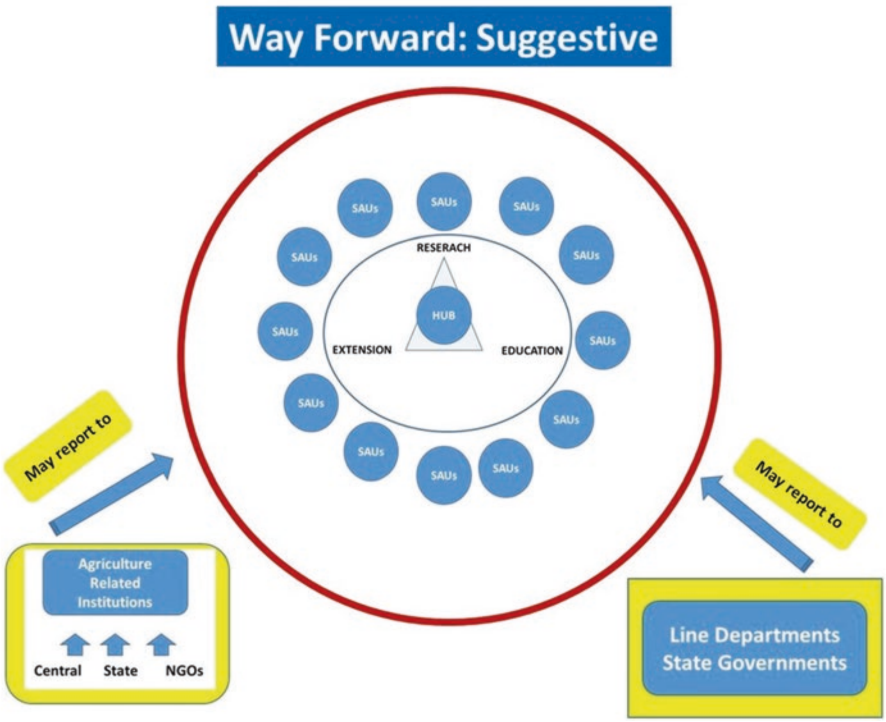

Fig. 3.15 Suggestive Plan to strengthen State Agricultural Universities (SAUS) for empowering farmers in India: Way Forward

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Chapter 4
Scaling-Up Land and Crop Management Solutions for Farmers Through Participatory Integrated Demonstrations "*Seeing is Believing*" Approach

Suhas P. Wani, Raghvendra Sudi, and G. Pardhasardhi

Abstract Farmers' distress is noted across the country and it can get worse with the impacts of climate change as the small farm-holders in tropical regions are most vulnerable to impacts of climate change. At present farmers' yields are lower by two to five folds than the achievable potential yields. Further, farmers receive only 30–40% of the price what consumers pay as the current value chains are inefficient and long. As a result, farmers' incomes are almost half as that of city households (Rs 40,925 rural vs. Rs 98,435 urban per capita). Given the choice, large number of farmers would like to come out of agriculture and youths are shying away from agriculture (National Sample Survey Organization (NSSO), Situation assessment survey of agriculture households in India (70th Round: July 2012–June 2013). Ministry of Statistics and Program Implementation, New Delhi, 2013). To achieve the sustainable development goal of no poverty (SDG 1) zero hunger (SDG 2) and good health and wellbeing (SDG 3) there is an urgent need to transform agriculture in India as well as in other developing countries in Asia and Africa. For scaling-up technologies such as improved cultivars, soil, water and nutrient management technologies, income-generating micro-enterprises particularly undertaken by women and youths to benefit farmers for increasing productivity and incomes "*Seeing is believing* "principle is a well-tested and proven tool to build the capacity of the

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farmers. Results from various scaling-up initiatives benefitting >10 million farmers in India, China, Thailand, and Vietnam are discussed and drivers of success are identified and way forward for scaling-up is discussed in this chapter.

Keywords Food security · Seeing is believing · Participatory demonstrations · Scaling-up solutions · Science-led technologies

4.1 Introduction

The greatest challenge of twenty-first century for the humankind is to achieve food, nutrition and income security through sustainable development (SDG 1, 2 & 3) with growing water scarcity and shortages, increasing land degradation and decreasing per capita land and water availability due to ever-growing population estimated to reach 9.1 billion globally and 1.6 billion in India by 2050 (Wani et al. 2003a; Sahrawat et al. 2010; Chander et al. 2013). Achieving the sustainable development goal of no poverty (SDG 1), zero hunger (SDG 2) and good health and wellbeing (SDG 3) with the already experienced impacts of climate change due to global warming is a challenge which is surmountable but it calls for innovative approaches, technology driven solutions to be taken at the door step of farmers through building partnerships and achieving convergence and collective action of millions of small farm-holders (500 million globally and 125 million in India) who cultivate <2 ha and produce 70% of food globally (World Bank 2016; Graueb et al. 2016).

4.1.1 Why Small Farm-Holders Are Distressed and Want to Quit Agriculture

Farmers in India have enabled the country to be self-sufficient in food production and the country has transformed from "*Ship to Mouth*" stage in 1967 to overflowing buffer stocks in the country which are almost three-folds higher than needed in 2020. The transformation was achieved through "Green revolution" by increasing total food production around 300 million tonnes in 2020 as compared to 50 million tonnes in 1950. The production during 2019–20 is higher by 25.89 million tonnes than the previous five years' (2014–15 to 2018–19) average production of food grain (GoI 2020; Financial Express 2020). Out of 295. 67 million tonnes food production 225 million tonnes production is of rice and wheat, which is becoming a point of concern for farmers' distress. As far as food production is concerned farmers are doing well, however, as per their incomes they are in stress as the per capita rural incomes are almost half that of urban incomes (for details refer Chap. 1 in this volume Wani 2021). Due to financial losses/crop failures, thousands of farmers committed suicides (11,772 in 2013, 12,360 in 2014, 12,602 in 2015 and 11,379 in 2016) in different states. Suicides in the farm sector have steadily declined by 10%

over four years (2016–2019), according to the latest data released by the National Crime Records Bureau (NCRB).With two successive years of drought, the year 2015 had seen a sharp jump in suicides among cultivators (Indian Express 2020) indicating drought/water scarcity (failure of bore well) as the main cause for distress amongst the farmers as 52% of agriculture is rain-fed. Another causes reported for farmers' suicides are increasing cost of inputs, low crop yields, crop failures, low price realisation for farm produce due to lack of market access, debt, losses in non-agricultural activities, and high post-harvest losses of major agricultural produce. In 2018, post-harvest loss was estimated at Rs. 92,651 crores ($ 13 billion) (Ministry of Food Processing) per year largely due to storage, logistic, and financing infrastructure inadequacies in India. As it is generally stated that farmers distress in India is largely due to 3 Ms-monsoon, middlemen and markets.

In spite of bumper harvest of food grains, in 2019, India's food security position globally was 72nd as compared to 3rd position for the United States of America, and 35th position for China. Affordability, quality, safety, and availability are the key factors considered for comparing the food security levels among the countries (Global Food Security Index 2019). Food security is very critical for the internal security concerns as well as at international level too for "*Atmanirbhar* India" (Singh and Wani 2020). In addition to food security agriculture is a major sector employing 44.2% workforce in the country with 65% rural population, however, it's contribution to the national gross domestic product (GDP) value is 16.5% in 2019–20 (NSO 2019) and transformation of agriculture sector is a must.

4.2 Urgent Need to Build the Confidence of our *Annadatas* by Adopting the Principle of "Seeing is Believing"

As small farm-holders are the backbone of India's food, nutrition and economic development, as they are the ones who largely feed the 1.3 billion people. Considering internal and external security concerns associated with food security as well as national commitment to meet the targets of sustainable development goals (SDG 1, 2, and 3) there is an urgent need to build the confidence amongst small farm-holders and ensure that agriculture becomes a respectable business proposition as against the subsistence agriculture at present. Outmigration of farmers and educated youths from rural areas to urban areas in search of better livelihood opportunities has to be minimised by providing urban facilities in rural areas (PURA) as envisaged by former late President Dr. Abdul Kalam. For transforming agriculture in to a business proposition empowerment of small farm-holders as well as developing needed infrastructure in rural areas is a must so that medium small and micro enterprises (MSMEs) doing value addition and processing can be established in rural areas for providing employment. Building trust is a continuous process and takes time but there is no other option to ensure that small farm-holders benefit through increased adoption of knowledge-driven technologies/products developed by the researchers/

scientists. As indicated in Chap. 1 of this volume (Wani 2021, Chap. 1) to build the trust between researchers and farmers, change of mind-set of researchers to work in partnership with small farm-holders is must. *The CERES 2030* Team has also highlighted that poverty is not reduced as researchers work in isolation and do not involve small farm-holders (Nature Food 2020). In this chapter we deliberate in detail the participatory on-farm demonstrations as an effective scaling-up tool to provide integrated and holistic solutions to the farmers. The principle of "*Seeing is believing*" has been perfected and successfully employed based on several scaling-up initiatives which have benefitted >ten million small farm-holders in Asia.

4.2.1 Basic Principles of "Seeing is Believing" *Participatory Holistic on-Farm Demonstrations*

As discussed in Chap. 3 of this volume (Bhattacharyya et al. 2021, Chap. 3) empowering farmers is a challenging task largely due to big number (145 million) and non-functional agricultural extension system (AES) in the country. As revealed by the national sample survey- 2013, 51% of farmers in the country are not getting any extension support (NSSO 2013).

(a) **Needs assessment.** In Chaps. 1 and 3 of this volume, following principles are discussed in detail (Wani 2021; Bhattacharyya et al. 2021) starting with farmers' needs assessment to provide demand driven solutions rather than supply driven solutions for increasing the productivity and profitability of farming through enhanced efficiency of inputs.
(b) **Identifying partners and consortium formation.** Once the needs assessment is undertaken then identifying the right stakeholders/partners needed to deliver the holistic solutions is critical. As discussed in Chap. 3 of this volume (Bhattacharyya et al. 2021) formation of consortium and empowerment of partners through capacity building workshops for bringing all partners on the same page about goal, objectives and approaches as well as standard operating processes (SOPs)is critical. To transform the agriculture across the country there is an urgent need for rejuvenating extension systems with innovations and use of new technologies such as information technology (IT), internet of things (IoT), linking knowledge- generating institutions with knowledge-transforming institutions, remote sensing (RS), geographical information system (GIS), simulation modelling, etc. (Wani et al. 2003a, b, d; Wani 2020). We adopted well developed, validated and scaled-up successfully, an integrated holistic approach with 4 ISECs as indicated below

Innovate	**S**ustainable	**E**conomic gain	**C**onsortium
Inclusive	**S**ocially acceptable	**E**quity	**C**ollective
Intensive	**S**calable	**E**fficiency	**C**apacity Building
Integrated	**S**ynergistic	**E**nvironment	**C**onvergence Protection

For each scaling-up initiative separate consortium of right partners including concerned state department of agriculture as well as needed private companies/corporate was formed. For example, in *Bhoochetana* in order to ensure availability of recommended fertilisers at right time based on soil test-based recommendations to balance widespread deficiencies of secondary and micro-nutrients (Wani et al. 2011), DoA identified suppliers and provision was made to store the fertilisers at village level before the season starts. To enhance the awareness about micronutrients, they were bundled with seeds for the farmers at *Raitu samparka kendras (RSKs).*

(c) **Changing mind-set of all actors for strengthening science of delivery.** Main reason for poor AES in India is the mind-set of researchers as well as other actors who consider extension as low rung academic/research activity. They think that trickledown effect will be there and new knowledge/products will be automatically disseminated amongst the farmers. Through team building workshops and delivering messages from top policy makers/heads of the partner institutions that achieving good impacts on large scale is must which helps in changing the mind-set of all the partners. Lack of awareness and access to the technologies are responsible for large yield gaps in farmers' fields across the world and more so in developing countries in Asia and Africa (Rockström and Falkenmark 2000; Wani et al. 2003a, b, d; Rockström et al. 2010; FAO and WEP 2020). Further, lack of synergy amongst the actors and deficiencies in technology delivery systems due to compartmental approach adopted without considering farmers' requirements for providing the solutions results in *"Death Valley" of impacts* (Wani and Raju 2018a, 2020). Ingraining the importance of science of delivery in minds of the partners is very critical and a game changer intervention which can be achieved by the good team leader with the help of policy makers and heads of institutions during the team building workshops. Finalising the strategy and plan development collectively with all consortium partners with clear roles and responsibilities of each partner along with financial provisions were done for all the initiatives (for more details refer 1.3.3 section in Chap. 1 in this volume, Wani 2021).

(d) **Institutionalisation of transparent monitoring, evaluation and learning (MEL) system.** For achieving desired impacts through consortium it is critical to have institutionalised MEL system in place. For example, in *Bhoochetana* and *Bhoosamruddhi* in Karnataka weekly videoconferencing with all the 30 district officials, chaired by Additional Chief Secretary (ACS) was institutionalised (Raju and Wani 2016). For *Rythu kosam* in Andhra Pradesh Chief Minister participated in state-level meetings as well as chaired and reviewed the progress throughout the day with all partners, concerned ministers and district officials (ICRISAT 2017; Raju et al. 2017). For *Yamnag Lupa* in Philippines Director, of Agriculture chaired the MEL and reviewed periodically in addition to internal departmental reviews.

(e) **Identifying knowledge-based entry point activity (EPA) to build trust with farmers by ensuring tangible economic benefits.** As indicated equity, economic benefits ensure participation by the small farm-holders and to achieve this suitable knowledge-based EPA for building rapport with the community played critical role in a community- based programme rural development (Wani et al. 2003a). During our watershed work over three decades, through participatory rural appraisal (PRA) we learnt that in Adarsha Watershed Kothapally farmers loose nearly 40–50% pigeon pea plants during flowering due to wilting once the moisture stress sets in. Introduction of developed wilt-tolerant pigeon pea cultivars as an EPA will benefit the farmers immensely. Following points while selecting an appropriate EPA for integrated community watershed management were considered as suggested by Wani et al. 2003a:

Conventional EPA activities such as opening a bore well, constructing a meeting room for panchayat/school etc. involving direct cash gave a wrong signal to the villagers that project has money to invest in our village and for subsequent activities also they expect that full cost should be covered by the project. The EPA should be knowledge-based and should not involve direct cash payment through the project in the village to avoid wrong signal which affected community partnership and ownership. The knowledge-based EPAs were found to be superior to the subsidy- or cash-based EPA for enabling community participation of higher order (cooperative and collegiate) rather than in a contractual mode (Dixit et al. 2007).

- The EPA should have a high success probability (> 80–90%), and be based on proven research results.
- The EPA should involve a participatory research and development approach, and community members should preferably be involved in undertaking the activity in watersheds.
- An EPA should result in the measurable tangible economic benefits to the farming community with a relatively high benefit–cost ratio.
- The EPA preferably should be simple and easy for the participating farmers to undertake its participatory evaluation.

For building rapport with the community, good participatory rural appraisal (PRA) and knowledge about local natural resources can be used to identify a knowledge-based EPA. For example, in *Adarsha* watershed, Kothapally which became model training site, wilt-tolerant pigeon pea cultivar ICPL 87119 (Asha) along with improved management practices was effectively used as EPA (Wani et al. 2003a; Wani and Raju 2020). In *Bhoocheatana* and *Bhoosamruddhi* initiatives in Karnataka (Wani et al. 2011) as well as in Andhra Pradesh Rural Livelihoods Program (APRLP), *Rythu kosam* (Fig. 4.1) in Andhra Pradesh, *Yamanglupa in the Philippines* and other corporate social responsibility (CSR) initiatives well tested and proven soil analysis was used as an EPA for building trust amongst the farmers (Wani and Raju 2018b).

Fig. 4.1 Training of farmers in stratified participatory soil sampling in scaling-up initiatives in Andhra Pradesh and Telangana, India

By adopting stratified soil sampling method (Sahrawat et al. 2008) 5339 soil samples across13 districts in Andhra Pradesh *Rythu* kosam were collected, analysed and soil analysis results were shared with the farmers.

(f) **Awareness creation about the project strategy, and capacity building for empowering stakeholders.** As detailed in Chaps. 1 and 3 in this volume (Wani 2021; Bhattacharyya et al. 2021) formal and informal methods for awareness, capacity building, empowerment and skill development as needed for different stakeholders were undertaken (Figs. 4.1 and 4.2).

For awareness building, training/capacity building/empowerment conventional as well as new technologies/approaches were used in various initiatives such as wall writings, class room trainings, team building workshops, digital technologies such as "*Krishi Gyansagar, Krishi Vani*, farmer to farmer videos", and field days, etc. To overcome the shortage of human resources in the existing AES in Karnataka a cadre of para extension workers (Farm Facilitators) one for each village/cluster of hamlets covering 500 ha was created to serve as link between DoA staff and farmers (for more details refer Chap. 1 and 3 in this volume – Wani 2021; Bhattacharya et al. 2021).

(g) **Adopting principle of "*seeing is believing*" and identification of farmers for conducting participatory demonstrations.** For empowering the farmers participatory field demonstrations approach for "*Seeing is Believing*" was adopted. For participatory demonstrations farm facilitators/ lead farmers identified suitable small farm-holders whose fields are approachable during rainy season and have good relation in the village. For each demonstration two treatments of half acre each were laid out randomly and users pay approach ensuring that no inputs were supplied free to the farmers except 50% government subsidy available for everyone in *Bhoochetana and Bhoosamrudhi* Karnataka. The farmers were registered with the DoA, the selected fields were geotagged along with the farmers' details. The FFs recorded all the details for each of the participatory demonstration and in each *taluk* villages were selected to represent areas, soil types and rainfall, etc. In each village at least five demonstrations for the intervention identified were conducted. The crops were sown and treatment applied in the presence of the FFS/LF and details of the farmers' practice were also recorded. The FFs guided the farmers during regular visits and ensured that the demonstration fields were well maintained during the crop growth. Two to three major crops grown in each *taluk*/district were identified for demonstrations. The number of crop cutting experiments (CCE) were decided by the DoA and ICRISAT technician and required number of villages/farmers were selected randomly and timing for harvesting of CCEs were planned. *District-level CCE Committee* chaired by the Joint Director Agriculture *for random selection of fields and sampling* was formed as the data need to be integrated in the state statistics for agricultural production from the CCEs in *Bhoochetana* plots.

The CCE Committee comprised of the members representing the DoA, the Department of Economics and Statistic (DES), the Watershed Development

Fig. 4.2 Training of different stakeholders for use of solar dryer of vegetables at Sadharahally, Lakya hobli, for *Rythu kosam* and technical training for surveying and protected vegetable cultivation in shade-net and grafted seedlings in *Bhoosamruddhi*, Chikmagaluru District, Karnataka

Department (WDD), the University of Agricultural Sciences (UAS), and ICRISAT represented by a research technician, farm facilitator and lead farmers serving the committee to ensure ownership for the data. Two major crops were identified for CCEs in each taluk of a district based on the DoA's project planning for *Bhoochetana* at its initiation. The Assistant Director of Agriculture (ADA) and Agricultural Officers (AOs) along with the ICRISAT research technician identified the crops in their districts to ensure the selection of major crops in terms of area coverage under *Bhoochetana*. Based on the registration, the data with the officials and the technician, ten farmers for each crop in a taluk were selected for the two identified crops. Three to four representative villages were selected, encompassing different zones of soils, seasonal rainfall and area coverage under *Bhoochetana*. Three to four farmers were selected randomly based on the registrations in the selected village.

However, a minimum number of ten farmers were duly selected per crop in each taluk. Each farmer was provided with a unique identification number (UIN) by ICRISAT before the CCEs were initiated in the season. The concerned in-charge Scientist/Scientific Officer at ICRISAT ensured timely supply of harvest bags (muslin cloth bags for stalk and kora cloth bags for pod/head samples) UIN and necessary data sheets for the CCEs in the district. The improved practice (IP) and farmers' practice (FP) samples were duly collected from the same selected farmer's field from a randomly selected representative area of 5 m × 5 m (total area of 25 m^2) at one spot for undertaking CCE. The samples were cut, separated, fresh weights recorded, bagged and sundried, sub-sampled (2 kg) for each plot harvested and dispatched to ICRISAT head quarter for further processing. The fresh weights were properly recorded in the given format and the signatures of all the representatives of the CCE Committee present in the field were obtained. It was ensured that all the identified team members participated in CCEs. Concerned JDAs had delegated the responsibilities to the ADAs and AOs for undertaking CCEs in the respective taluks. GPS (geographic positioning system)-enabled photographs of CCEs had to be provided to the JDA office. Similar approach with needed changes was adopted in all the scaling-up initiatives. Field days with the farmers from the surrounding villages in each *taluk* were conducted to ensure participatory evaluation of trials and the farmer explained all the details. It's well established that farmers believed much on their peers rather than outsiders explaining the trials which helped in better adoption of technologies by the farmers.

4.3 Scaling-Up of Soil Test-Based Fertility Management Trials Adopting "*Seeing is Believing*" Principle

Liebig's Familiar Letters on Chemistry and Its Relation to Commerce, Physiology, and Agriculture (1848) all advocated transformations in soil management in relation to the linked social and environmental crises of modern global market within agriculture. The practical implication that farmers could reliably overcome the local limits of fertility, however, for a long time the so called NPK mentality harmed the agriculture. Although, soil analysis as a powerful tool and formulation of NPK fertilisers were unique game changing inventions benefitting farmers, the science of soil analysis in totality did not reach to small farm-holders in developing Asia, Africa and other parts of the world. In India, Indian Council of Agricultural Research (ICAR) established the All India Coordinated Scheme of Micronutrients in Soils and Plants during 1967 at Punjab Agricultural University, Hisar with six centres and the project was expanded in terms of mandate as well as spread of centres (Shukla and Behera 2019).

In state agricultural universities as well as in other research institutions also micronutrient research was conducted. Just like NPK syndrome scientists also went in circles to address the soil variability considering statistical methods. For example, a 1 lb soil sample collected from a 5-acre field represents just 1/10,000,000 of the field! Therefore, it is vital that the soil sample be representative of the entire field. The most common and economical method for sampling an area is composite sampling, where sub-samples are collected from randomly selected locations in a field, and the subsamples are composited for analysis.

In a country like India with its 142 million ha arable land cultivated by 145 million farm households, with 46 of the 60 soil types in the world, along with 20 agro-climatic zones varying from arid to humid tropics, hot arid deserts, and a varying rainfall as high as 11,873 mm at Mawsynram, Meghalaya, to as low as 166 mm at Jaisalmer in Rajasthan (Singh and Wani 2020) puts forward a complex and great challenge to the soil scientists for sampling representative samples. Variability of soils in many fields is fairly obvious since there may be significant visual differences in topography, soil types, soil colour or other factors. But field variability exists that is not evident at first glance – even in fields that appear uniform. For +/−5% with reproducibility of 70%, 90 soil core samples are recommended for a composite sample and for 95% reproducibility 325 samples are recommended (Kansas State University) for a field size of 50 acres. Soil sampling is the weakest link in the soil testing-nutrient management plan development process and is the greatest source of error. Considering this challenge to collect representative sub-samples from field along with the mind-set of researchers to work on research farms, deprived the small farm-holders the benefit of soil analysis.

4.3.1 Soil Infertility and Water Scarcity- a Major Constraint for Bridging Yield Gaps in Agriculture

In rain-fed agriculture that covers globally 80% and 52% in India of cultivated land where the importance of water shortage and associated stress effects on crops can hardly be overemphasized, especially in the SAT regions (Bationo et al. 2008; Wani et al. 2009a; Pathak et al. 2009; Rockström et al. 2010). However, soil infertility is the issue for crop production and productivity enhancement even under water limited situations in much of the SAT regions of the world, and SAT regions of India are no exception (Twomlow et al. 2008; Wani et al. 2009a, 2015a, b; Sahrawat and Wani 2013; Chander et al. 2011, 2014). There was a common belief among researchers and agriculturists that at relatively low yields of crops in the rain-fed systems of

India, only the deficiencies of major nutrients (especially those of N and P) are important for the SAT Indian soils (El-Swaify et al. 1985; Rego et al. 2003) and it was assumed that the uptake and mining of secondary and micronutrient reserves in soils is much less than in irrigated production systems (Rego et al. 2003).

Equally importantly, deficiencies of secondary nutrients especially of S and micronutrients have been reported with increasing frequencies from the intensified irrigated production systems where deficiencies are managed through the fertilization of crops (Takkar 1996; Singh 2008) but little attention has been paid to diagnosing the deficiencies of secondary nutrients such as S and micronutrients in dryland rain-fed production systems especially in SAT regions of India (Sahrawat et al. 2007, 2010, 2016; Sahrawat and Wani 2013. On-farm research initiated under the Asian Development Bank (ADB) and several GoI supported watershed projects, Andhra Pradesh Rural Livelihood Project (APRLP), Sir Dorabji Tata Trust (SDTT), Sir Ratan Tata Trust (SRTT), and several corporate social responsibility (CSR) supported watershed projects in India, Thailand, Vietnam and later China since 1999 provided an opportunity to understand wide spread deficiencies of secondary nutrients such as sulphur and micronutrients (Zn, B, Fe, etc.).

Initial on-farm surveys across few states of India, revealed that out of 1926 farmers' fields samples, 88–100% were deficient in available sulphur(S), 72–100% in available boron (B), and 67–100% in available Zinc (Zn) (Sahrawat et al. 2007) and later with large number of samples across the country (Sahrawat et al. 2008, 2010, 2016; Wani et al. 2010, 2011, 2012b, 2017, 2018; ICRISAT 2016). As indicated above, the team continued to liaise with the policy makers in different states and at national level too. The team interacted with the higher authorities in Prime Minister's Office (PMO), India and submitted a strategy paper on soil health mapping (Wani et al. 2016a, b). The department of Agriculture, Cooperation and Farmers Welfare, GoI launched soil health card mission program covering farms in the country (Fig. 4.3). It is planned to cover all 145 million farms in three to four years for soil sampling and issuing soil health cards to all farmers with fertiliser recommendations for the crops grown in particular region.

This clearly indicated that after persuasion by ICRISAT Team as well as NARSs scientists, GoI took up the soil health card mission initiative in 2016, indicating that after starting and demonstrating the benefits of soil analysis and occurrence of multiple nutrients (micro- and secondary- nutrients) across the country since 1999 took almost 17 years to bring in policy at national level. The lag period for scaling-up across the country after Karnataka, Andhra Pradesh, Telangana and few other states showed positive benefits was almost 10 years.

The results presented in Table 4.1 showed widespread deficiencies of multiple secondary and micro-nutrient deficiencies across the rain-fed areas in India (Table 4.1). In Madhya Pradesh in *Milli* watershed at Lalatora micro-nutrient and secondary nutrient deficiencies were recorded in 1999. It was observed that in soybean growing areas of Madhya Pradesh, India sulphur deficiency emerged largely due to policy of subsidy on N-based fertilisers and as a result farmers shifted to di-ammonium phosphate (DAP as a source of phosphorus) for soybean in place of single super phosphate (SSP) which also contained sulphur (S). Soybean being a

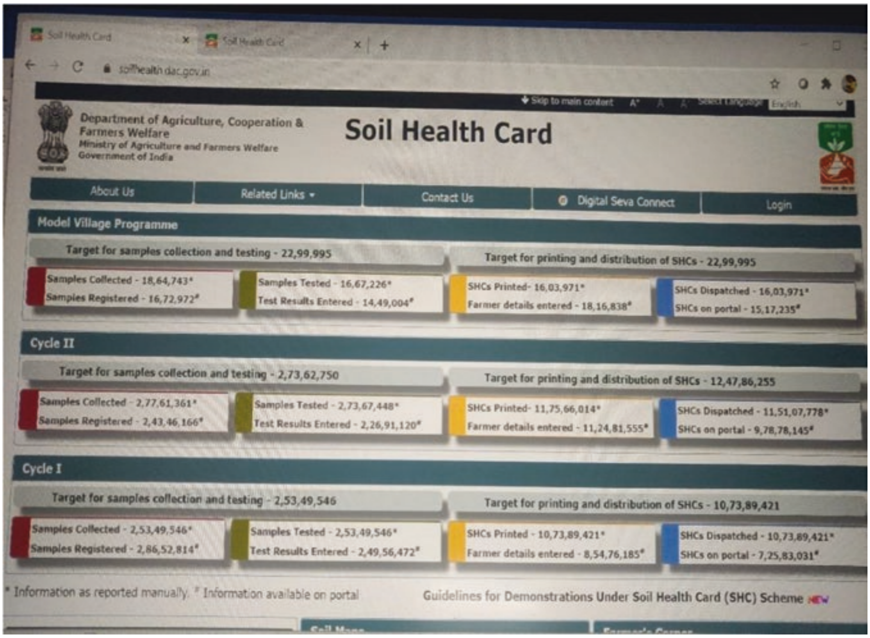

Fig. 4.3 Screen shot of Soil health card mission program of Department of Agriculture, Cooperation and Farmers' Welfare, government of India

crop needing sulphur depleted soil sulphur due to continued cultivation which was not replenished by the farmers. Another fallout of the fertilizer subsidy is that chemical fertilizers are cheaper than organic fertilizers.

Thus, farmers have moved away from using organic manure, which is very critical for preserving good soil health, as organic carbon is the key fuel for keeping the soil microbial activities in a good state. Good soil health is required to ensure the quality of food, and for food and nutritional security. To address malnutrition in India, it is more economical and efficient to address food quality issues through soil health and diet diversification rather than through bio-fortification and nutritional amendments externally.

Imbalance in fertilizer use also leads to depletion of particular nutrients in the soils as well as causing environmental degradation. It also substantially increases the cost of cultivation and also lowers its efficiency (Wani et al. 2016a, b).

For the first time detailed stratified and participatory soil sampling (Sahrawat and Wani 2013) was undertaken for 30 districts of Karnataka in 2009 under *Bhoochetana* initiative by collecting 92,864 farmers' fields' samples from 4699 villages covering 30 districts (Wani et al. 2013). Detailed analysis of farmers' field soil samples revealed that amongst the districts deficiency of macro-, secondary- and micronutrients varied a lot. For example, nitrogen deficiency (using organic C as criterion) varied amongst 30 districts from 0% to78%, similarly for P from 5% to 97%, for K from 1% to 68% for S from 2% to 92%, for Zn from 24% to 92 and for B from

Table 4.1 Diagnostic soil analysis of farmers' nutrient deficient fields in different states, India

State	pH	pH	pH	EC ds/m	OC	Av P	Av K	Av Ca
	Acidic	Neutral	Alkaline	Normal	% [a]	ppm	ppm	ppm
Andhra Pradesh	19	28	53	100	63	22	10	37
Range	4.95–9.59			0.05–3.76	0.1–1.79	0.3–8.97	20–2678	20–4599
Gujarat	5	16	80	100	28	57	4	
Range	6.25–8.98			0.05–2.43	0.21–1.51	0.4–66.5	30–635	
Jharkhand	88	10	1	100	65	51	35	
Range	5–8.3			0.05–0.61	0.12–1.13	0.4–68.6	20–247	
Karnataka	36	25	38	100	53	38	19	25
Range	4.95–9.56			0.05–3.76	0.1–1.8	0.3–68.95	20–2759	52–4597
Kerala	82	18		100	11	21	7	
Range	5.11–6.78			0.05–0.25	0.36–1.17	1.2–68.8	33–313	
Madhya Pradesh	3	19	80	100	22	76	0	
Range	5.56–8.82			0.05–1.56	0.28–1.54	0.3–68	48–895	4442–4525
Maharashtra	22	20	59	100	43	37	1	5
Range	4.95–9.03			0.05–3.75	0.1–1.74	0.3–68.8	23–2678	169–4596
Odisha	87	10	4	100	34	31	20	49
Range	4.95–8.24			0.05–3.75	0.1–1.73	0.35–68.97	20–2678	96–4488
Rajasthan	4	26	70	100	55	50	12	5
Range	5.71–9.43			0.05–3.75	0.1–1.78	0.34–67.6	21–1358	758–3804
Tamil Nadu	7	39	54	100	57	66	10	
Range	5–9.4			0.05–2.29	0.14–1.37	0.4–67.2	20–690	
Telangana	9	35	55	100	72	14	10	25
Range	4.96–9.59			0.05–3.75	0.1–1.79	0.33–68.8	20–2360	25–4593
Uttar Pradesh	9	28	64	100	52	33	14	17
Range	5.23–9.13			0.05–1.81	0.1–1.7	0.31–68.6	20–1009	312–4590
Grand Total	31	26	43	100	55	33	16	32
Range	4.95–9.59			0.05–3.76	0.1–1.8	0.3–68.97	20–2759	20–4599

(continued)

Table 4.1 (continued)

State	Av Mg ppm	Av S ppm	Av Zn ppm	Av B ppm	Av Fe ppm	Av Cu ppm	Av Mn ppm	No of samples
Andhra Pradesh	3	23	49	34	7	1	1	36,756
Range	20–3456	2–292	0.1–5.98	0.1–2.99	0.1–20.62	0.1–9.98	0.1–15.99	
Gujarat		14	83	54				180
Range		5.2–288	0.18–2.45	0.1–1.94				
Jharkhand		49	58	100				91
Range		2–282	0.24–2.9	0.1–0.42				
Karvnataka	2	28	43	53	9	3	9	117,176
Range	20–2672	2–299	0.1–5.99	0.1–2.99	0.1–20.62	0.1–9.99	0.1–15.99	
Kerala		38	4	100				28
Range		2–282	0.56–4.24	0.18–0.48				
Madhya Pradesh		46	49	73				425
Range	289–3276	2–288	0.1–4.36	0.1–1.3	6.1–19.88	1.42–7.38	3.02–15.88	
Maha-rashtra	0	29	59	46	1	0	0	6135
Range	20–2648	2–288	.1–5.93	0.1–2.95	0.2–20.62	0.1–9.7	0.96–15.99	
Odisha	1	25	18	81	0	0	0	3017
Range	20–1435	2–292	0.1–5.9	0.1–2.74	0.65–20.62	0.14–7.22	0.24–15.97	
Rajasthan	0	44	36	51	45	54	15	784
Range	20–488	2–290	0.12–5.92	0.1–2.76	0.12–17.8	0.1–4.4	0.94–15.92	
Tamil Nadu		44	28	83	23	9	23	769
Range		4–288	0.1–5.6	0.1–2.18	0.1–19.78	0.1–6.5	0.23–15.86	
Telangana	1	28	58	54	4	2	3	11,203
Range	20–3194	2–292	0.1–5.86	0.1–2.97	0.1–20.62	0.1–9.76	0.1–15.99	
Uttar Pradesh	1	43	69	58	13	0	2	1473
Range	20–1134	5–290	0.1–4.52	0.1–2.58	0.39–20.6	0.11–9.98	0.1–15.98	
Grand Total	3	28	45	50	7	2	5	177,387
Range	20–3456	2–299	0.1–5.99	0.1–2.99	0.1–20.62	0.1–9.99	0.1–15.99	

Source: Prepared by authors based on data from several projects implemented (ICRISAT 2004, 2009, 2012, 2016, 2018)
a = % deficient farmers' fields

34% to 91% (Wani et al. 2012a) *indicating that the current way of recommending fertiliser doses at state level for irrigated and dryland crops does not work and there is need to develop recommendations at village /taluk level. Similar variability amongst the districts was also observed in Andhra Pradesh across 13 districts after analysing 36,632 soil samples from farmers 'fields* (Table 4.2).

4.3.2 Developing Soil-Test Based Fertiliser Recommendations

Shukla and Behera (2019) assessed soil fertility status in the country based on analysis of GPS-guided more than 200, 000 soil samples and recorded deficiencies of sulphur (S) 40.5%, zinc (Zn) 36.5%, iron (Fe) 12.8%, manganese (Mn) 7.1%, copper (Cu) 4.2% and boron (B) 23.2% fields. Manganese (particularly in rice and wheat growing sandy loam areas) and B deficiencies (in acid soils) have started appearing in a big way. Over the years, multi-micro and secondary nutrient deficiencies have emerged in different areas of the country. Simultaneous occurrence of deficiencies of 4 or more than 4 nutrients was very low (<0.5%) in most of the states (Shukla and Behera 2019). Considering such large variability for soil infertility amongst the states and districts (Tables 4.1 and 4.2) as well as taluks and villages, fertiliser recommendations were developed at village/taluk level considering the state agriculture university recommendations for different crops and the current soil analysis using the critical limits given in Table 4.3. These results demonstrated that only the nutrient identified as deficient through soil or plant analysis should be applied to harvest the sustainable higher productivity.

For practical utilization of the soil-test-based nutrient management, we mapped, using the geographical information system (GIS)-based extrapolation using kriging methodology, the deficiencies of all nutrients including especially those of S, B and Zn along with soil fertility parameters pH, electrical conductivity (EC) (indicator of soluble salts) and organic C in all the 30 districts of Karnataka state, India and soil Atlas was prepared (Wani et al. 2011, 2013). The recommendations for villages/taluks were developed using the following rule, if more than 50% of farmers' fields were deficient then full dose was recommended, for >25–50% deficient fields half of recommended dose and < 25% deficient fields in the village 1/4th of recommended dose as a maintenance dose of a particular nutrient was recommended. For large scaling-up projects like *Bhoochetana, Bhoosamruddhi and Rythu kosam* in states of Karnataka, Andhra Pradesh arrangements were made to ensure availability of needed inputs at village level through policy interventions. For CSR projects as well as for watershed projects covering a village or a group of villages inputs were made available to farmers through project staff albeit on payment basis.

The soil-test-based fertilizer application has been made web-based so that the recommendations can be downloaded and made available nutrient-wise to farmers using colour codes depicting the deficiency or sufficiency of a nutrient. Such information can be easily used by smallholders, and the farmers can be kept updated regularly with the latest results on the website. The soil analysis results as well as

Table 4.2 Diagnostic soil analysis results for nutrient deficiency in different districts of Andhra Pradesh

State	District	pH			EC ds/m	OC	Av P	Av K	Av Ca
		Acidic	Neutral	Alkaline	Normal	% [a]	Ppm	Ppm	Ppm
Andhra Pradesh	Anantapuram	12	27	60	100	86	24	11	41
Range[1]	Anantapuram	5–9.58			0.05–3.68	0.1–1.74	0.33–68.96	20–1061	99–4585
Andhra Pradesh	Chittoor	18	33	49	100	55	18	20	40
Range	Chittoor	4.96–9.39			0.05–3.75	0.1–1.47	0.37–68.8	20–1307	56–4451
Andhra Pradesh	East Godavari	37	34	29	100	50	30	12	36
Range	East Godavari	4.96–9.4			0.05–3.75	0.1–1.79	0.32–68.97	20–2678	20–4599
Andhra Pradesh	Guntur	2	11	87	100	54	4	2	7
Range	Guntur	4.98–9.39			0.05–3.76	0.1–1.42	1–68.88	23–1553	226–4599
Andhra Pradesh	Krishna	10	41	48	100	61	16	3	54
Range	Krishna	5–9.43			0.05–3.75	0.1–1.72	0.33–68.92	21–1572	29–4599
Andhra Pradesh	Kurnool	5	20	75	100	77	20	3	21
Range	Kurnool	5–9.48			0.05–3.75	0.1–1.5	0.31–68.8	20–2409	52–4597
Andhra Pradesh	Nellore	17	23	59	100	60	18	14	32
Range	Nellore	4.95–9.54			0.05–3.75	0.1–1.36	0.4–68.8	20–2069	80–4589
Andhra Pradesh	Prakasam	6	10	83	100	74	25	4	19
Range	Prakasam	5–9.54			0.05–3.75	0.1–1.77	0.3–68.8	21–1529	67–4596
Andhra Pradesh	Srikakulam	44	33	22	100	56	22	18	50
Range	Srikakulam	4.95–9.04			0.05–3.75	0.1–1.62	0.35–68.8	20–2009	25–4526
Andhra Pradesh	Visakhapatnam	40	28	32	100	41	31	6	48
Range	Visakhapatnam	4.95–9.42			0.05–3.75	0.1–1.78	0.33–68.8	22–2037	113–4479
Andhra Pradesh	Vizianagaram	44	32	24	100	64	43	18	52

(continued)

Table 4.2 (continued)

State	District	pH			EC ds/m	OC	Av P	Av K	Av Ca
Range	Vizianagaram	4.95–9.5			0.05–3.75	0.1–1.32	0.3–68.8	20–1071	74–4589
Andhra Pradesh	West Godavari	28	46	26	100	53	11	14	44
Range	West Godavari	4.96–9.39			0.05–3.76	0.1–1.47	0.37–68.8	20–2127	52–4598
Andhra Pradesh	YSR Kadapa	4	10	86	100	71	24	7	17
Range	YSR Kadapa	5–9.59			0.05–3.76	0.1–1.5	0.32–68.8	20–1317	144–4599
Andhra Pradesh total		19	28	53	100	63	22	10	37
Range		4.95–9.59			0.05–3.76	0.1–1.79	0.3–68.97	20–2678	20–4599

State	District	Av Mg ppm	Av S ppm	Av Zn ppm	Av B ppm	Av Fe ppm	Av Cu ppm	Av Mn ppm	No of samples
Andhra Pradesh	Anantapuram	1	32	62	62	11	1	1	3875
Range	Anantapuram	20–1873	2–292	0.1–5.9	0.1–2.94	0.1–20.6	0.1–8.54	0.42–15.98	3875
Andhra Pradesh	Chittoor	2	22	32	45	1	1	1	2577
Range	Chittoor	20–1271	5–290	0.1–5.9	0.1–2.95	0.1–20.6	0.1–8.24	0.1–15.98	2577
Andhra Pradesh	East Godavari	3	21	38	38	26	0	0	2799
Range	East Godavari	20–2378	5.01–292	0.1–5.96	0.1–2.99	0.1–20.62	0.1–9.98	1.18–15.98	2799
Andhra Pradesh	Guntur	0	14	42	4	6	1	2	2263
Range	Guntur	20–2490	5–292	0.1–5.94	0.1–2.96	0.24–20.58	0.1–9.96	0.1–15.92	2263
Andhra Pradesh	Krishna	1	23	49	19	4	0	1	4644
Range	Krishna	20–3310	5.01–292	0.1–5.94	0.1–2.99	0.14–20.6	0.1–9.94	0.82–15.98	4644
Andhra Pradesh	Kurnool	1	31	71	24	7	0	1	2858
Range	Kurnool	23–1766	2–292	0.1–5.96	0.1–2.99	0.36–20.6	0.14–9.72	0.73–15.96	2858
Andhra Pradesh	Nellore	2	13	46	22	3	1	3	2315
Range	Nellore	20–1989	5.02–292	0.1–5.94	0.1–2.96	0.1–20.62	0.1–9.73	0.1–15.98	2315

(continued)

Table 4.2 (continued)

State	District	Av Mg ppm	Av S ppm	Av Zn ppm	Av B ppm	Av Fe ppm	Av Cu ppm	Av Mn ppm	No of samples
Andhra Pradesh	Prakasam	3	25	78	32	17	2	2	2789
Range	Prakasam	20–2240	2–292	0.1–5.96	0.1–2.99	0.1–20.62	0.1–9.38	0.1–15.94	2789
Andhra Pradesh	Srikakulam	12	20	43	50	4	6	1	2799
Range	Srikakulam	20–1956	5–290	0.1–5.82	0.1–2.87	0.52–20.62	0.1–9.52	0.46–15.98	2799
Andhra Pradesh	Visakhapatnam	2	26	35	37	1	0	0	2158
Range	Visakhapatnam	20–1811	5–292	0.1–5.98	0.1–2.98	1.02–20.62	0.1–8.52	1.72–15.96	2158
Andhra Pradesh	Vizianagaram	7	23	49	52	0	0	0	2291
Range	Vizianagaram	20–1699	5.02–290	0.1–5.92	0.1–2.87	0.33–20.62	0.1–9.63	0.28–15.96	2291
Andhra Pradesh	West Godavari	9	17	17	34	1	1	2	2539
Range	West Godavari	20–3456	2–292	0.1–5.97	0.1–2.99	0.1–20.62	0.1–9.98	0.1–15.96	2539
Andhra Pradesh	YSR Kadapa	0	29	64	19	15	0	1	2715
Range	YSR Kadapa	20–1944	2–292	0.1–5.88	0.1–2.99	0.1–20.6	0.12–9.9	0.44–15.99	2715
Andhra Pradesh total		3	23	49	34	7	1	1	36,622
Range		20–3456	2–292	0.1–5.98	0.1–2.99	0.1–20.62	0.1–9.98	0.1–15.99	36,622

Source: Compiled by Authors, ICRISAT (2016)
a = percent deficient farmers' fields; 1 = mg per kg soil

fertiliser recommendations were disseminated amongst the farmers using wall writings, soil health cards as well as through FFs in each village.

4.3.3 On-Farm Participatory Demonstrations, Data Recording and Dissemination of Results

By adopting detailed process described above under 4.2.1 registered farmers were selected based on the crops they were to grow and with half acre plot for each treatment (farmer's practice (FP) and improved practice (IP) soil-test based balanced fertiliser recommendation) were selected. The farmers were guided by the FFs/LFs and farmers had to buy their inputs as recommended. The crops were grown and

Table 4.3 Critical limits in the soil of plant nutrient elements to separate deficient samples from non-deficient samples

	Soil Critical Limits	Soil Critical Limits	Soil Critical Limits
Particulars of analysis			
PH (1:2 soil: Water)	<6.5 acidic	Salinity (electrical)	<1.0 Normal
	6.5–7.5 neutral	Conductivity (dS/m)	1–2 warning
	>7.5 alkaline		>4 injurious to all crops
Organic carbon %		Total nitrogen kg ha^{-1}	<140 very low (62 ppm)
	0.0–0.5 low		140–280 low (62–125 ppm)
	0.5–0.75% medium		280–560 medium (125–250 ppm)
	0.75–1.0 high		560–700 high (250–312 ppm)
			>700 very high (>312 ppm)
Available P_2O_5 (kg ha^{-1})		Available P (ppm)	
(Olsen's method)	5.0–10 low	(Olsen's method)	<5 low
	10–25 medium		5–10 medium
	25–40 high		>10 high
Available K_2O (kg ha^{-1})		Available K (ppm)	
(1 N neutral ammonium acetate)	0–120 low	(1 N neutral ammonium acetate)	0–50 low
	100–280 medium		50–125 medium
	280–560 high		>125High
Available Ca ppm (1 N neutral		Available Mg ppm (1 N neutral	
Am. Acetate)	0–1000 ppm low	Am. Acetate)	0–40 ppm low
	1000–1600 ppm medium		40–80 ppm medium
	1600–2400 ppm high		80–120 ppm high
	Critical limits		**Critical limits**
Cacl2 extractable S ppm	10	Hot water extractable Boron ppm	0.5
DTPA extractable micronutrients ppm			
Zinc (Zn) ppm	0.6	Copper (Cu) ppm	0.2
Iron (Fe) ppm	4	Manganese (Mn) ppm	2

Data gleaned from various literature sources, for details see Rego et al. (2007), Sahrawat et al. (2007, 2016)

Fig. 4.4 Farmers visiting groundnut field demonstration in V. Kota, Chittor district in Andhra Pradesh, Chickpea in Gumla district of Jharkhand and Farmers' Day in Madhya Pradesh

monitored regularly and observations were recorded for both the treatments using randomly selected and labelled plants from each treatment. Field days (Fig. 4.4) were conducted to disseminate the results where farmers explained the interventions as well as explained the results and discussed with the farmers from the neighbouring villages. From the randomly selected farmers' fields crop cutting experiments were done and data recorded as described above under 4.2.1.

Table 4.4a State and crop wise grain yield (kg ha^{-1}) with farmers' practice and balanced micro- and secondary- nutrients participatory on-farm demonstrations in Andhra Pradesh and Telangana states

State	Crop	Yield (kg ha^{-1})		% Increase over FP	No of Samples
		Grain IP	Grain FP		
Andhra Pradesh	*Kharif* Blackgram	590	430	37	15
Andhra Pradesh	*Kharif* Castor	1290	860	50	3
Andhra Pradesh	*Kharif* Chilly	8860	8120	9	25
Andhra Pradesh	*Kharif* Cotton	4610	4040	14	25
Andhra Pradesh	*Kharif* Groundnut	1440	1080	33	171
Andhra Pradesh	*Kharif* Maize	7170	6350	13	13
Andhra Pradesh	*Kharif* Paddy	5250	4330	21	237
Andhra Pradesh	*Kharif* Pigeonpea	2070	1500	38	68
Andhra Pradesh	*Rabi* Chickpea	1920	1510	27	27
Andhra Pradesh	*Rabi* Sorghum	4360	3180	37	11
Telangana	*Kharif* Castor	1130	700	61	27
Telangana	*Kharif* Greengram	1230	790	56	27
Telangana	*Kharif* Groundnut	1240	710	75	15
Telangana	*Kharif* Maize	4590	2670	72	62
Telangana	*Kharif* Pigeonpea	1120	670	67	42
Telangana	*Kharif* Sesame	910	530	72	2
Telangana	*Kharif* Sorghum	1980	910	118	6

Source: Derived from data from different scaling-up projects (ICRISAT 2004, 2016)

4.3.4 Increased Crop Yields and Farmers' Incomes with Improved Fertility Management

In all the scaling-up projects based on soil fertility assessment by adopting stratified soil sampling in the villages/taluks and districts balanced nutrient management recommendations were adopted in "*seeing is believing*" demonstrations (Wani et al. 2012b, 2013). Data from crop cutting experiments were analysed using statistical methods and results are presented as a summary for different states and crops. In scaling-up projects such as in Karnataka and Andhra Pradesh 15,000 participatory trials on farmers' fields were conducted as described above and data collected by adopting crop cutting experiments (CCE) strategy. In Tata Foundation supported projects 1500 trials were conducted in 11 target districts of Madhya Pradesh and Rajasthan. Average data for district and crops are presented in Tables 4.4a, 4.4b, 4.4c, 4.4d, 4.4e, 4.4f, and 4.4g for the farmers' practice (FP) and improved management practice (IP) of balanced nutrient treatments. Response to added balanced nutrients varied with crops, states, districts (Tables 4.4a, 4.4b, 4.4c, 4.4d, 4.4e, 4.4f, and 4.4g).

For example, maximum increase in *kharif* sorghum yield with balanced nutrient management in Telangana state was 118%, in Karnataka, 30%, for soybean in

Table 4.4b State and crop wise grain yield (kg ha^{-1}) with farmers' practice and balanced micro- and secondary- nutrients participatory on-farm demonstrations in Karnataka, Madhya Pradesh and Rajasthan

State	Crop	Yield (kg ha^{-1})		% Increase over FP	No of Samples
		Grain IP	Grain FP		
Karnataka	*Kharif* Blackgram	1030	780	32	114
Karnataka	*Kharif* Cotton	1630	1360	20	497
Karnataka	*Kharif* Cowpea	440	320	38	51
Karnataka	*Kharif* Fieldbean	1110	830	34	56
Karnataka	*Kharif* Greengram	790	580	36	255
Karnataka	*Kharif* Groundnut	1450	1110	31	1355
Karnataka	*Kharif* Horsegram	130	100	30	4
Karnataka	*Kharif* Maize	4650	3730	25	2399
Karnataka	*Kharif* Paddy	4480	3680	22	2277
Karnataka	*Kharif* Pearl Millet	2270	1740	30	565
Karnataka	*Kharif* Pigeonpea	990	770	29	885
Karnataka	*Kharif* Ragi	1910	1470	30	2121
Karnataka	*Kharif* Sorghum	2890	2230	30	245
Karnataka	*Kharif* Soybean	1740	1370	27	459
Karnataka	*Kharif* Sugarcane	131,380	116,960	12	33
Karnataka	*Kharif* Sunflower	1360	1020	33	240
Karnataka	*Rabi* Chickpea	980	750	31	1105
Karnataka	*Rabi* Safflower	820	630	30	56
Karnataka	*Rabi* Sorghum	1540	1210	27	1022
Karnataka	*Rabi* Sunflower	1020	780	31	134
Karnataka	*Rabi* Wheat	750	560	34	33
Madhya Pradesh	*Kharif* Soybean	2290	1830	25	257
Madhya Pradesh	*Rabi* Chickpea	1440	1250	15	169
Rajasthan	*Kharif* Groundnut	1090	960	14	7
Rajasthan	*Kharif* Maize	2980	2730	9	17
Rajasthan	*Kharif* Pearl Millet	2510	2310	9	16
Rajasthan	*Kharif* Sorghum	2980	2740	9	8

Source: Derived from data from different scaling-up projects

Madhya Pradesh maximum increased yield was 34%, in Karnataka it was 27%, for groundnut in Telangana it was 102%, in Rajasthan 14%, in Karnataka 31%, in Andhra Pradesh 33% over the crop yield in farmers 'practice. Similar variation is response to crops was observed for *rabi* crops also. Castor responded well 64% in Telangana, 61% in Karnataka over the farmers' practice (Table 4.4a, 4.4b, 4.4c, 4.4d, 4.4e, 4.4f, and 4.4g and Figs. 4.5a, 4.5b, and 4.5c). All crops responded to balanced nutrient management and minimum increased yield recorded was 10% over the farmers' practice. Similar benefits with balanced nutrient management were also recorded in a collaborative scaling-up project between Central Dryland Research Institute for Agriculture (CRIDA) and ICRISAT in tribal and backward

Table 4.4c State and crop wise grain yield (kg ha^{-1}) with farmers' practice and balanced micro- and secondary- nutrients participatory on-farm demonstrations in Karnataka

State	District	Crop	Yield (kg ha^{-1})		% Increase over FP
			Grain IP	Grain FP	
Karnataka	Ballari	*Kharif* Cotton	2190	1840	19
Karnataka	Chitradurga	*Kharif* Cotton	1220	1050	16
Karnataka	Davanagere	*Kharif* Cotton	1440	1200	20
Karnataka	Haveri	*Kharif* Cotton	1290	1120	15
Karnataka	Mysuru	*Kharif* Cotton	1880	1450	30
Karnataka	Raichur	*Kharif* Cotton	1720	1470	17
Karnataka		*Kharif* Cotton Total	1630	1360	20
Karnataka	Chikkaballapura	*Kharif* Fieldbean	1320	970	36
Karnataka	Davanagere	*Kharif* Fieldbean	1190	930	28
Karnataka	Hassan	*Kharif* Fieldbean	580	450	29
Karnataka	Kolar	*Kharif* Fieldbean	1940	1490	30
Karnataka	Ramanagara	*Kharif* Fieldbean	1030	750	37
Karnataka		*Kharif* Fieldbean Total	1110	830	34
Karnataka	Bagalkot	*Kharif* Greengram	340	250	36
Karnataka	Bidar	*Kharif* Greengram	1270	950	34
Karnataka	Chitradurga	*Kharif* Greengram	360	290	24
Karnataka	Dharwad	*Kharif* Greengram	1380	950	45
Karnataka	Gadag	*Kharif* Greengram	500	340	47
Karnataka	Kalaburagi	*Kharif* Greengram	810	610	33
Karnataka	Vijayapura	*Kharif* Greengram	380	270	41
Karnataka	Yadgir	*Kharif* Greengram	810	600	35
Karnataka		*Kharif* Greengram Total	790	580	36
Karnataka	Ballari	*Kharif* Groundnut	1430	1030	39
Karnataka	Belagavi	*Kharif* Groundnut	1470	1130	30
Karnataka	Chamarajanagar	*Kharif* Groundnut	890	740	20
Karnataka	Chikkaballapura	*Kharif* Groundnut	1570	1140	38
Karnataka	Chikkamagaluru	*Kharif* Groundnut	2220	1680	32
Karnataka	Chitradurga	*Kharif* Groundnut	710	580	22
Karnataka	Davanagere	*Kharif* Groundnut	2060	1650	25
Karnataka	Dharwad	*Kharif* Groundnut	1820	1390	31
Karnataka	Gadag	*Kharif* Groundnut	1300	980	33
Karnataka	Haveri	*Kharif* Groundnut	2560	2050	25
Karnataka	Kolar	*Kharif* Groundnut	1850	1420	30
Karnataka	Koppal	*Kharif* Groundnut	1460	1040	40
Karnataka	Raichur	*Kharif* Groundnut	1910	1500	27
Karnataka	Ramanagara	*Kharif* Groundnut	1380	1060	30
Karnataka	Tumakuru	*Kharif* Groundnut	820	650	26
Karnataka	Vijayapura	*Kharif* Groundnut	640	470	36
Karnataka		*Kharif* Groundnut Total	1450	1110	31

Source: Derived from different scaling-up projects data (ICRISAT 2009, 2012, 2017)

Table 4.4d State and crop wise grain yield (kg ha^{-1}) with farmers' practice and balanced micro- and secondary- nutrients participatory on-farm demonstrations in Karnataka

State	District	Crop	Yield (kg ha^{-1})		% Increase over FP
			Grain IP	Grain FP	
Karnataka	Bagalkot	*Kharif* Pigeonpea	940	740	27
Karnataka	Ballari	*Kharif* Pigeonpea	470	330	42
Karnataka	Bidar	*Kharif* Pigeonpea	1330	1060	25
Karnataka	Chikkaballapura	*Kharif* Pigeonpea	1360	1060	28
Karnataka	Chitradurga	*Kharif* Pigeonpea	460	360	28
Karnataka	Davanagere	*Kharif* Pigeonpea	440	360	22
Karnataka	Hassan	*Kharif* Pigeonpea	270	190	42
Karnataka	Kalaburagi	*Kharif* Pigeonpea	1430	1110	29
Karnataka	Kolar	*Kharif* Pigeonpea	1850	1360	36
Karnataka	Mysuru	*Kharif* Pigeonpea	180	130	38
Karnataka	Raichur	*Kharif* Pigeonpea	910	720	26
Karnataka	Ramanagara	*Kharif* Pigeonpea	1060	770	38
Karnataka	Vijayapura	*Kharif* Pigeonpea	950	730	30
Karnataka	Yadgir	*Kharif* Pigeonpea	1430	1100	30
Karnataka		*Kharif* Pigeonpea Total	990	770	29
Karnataka	Bagalkot	*Kharif* Soybean	1680	1290	30
Karnataka	Belagavi	*Kharif* Soybean	1640	1340	22
Karnataka	Bidar	*Kharif* Soybean	1920	1470	31
Karnataka	Dharwad	*Kharif* Soybean	1610	1240	30
Karnataka	Haveri	*Kharif* Soybean	1810	1460	24
Karnataka	Kalaburagi	*Kharif* Soybean	1830	1390	32
Karnataka		*Kharif* Soybean Total	1740	1370	27
Karnataka	Davanagere	*Kharif* Sugarcane	131,280	120,380	9
Karnataka	Mysuru	*Kharif* Sugarcane	131,450	114,730	15
Karnataka		*Kharif* Sugarcane Total	131,380	116,960	12
Karnataka	Bagalkot	*Kharif* Sunflower	1580	1190	33
Karnataka	Ballari	*Kharif* Sunflower	860	600	43
Karnataka	Chamarajanagar	*Kharif* Sunflower	1720	1350	27
Karnataka	Davanagere	*Kharif* Sunflower	1170	910	29
Karnataka	Haveri	*Kharif* Sunflower	1030	830	24
Karnataka	Kalaburagi	*Kharif* Sunflower	1990	1430	39
Karnataka	Koppal	*Kharif* Sunflower	760	530	43
Karnataka	Raichur	*Kharif* Sunflower	790	580	36
Karnataka	Vijayapura	*Kharif* Sunflower	2070	1550	34
Karnataka	Yadgir	*Kharif* Sunflower	750	600	25
Karnataka		*Kharif* Sunflower Total	1360	1020	33

Source: Derived by authors from data *Bhoochetana* scaling-up projects (ICRISAT 2018)

Table 4.4e State and crop wise grain yield (kg ha^{-1}) with farmers' practice and balanced micro- and secondary- nutrients participatory on-farm demonstrations in Karnataka

State	District	Crop	Yield (kg ha^{-1})		% Increase over FP
			Grain IP	Grain FP	
Karnataka	Bidar	*Kharif* Blackgram	1190	900	32
Karnataka	Kalaburagi	*Kharif* Blackgram	740	550	35
Karnataka	Mysuru	*Kharif* Blackgram	190	160	19
Karnataka		*Kharif* Blackgram Total	1030	780	32
Karnataka	Ballari	*Rabi* Chickpea	900	670	34
Karnataka	Belagavi	*Rabi* Chickpea	730	570	28
Karnataka	Bidar	*Rabi* Chickpea	1660	1300	28
Karnataka	Chitradurga	*Rabi* Chickpea	840	670	25
Karnataka	Davanagere	*Rabi* Chickpea	1210	950	27
Karnataka	Dharwad	*Rabi* Chickpea	1420	1060	34
Karnataka	Gadag	*Rabi* Chickpea	570	390	46
Karnataka	Haveri	*Rabi* Chickpea	700	550	27
Karnataka	Kalaburagi	*Rabi* Chickpea	1230	930	32
Karnataka	Koppal	*Rabi* Chickpea	1120	910	23
Karnataka	Raichur	*Rabi* Chickpea	1010	800	26
Karnataka	Vijayapura	*Rabi* Chickpea	680	520	31
Karnataka	Yadgir	*Rabi* Chickpea	750	560	34
Karnataka		*Rabi* Chickpea Total	980	750	31
Karnataka	Bidar	*Rabi* Safflower	970	740	31
Karnataka	Haveri	*Rabi* Safflower	680	540	26
Karnataka	Koppal	*Rabi* Safflower	270	200	35
Karnataka		*Rabi* Safflower Total	820	630	30

Source: Derived by authors from data from *Bhoochetana & BhooSamruddhi* scaling-up projects (ICRISAT 2009, 2012, 2017, 2018)

districts of Andhra Pradesh (undivided) (Srinivasa Rao et al. 2011). Varied response was associated with soil type, rainfall as well as management practices, however, it established that Indian soils are hungry also along with thirsty.

Increased crop yields with application of balanced nutrients to crops were largely due to increased rainwater use efficiency and it also resulted in increased profitability for the farmers. Highest rainwater use efficiency was observed in case of integrated nutrient management treatments, followed by balanced nutrient management and least was in farmers 'practice (Table 4.5).

As indicated in Table 4.5 application of S, Zn and B above farmers' practice increased RWU as well as profitability for the farmers. Response to balanced nutrient management varied with seasons largely due to rainfall and INM involving 50% N through vermicompost showed highest returns as well as RWU efficiency (Table 4.5) indicating the need to adopt INM strategy for enhancing productivity, profitability as well as sustainability. Similarly, enhanced water use efficiency was recorded across the crops and locations (Tables 4.6 and 4.7). In Chhattisgarh, Jharkhand, Madhya Pradesh and Rajasthan several trials conducted with balanced

Table 4.4f State and crop wise grain yield (kg ha^{-1}) with farmers' practice and balanced micro- and secondary- nutrients participatory on-farm demonstrations in Madhya Pradesh and Rajasthan

State	District	Crop	Yield (kg ha^{-1})		% Increase over FP
			Grain IP	Grain FP	
Madhya Pradesh	Guna	*Kharif* Soybean	1950	1580	23
Madhya Pradesh	Indore	*Kharif* Soybean	2600	2320	12
Madhya Pradesh	Raisen	*Kharif* Soybean	2580	1930	34
Madhya Pradesh	Rajagarh	*Kharif* Soybean	1800	1260	43
Madhya Pradesh	Sehor	*Kharif* Soybean	2500	2090	20
Madhya Pradesh	Sehore	*Kharif* Soybean	1890	1620	17
Madhya Pradesh	Vidisha	*Kharif* Soybean	2360	1770	33
Madhya Pradesh		*Kharif* Soybean total	2290	1830	25
Madhya Pradesh	Barwani	*Rabi* Chickpea	540	520	4
Madhya Pradesh	Guna	*Rabi* Chickpea	1740	1430	22
Madhya Pradesh	Indore	*Rabi* Chickpea	1370	1370	0
Madhya Pradesh	Mandla	*Rabi* Chickpea	610	410	49
Madhya Pradesh	Raisen	*Rabi* Chickpea	1560	1350	16
Madhya Pradesh	Rajagarh	*Rabi* Chickpea	1110	930	19
Madhya Pradesh	Sagar	*Rabi* Chickpea	1560	1330	17
Madhya Pradesh	Sehore	*Rabi* Chickpea	2060	1800	14
Madhya Pradesh	Vidisha	*Rabi* Chickpea	1560	1330	17
Madhya Pradesh		*Rabi* Chickpea Total	1440	1250	15
Rajasthan	Tonk	*Kharif* Groundnut	1090	960	14
Rajasthan		*Kharif* Groundnut Total	1090	960	14
Rajasthan	Sawai Madhopur	*Kharif* Maize	3220	2920	10

(continued)

Table 4.4f (continued)

Rajasthan	Tonk	*Kharif* Maize	2810	2600	8
Rajasthan		*Kharif* Maize Total	2980	2730	9
Rajasthan	Sawai Madhopur	*Kharif* Pearl Millet	2620	2380	10
Rajasthan	Tonk	*Kharif* Pearl Millet	2400	2230	8
Rajasthan		*Kharif* Pearl Millet Total	2510	2310	9
Rajasthan	Sawai Madhopur	*Kharif* Sorghum	2980	2740	9
Rajasthan		*Kharif* Sorghum Total	2980	2740	9

Source: Derived by authors from data from different scaling-up projects supported by Sir Dorabji Tata Trust

Table 4.4g State and crop wise grain yield (kg ha^{-1}) with farmers' practice and balanced micro- and secondary- nutrients participatory on-farm demonstrations in Telangana

State	District	Crop	Yield (kg ha^{-1}) Grain IP	Grain FP	% Increase over FP
Telangana	Mahabubnagar	*Kharif* Castor	1650	1050	57
Telangana	Nalgonda	*Kharif* Castor	820	500	64
Telangana		*Kharif* Castor Total	1130	700	61
Telangana	Nalgonda	*Kharif* Greengram	1230	790	56
Telangana	Nalgonda	*Kharif* Groundnut	1240	710	75
Telangana	Mahabubnagar	*Kharif* Maize	4480	2780	61
Telangana	Nalgonda	*Kharif* Maize	4840	2400	102
Telangana		*Kharif* Maize Total	4590	2670	72
Telangana	Mahabubnagar	*Kharif* Pigeonpea	820	410	100
Telangana	Nalgonda	*Kharif* Pigeonpea	1220	760	61
Telangana		*Kharif* Pigeonpea Total	1120	670	67
Telangana	Nalgonda	*Kharif* Sesame	910	530	72
Telangana	Mahabubnagar	*Kharif* Sorghum	1990	930	114
Telangana	Nalgonda	*Kharif* Sorghum	1920	800	140
Telangana		*Kharif* Sorghum Total	1980	910	118

Source: Derived by authors from data collected in APRLPproject (ICRISAT 2004)

nutrition for enhancing WUE (productivity and profitability) through the GoI's program "*More crop per drop*" supported by Water Resources Ministry, GoI demonstrated increased crop yields by 14–33% with balanced nutrient management along with increased benefit: cost ratios 1.6–10 as compared to1.2–9 in case of farmers 'practice (Table 4.6).

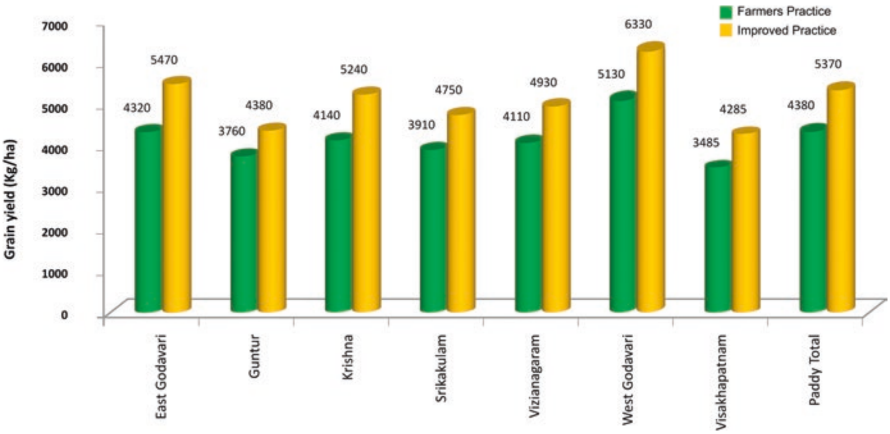

Fig. 4.5a Effect of soil test-based micro & secondary nutrient application in paddy crop yield in Andhra Pradesh

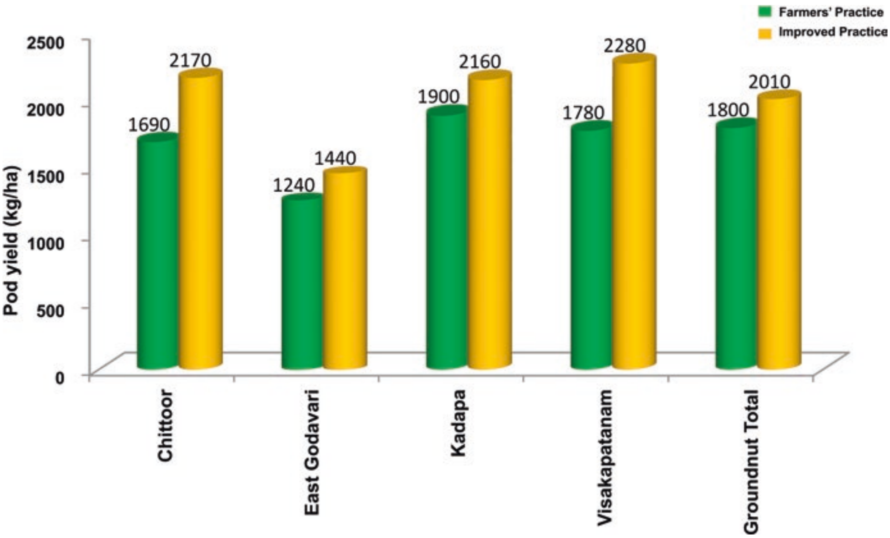

Fig. 4.5b Effect of soil test-based micro & secondary nutrient application in groundnut crop yield in Andhra Pradesh

4.4 Scaling-up of Land and Water Management Interventions

A large yield gap of two-fold to four-fold existing in Asia and Africa between current productivity and achievable potential, with farmers' yields than the achievable yields (Wani et al. 2003b, c; Rockström et al. 2007). Large opportunities for enhancing food production through enhanced water productivity (WP) by adopting

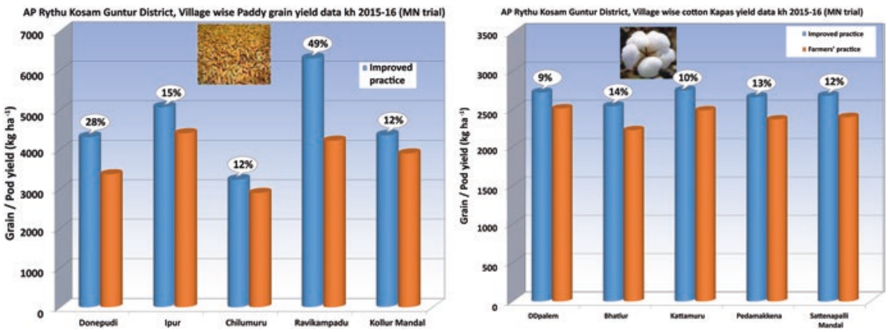

Fig. 4.5c Increased crop yields due to micronutrients application in Andhra Pradesh. (Source: ICRISAT 2016)

Table 4.5 Effects of nutrient managements on soybean (*Glycine max*) grain yield, benefit to cost ratio and rainwater use efficiency under rain-fed conditions in Madhya Pradesh, India

	Grain yield (kg ha^{-1})			Benefit: cost ratio		Rainwater use efficiency (kg/mm/ha)		
District	FP[a]	BN	INM	FP	BN	FP	BN	INM
2010								
Guna	1270	1440	1580	1.31	4.58	1.76	1.99	2.19
Raisen	1360	1600	1600	1.85	3.55	1.76	2.07	2.07
Shajapur	1900	2120	2410	2.99	10.2	3.45	3.85	4.38
Vidisha	1130	1410	1700	2.16	8.43	1.48	1.84	2.22
2011								
Guna	1370	1560	1600	1.47	3.4	0.83	0.95	0.97
Shajapur	1220	1400	1510	2.45	5.8	1.12	1.28	1.38
Vidisha	1190	1380	1460	1.47	3.99	0.88	1.02	1.08

[a]*FP* Farmers' practice (NPK only), *BN* Balanced nutrition (FP + S + B + Zn), and *INM* Integrated nutrient management (50% BN inputs + vermicompost) (Derived from Chander et al. 2011)

appropriate soil, water and crop management options exists to be harnessed (Wani et al. 2009a). A linear relationship is generally assumed between biomass growth and vapour flow/evapotranspiration (ET) for grain yield >3 t ha^{-1}, which describes WP ranging between 1000 and 3000 m^3 t^{-1} for grain production (Rockström 2003). The reason is that improvements in agricultural productivity, resulting in increased yield and denser foliage, will involve a vapour shift from non-productive evaporation (E) in favour of productive transpiration (T) and a higher T/ET ratio as transpiration increases (essentially linearly) with a higher yield (Stewart et al. 1975; Rockström et al. 2007).

Evidence from water balance analyses of farmers' fields around the world shows that only a small fraction, less than 30% of rainfall, is used as productive green water flow (plant transpiration) supporting plant growth (Rockström 2003). In arid areas, as little as 10–15% of the rainfall is typically consumed as productive green water flow (transpiration) and 85–90% flows as non-productive evaporation, that is,

Table 4.6 Effect of balanced nutrient management on water use efficiency of crops and crop yields in different states in India

Sl. No.	State	Crop	Crop yields (kg ha^{-1})			Water use efficiency (kg mm^{-1} ha^{-1})		Benefit cost ratio	
			FP	IP	% Increase	FP	IP	FP	IP
1	Chhattisgarh	Rice[a]	4410	5450	24	7.0	9.0	6.0	6
		Chickpea[b]	Fallow	745	–	–	9.0	–	4
2	Jharkhand	Rice[a]	5160	5982	14	4.7	6.0	9.0	10
		Chickpea[b]	Fallow	975	–	–	6.0	–	7
		Groundnut	1470	1950	33	2.7	3.5	2.45	3.25
		Maize	5500	6970	27	6.9	8.6	2.75	7.5
3	Madhya Pradesh	Soybean[c]	Fallow	2134	–	–	4.5	3.0	4.0
		Soybean	2120	2680	25	2.6	3.7	2.8	3.8
		Chickpea	1562	1817	16	3.0	4.0	2.8	1.9
		Wheat	1848	2305	24	8.0	9.0	2.0	2.6
4	Rajasthan	Black gram	326	385	20	0.7	0.9	1.5	1.8
		Groundnut	734	872	20	1.3	1.6	2.1	2.9
		Maize	1746	2035	17	3.2	3.7	1.5	1.9
		Pearl millet	616	718	16	1.8	2.1	1.2	1.6
		Chickpea	1270	1520	19	6.2	7.8	4.6	5.8
		Wheat	3952	4580	16	4.6	7.3	1.9	2.4
		Mustard	1242	1436	16	8.3	12.3	1.6	2.3
		Green peas	3530	4160	18	7.8	9.2	4.7	5.5

Source: Derived from Wani et al. (2010, 2012a)
[a]Rice in rainy season;
[b]After harvest of rice that is grown in rainy season followed by chickpea in post-rainy season on residual moisture;
[c]Fallow during rainy season in conventional practice

no or very limited blue water generation (Oweis and Hachum 2001). Agricultural water management interventions in the watershed in the Indian SAT converted more rainfall into green water and also reduced the amount of run-off by 30–50%, depending on rainfall amount and distribution (Garg et al. 2011).

In order to bridge the existing yield gaps improved landform management practices were scaled-up in different agro-eco regions of India to benefit the farmers. Different land form treatments in each region as per the soil type and rainfall with major crops were scaled-up based on the earlier on-farm research. Summary results presented in Table 4.8 showed average increased grain yield from 11% to 43% with improved landform treatment over the farmers' practice in different regions. Increased grain yields with improved landform treatment ranged from 7% to 52% over the farmers 'practice with different crops in different regions. Along with land form treatment effects of balanced nutrient management were also demonstrated in

Table 4.7 Average water use efficiency of crops grown with farmers 'practice and balanced nutrient management (IP) from different locations in India

	Crop yields (kg ha^{-1})			Water use efficiency (kg mm^{-1} ha^{-1})			Benefit cost ratio		
Crop	FP	IP	% Increase	FP	IP	% Increase	FP	IP	% Increase
Wheat	2900	3443	20	6	8	33	2.0	2.5	25
Soybean	2120	2407	25	3	4	33	3.0	4.0	33
Rice	4785	5716	19	6	8	33	7.5	8.0	7
Pearl millet	616	718	16	2	2	0	1.2	1.6	33
Mustard	1242	1436	16	8	12	50	1.6	2.3	44
Maize	3623	4503	22	5	6	20	2.1	4.7	124
Groundnut	1102	1411	27	2	3	50	2.3	3.1	35
Green peas	3530	4160	18	8	9	13	4.7	5.5	17
Chickpea	1416	1264	18	5	7	40	3.7	4.7	27
Black gram	326	385	20	0.7	0.9	29	1.5	1.8	20
Mean of all crops	**2166**	**2544**	**20**	**4.6**	**6.0**	**30**	**3.0**	**3.8**	**27**

Source: Derived from Wani et al. (2010), ICRISAT (2012)

Madhya Pradesh with assured rainfall and Vertisol (black cotton soils), the superiority of BBF landform treatment was showed over conservation furrow method (Table 4.8).

4.5 Scaling-up of Improved Cultivars Thorough Participatory Evaluation/Selection

One of the most important intervention for enhancing the productivity and profitability for the farmers is introduction of stress-tolerant climate smart cultivars of the crops and ensure availability of seeds for the farmers along with improved management of soil, water and nutrient management interventions. In all the scaling-up initiatives conducted in Andhra Pradesh, Chhattisgarh, Madhya Pradesh, Jharkhand, Karnataka, Telangana, Odisha, Maharashtra, Gujarat, Rajasthan, Uttar Pradesh, etc. in India, Thailand, Vietnam, and China were conducted with identified improved cultivars. Improved cultivars were identified through discussions with the NARSs partners for each project and seeds were made available to the farmers. List of improved cultivars evaluated in different districts of Karnataka during *kharif* and *rabi* seasons is indicated in Table 4.9.

The efforts were made to make available climate smart crop cultivars which are tolerant of mid-season and end-of-season drought, and are high yielding were made available to farmers for their evaluation. The results are presented in Tables 4.10a, 4.10b, 4.10c, and 4.10d and Figs. 4.8a to 4.8h). In Karnataka yields of improved cultivars of different crops were compared with the average yield of a particular crop in Karnataka and also with average crop yield at national level. The results

Table 4.8 Effect of land management systems on crop yields in different states in India

Sl. No.	State	Crop	No. of trials	Land management system[b]	Grain yield (kg ha^{-1})				% Increase	
					FP[c]	Range	IP[c]	Range	Av.	Range
1	Andhra Pradesh[a]-APRLP-DFID	Groundnut	30	CF	964	910–972	1090	1010–1130	13	9–17
		Green gram	10	CF	810	750–950	1050	900–1150	30	26–33
2	Andhra Pradesh-*Rythu kosam*-GoA.P.	Pigeonpea	20	CF	950	860–1050	1150	950–1240	21	17–24
		Cowpea	20	CF	350	240–480	470	280–720	34	29–38
		Black gram	20	CF	450	360–650	570	380–810	27	24–31
		Maize	10	BBF	2550	1850–3300	3100	1900–3700	22	16–28
3	Madhya Pradesh-WUE-GoI	Soybean	235	BBF	2134	1831–2550	2793	2397–3110	31	22–39
		Chickpea	184	BBF	1240	1050–1480	1610	1580–1650	32	10–52
4	Rajasthan-WUE-GoI	Blackgram	9	CF	326	270–360	385	240–425	18	14–20
		Groundnut	5	CF	734	685–770	872	785–930	19	15–24
		Maize	6	CF	1746	1350–1950	2035	1750–2350	17	13–22
		Pearl millet	8	CF	616	550–660	718	680–760	16	11–24
5	Karnataka-Sujala-WB program	Maize	20	CF	3480	3110–4210	4060	3610–5080	17	13–21
		Soybean	20	CF	1470	1310–1590	1800	1660–1930	23	20–27
		Groundnut	25	CF	1120	500–1240	1320	1070–1930	19	13–22
		Finger millet	25	CF	1280	1120–1480	1590	1380–1840	24	21–29
		Maize	15	BBF	3630	3130–4210	4790	4620–5080	43	21–50

(continued)

Table 4.8 (continued)

Sl. No.	State	Crop	No. of trials	Land management system[b]	Grain yield (kg ha^{-1}) FP[c]	Range	IP[c]	Range	% Increase Av.	Range
6	Karnataka-*Bhoo Chetana*	Pigeonpea	20	CF	925	630–1540	1165	830–1940	26	22–32
		Pearl millet	20	CF	1095	960–1220	1385	1270–1550	26	10–44
		Soybean	10	BBF	1400	1180–1610	1740	1480–2000	24	22–26
		Finger millet	10	CF/BS[1]	1030	800–1440	1330	970–1930	29	24–37
		Groundnut	5	BBF	1160	1070–1270	1470	1370–1590	27	23–29
7	Karnataka-*Bhoo Samrudhi*	Soybean	40	BBF	1238	1380–1500	1523	1580–1960	23	14–37
		Green gram	30	BBF	520	180–880	665	210–1200	28	22–34
		Groundnut	10	BBF	1152	900–1450	1356	1000–1630	18	10–21
		Maize	20	BBF	2400	1800–2900	3000	2500–3600	25	20–28
		Pearl millet	20	BBF	810	700–920	910	800–1020	12	11–14
		Pigeonpea	25	BBF	756	430–1200	840	500–1500	11	7–16
		Chickpea	10	BBF	1250	850–1350	1450	1120–1650	16	11–18

Sources: ICRISAT (2004, 2009, 2012, 2018), Wani et al. (2012a)
[a]Former undivided Andhra Pradesh state
[b]Land management systems – CF: Conservation Furrow; BBF: Broad bed and furrow; BS: Border strip
[c]FP: Farmers practice with flat land configuration; IP: Improved land configuration with CF/BBF

presented in 4.10b demonstrated increased yield of 29% over average Karnataka yield and 67% over national yield average in case of finger millet cv. MR 1 and 144% in case of soybean cv. JS 9560 over average soybean yield in Karnataka and India (Table 4.10b). Maximum yield increase was observed with improved cultivar of sunflower DRSH 1 (166–169%) over average yield in Karnataka and national average. These results revealed that there is ample scope to increase the potential yield of different varieties in the state of Karnataka to benefit small and marginal farmers. Field trials for groundnut crop with cultivar ICGV 91114 were planned in twelve districts of Karnataka. Maximum yield (2590 kg ha^{-1}) was observed in Raichur district (Fig. 4.7b). Low grain yields in Bagalkot (1050 kg ha^{-1}) and Gadag (1140 kg ha^{-1}) were because of poor rainfall. Poor rainfall distribution also affected crop establishment in Dharwad, Davangere and Hassan districts.

Trials for two sorghum cultivars (viz, CSV 15 and CSV 23) demonstrated in eight districts showed maximum yield for CSV 15 was 2640 kg ha^{-1} in Koppal and

Table 4.9 List of crop cultivars demonstrated in farmer's fields in different districts of Karnataka

District Name	Pigeon pea	Green gram	Groundnut	Soybean	Ground nut	Cluster bean	Chickpea
Belgaum	ICPL 87119 (Asha), hybrid (Puskal) ICPH 2671	SML 668	ICGV 91114	JS 9560, JS 335, DSB 21		HG 563	JG 11, JAKI 9218
Davanagere	Lakshmi (ICPL 85063), Asha (ICPL 871119), ICPH 2740, Puskal (ICPH 2671)	–	ICGV 91114			–	JG 11, JAKI 9218, ICCC 37
Haveri	Asha (ICPL 87119), Lakshmi (ICPL 85063), Puskal (ICPH 2671), ICPH 2740	–	–			–	ICCC 37, JG 11, JAKI 9218
Bijapur	Asha (ICPL 87119), Lakshmi (ICPL 85063)	SML668	–			HG 563	KAK 2, ICCC 37, JG 11, JAKI 9218
Chikkamagalur	Lakshmi (ICPL 85063), Asha (ICPL 87119), Puskal (ICPH 2671), ICPH 2740	SML 668	–			HG 563	ICCC 37, JG 11, JAKI 9218
Chamarajnagar	Lakshmi (ICPL 85063), Puskal (ICPH 2671)	SML 668	–			HG 563	KAK 2, ICCC 37, JG 11, JAKI 9218
Gadag	Lakshmi (ICPL 85063), Puskal (ICPH 2671), Asha (ICPL 87119)	–	ICGV 91114			–	JG 11, JAKI 9218
Bangalore 2	Laxmi (ICPL 85063), Asha (ICPL 87119), Puskal (ICPH 2671)	–	–			–	

(continued)

Table 4.9 (continued)

District Name	Pigeon pea	Green gram	Groundnut	Soybean	Ground nut	Cluster bean	Chickpea
Tumkur	Lakshmi (ICPL 85063)	–	ICGV 91114, ICGV 02266, ICGV 00308, ICGV 00351		ICGV 91114,	HG 563	JG 11, JAKI 9218
Chitradurga	Laxmi (ICPL 85063), Asha (ICPL 87119), Puskal (ICPH 2671), ICPH 2740	–	ICGV 91114			HG 563	JG 11, JAKI 9218
Yadgiri	Puskal (ICPH 2671), Asha (ICPL 87119), Laxmi (ICPL 85063)	–	–		ICGV 91114,	–	JG 11, JAKI 9218
Gulbarga	Puskal (ICPH 2671), Asha (ICPL 87119), Laxmi (ICPL 85063), ICPH 2740	SML 668	–		ICGV 91114	HG 563	JG 11, JAKI 9218
Bidar	Puskal (ICPH 2671), Asha (ICPL 87119), Laxmi (ICPL 85063), ICPH 2740	SML 668	–	JS 9560, JS 335, DSB 21		HG 563, N 87, RGE-986	JG 11, JAKI 9218
Bellary	Puskal (ICPH 2671), Asha (ICPL 87119), Laxmi (ICPL 85063), ICPH 2740	SML 668	ICGV 91114			HG 563	JG 11, JAKI 9218, KAK 2

(continued)

Table 4.9 (continued)

District Name	Pigeon pea	Green gram	Groundnut	Soybean	Ground nut	Cluster bean	Chickpea
Raichur	Puskal (ICPH 2671), Asha (ICPL 87119), Laxmi (ICPL 85063), ICPH 2740	SML 668	ICGV 91114, ICGV 02266, ICGV 00308, ICGV 00351			HG 563	JG 11, JAKI 9218, KAK 2

Source: Compiled from data collected from *Bhoochetana* scaling-up projects (ICRISAT 2018)

Table 4.10a Grain yield and pod yield of different participatory demonstrations in Jharkhand

kharif-2013	Crop variety	Yield (t ha^{-1})
Groundnut		Av. Pod yield (t ha^{-1})
	ICGV 9346 with agribore	1.90
	ICGV 9346 with no agribore	1.84
	Jhumku (**local**) with agribore	1.48
	Jhumku with no agribore	1.42
Soybean		Av. Seed yield (t ha^{-1})
	PUSA-9712 with agribore	0.72
	PUSA-9712 with no agribore	0.65

for CSV 23 was 2880 kg ha^{-1} in Raichur. Overall average yield for CSV 15 cultivar was 2240 kg ha^{-1} and for CSV 23 was 2580 kg ha^{1}. Observed data from Belgaum and Davangere indicated that CSV 23 had 18–22% more grain yield than CSV 15 cultivar (Figs. 4.6a1, 4.6a2, and 4.6b). Heavy rainfall during crop season damaged trials of both the cultivars in Bidar and Gulburga districts and CSV 23 cultivar in Koppal and Haveri districts. Similarly, increased crop yields with improved cultivars of pearl millet, finger millet and other crops in different districts were recorded (Figs. 4.6c, 4.6d, and 4.6e). Early maturing cultivar of pearl millet like HHB 67 showed better performance over ICTP 8809 which suffered due to drought at maturity. Maximum yield (2325 kg ha^{-1}) was observed in Yadgir district with average yield of 1370 kg $ha^{-1}$for ICTP 8203 and1420 kg ha^{-1} for HHB 67. (Fig. 4.6c). Grain yields of castor trials showed maximum yield in Raichur. Yield for DCH 177 that is 5–19% more than cultivar Jyothi (Fig. 4.6e).

In Jharkhand improved cultivars of chickpea benefitted farmers well as they sold green chickpea to the nearby city market and made on an average income of Rs 15,000 per acre as compared to no income from field which they had kept fallow after harvesting rice previously. For seed production, specified farmers' fields were maintained till maturity and both the cultivars produced 1300–1500 kg ha^{-1}. Groundnut yields and other agronomic parameters were analysed among farmers' participatory experimental fields in Jharkhand and compared with traditional variety (*Jhumku*).

Table 4.10b Average crop yields of various varieties during rainy season 2013 in Karnataka and average yields of Karnataka state during rainy season 2011 and average yields of different crop s during rainy season 2012 at all India level

S. No	Crop	Variety	ICRISAT, varietal trial Average yield 2013 (kg ha^{-1})	National Average yield 2012 (kg ha^{-1})[a]	% increase over national average	Karnataka average yield 2011 (kg ha-1)[b]	% increase over Karnataka average
1	Groundnut	ICGV 91114	1517	985	54	665	128
2	Finger millet	MR 1	2527	1514	67	1966	29
3	Soybean	JS 9560	2321	950	144	950	144
4	Sorghum	CSV 15	2240	1070	109	1556	44
5	Sorghum	CSV 23	2579	1070	141	1556	66
6	Pearl millet	ICTP 8203	1372	1124	22	1025	34
7	Pearl millet	HHB 67	1417	1124	26	1025	38
8	Sunflower	DRSH 1	1462	544	169	547	167
9	Castor	DCH 177	1225	1329	-8	926	32
10	Castor	DCH 32	1280	1329	-4	926	38

Source: Compiled by authors from *Bhoocheatana* sites (ICRISAT 2018)
[a]State of Indian agriculture 2012–13
[b]Final advance estimates of area, production and yield of important agricultural crops in Karnataka 2011–12 – Directorate of Economics and Statistics, Government of Karnataka

Table 4.10c Performance of participatory trials at Parasai-Sindh watershed, Jhansi district, Uttar Pradesh during *Rabi*

Crop	Variety	Average grain yield (kg/ha)	Per cent yield increase
Chick pea	Vaibhav	1870	33
	Desi	1402	–
Lentil	DPL 62	1130	18
	Desi	960	–
Mustard	Pusa Bold	1470	25
	Desi	1180	–

Improved groundnut variety (TAG 24) had the highest pods (19.2 pods/plant). Wheat yield obtained by HI 1544, HI 1531, HI 1479 and HI 1418 were found relatively higher than Lok 1. The HI 1544 recorded highest grain yield of 3.59 t ha^{-1} compared to 2.25 t ha^{-1} by Lok 1. Chickpea yield for JG 11 recorded grain yield 2.65 t ha^{-1} compared to 1.24 t ha^{-1} by local cultivars. Due to heavy rainfall in *Kharif 2013,* no effect of agribore observed in groundnut and soybean fields on harvested yield. Groundnut (ICGV 9346) produced pod yield 1.90 t ha^{1} (with agribore) compared to 1.48 t ha^{-1} by local cultivar (*Jhumku)* with application of agribore. Soybean

Table 4.10d Participatory demonstrations at Parasai-Sindh watershed during *Rabi* 2013–2015 seasons

Crop	Varieties introduced	Av. Grain yield kg ha^{-1}		Percent increase over local
		Improved	Local	
Barley	RD 2552	2395	1473	62
Mustard	Maya	1194	1019	17
Chickpea	JG 130	1398	823	69
Pigeonpea	ICPL-85063 (Lakshmi), ICPL 88039	762	628	21
Green gram[a]	Samrat	146	131	11
Chickpea	JG 130	1211	821	47
Mustard	NRC HB 101, NRC HB 506, NRC DR 02	1184	923	28
Wheat	HI 1532; HI 1544; HI 1418; HI 1479	4423	3450	28

[a]Due to long dry spell, crop yield drastically reduced

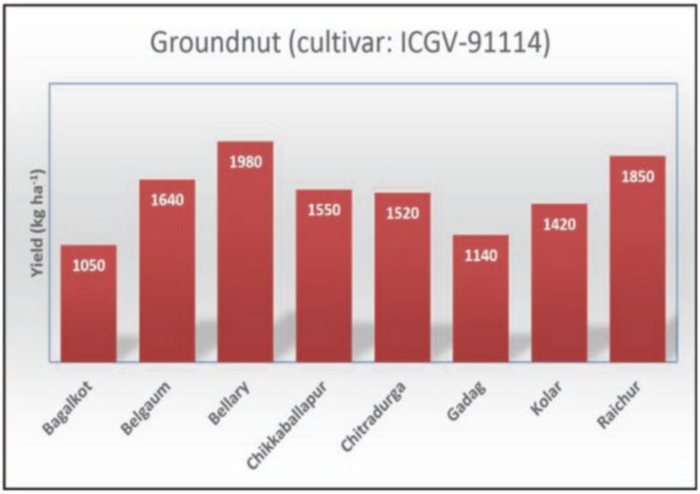

Fig. 4.6a1 Increased pod yield of improved groundnut cultivars over farmers' cultivar in districts of Karnataka

(PUSA 9712) yield was s 0.72 t ha^{-1}(with agribore), and 0.65 t ha^{-1} (without agribore) during *Kharif* 2013. Unexpected rainfall during pod formation reduced total yield in *Kharif* 2013 in watershed (Table 4.10a). Correspondingly, this variety had highest kernel yield (1.68 t ha^{-1}) and pod yield (2.42 t ha^{-1}). Data showed that introducing improved groundnut variety enhanced crop yield by 30–50% compared to local variety. In Uttar Pradesh, increased grain yields with improved cultivars of barley, mustard, pigeon pea, green gram, lentil and wheat were recorded in the range of 11–69% over the local cultivars (Table 4.10c and 4.10d). In Andhra Pradesh grain yield of improved cultivars of green gram and black gram were increased by

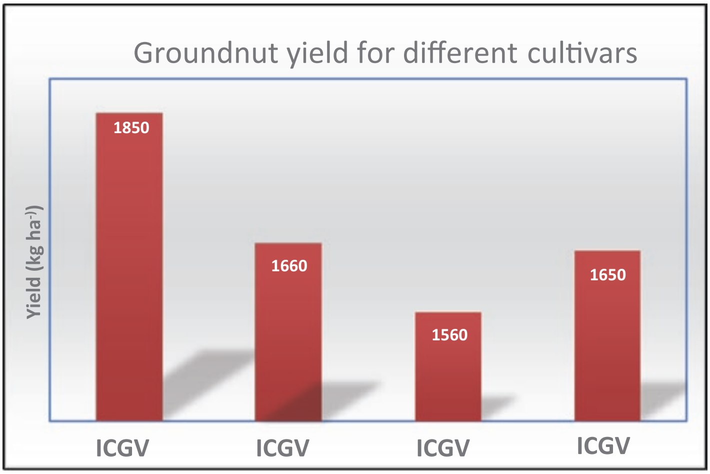

Fig. 4.a2 Yield of participatory trials with different groundnut cultivars in Raichur and Belgaum districts of Karnataka

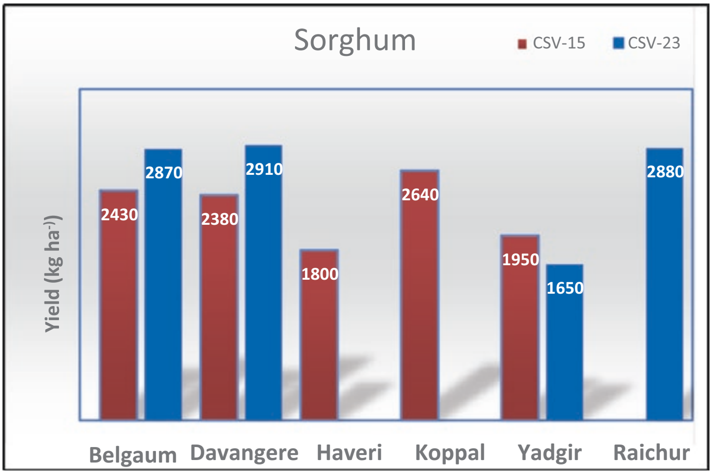

Fig. 4.6b Performance of improved sorghum cultivars (grain yield/ha) in districts of Karnataka

70–126% over the farmers' cultivars. Similarly, the results from farmers' fields revealed 12–24% increased legumes productivity compared to local popular cultivar (Fig. 4.6g).

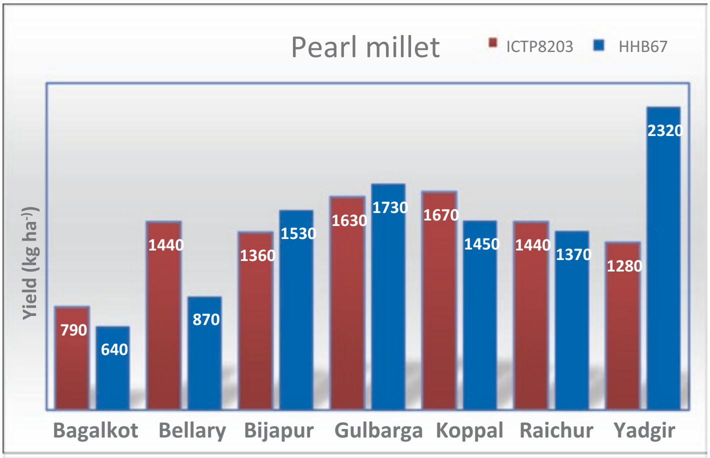

Fig. 4.6c Average grain yield of ICTP 8203 and HHB 67 improved pearl millet cultivars in districts of Karnataka

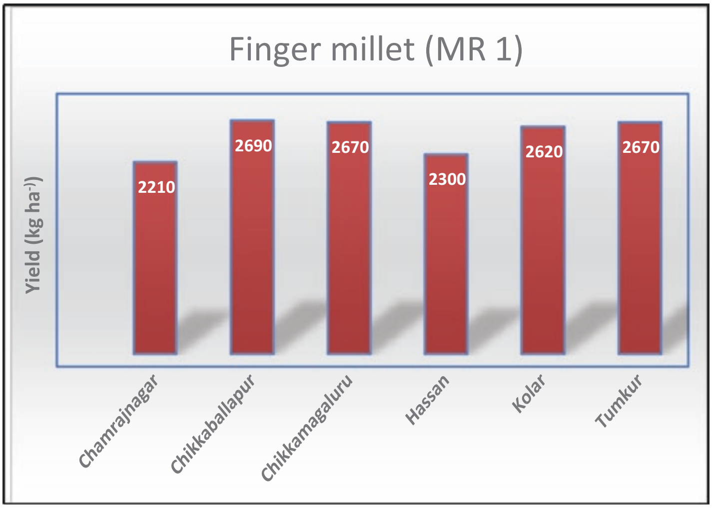

Fig. 4.6d Average grain yield of improved finger millet cultivar MR 1 in districts of Karnataka

4.6 Participatory Evaluation of Crop Diversification, Income-Generating Livelihood Activities

Diversification of livelihood in scaling-up initiatives in rural areas builds income security as well as empowerment of women and youths enabling them to build the resilience against climate change. First and foremost, change after rainwater harvesting interventions is the diversification of crops, cropping systems and livelihood

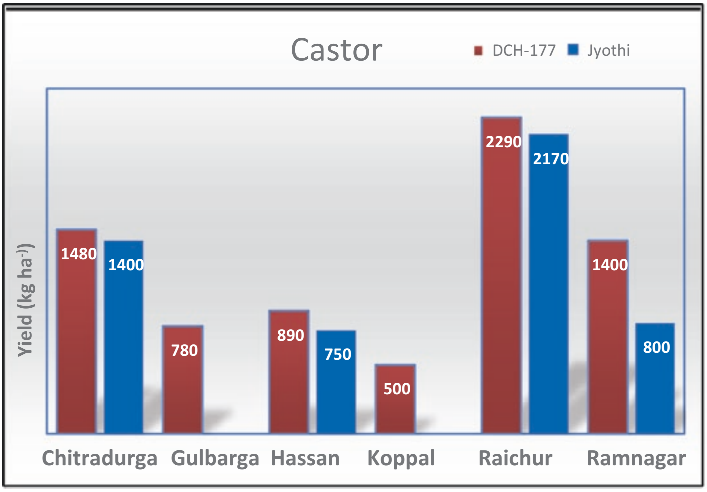

Fig. 4.6e Average yield of improved castor cultivars in districts of Karnataka state

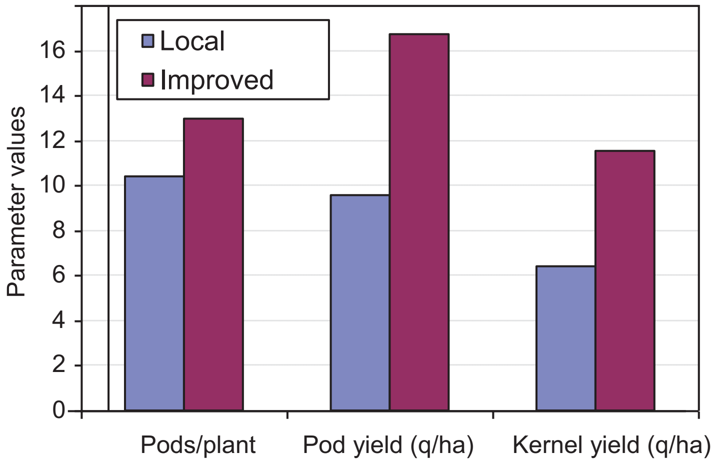

Fig. 4.6f Increased yield of improved cultivars of groundnut and local variety in Jhansi, Uttar Pradesh

systems. With increased water availability cultivation of high-value crops such as fruits, vegetables, flowers and fodder cultivation take place. With the increased water availability and increased crop productivity quantity of crop residues also increased in the area. In addition, introduction of improved dual purpose cultivars improved quality fodder also. With water availability, farmers started cultivating green fodder in the watershed (Chander et al. 2020). Nursery raising of fruits, plantation, vegetable, ornamentals is a potential opportunity for women farmers as a livelihood activity.

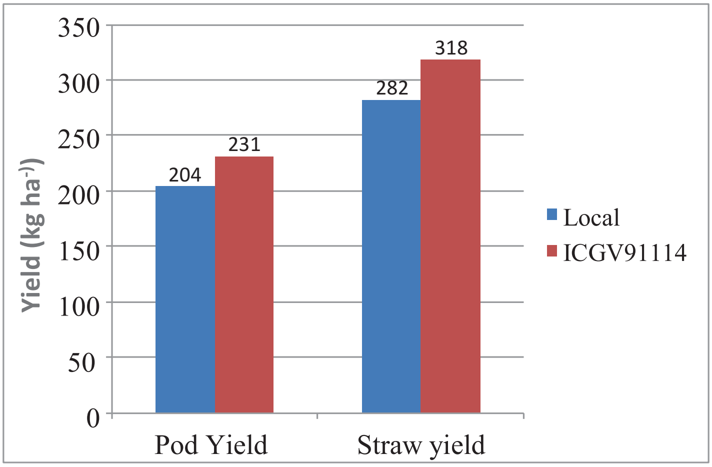

Fig. 4.6g Increased pod yield of improved cultivar ICGV 91114 as compared to local cultivar

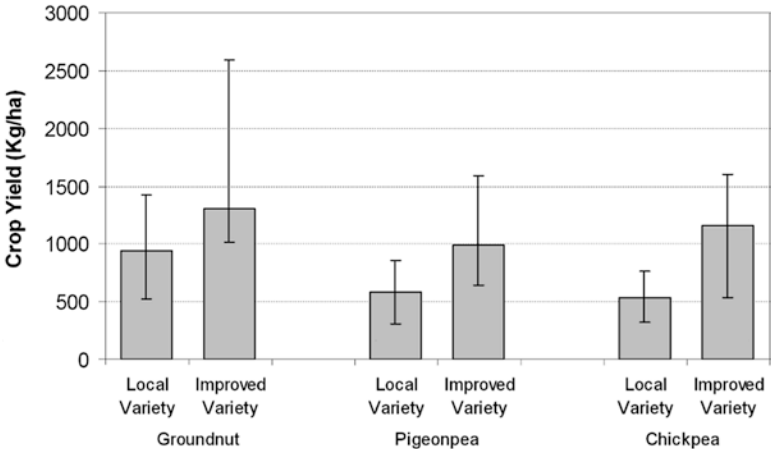

Fig. 4.6h Increased yields with improved varieties of legume over the local varieties in farmers' fields

Women in various villages, adopted nursery raising of fruits, plantation crops as a livelihood activity. Women raised nurseries and supplied hundreds of fruit trees and teak plants along with *Gliricidia* saplings to be planted on bunds for generating N-rich organic matter. Nurseries in horticulture plants is important area for income generation for women due to the large scope of horticulture sector as it contributes share of around 30% in agricultural output and a key area to achieve desired doubling of farmers' income and resilience in the drylands. In horticulture sector, percent share of production of fruits and plantation crops is quite significant at 37%. Raising ornamental plants for city markets is also a big opportunity. Well tested

Table 4.11 Nutritive value of spent malt and recommended mineral mixture

Nutrient	Spent-malt: nutrient composition	2 kg Spent-malt: nutritive value (g)	100 g mineral mixture: nutritive value (g)
Nitrogen (%)	3.66%	73.2	–
Protein (%)	22%	440	–
Phosphorus	0.46%	9.20	9.00
Iron	205 ppm	0.41	0.40
Zinc	52 ppm	0.11	0.30
Copper	248 ppm	0.50	0.06
Manganese	29.5 ppm	0.06	0.10
Sulfur	2655 ppm	5.31	0.40
Calcium	2098 ppm	4.20	18.0
Magnesium	1602 ppm	3.21	5.00

model of nutri-kitchen gardens through which women can improve nutrition of household, and also earn income (or save expenditure) through sale of vegetables was promoted in all the scaling-up initiatives. Women were provided seeds of vegetable for cultivation in 10–20 m^2 as kitchen gardens along with know-how of cultivation. Most women used house-made compost for vegetable production. Nutri-kitchen garden kits with different vegetable crops (Tomato, Brinjal, Okra, Bottle gourd, Bitter Gourd, Ridge gourd, *Palak* and Amaranthus) were provided to households every year to grow vegetables in their backyard for their household consumption resulting in saving expenditure on purchase of vegetables. These households produced thousands of kg of vegetables and marketed collectively. The average household production was about 28 kg of vegetables with a saving of around Rs 800/family while improving household nutrition (Chander et al. 2018, 2020; Petare et al. 2018, Patil et al. 2018; Sawargaonkar et al. 2018; Sudi et al. 2018).

Productivity of milch animals and business profitability is largely dependent on fodder/feed availability as well as its cost and quality. In a common situation of lack of green fodder in general, especially with lactating animal, feed/concentrate is required to make up for lacking protein and nutrients. In addition to cultivating green fodder women groups also were empowered touse spent malt as a good feed material for livestock for improving health, milk yield and fat content. Spent malt is a by-product of brewing industry which contains carbohydrates, proteins, lignin and water-soluble vitamins as animal feed which is quite palatable. Two kg of spent malt (on dry weight basis) provide about 400 g protein which very well meets the requirement of 350 g per day protein required for maintenance of adult cattle of ~500–600 kg weight (Table 4.11). Spent malt provides macro and micro nutrients required for good health and immunity in cattle – 2 kg spent malt provides nutrients at par or more than the recommended 100 g mineral mixture per day.

During exposure visit of farmers to learn the watershed interventions, farmers from Kothapally watershed came to know about the spent malt initiative and its benefits realized by Fasalvadi women. Kothapally is village with milk production activity of around 2100 litre per day. In this context, lead women farmers in *Adarsha* watershed, Kothapally realized opportunities of improving milk production through getting spent-malt from nearby SABMiller brewery. Training of women groups by ICRISAT team to handle spent malt was undertaken and major points to take care in spent malt use are as under:

- Spent malt (wet) to be consumed within 24 h. Thereafter, it gets fermented and sour.
- Not be fed to cattle after 48 h – worms may get developed and cattle health may be affected.
- Fresh spent malt needs to be dried for storage and use later on.
- Quantity to be fed is 4–5 kg spent malt/day/animal (2–2.5 kg in the morning and same in the evening)

The basic requirements in this initiative are;

- Vehicle arrangement for lifting spent malt from brewery to respective village.
- Place with rooftop for unloading and storing spent malt.
- Plastic drums (200 liters' size) for storing spent malt.
- Buckets/baskets for unloading spent malt.
- Weighing balance for distribution of spent malt to farmers.
- Inventory books for maintaining disbursement details etc.

Tejasri womens' SHG (12 women members) in *Adarsha* watershed, *Kothapally* village in Medak (erstwhile Ranga Reddy in undivided Andhra Pradesh) district is handling the spent malt based activity benefitting 96 households in the watershed to feed around 559 milch animals. Daily around 2580 kg spent malt is used to feed cattle. With use of spent malt as animal feed, farmers have observed increased milk production of about 2 litre per animal per day with improved fat content. Due to this the gross income in the village is increased by about Rs. 46,000 per day (about Rs 36,000 net income) on account of increased milk production in the village. On a monthly basis, more than Rs 11,000/− net income is increased per household of participating farmers. *Tejasri* group that handles the activity procure spent malt at the rate of Rs 2.75 per kg and sells at the rate of Rs 4 per kg. Members use Rs 1.25 per kg for transportation and handling charges by the group. Through this, member handling day to day operations get around Rs 10,000/− per month income and contributes Rs 1000/ – for the group corpus fund (Chander et al. 2020).

Composting activity adopted by women farmers (Wani et al. 2016a, b), one unit produces around 2500 kg compost in a year. Farmers got a price of about Rs 4/− per kg compost and thus each person was able to earn around Rs 10,000/− a year through this activity. This side activity not only brought incomes to women farmers, but also recycled household and on-farm wastes which otherwise did not find any effective alternate use except creating a nuisance. This activity also contributed to cleanliness drive in the village. Some SHGs are also engaged in making vermi-wash through making outlets for collection of washings in composting unit. Per unit 150–200 litre vermi-wash was produced and is sold at Rs 4/− per litre. It is quite

Fig. 4.7a Income-generating activities undertaken in scaling-up initiative in Andhra Pradesh, India

popular with vegetable farmers to improve quantity and quality of the produce. (Wani et al. 2014; Chander et al. 2013).

In addition, based on the needs assessment, potential and availability of market, specific activities were identified as livelihood activities for women and youths in the villages. For example, in Lucheba watershed in Guizao province of China, women undertook grading, sorting and packaging of vegetables which were directly marketed on line to city markets (Wani et al. 2009b) in addition to rearing of rabbits, goats, pigs, biogas production etc. (Wani et al. 2012b). In India, women groups took up value addition to pigeon pea through processing for making *Daal* (Split pigeon pea) which is consumed in India and fetches good price over the unprocessed pigeon pea. In several initiatives women took up sewing activities as well as power generation using *Pongamia* seeds oil and also running highway restaurant as IGA (Sreedevi and Wani 2007). Wherever, opportunities existed for undertaking fisheries related activities, in addition to collecting/catching fish, sun drying of fish using solar dryers was taken up as income-generating activity (Fig. 4.7 & ICRISAT 2016; Raju et al. 2017. For young educated boys and girls opportunities for employment as farm facilitators, lead farmers as well as para-extension workers were created in villages by linking them with knowledge generating institutions

Fig. 4.7b (continued)

Fig. 4.7c (continued)

(Chap. 1 by Wani 2021 and Chap. 3 by Bhattacharyya et al. 2021). With support of knowledge-generating institutions like ICRISAT, SAUs, KVKs, women SHGs also undertook specialized activities like *Helicoverpa* nuclear polyhedrosis virus (HNPV) production for minimizing pest damage in crops like cotton, pigeon pea and chickpea.

4.7 Lessons Learnt and A Way Forward

Most important learning is the realisation of "*Death Valley of impacts*" which must be crossed to achieve the SDGs particularly 1, 2 and 3 related with no poverty, zero hunger and well-being of people. The poverty is not reduced largely because the scientists have worked in isolation without involving small farm-holders across the world as described by the CERES 2030 team based on meta-analysis of >100,000 research papers published globally. Change of mind-set of researchers as well as policy makers, development investors, extension agencies and the editors/publishers of the scientific journals is must to transform small farm-holders particularly in developing world. Blasting of compartmentalization for providing solutions to the farmers is urgently needed to provide integrated and holistic solutions to the farmers. Changing mind-set of all the stakeholders is a challenging task and parameters for scientific evaluations for scientists need to be changed by the research managers from research papers published to on-farm impacts achieved by introducing new products/knowledge.

Similarly, for overcoming compartmental solutions the funding agencies need to adopt a basic criterion along with involving small farm-holders for approval of the research proposals. For encouraging and promoting partnerships the World Bank aided projects like National Agriculture Technology Project (NATP) and National Agriculture Innovation Project (NAIP) in India adopted such criteria for approval. Building partnerships amongst different stakeholders through consortium is essential for providing holistic solutions and particularly corporates should be involved and their strength for networking as well as establishing backward and forward linkages to benefit farmers are essential. The approach proposed should be innovative, inclusive, integrated and impact oriented to provide sustainability, scalability, socially acceptable and synergistic by ensuring economic gain, equity, environment protection and efficient by promoting collective action, converging with different schemes and departments, cooperative consortium through consortium formation (4 ISECs approach).

Most important thing is to empower farmers with knowledge and enabling them to take right decisions based on new knowledge developed by the researchers as well as the market information to guide them for undertaking diversification. The existing gap in the extension systems/knowledge delivery systems in the diverse country like India must be eliminated by harnessing new scientific tools like IT, 5 G, IoT, GIS, RS, modelling and small farm-holders must be empowered. For increasing adoption of improved technologies/products by the small farm-holders "*Seeing is believing"* principle is a well-tested and validated method during scaling-up. It is of paramount importance to work with small farm-holders for participatory on-farm demonstration through highest rung of collaboration i.e. collegiate mode over cooperative, consultative and contractual mode of community participation.

The technologies/products to be provided must be demand driven based on the detailed needs assessment of the farmers and solutions must be holistic i.e. end to end and not only recommendations as against supply driven solutions as generally provided by the researchers. The on-farm *"Seeing is believing*" demonstrations must be at least half to one-acre plot size for each treatment and must be managed by small farm-holders and not by the research team. The researchers should empower the farmers to take right decisions and interventions for managing demonstrations. The researchers must adopt different methods of empowerment/capacity building for the farmers and the results as well as the interventions must be described by the farmers to other farmers during formal field/farmers' days or informal meetings. It is essential that to adopt *"Seeing is believing"* approach in the selected village there must be three to four participatory demonstrations.

Important thing is to maintain transparency in all operations, accounts, crop cutting experiments and evaluations must be done collectively by all the concerned partners and farmers. The evaluation and monitoring must be concurrent and not as a post-mortem activity and should be used as learning tool. The results should be publicised amongst policy makers, researchers, extension staff as well as farmers and consortium partners with clear SOPs to benefit the farmers. For farmers' meetings, Field Days, workshops, training events suitable policy makers should be involved for greater impact.

As the small farm-holders' livelihood systems are complex, we need to ensure that for improving livelihoods and incomes for small fam-holders allied sector activities for livelihoods also must be integrated in to scaling-up initiatives. Selection of allied sector activities should be based on needs, availability of market as well as raw material and such activities need to be promoted collectively through SHGs, FPOs, etc. Empowerment of women, youths for undertaking IGAs is critical and suitable consortium partner must be identified for providing quality trainings holistically ensuring credit as well as market for the produce.

In order to achieve the SDGs of zero hunger, no poverty and wellbeing through balanced nutrition of people in the country/region scaling-up of new technologies, knowledge, products through building partnerships adopting 4 ISECs model to build consortium is essential. Changing mind-set of stakeholders particularly researchers and policy makers is a must and efforts must be made to achieve this for meeting the SDG goals.

Acknowledgement We gratefully acknowledge the help of team of scientists, all our partners involved in the scaling-up initiatives in different countries and most importantly the policy makers for putting enabling policies in place for scaling-up and farmers who readily conducted participatory trials and shared all the information for analysis which is used in this chapter.

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Chapter 5
A Journey from Neglected and Underutilized Species to Future Smart Food for Achieving Zero Hunger. How can Scaling-Up be Achieved?

Xuan Li, Suhas P. Wani, and Zixi Li

Abstract High prevalence of hunger and malnutrition remains a major challenge, particularly in the developing world. Over-reliance on a few staple crops in our food systems leads to low production diversity contributing to low dietary diversity. How can we ensure that our food systems provide sufficient, adequate and nutritious food for all? Rediscovering and developing Neglected and Underutilized Species (NUS) could be an answer. Also known as 'traditional foods', 'minor' or 'promising' crops, NUS may be marginally consumed locally, but have been overlooked by research, extension services and policy makers. To realize the potentials of relevant NUS and update what local communities know for generations for tackling today's food production and nutrition challenges, FAO launched a Future Smart Food (FSF) initiative in Asia and the Pacific to select and prioritize NUS that are nutrient-dense, climate-resilient, economically viable, and locally available or adaptable as Future Smart Food. Turning NUS into FSFs could be the beginning of a journey that will transform conventional agriculture from a mere producer of staple foods into a pro-

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vider of diversified food, add new species to our diets that can result in better supply of nutrients, and provide economic and environmental benefits. But how to achieve this? This chapter will outline how the Future Smart Food initiative can be scaled up along the food system for achieving Zero Hunger.

Keywords Zero Hunger · Agriculture diversification · Sustainable food system · Healthy diets · Future Smart Food · Neglected and underutilized species · Asia-Pacific

5.1 Context: Zero Hunger/Sustainable Development Goal (SDG) 2

5.1.1 Zero Hunger: A Challenge in the Twenty-First Century

Eradication hunger and all forms of malnutrition by 2030 stands at the core of the SDG 2 (Zero Hunger). Despite significant progress, the world is not on track to achieve Zero Hunger, especially in the context of climate change and pandemic threats. More than 690 million people globally were still hungry in 2019, accounting 8.9% of the world population- up by 10 million people in one year and by nearly 60 million in five years, a number which underscores the huge challenge for achieving the Zero Hunger target by 2030 (FAO et al. 2020).

The Asia and Pacific region is home to more than half of the total global population affected by moderate or severe food insecurity- an estimated 479 million in 2018 (FAO et al. 2019). The region, while making progress in reducing the number of hungry people by 8 million since 2015, will find it difficult to achieve the 2030 target considering recent trends. In Asia, undernourishment affects 11% of the population. South Asia although saw great progress over the past years, it is still the sub-region globally with the highest prevalence of undernourishment (FAO et al. 2019). It is women and children who are the most affected by malnutrition. Women, especially those of reproductive age has higher prevalence of food insecurity and the gender gap in accessing food increased from 2018 to 2019 (FAO et al. 2020). Fifty-four percent of all stunted children in the world live in Asia- an estimated 77.2 million children under 5 years of age suffer from stunting and 32.5 million suffer from wasting (FAO et al. 2019).

The burden of malnutrition in all its forms remains a challenge. The prevalence of overweight and obesity among children and adults are increasing in the Asia-Pacific region (FAO et al. 2020). The prevalence of obesity-related diseases, including non-communicable diseases (NCDs), such as diabetes, heart disease, stroke and cancer, have increased in many countries in the region, particularly the Pacific Islands (FAO et al. 2019). Micronutrient deficiencies remain problematic particularly in Southeast Asia and South Asia. For instance, the prevalence of anemia (iron deficiency) in most ASEAN countries is alarming, sometimes affecting more than 40% of children under the age of five. In Myanmar, the prevalence of anemia in children under five years age and reproductive and pregnant women is 57.4, 46.6, and 54.0%, respectively. The prevalence of anemia in Cambodia, Lao PDR, and Nepal ranges from 40–55% (Li and Siddique 2018). Malnutrition typically leads to diseases and premature death, and thus has a direct negative effect on the socio-economic development of the country (Li and Siddique 2018).

5.1.2 Key Issues: Low Dietary Diversity and Low Production Diversity Due to Over-Reliance of a Few Staple Crops in Food System

A functioning agriculture and food system would provide sufficient and adequate food for the entire population and thus guarantee Zero Hunger. Yet, agriculture in the Asia and Pacific region is over-reliant on a few staple crops: a limitation that poses inherent nutritional, agronomic, ecological and economic risks. Globally, only three crops—wheat, rice and maize—cover 40% of all arable land globally, delivering more than 60% of the world's consumption of calories and protein. About 95% of the world's food needs are provided by just 30 species of plants. This pattern also prevails in Asia: there is a lack of diversification and rice continues to be the dominant food (FAO 2016).

The current agriculture pattern poses great challenges for achieving Zero Hunger. To date, agriculture and food systems have relied on staple crop production, which has led to two significant gaps: (a) production gap (FAO projections suggest that by 2050, agricultural production must increase by 50% globally to meet food demand) and (b) nutrition gap (the current high levels of malnutrition are an expression of unbalanced diets with low nutrition diversity). Both gaps are unlikely to diminish following conventional approaches: increased production of staple crops, which dominate current agricultural systems, are unlikely to meet the increasing demand, as irrigated wheat, rice and maize systems appear to be near 80% of their yield potential (Ray et al 2013; Li and Siddique 2018).

From the nutrition side, since the last century, staple foods production was emphasized as strategies to meet dietary energy needs. But evidences shown that malnutrition is associated not only with under nutrition, but often with micronutrient deficiency, obesity and overweight, caused by poor diets and lack of dietary diversity. The low production diversity of current staple foods fails to provide the necessary nutrients for healthy diets (Li and Siddique 2018). Healthy diets should contain a balanced, diverse and appropriate selection of foods eaten over a period of time, which ensures a person's needs for macronutrients (proteins, fats and carbohydrates including dietary fibers) and essential micronutrients (vitamins and minerals) are met, specific to their gender, age, physical activity level and physiological state (FAO et al. 2020).While rice fills the stomach, a rice-dominated diet provides for only low amounts of protein, amino acids and essential micronutrients, which can be, for instance, found in pulses, fruits, nuts, tubers, vegetables, fish, meat, and edible insects. The dependency mainly on rice thus is a leading cause of the "nutrition gap" (Li and Siddique 2018).

From the production side, yield growth of major staple crops has been slowing down and appears to have reached a plateau. In addition, climate change projections indicate a worsening environment for agriculture, with Asia being especially hard hit. From 1989 to 2008, global yield increase rates averaged only 1.6% for maize, 1.0% for rice, and 0.9% for wheat (Nelson et al. 2009). It is expected that weather, and with it, agricultural seasons will become more extreme, and agriculture will be negatively affected by climate change. Climate change will have varying effects on irrigated yields across regions, but irrigated yields for all crops in South Asia will experience large declines (Nelson et al. 2009). These figures suggest that a food systems transformation is needed to move beyond producing more food towards producing diverse and healthy foods (Haddad et al. 2016).

To achieve the Zero Hunger goal, the agriculture and food system has to be transformed into economically efficient, socially inclusive, and environmentally sustainable to improve dietary and production patterns, allowing everyone to access sufficient amounts of nutritious food (UN 2017). This requires agriculture to be more climate resilient, less dependent on chemical fertilizers, and associated with lower methane emissions from rice cultivation and methane and nitrous oxide emissions from livestock. At the same time, farmers, particularly smallholders (where much hunger and malnutrition persist) need to improve their incomes in order to achieve economic sustainability, which in turn will enable them to afford a better, healthier diet, with higher intakes of protein as well as micronutrients (FAO 2016). NUS may be the key to the food system transformation, agricultural diversification, and can play a significant role in narrowing and closing production and nutritional gaps (FAO 2019).

5.1.3 SDGs and FAO's Commitment for Zero Hunger

Zero hunger means "end hunger, achieve food security and improved nutrition, and promote sustainable agriculture" and bringing the number of people who suffer from hunger and malnutrition to zero. The Zero Hunger goal, or the SDG 2 is key to achieving the other 16 SDGs' objectives since eradicating hunger is a prerequisite for peace, education, health and wellbeing for all. Zero Hunger is the name of FAO's most important operation (FAO 2018). Embedded within this goal are other ambitious targets, including doubling agricultural productivity and income for small-scale food producers, developing sustainable food systems, and ending all forms of hunger and malnutrition (FAO 2019).

FAO's Regional Initiative on Zero Hunger in Asia and the Pacific has been working closely with national governments and stakeholders in the region to formulate food security and nutrition strategy and policy mechanisms, promote nutrition-sensitive agriculture and provide data analysis and monitoring of SDGs for decision-making. The main focus of the Regional Initiative's work is to address the production gap and nutrition gap resulting from the current agricultural practices. In practical terms, this involves increasing crop productivity and maximizing their nutritional outputs through the introduction of alternative crops such as the NUS. The FAO proposes to resort to agrobiodiversity so as to identify a new generation of crops that will be both productive and nutritious (FAO 2019).

5.2 How to Diversify Agriculture and Food System to Provide Sufficient, Adequate and Nutritious Food for All

5.2.1 About Neglected and Underutilized Species

Agrobiodiversity is foundation for sustainable agriculture. Broadly speaking, crops can be divided into two main categories: staple crops and underutilized crops. Underutilized crops (sometimes called 'neglected', 'minor', 'orphan', 'promising', coarse or 'little-used') mostly belong—but are not limited to—the non-staple foods (Li and Siddique 2018). Neglected and underutilized species (NUS) are main components of agrobiodiversity. Globally, between 300,000 and 500,000 plant species exist, of which 30,000 are identified as edible plant species; of these, more than 7000 crop species have been either cultivated, domesticated, or collected from the wild as food throughout the history of humanity (Garn and Leonard 1989). However, currently, no more than 150 crop species are cultivated commercially and only 103 out of which provide up to 90% of the calories in the human diet. Only three main crops, namely rice, maize, and wheat, provide 60% of the world's food energy intake (FAO 1995). Thus, tens of thousands of edible plant species remain relatively 'underutilized', with respect to their ability to contribute to the world's increasing food requirements (Chivenge et al. 2015).

NUS are mostly wild or semi-domesticated species adapted to local environments. These traditional foods were in use for centuries or even thousands of years but became increasingly neglected resulted from agricultural modernization and replaced by more productive, profitable and improved crops with high-yielding varieties. Increasing monoculture of agriculture and food systems has led to NUS playing a marginal role in current farming and food systems. Worse still, their perception as 'food of the poor' often stigmatizes them, creating a disincentive for their production and consumption (Li and Siddique 2018).

5.2.2 Potentials of NUS for Achieving Zero Hunger: Entry Point for Agriculture Diversification

NUS offer tremendous opportunities for fighting poverty, hunger and malnutrition, as well as huge potential for achieving nutrient-dense, climate-resilient and sustainable agriculture. Historically, underutilized plants have been grown for food and other uses often on a larger scale, and in some countries are still common especially among small or marginal farmers in rural areas - many are traded locally, and a few have been lucky to make their way to export niche markets around the world (Akinnifesi et al. 2008). NUS often have high nutritional value and can be an essential source of micronutrients, protein, energy and fiber, thus potentially contributing to food and nutrition security. Apart from their superior nutritional qualities, many NUS crops can be grown on marginal soils, are easily intercropped or rotated with staple crops and can easily fit with integrated practices, which may enhance the resilience of production systems exposed to both biotic and abiotic stresses. Because many NUS have the unique ability to tolerate various stresses, they can make production systems not only more diverse but also more sustainable and climate-resilient (Li and Siddique 2018). Some NUS have considerable commercial value, such as vegetables and fruits, and could therefore contribute to increasing livelihoods. By virtue of being locally available or adaptable, NUS are easily accessible and affordable to the local population, thus potentially contributing to food security, nutrition and cultural dietary diversity (Li and Siddique 2018).

5.2.3 FAO's Engagements to Conservation and Sustainable Use of NUS

The importance of NUS is widely recognized by the global scientific community (Joint FAO/IAEA 2004; Kahane et al. 2013; Khoury et al. 2014; Nyadanu et al. 2016; Rutto et al. 2016; Li and Siddique 2018). However, their promotion requires the development and implementation of policies as a key component for integrating NUS into agricultural production systems (Noorani et al. 2015). The development of relevant international policy frameworks for the conservation and sustainable use of plant diversity is a long and ongoing process (Fig. 5.1).

In 1996, the first Global Plan of Action (GPA) for the conservation and sustainable use of Plant Genetic Resources for Food and Agriculture (PGRFA) was adopted by 150 countries (FAO 1996). This framework for action highlighted the need for plant diversity to increase environmental resilience, buffer economic shocks and improve nutrition (Li and Siddique 2018). It is then extended into International Treaty on Plant Genetic Resources for Food and Agriculture (the Treaty), which provides a legal framework whereby governments, farmers, research institutes and agro-industries can share and exchange PGRFA and benefits derived from their use (FAO 2009). Its Article 5 (Conservation, Exploration, Collection, Characterization, Evaluation and Documentation of Plant Genetic Resources for Food and Agriculture) and Article 6 (Sustainable Use of Plant Genetic Resources) directly pointed out the values and importance of NUS (Li and Siddique 2018).

In 2011, given the changes in policy environment for biodiversity, including the entry into force of the Treaty, the Cartagena Protocol on Biosafety and the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of

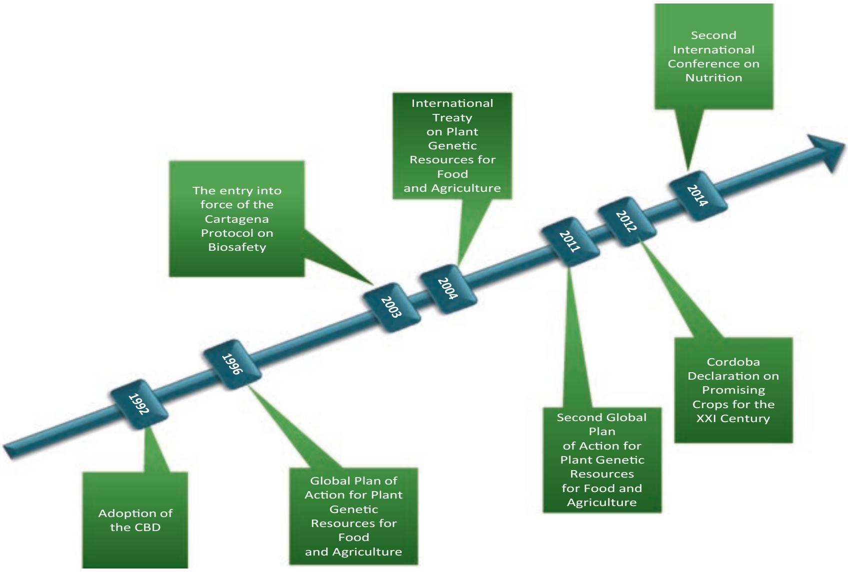


Fig. 5.1 Major relevant international policy frameworks for the conservation and sustainable use of plant diversity. (Li and Siddique 2018)

Benefits Arising from their Utilization, the Second Global Plan of Action for Plant Genetic Resources for Food and Agriculture (Second GPA) was developed. NUS was recognized as an essential component to achieve food security and nutrition and was given special place under Priority Activity 11 with focus on indigenous crops and farmer varieties (Li and Siddique 2018)

In 2012, the Cordoba Declaration concretized the steps to develop underutilized and promising crops for international agricultural development. It called for initiatives in: raising awareness of NUS's strategic roles; conserving genetic and cultural diversity of NUS; promoting NUS in small-scale farming and to improve rural livelihoods; developing NUS value chains from production to consumption; enhancing research and development capacities for promoting NUS; building inter-sector and inter-disciplinary collaborations for NUS; and creating conducive policy environments for NUS (FAO 2012a, b; Li and Siddique 2018).

In 2013, The Accra Statement for a Food Secure Africa from the 'Third International Conference on Neglected and Underutilized Species for a food-secure Africa', became the first regional action plan for NUS, establishing a good model for international efforts (Bioversity International 2014; Li and Siddique 2018). In 2014, the profile of NUS was further showcased at the Second International Conference on Nutrition (ICN2) in Rome. This high-level conference emphasized the importance of NUS through Recommendation 10: "*Promote the diversification of crops including underutilized traditional crops, more production of fruits and vegetables, and appropriate production of animal-source products as needed,* *applying sustainable food production and natural resource management practices*" (FAO 2014; Li and Siddique 2018).

5.3 Future Smart Foods (FSFs)

5.3.1 FSFs Initiative: FAO's Process to Assist Asian and Pacific Countries to Identify and Adopt FSFs

5.3.1.1 Regional Priority-Setting Exercise on NUS in Asia

As recognizing NUS plays an important role in closing the production and nutritional gaps, FAO's Regional Office for the Asia Pacific launched a 'Future Smart Food' initiative to identify and prioritize promising NUS as a way of addressing Zero Hunger in a changing climate. A regional priority-setting exercise on scoping and prioritizing was conducted to identify and prioritize NUS based on the established criteria to qualify as Future Smart Food. Overall, the regional priority-setting exercise on NUS was comprised of the steps as follows:

1. **Step 1: Conceptualization**

Given the vast number of NUS in the region and their multiple benefits, the issue was to develop goals and criteria for prioritization of NUS. In line with FAO's mandate to address malnutrition, climate change and socio-economic development, the participating countries requested the priority-setting exercise to focus on NUS which would be climate-smart, nutrition-sensitive, economically viable, and socially acceptable. The ultimate outcome of the priority-setting exercise should contribute to closing the production and nutrition gaps that present the greatest obstacles for Zero Hunger.

2. **Step 2: Partnership-building**

To conduct this interdisciplinary analysis, FAO built a strong partnership with national and international partners and experts in the priority-setting exercise. Participating countries were Bhutan, Bangladesh, Cambodia, Lao PDR, Myanmar, Nepal, Vietnam, and West Bengal, India (Li and Siddique 2018).

At national level, governments played a key role in organizing and facilitating the preparation of the country study on NUS at the national level, coordinated by National Focal Points of Zero Hunger Challenge, in coordination with national agricultural research councils and institutes The national agricultural research partners took the lead in undertaking and finalizing the priority-setting study on NUS, i.e. National Agriculture and Forestry Research Institute (NAFRI), Lao PDR; Nepal Agriculture Research Council (NARC); Plant Resources Centre (PRC), Vietnam; Uttar Banga Krishi Viswavidyalaya (UBKV), West Bengal, India; Bangladesh

Agriculture Research Institute (BARI); Cambodian Agricultural Research and Development Institute (CARDI); Department of Agriculture, Ministry of Agriculture and Forests, Bhutan; Department of Agricultural Research (DAR), Myanmar (Li and Siddique 2018).

At international level, organizations with expertise from agriculture, ecology, socioeconomic disciplines and experiences on NUS were the main stakeholders in the priority-setting exercise on NUS, with the support from ACIAR. Nominated international experts were organized by discipline to offer technical assistance to support the country on prioritization through interdisciplinary reviews. Specifically, from a nutrition dimension, the MS Swaminathan Research Foundation — Leveraging Agriculture for Nutrition in South Asia (MSSRF-LANSA) and the Mahidol University of Thailand supported the technical review, especially on the nutrient value of NUS. From an agricultural production and ecological perspective, the FAO Special Ambassador in the International Year of Pulses 2016, ICARDA; International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Bioversity International (BI), The University of Western Australia (UWA), and the Chinese Academy of Tropical Agricultural Sciences-Tropical Crops Genetic Resources Institute (CATAS-TCGRI) supported the technical review, mainly on agricultural traits and climate-resilience character of NUS. From a socioeconomic perspective, the International Centre for Integrated Mountain Development (ICIMOD), Crops for the Future (CFF), and the International Tropical Fruits Network (TFNet) supported the technical review (Li and Siddique 2018).

3. **Step 3: National scoping and prioritizing study on NUS**

The national study on NUS focused on scoping, identifying and prioritizing the promising NUS following an established methodology at a country level. Following the overall guidelines, each country prepared a preliminary country report based on an assessment on NUS with four criteria, i.e. they had to be: (1) nutrient-dense, (2) climate-resilient, (3) economically viable, and (4) locally available or adaptable to qualify as Future Smart Food (Li and Siddique 2018). The preliminary country reports were subsequently reviewed by an international panel of experts with a background in agriculture, ecology, and socioeconomic aspects of crops.

4. **Step 4: Regional Expert Consultation on scoping and prioritizing NUS**

Under Regional Initiative on Zero Hunger in Asia and the Pacific, FAO organized a Regional Expert Consultation on scoping and prioritizing NUS, in collaboration with international and national partners. The objectives of the event were to: (a) review and validate the preliminary scoping report on crop-related NUS in the selected countries; (b) rank and prioritize high-potential NUS based on the established priority criteria; (c) identify up to 6 crops-related NUS per country, and (d) strategize to enhance production and utilization of the selected crops in local diets. Based on the country studies, through the multidisciplinary review, promising NUS were discussed and identified at country level (Li and Siddique 2018).

5.3.2 Prioritizing NUS as FSFs: Characterization, Identification Through Multidisciplinary Screening and Participatory Prioritization by Countries

For regional priority-setting exercise, the target food crops cover: (a) cereals, (b) roots and tubers, (c) nuts and pulses, (d) horticulture, and (e) others. The scope of NUS was limited to the available plant genetic resources in the national gene bank. *In-situ* collections of NUS in different agro-ecological zones were not included.

For the priority-setting exercise on NUS, four-dimensional prioritization criteria were established to address agriculture's multi-dimensional challenges; NUS had to: (a) display nutrition density; (b) fit into, and possibly improve, agricultural production practices; (c) enhance ecological sustainability; and (d) promise socioeconomic sustainability. Specifically, the criteria were elaborated as follows:

(a) Nutrition	Nutritional value and health benefits
(b) agricultural production practices	Local knowledge, availability, and seasonality
	Productivity, intercropping and competing with other crops
	Processing
	Agro-ecology
(c) Ecological sustainability	Adaptation to local climate and soil types
(d) Socioeconomic sustainability	Cultural acceptance and consumer preferences
	Access to markets and potential income generation

The NUS scoping and prioritization established the principle of country ownership: results are owned by the participating country. For instance, in Nepal, based on national expert and government consultation, green amaranth and lamb's quarter were ranked the highest based on their nutritional value. The crops ranked as most climate-resilient were foxtail millet and proso millet. The crop ranked highest in economic value was jackfruit, followed by chayote and fenugreek. With respect to social acceptance, sweet belladonna was ranked highest, followed by faba bean (Joshi et al. 2019; 2020). After the identification, the National Agriculture Genetic Resources Center under the Government of Nepal has developed further on-farm research and adopted 60 good practices for maximizing the utilization and conservation of NUS and FSFs at local and national levels (Joshi et al. 2019). In addition, considering that NUS is contingent to the local context of each country and contains different nutritional value within inter- and intra-specific diversities (Burlingame et al. 2009), a species considered as NUS in one country may not be in another country.

Consequently, 39 NUS were selected as FSFs. A combined list of the NUS suggested as FSFs from the national studies for the eight countries is presented in Table 5.1. The identification, integration and promotion of FSFs offer a promising

Table 5.1 Potential Future Smart Food in eight countries in South and Southeast Asia

Cereals	Roots & Tubers	Pulses	Fruits & Vegetables	Nuts, Seeds & Spices
Buckwheat	Taro	Grass pea	Drumstick	Linseed
Tartary buckwheat	Swamp taro	Faba bean	Chayote	Walnut
Foxtail millet	Purple yam	Cow pea	Fenugreek	Nepali butter tree
Proso millet	Fancy yam	Mung bean	Snake gourd	Perilla
Finger millet	Elephant's foot yam	Black gram	Pumpkin	Nepali pepper
Sorghum	Sweet potato	Rice bean	Roselle	
Amaranth		Lentil	Indian gooseberry	
Grain amaranth		Horse gram	Jack fruit	
Quinoa		Soybean	Wood apple	
Specialty rice				

future for transforming the current agricultural system to be more sustainable, nutrition-sensitive and climate-resilient (Li and Siddique 2018).

5.3.3 A Case Study: How FSFs Provide Opportunities for Sustainable Mountain Agriculture Development

Mountain agriculture faces particular challenges due to their climate and topography, and often also their remoteness. FSFs have comparative advantages to grow in the mountains with remarkable climate-resilient and nutritional qualities that can adapt to the marginal environment and contribute to mountain agriculture development thus achieving Zero Hunger (FAO 2019). This section illustrates the multidimensional benefits of FSFs for the mountain agriculture development.

(a) **Nutrition density — mountain agriculture, hunger and malnutrition**

FSFs have outstanding nutritional value which are distinct from their staple counterpart in many nutritional aspects for a healthy diet. For instance, pulses are rich in proteins, nutrients and can help to reduce the risk of developing several chronic non-communicable diseases. Pulses include chickpea, cowpea, lupin, field pea, dry bean, lentil, mung bean, pigeon pea and others, which are well adaptable to the mountains. In comparison with white polished rice, with similar energy levels, chickpea contains three times more protein, four times more dietary fiber, four times more iron, and 70 times more folate. Similarly, lupin contains five times more protein, eight times more dietary fiber, four times more iron, and 44 times more folate than rice. Pulses have been prioritized as FSFs by many countries in Asia, including Cambodia, India, Nepal, Myanmar and Vietnam (FAO 2019).

Cowpea (*Vigna unguiculata*) is a protein-rich legume that complements staple cereals and starchy tuber crops, which contains 25% protein and several vitamins and minerals: cowpea has huge potential to contribute to Zero Hunger goal by providing vitamins and minerals when consumed as a leafy vegetable, and protein when consumed as a grain legume (Chivenge et al. 2015). It also provides fodder for livestock, improves soils through nitrogen fixation, and benefits household in the form of cash and income diversity. It thrives in arid and semi-arid tropics covering Asia, Africa, Europe, United States, and Central and South America (CGIAR 2019). Cowpea is a FSFs prioritized by Vietnam and Cambodia (FAO 2019).

Millets are often referred to as a 'high-energy' cereals as their protein and vitamin A contents are higher than maize, and their oil content is higher than maize grains. Millets contain vitamin A, a major deficiency in staple diets, which make them an excellent choice for combating food security and nutritional challenges in mountains (Chivenge et al. 2015). Table 5.2 illustrates the difference between the nutritional value of selected millets and staple crops. For instance, pearl millet has higher micronutrient (such as calcium, iron, zinc, riboflavin and folic acid) contents than rice or maize, and higher micronutrient (excluding calcium) contents than wheat (Adhikari et al. 2017). Millets are prioritized as FSFs by most South Asian countries including Bangladesh, Bhutan and India (Adhikari et al. 2017). With the efforts of Government of India, FAO has decided to celebrate International year of millets in 2023.

(b) Climate-resilience — mountain adaptability

Table 5.2 Comparison of nutritional value between selected millets and staple crops (Gopalan et al. 1971)

	Selected millets (/100 g)							Staple food (/100 g)		
Nutrient	Pearl Millet	Sorghum	Finger Millet	Foxtail Millet	Proso Millet	Barnyard Millet	Kodo Millet	Rice (Milled)	Maize	Wheat Flour
Energy (kcal)	361	349	328	331	341	397	309	345	342	346
Protein (g)	11.6	10.4	7.3	12.3	7.7	6.2	8.3	6.8	11.1	12.1
Fat (g)	5.0	1.9	1.3	4.3	4.7	2.2	1.4	0.4	3.6	1.7
Calcium (mg)	42.0	25.0	344	31.0	17.0	20.0	27.0	10.0	10.0	48.0
Iron (mg)	8.0	4.1	3.9	2.8	9.3	5.0	0.5	3.2	2.3	4.9
Zinc (mg)	3.1	1.6	2.3	2.4	3.7	3.0	0.7	1.4	2.8	2.2
Thiamine (mg)	0.33	0.37	0.42	0.59	0.21	0.33	0.33	0.06	0.42	0.49
Riboflavin (mg)	0.25	0.13	0.19	0.11	0.01	0.10	0.09	0.06	0.10	0.17
Folic acid (mg)	45.5	20	18.3	15.0	9.0	–	23.1	8.0	20	36.6
Fiber (g)	1.2	1.6	3.6	8.0	7.6	9.8	9.0	0.2	2.7	1.2

Source: NIN (1989)

FSFs can help climate change adaptation by enhancing the diversification and building agroecosystems resilience under various climate change scenarios such as drought, cold, and extreme weather events). FSFs can withstand the harsh environment and grow in upland or marginal lands where staple crops such as rice and wheat can hardly grow (FAO 2019).

With regard to drought resistance, FSFs such as pulses and millets integrate well into more marginal farming systems. During the dry season, most highlands are left fallow after harvesting the main crops. However, FSFs that are drought-tolerant can grow on the moisture remaining from harvesting in the rainy season. In integrated farming practices such as intercropping and relay cropping, which utilize land for planting forages, as well as main crops and other high-value crops, FSFs can be an ideal fallow crop. For instance, India has actively integrated pulses into rice fallow on a larger scale (Wani and Sawargaonkar 2018). The selection of crops and varieties with different root architecture (i.e., longer and finer roots, more root tips, greater branching angle, and lower shoot: root ratios) and *in-situ* moisture conservation practices (e.g., ridging, mulching) helps to minimize irrigation requirements during dry periods (Barrow 2013).

Mung bean (*Vigna radiata* var. *radiata*) is a good source of dietary protein with high contents of folate and iron (Keatinge et al. 2011). It is s a short-duration legume, which fits well into the fallow period between rice–rice, rice–wheat, rice–potato–wheat, maize–wheat, cotton, and other cash crop cropping systems. It also improves soil fertility and provides additional nitrogen to subsequent crops. The yield of rice following a mung bean intercrop can increase by up to 8% through the nitrogen fixed by mung bean in the soil and reduced pest and disease pressure (Ebert 2014). Mung bean is an FSFs prioritized by Nepal (Li and Siddique 2018).

The Moringa tree (*Moringa oleifera*) is drought tolerant that well adapts to hot, semi-arid regions with as little as 500 mm annual rainfall (Grubben and Denton 2004), and can adapt to altitudes above 2000 m. It also tolerates occasional wet or waterlogged conditions for short durations, but prolonged flooding leads to a significant loss of plants (Elbert 2014). It has high nutrient density especially rich in many essential micronutrients and vitamins as well as antioxidants and bioavailable iron, which is famous as the ‘wonder tree’. Moreover, it is easy to grow, has excellent processing properties, and good palatability (Yang et al. 2006). Boiled fresh moringa leaves and dried powder in water enhanced the aqueous antioxidant activity and increased bioavailable iron by 3.5 and 3 times, respectively (Elbert 2014). Moringa is a FSFs prioritized by Bhutan, Myanmar, Nepal and other countries in Asia (FAO 2019).

Quinoa is a crop originating in the mountains of Bolivia, Chile and Peru, not only survives but thrives in marginal areas due to its high adaptability. It is a high-altitude plant with high nutritional value that grows at 3600 m above sea level and higher, where oxygen is thin, water is scarce, and the soil is saline. Recently, experimental cultivation of quinoa in saline and marginal soils of Pakistan has shown that quinoa can produce respectable yields under these stressful conditions (Padulosi et al. 2011).

Barley is a good example of a FSS that tolerates water stress and extremely cold conditions. For example, with its short growing period, barley is cultivated in the high altitudes and cold climate of the Tibetan Plateau, China and the Gatlang area of the Rasuwa district, Nepal (Padulosi et al. 2011).

(c) **Economic viability — mountain livelihoods**

FSFs are good source for income generation for poor mountain communities. They can contribute to the improvement of livelihood in mountain populations thanks to their higher nutritional and health value, as well as off-season products. Several studies highlighted the consistent contribution of NUS to generating income in both domestic and international markets (Asaha et al. 2000; Mwangi and Kimathi 2006; Chadha and Oluoch 2007; Joordan et al. 2007; Rojas et al. 2009). In India, for example, little millets enhanced farmer incomes threefold and generated employment in villages, particularly for women, which enhanced women's social status and self-esteem (Vijayalakshmi et al. 2010).

Many former NUS have become globally well-known crops; oil palm and kiwi are examples of crops which have contributed to dietary and production diversity as well as income generation.

Quinoa is a good example of a FSFs that became globally known with high economic benefits for mountain people. Quinoa has attracted increasing attention internationally with increased global demand for quinoa, particularly after the International Year of Quinoa in 2013. For instance, Bolivia has emerged as a bright spot in its region, posting an average annual production growth rate of 5% for quinoa from 2005 to 2014, with an outstanding 6.8% in 2013. Farmers who once struggled to make ends meet are now earning substantial revenue from quinoa cultivation. Likewise, Peru has become one of the world's leading producers of quinoa. Peruvian quinoa exports have increased almost tenfold since 2010, growing from $15 million in 2010 to $143 million in 2015 (Bellemare et al. 2016). The success of quinoa has led to improved livelihoods for mountain people in the Andes.

FSFs growing in the mountains are often considered organic due to the minimal or absent use of fertilizer or pesticides and thus often have a higher market value. For instance, in India's Central Himalayan Region, women farmers are knowledgeable of traditional agricultural practices that use no chemical inputs. Organized by agricultural microenterprises, 2800 women farmers have increased supply and capitalized on the growing demand for organic products. Eighteen different types of traditional crops are marketed in Indian cities, including buckwheat, horse gram and foxtail millet. Recognizing its high quality, a Japanese company is purchasing foxtail millet in bulk for the preparation of baby foods (Khalid and Kaushik 2008).

Besides, some FSFs have high medicinal importance. In China, Traditional Chinese Medicine (TCM) relies heavily on the availability of high-quality medicinal plants. The health and medicinal value of a specific plant, often grown in the mountains, varies significantly according to where it is grown, climatic conditions, soil type, use of fertilizers or pesticides, and when and how it is harvested and processed. Traditional medicinal plants with special origins are recognized as 'Dao Di Yao Cai', which have a high reputation in TCM. For instance, the Lei Gong mountain is a plant hub for traditional Chinese (Miao Minorities) medicinal that produces 774 species of medicinal plants from 179 families and 462 genera. (Long et al. 2009). It includes endangered and precious Chinese traditional medicinal plants, such as Du Zhong/*Eucommiaulmoides* (*Eucommiae cortex*), Tian Ma/Tall Gastrodiae (*Gastrodiae rhizoma*) and Hou Pu (Magnolia of ficinalis). Traditional Chinese medicines using these traditional medicinal plants in Lei Gong mountain, are well-known in the traditional Chinese medicine market.

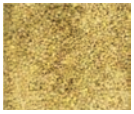
(d) **Local availability or adaptability — traditional mountain knowledge**

FSFs recognize traditional knowledge and cultural identities of indigenous people in mountains. Being locally available or adaptable is an important feature of FSFs that can contribute to sustainable mountain agriculture development. The indigenous people acquired the knowledge to conserve and manage natural and agricultural ecosystems over thousands of years. They have domesticated, improved and conserved thousands of crop species and varieties, and recognized that crop success is subject to variability and the unpredictability of weather events and occurrence of pests. Many traditional food systems have healthy elements based on local species of high nutritional value and high climate change adaptation. Evidences show that indigenous people acquired traditional knowledge in the selection of traditional crop varieties and new varieties/landraces in adapting to climate change. For instance, there is a dependence on finger millet in Northern India; even as the rainfall has declined to 300 mm in recent years, the finger millet varieties grown and conserved by farmers have excellent drought resistance and have therefore remained unchanged. This suggests that these varieties have sufficient adaptability to enable farmers to cope with periods of significant rainfall shortage (Chivenge et al. 2015). Consequently, many FSFs species and varieties have excellent traits to both survive and thrive in difficult conditions, especially mountain areas.

Moreover, traditional food systems in mountain areas are intertwined with the cultural identity of the indigenous people. With their knowledge of local ecosystems and traditional food systems evolved over generations, it is important to protect local ecosystems and promote conservation and sustainable use of traditional food systems, which will empower mountain indigenous people (FAO 2019).

Table 5.3 lists some examples of FSFs that can be grown in the mountains with different latitudes in Asia (FAO 2019).

Table 5.3 Examples of FSFs in selected countries (FAO 2019)

FSFs	Image	Nutritional and climate-resilient traits	Country
Lentil		Second-highest ratio of protein	Bhutan, India
		Huge potential to be grown as a winter crop in warm temperate and subtropical zones	
Buckwheat		Rich in iron and zinc—deficiencies of which are a major cause of hidden hunger	Bhutan
		Cultivated from alpine regions to the subtropical regions	
Moringa Drumstick		Significant source of vitamins, manganese, iron and protein	Bhutan, Myanmar, Cambodia, Nepal, Viet Nam, India, Lao PDR
		Fast growing and drought tolerant	
		Rich in calcium, potassium, vitamin A, vitamin C and protein	
		Popular vegetable with medicinal value	
		Powerful anti-inflammatory and antioxidant properties	
		Fast growing, drought tolerant	
Mung bean		High in protein, resistant starch and dietary fiber	Bangladesh, Nepal and Viet Nam
		Short growing cycle, increased adaptability, drought tolerant	
Taro		Rich in carbohydrates and high levels of calcium and vitamin A	Bangladesh, Cambodia, Lao PDR, Nepal, Viet Nam and India
		Cultivatable in a wide range of areas; multipurpose vegetable with high market value	
Quinoa		Rich in fiber, antioxidants, protein, iron and zinc	Bhutan, Nepal and Lao DPR
		Climate resilient; adapts well to various altitudes	
Foxtail millet		Helps to control blood sugar levels and reduces the risk of heart attack	Bangladesh and India
		Climate-resilient crop; grows in a wide range of agro-climatic conditions	
		Suitable for cultivation in marginal soils of char land	

5.4 How can Scaling-Up be Achieved? Promoting FSFs Identification, Production, Marketing and Consumption

5.4.1 Harnessing the Potential of Future Smart Foods for Sustainable Agriculture Development: Adopting a Food System Approach

From a food system perspective, we need to transform agriculture and food systems to become more diversified, nutrition-sensitive, climate-resilient, economically viable and locally adaptable. Food systems are complex and several actors are involved in harnessing the potential of such diversified, nutrition-sensitive, climate resilient and economically and socially acceptable through scaling-up. FSFs can play a significant role in transforming these systems if they are mainstreamed. To tap into the opportunities that FSFs offer for achieving Zero Hunger and poverty reduction, focus is needed on the identification and prioritization of FSFs in terms of production, post-harvest and processing, marketing and consumption, and linking to markets (Fig. 5.2). Overall, the emphasis should be on building capacity for FSFs products at each development stage of the food system, i.e., prioritization, production, post-harvest and processing, marketing and consumption, and connecting all stages of the food system to minimize transaction costs (FAO 2019).

A holistic food systems approach for FSFs is as follows (Li and Siddique 2020):

1. Prioritization: identify and prioritize NUS to be potentially FSFs.
2. Production: increase production of targeted mountain FSFs in farming systems adaptable to various agro-ecological zones.
3. Processing: improve the efficiency of post-harvest and processing of FSFs.
4. Marketing: promote the distribution and marketing of FSFs.
5. Consumption: Increase the demand for FSFs among consumers by increasing awareness and knowledge on their multi-dimensional benefits including nutritional value.
6. Build partnerships with countries and value-chain partners to benefit small farm holders and increase their incomes while achieving the Zero hunger.

Fig. 5.2 Development stages of food systems for Future Smart Food

5.4.2 Building an Enabling Environment Conducive for Promoting FSFs Identification, Production, Processing, Marketing and Consumption

To harness the potential of FSFs, it is important to establish an enabling environment that promotes diversified, nutrition-sensitive, climate-resilient, economically viable agriculture and food systems through the identification, production, processing, marketing and consumption of FSFs. Traditional food systems have developed over hundreds of years, featuring an abundance of foods that were nutritionally dense and climate-resilient: promoting these alternative options offer greater yield increase potential, an opportunity to diversify dietary patterns, and generate income for the rural poor. While these alternative crops were often traditionally grown by local farmers, there have been no incentives to maintain or increase production (incentives were mostly geared toward staple production). Governments need to move away from the strong focus on staple crops only and tap into the enormous potential of alternative crops that are nutritionally dense and climate-resilient as well as economically viable and locally available. This is especially meaningful for the rural poor, who suffer the most from production and nutrition gaps, as well as shocks and uncertainties. Government leadership is needed when it comes to building an enabling environment for popularizing FSFs for agriculture development. To unlock the hidden potential of FSFs, the actions and policies covering all stages of FSFs development are indispensable (FAO 2019; Li and Siddique 2020).

5.4.2.1 Identifying Traditional Foods Used by Indigenous People and Prioritizing FSFs

By identifying FSFs by following the four established criteria (nutrient density, climate-resilience, economic viability, and local availability/adaptability), farmer communities could produce sufficient, nutritious and safe FSFs for themselves and benefit from the marketing of surplus agricultural produce and services, while promoting conservation and the sustainable use of biodiversity, and ensuring environmental sustainability. It is important to adopt a multi-stakeholder and participatory approach that rediscovers and recognizes local communities' and indigenous people's knowledge. (Li and Siddique 2020).

5.4.2.2 Mapping Farming Systems Suitable for Integrating FSFs

Only a systematic analysis of existing farming systems will facilitate the integration of FSFs and their eventual scaling up. A key bottleneck is the lack of scientific analysis of farming systems concerning the possible integration of FSFs by adopting agro-eco region and market-based agriculture, and subsequently the promotion of FSFs into national farming systems in order to foster the agriculture transformation. To make it possible, mapping the areas suitable for FSFs based on agro-ecological zones and using digital tools, especially GIS, will provide an important entry for the integration and growth of FSFs crop productivity in the context of climate and socio-economic changes (Chandra 1994). A proven example from India where rice-fallows are efficiently used for growing short duration legumes-FSFs (Wani and Sawargaonkar 2018; Rajender et al. 2021, Chap. 6 in this book).

The most common indicators for mapping the drivers of the agroecosystem and its services are land use cover, water resources, soils, vegetation, climate and nutrient-related indicators. The digitization of agroecosystems is one of the key entry points for development efforts ranging from sustainable crop diversification and intensification, to efficient use of farm inputs, good agronomic practices, stable economic return, and sustainable agroecosystem services management. Recent advances in digital technologies, such as Earth Observation Systems including satellite to terrestrial platforms, Open access, Artificial Intelligence (AI), Machine Learning (ML), Information and Communication Technologies (ICT), Cloud Computing Platforms, block chain along with smartphone-enabled Citizen Science make resource management smarter, and much more useful for decision-making.

5.4.2.3 Increasing Production of FSFs by Integrating FSFs into Production System

To increase production of FSFs, it is important to conduct research and development on FSFs, especially the development of improved cultivars of FSFs. The improved cultivars need to be integrated into various farming systems and adapted to local agro-ecological zones. Meanwhile, it is important to build the capacity of smallholder farmers to grow FSFs so that they have surplus FSFs for household consumption and extra to sell to markets. Part of improving capacities is to improve production efficiencies by optimizing the use of resources while maximizing the output. This can sustain production and potentially make FSFs more affordable to consumers (FAO 2019; Li and Siddique 2020).

5.4.2.4 Strengthening Processing FSFs

Processing FSFs includes many forms of processing foods, from grinding grain, to make raw flour to home cooking, to making jams and pickles to complex industrial methods used to make convenience foods for direct consumption. It includes post-harvest, processing, packaging, labeling and certification to make the FSFs more convenient, accessible and informative with nutritional panels. These activities result in value-added products that can reduce food losses along the value chain, and enhance smallholder farmers' income (FAO 2019; Li and Siddique 2020).

5.4.2.5 Promoting Marketing and Distribution of FSFs

Introducing FSFs to the market requires the building of links between production, processing, distribution, marketing and consumption. Good marketing should cover advertising to build awareness about FSFs and their superiority, promotion, public relations and connection to market channels. Policy makers, especially local governments, should play a proactive role in the coordination of stakeholders to help indigenous people to develop market-oriented strategies for the sustainable development of FSFs, including market expansion of FSFs through fair trade and mountain product promotion. Expanding distribution should not only be focusing on developing niche markets, but also by exploring new narratives through diversification of school feeding and public procurement programs that link smallholders to stimulated demands (Hunter et al. 2019). Advanced technical means could be used, including e-commerce, to overcome the barriers of geographical isolation for the promotion of FSFs products (FAO 2019; Li and Siddique 2020).

5.4.2.6 Promoting FSFs for Consumers

Increasing the demand for FSFs could be the driver for transforming agriculture and food systems, which will benefit consumers, smallholder farmers and other value chain actors. The demand for FSFs can be increased by increasing consumer and smallholder farmer awareness on the multi-dimensional benefits of consuming FSFs. This requires more information on the nutrients of FSFs, the preparation of FSFs crops, and techniques to access the population through processing and other value additions. Establishing trusted brands and changing consumer perception towards FSFs is vital at all stages of the process to bring FSFs products to markets. There are a growing number of chefs and civil societies popularizing NUS through food fairs, campaigns, and culinary tourisms (Hunter et al. 2019). Current research findings and knowledge on FSFs need to be disseminated through various media, local agencies, newsletters and advertisements to promote the consumption of FSFs (FAO 2019; Li and Siddique 2020).

5.5 Summary and Way Forward

The Zero Hunger/SDG2 goal of eradicating hunger and all forms of malnutrition by 2030 remains a major challenge for the Asia-Pacific region. NUS, although under researched and promoted, commonly have superior nutrition content and climate adaptivity to the crops dominating our food systems, and hold particular high potential in combating ‘hidden hunger’ such as micronutrient deficiency and climate shocks in disadvantaged areas like mountains. Future Smart Foods (FSFs) are NUS that are nutrition-dense, climate-resilient, economically viable and locally available or adaptable. It is the aim of FAO’s FSFs initiative to shift the over-dependence of staple crops as the center of food systems towards one that is more diverse, sustainable and healthy for human and environment. This chapter demonstrates the multi-dimensional benefits of FSFs and provides practical examples and strategic actions in Asia-Pacific region on how to mainstream FSFs into national policies and markets and how to scale up from local, national to global levels.

Improving evidence-based decision making and securing the full potential of these promising but underutilized species in production and consumption systems will require actions on many fronts and global collaboration. FSFs initiative has worked closely with governments in Asia-Pacific region to create an enabling environment for diversified and resilient agricultural systems. Outside the region, there are similar efforts and synergies can be drawn. For instance, Brazil has established a national Plants for the Future initiative which identifies, promotes, and increases the market capacity for native Brazilian flora. UN agencies and CGIAR centers have also conducted projects in promoting biodiversity for food and nutrition across regions. Together with such international efforts to mobilize NUS for improving nutrition and combating climate change, FSFs will be an integral part of a holistic food system that exposes the sustainable production, processing and consumption principles necessary for achieving SDG2.

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Chapter 6
Pulses Revolution in India Through Rice-Fallows Management

Rajender B., A. K. Tiwari, and S. K. Chaturvedi

Abstract Globally, India is known to have largest share in acreage (38%) and production (28%) of pulse crops. At the same time, it is also a largest consumer and processor of pulses in the world. Recently, India has witnessed a silent 'Pulses Revolution' achieving pulse production of 25.23 million tons (Mt) in 2017–18 consortium, collective action, convergence and capacity building with integrated approach since 2014–15. A positive trend in area, production and productivity of pulse crops during last 15 years is recorded. Pulses revolution could happen due to development of indigenous science-led technologies, policy initiatives and scaling-up across the country ensuring food and nutritional security. To meet the estimated demand of 33 Mt of pulses by 2024 innovative- multipronged strategies, partnerships and technologies for enhancing productivity and area expansion are must. Vast scope exists for area expansion as 11.65 m ha rice-fallow areas in the country can be successfully cultivated with pulses during *rabi* season as well for productivity enhancement through adoption of improved technologies and scaling up in a mission mode.

Keywords Pulses self-sufficiency · Rice-fallows · Scaling-up · Food & nutrition · Mission approach

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6.1 Introduction

Pulses are an important group of food crops that play a vital role to address national food and nutritional security and also tackle environmental challenges. The share of pulses to total food grain basket in India is around 9–10% and is a critical and inexpensive source of plant-based proteins, vitamins and minerals. Pulses are critical in food basket (*dal-roti, dal-chawal*), are a rich source of protein (@ 20–25%, it is double the protein content of wheat and thrice that of rice) and help address obesity, diabetes, malnutrition etc. Besides being rich source of protein for largely vegetarian and agrarian population, pulses are known to fix atmospheric 'N' to the tune of 72–350 kg N per ha per year (meeting 70–90% of crop demand) in readily available form and also benefit the succeeding crop through residual benefits, besides opening up soil to the deeper strata thereby increasing aeration and more microbial activities. Associated non-legume intercrop also gets benefited by 'N' transfer from pulses' roots to some extent. It also contributes in sustaining agricultural production base through physical, chemical and biological improvements of soil properties besides low carbon footprint. India is the largest producer (~23–24 m t) of the pulses in the world accounting for 28% of global production from 38% of total global sown area under pulses. Pulses are identified as future smart foods (FSFs) by the FAO for achieving the sustainable development goal 2 (SDG 2) of zero hunger (Li and Siddique 2018). In India, 23.15 m t of pulses could be produced during 2019–20 from over 27 m ha area registering 843 kg/ha average yields. India has witnessed significant growth not only in production but also in productivity and realized '**Pulses Revolution**' when total pulses production crossed 25 m t mark in 2017–18 (Chaturvedi and Sandhu 2020). To meet the protein demand for ever-growing population, India needs to produce 33 m t of pulses by 2024 which will require an annual growth rate of 3.62%. Presently, the demand for pulses continues to grow at 2.8% per annum (Working Group Report, NITI Aayog 2016).

6.2 Indian Pulses Scenario

The total world acreage under pulses is about 95.72 M ha with production of 92.28 M t at 964 kg/ha yields level (FAO 2018). Pulses are the main source of protein for the large Indian vegetarian population (50% of 1.33 billion). India, with >27 m ha area under pulses cultivation, is the largest pulse producing country in the world (2018–19) as well as largest consumer also. Globally, India ranks first in area (38%) and production (28%) of pulses. In India, pulses are generally cultivated as rain-fed crops (78%) on marginal and sub-marginal soils mostly characterized by low fertility and less water holding capacity and (28%) chickpea, lentils, rajmash, and pea etc. are grown during *rabi* season *(DES, 2018–19)*. The pulses are low water requiring crops therefore have a very low water footprint. The rain-fed regions of the country support 40% of human population and 2/3rd of the livestock besides contributing as high as 90% to the total nutri-cereals (millets) followed by pulses (80%), oilseeds (74%), cotton (65%) and rice (48%) crops. The multi-pronged innovative strategies adopted by the government such as adopting mission approach through convergence, partnerships and providing integrated solutions through increased availability of quality seeds of newly released varieties, promotion of micronutrients, micro-irrigation, integrated diseases and pest management along with positive policy support from the Government of India in terms of announcement of remunerative minimum support price (MSP) well before sowing and assured procurement at MSP etc. led into enhanced contribution (8–9%) of the pulses to total food grains basket in 2018–19 in comparison to the previous years (6–7%), which was the ever highest after 2000–01. Due to pro-active pulse programme implementation strategies and robust monitoring mechanism of Government of India, Department of Agriculture, Cooperation and Farmers Welfare (DAC&FW), significant growth in area, production and productivity of pulses was recorded. The productivity of pulses increased by 41% to reach 853 kg/ha during 2017–18 from 607 kg/ha during 2000–01, and the production by 90% whereas area increased by 35% (Tables 6.1a and 6.1b) only during same period. The impressive progress made in production of different pulses during last 5 years has been presented in Fig. 6.1 which indicates that major pulses including chickpea, pigeonpea showed impressive progress.

Table 6.1a Contribution of pulses to food grains basket

{Area- million ha (A), Production- million tons (P), Yield- kg/ha (Y)}

Year	Pulses			Food grains			Pulses share to food grains (%)	
	A	P	Y	A	P	Y	A	P
2000–01	22.01	13.37	607	121.05	196.81	1626	18	7
2010–11	26.40	18.24	691	126.67	244.49	1930	21	7
2011–12	24.46	17.09	699	124.75	259.32	2079	20	7
2012–13	23.26	18.34	789	120.78	257.12	2129	19	7
2013–14	25.22	19.26	764	125.05	265.05	2120	20	7
2014–15	23.55	17.15	728	124.30	252.03	2028	19	7
2015–16	24.91	16.32	655	123.22	251.54	2041	20	6
2016–17	29.45	23.13	786	129.23	275.11	2129	23	8
2017–18	29.81	25.42	853	127.52	285.01	2235	23	9
2018–19	29.16	22.08	757	124.78	285.21	2286	23	8
2019–20[a]	27.44	23.15	843	125.00	296.65	2373	22	8

Source: DES, Ministry of Agri. &FW (DAC&FW), Govt. of India; 2019–20[a]: IV Adv. Est

Table 6.1b Trends in area, production and yields of pulses in India

Year	Area (m ha)			Production (m t)			Yield (kg/ha)		
	Area	Increase over 2000–01	% increase	Production	Increase over 2000–01	% increase	Yield (kg/ha)	Increase over 2000–01	% increase
2000–01	22.01	–	–	13.37	–	–	607	–	–
2010–11	26.40	4.39	19.95	18.24	4.87	36.4	691	84	13.8
2011–12	24.46	2.45	11.13	17.09	3.72	27.8	699	92	15.2
2012–13	23.26	1.25	5.68	18.34	4.97	37.2	789	182	30.0
2013–14	25.22	3.21	14.58	19.26	5.89	44.1	764	157	25.9
2014–15	23.55	1.54	7.00	17.15	3.78	28.3	728	121	19.9
2015–16	24.91	2.90	13.18	16.32	2.95	22.1	655	48	7.9
2016–17	29.45	7.44	33.80	23.13	9.76	73.0	786	179	29.5
2017–18	29.81	7.80	35.44	25.42	12.05	90.1	853	246	40.5
2018–19	29.16	7.15	32.49	22.08	8.71	65.1	757	150	24.7
2019–20	27.44	5.43	24.67	23.15	9.78	73.1	843	236	38.9

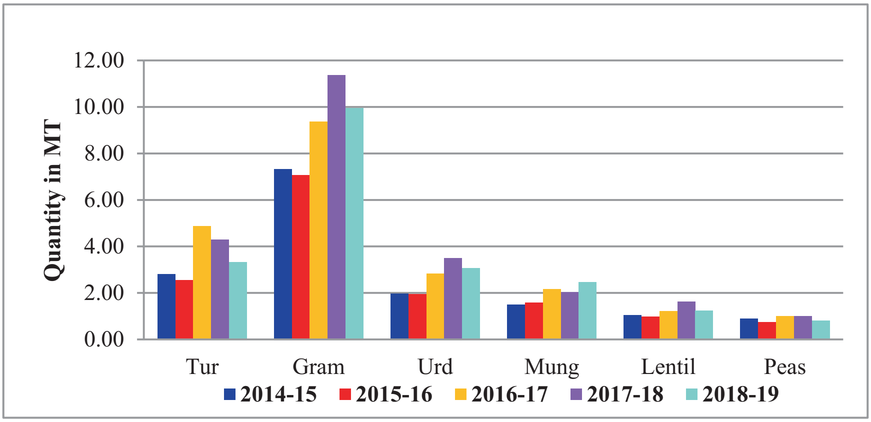

Fig. 6.1 Domestic production of major pulses (during last 5 years)

Table 6.2 Demand, production, growth and projected target

(Qty: million tons)					
Year	Demand[a]	Production	Growth (%)	Gap	Target
2015–16	22.05	16.32		−5.73	20.05
2016–17	22.74	23.13	41.70	0.39	20.75
2017–18	23.44	25.42	9.88	1.98	22.90
2018–19	24.14	22.08	−13.14	−2.06	25.95
2019–20[b]	24.85	23.15	4.30	−1.70	26.30

Source: Working Group on Crop Husbandry, Demand & Supply Projection of NITI Aayog, the demand of pulses worked out @ 3% per annum growth
Note: [a]Demand incl. seed, feed and wastage and based on behaviouristic approach. 2019–20[b] IV Adv. Est

6.3 Pulses Demand Projections

India is the home of largely vegetarian people (>50%), therefore to meet their dietary protein requirement they mainly depend on pulses. India is bound to be global leader in terms of production and consumption of pulses. India has been a leading importer of pulses due to stagnant production till 2017–18. The multi-pronged innovative strategies were implemented and as a result India could achieve almost self-sufficiency in pulses production through indigenous technologies when the total pulses production reached 23.42 Mt during 2017–18 (Table 6.2). This impressive increase in production of pulses during 2016–17, 2017–18 and 2019–20, consequent upon the implementation of short-term, mid-term and long term strategies to promote the pulse sector, could meet/minimize the demand-supply gap and moving closer to achieve its target to attain nutritional security by achieving self-sufficiency in production. The major challenge is not only to sustain current level of production but also to produce more for ever increasing population.

6.4 Challenges in Further Increase in Pulses Production

Several technological, social, socioeconomic and policy challenges exist for increasing the pulses production. Further, cultivation of pulses is usually considered a source of livelihood and it is not turning to a commercial business. Hence, farmers' shifting of crops from pulses to others crops is highly unlikely. Small farmers usually move away from the more profitable but risky pulse crops to the less profitable but more stable crops such as cereals (rice and wheat).

6.4.1 Import and Export of Pulses

India imported 3 million tons (Mt) of pulses during 2018–19 and 2019–20, draining huge hard foreign earning. Farmer-friendly policy measures have helped to reduce import of pulses. The statistics about import and export of pulses and demand has been presented for last 5 years indicating perceptible changes in Indian pulse industry (Tables 6.3 and 6.4). Consequently, India's pulses output has grown from the level of 16.32 million tons in 2015–16 to more than 23 million tons in 2019–20. During this period, however, India's imports declined from the level of over 6 million tons to a mere 3 million tons, resulting in saving of foreign exchange. Owing to year on year record production, there is needed to make all out efforts to reduce import though it may impact on ensuring availability of pulses to the consumers at cheaper rate. Accordingly, the import duties on various pulses have been revised and fixed at 60% (chickpea), 50% (yellow pea), 30% (lentil) and 10% (pigeon pea). As a result, pea which accounted for major share in India's pulses import, saw a sharp decline which helped in ensuring remunerative price for pea and other companion *rabi* season pulses to a large extent.

The duties on import were imposed and simultaneously export was also encouraged to support the farmers. "The Cabinet Committee on Economic Affairs" (CCEA) has given its approval for removal of prohibition on export of all types of pulses to ensure that farmers can exercise greater choice in marketing their produce and in getting better remuneration for their produce. The government lifted ban on

Table 6.3 Import/export and availability of pulses

(Quantity – million tons)

Year	Demand[a]	Prod.	Gap	Import	Change to pre. year (%)	Export	Change to pre. year (%)	Total availability
2013–14	20.75	19.26	−1.49	3.65		0.34		22.57
2014–15	21.39	17.15	−4.24	4.58	25	0.22	−35	21.52
2015–16	22.05	16.32	−5.73	5.80	26	0.26	15	21.87
2016–17	22.74	23.13	0.39	6.61	14	0.14	−46	29.60
2017–18	23.44	25.42	1.98	5.61	−15	0.18	31	30.84
2018–19	24.14	22.08	−2.06	2.53	−55	0.29	59	24.32
2019–20[b]	24.85	23.15	−1.70	2.72	8	0.19	−34	25.68

Source: Working Group on Crop Husbandry, Demand & Supply Projection of NITI Aayog, the demand of pulses worked out @ 3% per annum growth. **Import & Export:** Ministry of Commerce and Industry

Note: [a]Demand incl. seed, feed and wastage and based on behaviouristic approach. 2019–20[b] IV Adv. Est

Table 6.4 Availability of major pulses (2013–14 to 2018–19)

(Quantity – million tons)						
Crops/ year	Domestic production	Import	Change to pre. year (%)	Export	Change to pre. year (%)	Total availability
Pigeon pea						
2013–14	3.17	0.47	–	0.0001	–	3.64
2014–15	2.81	0.58	24	0.001	1120	3.38
2015–16	2.56	0.46	−20	0.004	230	3.02
2016–17	4.87	0.70	52	0.012	206	5.56
2017–18	4.29	0.41	−41	0.011	−14	4.69
2018–19	3.32	0.53	29	0.009	−11	3.84
Chickpea						
2013–14	9.53	0.28	–	0.334	–	9.47
2014–15	7.33	0.42	52	0.190	−43	7.56
2015–16	7.06	1.03	146	0.217	14	7.87
2016–17	9.38	1.08	5	0.088	−60	10.37
2017–18	11.38	0.98	−9	0.128	47	12.23
2018–19	9.94	0.19	−81	0.229	78	9.90
Mungbean and urdbean						
2013–14	3.31	0.62	–	0.002	–	3.93
2014–15	3.46	0.62	−0.2	0.004	156	4.08
2015–16	3.54	0.58	−7	0.006	50	4.11
2016–17	5.00	0.57	−1	0.011	65	5.56
2017–18	5.52	0.35	−40	0.017	60	5.85
2018–19	5.52	0.57	65	0.019	11	6.07
Peas						
2013–14	0.92	1.33	–	0.001	–	2.25
2014–15	0.89	1.95	47	0.004	360	2.84
2015–16	0.74	2.25	15	0.006	65	2.98
2016–17	1.01	3.17	41	0.008	18	4.18
2017–18	0.99	2.88	−9	0.004	−42	3.87
2018–19	0.81	0.85	−70	0.002	−51	1.66
Total pulses						
2013–14	19.26	3.65	–	0.344	–	22.57
2014–15	17.15	4.58	25	0.222	−35	21.52
2015–16	16.32	5.80	26	0.256	15	21.87
2016–17	23.13	6.61	14	0.137	−46	29.60
2017–18	25.42	5.61	−15	0.179	31	30.84
2018–19	22.08	2.53	−55	0.286	59	24.32

export of pigeonpea, *urdbean* (black gram) and mungbean (splits- *dal*), although shipments of these varieties were allowed only through permission from agriculture export promotion body The Agricultural and Processed Food Products Export Development Authority (APEDA). All varieties of pulses, including organic pulses, have been made ‘free’ for export. Kabuli chickpea has also been permitted in limited quantity. Gram which accounted for major share in India's pulse exports increased. Opening of exports of all types of pulses will help the farmers dispose of their products at remunerative prices and encourage them to expand the area of sowing.

6.4.2 Large Yield Gaps and Low Adoption of Improved Technologies

Major challenge is the existence of large yield gaps between the current farmers' yields and the achievable potential for all crops including pulses in India and also in other countries in Asia and Africa (Bhatia et al. 2008; Singh et al. 2009) largely due to existence of *Death Valley of Impacts* (Wani 2016, 2021, in this volume). Main reason for large yield gaps is the availability of technical support for the farmers. As per the national sample survey data, 59% of farmers in India do not get any knowledge support (extension support) and only 11% farmers get support from the government machinery while remaining farmers get support from peers, media and private agencies (GoI 2013). The situation cannot be different in other developing countries in Asia, Africa and Latin America. International meta-analysis of trials conducted by the Ceres 2020 researchers found that lack of technical advice, input and ideas, collectively known as extension services for the small farm-holders was a major constraint for adoption of new approaches/technologies/products resulting in low impact on ending hunger (Nature 2020).

6.4.3 Major Problems for Achieving Higher Pulses' Productivity

The major problems related to achieving higher productivity of pulses in India are:

- Technological setbacks in terms of farm machineries suitable for smallholders.
- Large yield gaps as indicated above.
- lack of a managerial set-up to supervise the landscape.
- Unmatched inter-crop price parity.
- Remuneration and gross return over cost of production is higher in case cereals and cash crops in comparison with pulses.
- Price fluctuation is very common in the largely un-organized pulses market of the country and often exacerbated by the lack of assured procurement whenever there is bumper production.
- The vulnerability of high-yielding varieties to succumb abiotic stresses remains a major bottleneck in yield stability. Low genetic yield potential under rain-fed agro-ecologies losses due to pests and diseases in general have been still consid-

ered major productivity limiting constraints though a large number of varieties insulated against diseases and pests have been developed.

Further, cultivation of pulses is usually considered a source of livelihood and it is not turning to a commercial business. Hence, farmers' shifting of crops from pulses to others crops is highly unlikely. Small farmers usually move away from the more profitable but risky pulse crops to the less profitable but more stable crops such as cereals (rice and wheat).

6.5 Strategies for Enhancing Pulses Production

It is learnt from the earlier experiences that whenever government of India has adopted mission approach success was observed in programs like Green Revolution, Oilseed Mission, White Revolution- Operation Flood (milk), Blue Revolution (fisheries), etc. for pulses revolution too, technology alone and business as usual won't work and a mission approach by adopting integrated holistic system approach through convergence, capacity building, Consortium and building partnerships amongst the knowledge-generating and knowledge transforming institutions, non-government organizations, farmers' groups/FPOs, private companies, national and international research institutions along with innovative extension and capacity building, social engineering, enabling policies such as good and assured minimum support price (MSP) and institutions ensuring transparent inputs supply chain is must (Wani and Sawargaonkar 2018).

Sustainable intensification (vertical growth) and extensification (horizontal expansion) of pulses production system is must to achieve the goal of self-sufficiency for pulses production in the country. Sustainable intensification of pulses production can be achieved through improved seed supply of stress-tolerant and climate resilient cultivars of identified pulses, soil-test based integrated nutrient management practices (INM), integrated pest management (IPM), integrated crop management (ICM), ensuring seed supply of improved cultivars, innovative extension using new technologies such as information technologies (IT) along with needed inputs and most importantly market support. Enhancing area under pulses is a feasible and economically remunerative option as pulses are endowed with drought tolerance, nitrogen-fixation, less water requirement resulting in low carbon and water footprint with high protein content and higher price than cereal crops (Wani and Sawargaonkar 2018). For potential area to cultivate pulses during rainy and post-rainy seasons new science tools and technologies such as remote sensing (RS), geographical information system (GIS), information technology (IT), simulation modeling, water budgeting has been successfully applied (Subba Rao et al. 2001; Dwivedi et al. 2003; Garg and Wani 2011; Wani et al. 2011; Pathak and Wani 2011).

6.5.1 Mission Mode Approach for Pulses Revolution

To meet domestic demand for pulses there is need to develop and implement strategies in mission mode targeting both, horizontal and vertical expansion. The strategies targeting horizontal expansion through crop diversification, intensification, crop substitution and introducing pulses in new niches like, rice fallows (with an estimated area of 11.65 M ha) have tremendous scope for realization of higher production and productivity so as to make the country self-reliant in pulses availability on sustainable basis. It is quite possible by harnessing synergies of appropriate technologies in integrated manner. Development of strategies to achieve sustainable intensification of existing crops/cropping systems especially of rice-fallows through low input requiring pulses will be rewarding and have potential to meet the projected demand of pulses (33 Mt) in the country by 2024. In order to sustain the growth of pulses at various levels *i.e.* among the states, districts, within districts and to bridge the yield gap between front line demonstrations (FLDs) and farmers' practice, Department of Agriculture and Farmers Welfare (DAC&FW) has envisioned a road map with two pronged strategies:

(a) **Horizontal Expansion** by bringing additional area under pulses, and diversification of rice-wheat system in Indo-Gangetic plains (IGP) through popularization of short duration varieties of chickpea, lentil, pea, pigeonpea, kabuli chickpea during *rabi* season in northern and central India; mung bean, urdbean and cowpea during spring/summer in irrigated belt of central India (Madhya Pradesh, Chhattisgarh), north-east and north-west plains; bringing additional area under pulses through promoting urdbean cultivation in rice fallow in peninsular India; promotion of pulses in intercropping viz., tall and erect varieties of chickpea with autumn sown sugarcane, short duration thermo-insensitive varieties of mung bean/urdbean with spring sugarcane; early sown chickpea with mustard/linseed; pigeonpea with groundnut/soybean/millets; and urdbean under for late planting (mid Aug-early September) in northern India offers vast potential (Table 6.5).

(b) **Vertical Expansion** through increasing productivity and bridging the yield gaps; development of high-yielding short duration varieties (Table 6.6) having multiple and multiracial resistance to diseases; development of new and efficient plant types; development of input use efficient genotypes; hybrids of short duration pigeon pea; popularization of improved crop management practices and bridging yield gaps.

6.5.2 Detailed Plan Preparation

Department of Agriculture, Co-operation and Farmers Welfare (DAC&FW) in India meticulously planned the pulses revolution mission for increasing productivity as well as expanding the pulses area using rice-fallows. ICRISAT had focused on crop intensification in paddy fallows through the introduction of chickpea and DAC&FW

Table 6.5 Potential of bringing additional area under pulses

S. no.	Potential crops/cropping system/niches	Specific areas	Potential area (Mha)	Target area (2030)
1.	Intercropping			
	Sugarcane (Irrigated) and with urdbean/mungbean	Western, central and eastern Uttar Pradesh, Bihar, Maharashtra, Andhra Pradesh and Tamil Nadu	0.70	0.50
	Pigeonpea with soybean, sorghum, cotton, millet and groundnut (Rain-fed upland)	Andhra Pradesh, Malwa Plateau of Madhya Pradesh, Vidarbha of Maharashtra, North Karnataka and Tamil Nadu	0.50	0.50
	Chickpea with barley, mustard, linseed and safflower (rain-fed)	South-east Rajasthan, Punjab, Haryana, Uttar Pradesh, Bihar, Vidarbha of Maharashtra	0.50	0.30
	Chickpea/lentil with autumn planted/ratoon sugarcane	Maharashtra, Uttar Pradesh, Bihar	1.00	0.60
2.	Catch Crops			
	Spring/Summer	Western and Central Uttar Pradesh, Haryana, Punjab, Bihar, West Bengal	3.00	2.00
3	Rice fallow			
	Chickpea	Eastern Uttar Pradesh, Bihar, Jharkhand, Odisha, Chhattisgarh, West Bengal	0.40	0.40
	Urdbean	Andhra Pradesh, Tamil Nadu, Odisha, Karnataka	0.50	0.40
	Lentil	Eastern Uttar Pradesh, Bihar, West Bengal, Assam, Jharkhand	0.30	0.30
	Lentil/pea	North east plains	0.10	0.10
4	Kharif Fallow			
	Urdbean	Bundelkhand part of Uttar Pradesh and Madhya Pradesh	1.20	1.00
	Total		8.20	6.10

Source: Pulses in India: Retrospect & Prospects-2018

brought associated state departments, SAUs and international, national research institutions as mission partner for bringing in 3 million ha of paddy fallow from the eastern states under FSF crops. DAC&FW along with ICRISAT conducted a national-level workshop at Bhubaneshwar for scientists, researchers, farmers and policymakers on the introduction of FSF crops to existing single cropping of paddy. In 2016/17, the DAC&FW-led consortium introduced chickpea to almost 1.8 million ha along with best management practices, including seed priming and mechanized sowing with zero-till multi-crop planters with minimal tillage.

There are many issues related to technologies those need to be tackled (Table 6.7) through various interventions. The responsibilities have been assigned to different institutions like State Department of Agriculture (SDA), National Seed Corporation

Table 6.6 Potential crops and varieties for rice fallows in different states

Crop	Varieties	State
Lentil	HUL 57, Pusa Vaibhav, IPL 316, IPL 526, IPL 220	Assam, Bihar, Odisha, Eastern Uttar Pradesh, West Bengal, Chhattisgarh, Jharkhand
Lathyrus	Ratna, Prateek, Mahateora	*Tal* area of Bihar, Chhattisgarh, West Bengal
Pea	IPFD 10-12, IPF 11-5, Aman	Jharkhand, Chhattisgarh, Eastern Uttar Pradesh, Madhya Pradesh
Chickpea	IPC 2006-77, RVG 202, RVG 203, JG 14, Rajas, Pusa 547, Vaibhav, GCP 105	Chhattisgarh, West Bengal, Bihar, Jharkhand
Mungbean	Virat, Shikha, Varsha, Kanika	Odisha, Chhattisgarh, Jharkhand, Bihar, Andhra Pradesh, Tamil Nadu, Karnataka.
Urdbean	Navin, ADT 3, ADT 4	Coastal Andhra Pradesh, Tamil Nadu, Karnataka, Odisha, Jharkhand

Source: Pulses in India: Retrospect & Prospects-2018

Table 6.7 Major technological interventions

Issues	Interventions	Action
Lack of suitable cultivars	Development of high-yielding varieties with appropriate maturity duration	ICAR-IIPR
Poor crop stand and establishment	Tillage machines, sowing methods, seed priming, higher seed rate, timely planting, seed treatment with fungicides	SDA/SAUs
Diseases and pests	Development of IPM modules	SDA/SAUs/NCIPM
Weed menace	Post-emergence herbicides like Quizalophop ethyl and Imazethapyr	SDA/SAUs/DWR
Nutrient management	Foliar spray of urea/DAP to supplement N and P	SDA/SAUs
Micronutrient deficiencies	Mo, B, Zn as seed pelleting	SDA/IISS
Terminal moisture/heat stress	Residue mulching	SDA/SAUs/CRIDA
Non-availability of quality seeds	Informal and formal seed production and supply systems	SDA/SSC/NSC
Lack of mechanization	Tillage machines, zero-till planter and harvester	SDA/SAUs/CIAE
Poor transfer of technology	Innovative farmer's participatory approach	SDA/SAUs/KVKs

Source: Pulses in India: Retrospect & Prospects-2018

(NSC), State Seed Corporations (SSCs), State Agricultural Universities (SAUs), *Krishi Vigyan Kendra* (KVKs), research institutions working under Indian Council of Agricultural Research (ICAR) viz., Indian Institute of Pulses Research-IIPR, National Institute of Integrated Pest Management-NCIPM, Directorate of Weed Research-DWR, Indian Institute of Soil Sciences (IISS), Central Research Institute for Dryland Agriculture-CRIDA, Central Institute of Agricultural Engineering-CIAE etc. to ensure proper implementation of the scheme.

The major districts having larger area in different states is Assam, Bihar, Chhattisgarh, Odisha, West Bengal etc. (Table 6.8) covering 92 districts of 11 states (Table 6.9) were identified as target areas.

Table 6.8 Action plan for targeting Rice Fallow Area (TFRA)-Oilseeds and Pulses (2019–20)

Sl. no.	State	Programme	No. of districts	No. of villages	Area target (Mha)	Production target (Mt)
Existing States						
1	Assam	TRFA- Oilseeds & Pulses	8	800	0.265	0.179
2	Bihar		7	700	0.045	0.046
3	Chhattisgarh		9	900	0.495	0.324
4	Jharkhand		5	500	0.045	0.042
5	Odisha		11	1100	0.530	0.290
6	West Bengal		10	1000	0.485	1.350
Newly included States						
7	Andhra Pradesh	TRFA – Oilseeds	3	466	0.024	0.019
8	Gujarat	TRFA – Pulses	3	300	–	
9	Madhya Pradesh		3	300	–	
10	Karnataka	TRFA- Oilseeds & Pulses	7	60	0.005	0.003
11	Maharashtra		6	600	0.010	0.006
12	Tamil Nadu		3	15	0.002	0.001
	Total		75	6741	1.906	2.260

Table 6.9 Districts and Targeted area under TRFA during 2019–20

State	# Districts	Name of the districts
Assam	8	Lakhimpur, Jorhat, Sibsagar, Dibrugarh, Golaghat, Karbi, Nagaon, Morigon, Karbi-Anglomg
Bihar	7	Kisangang, Katihar, Banka, Gaya, Aurangabad, Nawada, Jamui
Chhattisgarh	9	Raipur, Rajnandgaon, Sarjgja, Raigarh, Baloda bazar, Bilaspur, Jagdalpur, Kondagaon, Kankar
Odisha	11	Koraput, Kalahandi, Balasore, Sambalpur, Sundargarh, Bhadrak, Puri, Dhankanal, Mayurbhanj, Bolangir, Nabarangpur
West Bengal	10	Bankura, Birbhum, Bardhaman, E. Medinipur W. Medinipur, Coochbiher, Malda, Murshidabad, South 24 Pargana, Purulia
Jharkhand	5	Ranchi, W, Singhbhum, Dumka, Palamau, Chatra
Tamil Nadu	3	Thanjavur, Trichy, Erode
Karnataka	12	Belagavi, Ballari, Dharwad, Kalburgi, Haveri, Coppal, Mandya, Mysuru, Shivamogga, Udupi, U. Kannada, Yadgir,
Maharashtra	6	Thane, Ratnagiri, Sindudurg, Bhandaran, Gondia, Gadchiroli
Gujarat	5	Panchmahal, Navsari, Tapi, Valsad, Dang
Madhya Pradesh	16	Katni, Balaghat, Chhindwara, Seoni, Damoh, Dindori, Mandla, Narsinghpur, Rewa, Sidhi, Singouli, Satna, Umariya, Anuppur, Raisen, Betul
Total	**92**	

6.5.3 Potential Pulses Area Expansion Using Rice Fallows

In Southeast Asia, rice is mostly grown in the *kharif* season. A substantial part of this area (15 million ha) remains fallow during the *rabi* (post-rainy) season, primarily due to limited soil moisture availability in the top soil layer for crop establishment (Subbarao et al. 2001). Rice fallow is the land used to grow rice in the *kharif* season but is left uncropped during the following *rabi* season. Of the total rice fallow area in South and Southeast Asia, 2.11 million ha (33% of the *kharif* rice growing area) is in Bangladesh, 0.39 million ha (26%) is in Nepal, and 11.65 million ha (29%) is in India. Since rice is grown on some of the most productive lands in this region, there is scope for increasing the cropping intensity by introducing a second crop during the *rabi* season using appropriate technologies (Wani and Sawargaonkar 2018). Currently, rice fallow area contributes only 4% in total pulses production of the country which can be increased substantially. In India, rice contributed about 39.9% (118.43 m t) to the total food grains production (296.65 m t) during 2019–20 attaining highest peak. In India, rice is cultivated under both rain-fed and irrigated agro-ecosystems under diverse cropping systems across the country occupying 43.60 m ha (DES, 3rd Est. 2019). In India, nearly 82% of the rice fallow is located in the states of Assam, Bihar, Chhattisgarh, Madhya Pradesh, Orissa (Odisha) and West Bengal. GIS analysis of this fallow land identified diverse soil types and climatic conditions (Kumar Rao et al. 2008). The available soil water-holding capacity (1 m soil profile) for most of this land ranges from 150 to 200 mm (Singh et al. 2010). Wani et al. (2009) assumed that these soils are fully saturated during most of the rice-growing season, then there will be residual moisture in the soil at rice harvest that could be used by the following crop. They reported that these rice fallows offer a potential niche for legume production due to the considerable amount of available green water after the monsoon, which could be used by a short-duration legume crop after simple seed priming and micronutrient amendments (Kumar Rao et al. 2008; Singh et al. 2010).

Rice fallow, a rain-fed lowland agro-ecology is presently gaining attention for sustainable cropping intensification and enhancing productivity of targeted crops to enhance production and increase farmers' income in India by the government of India for enhancing pulses production for minimizing import of pulses. Most of the time discussions are held for intensification and increasing production of pulses bringing additional area under these crops in eastern states. These states comprising Assam, Bihar, Chhattisgarh, Jharkhand, Odisha and West Bengal cover more than 19 million ha (45%) under rice. As per revised estimates approximately 11.65 M ha of land in India is left fallow during *rabi* and summer after the *kharif* rice harvest (Gumma et al. 2016), and it is mostly concentrated in states like Chhattisgarh, Madhya Pradesh, Odisha, Jharkhand, Maharashtra, West Bengal and Telangana (Fig. 6.2 and Table 6.10).

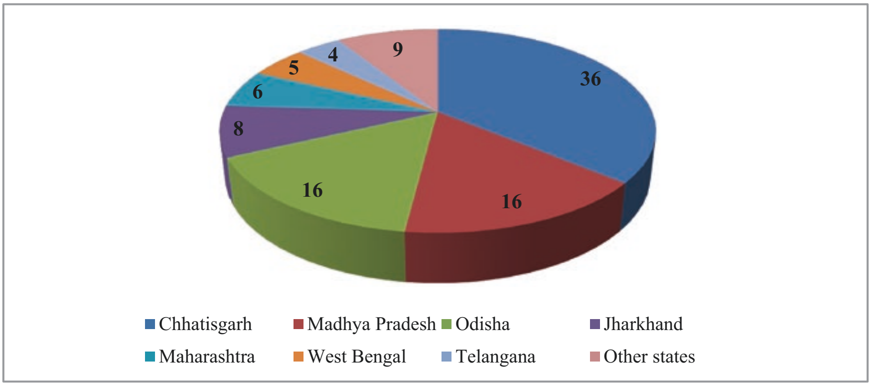

Fig. 6.2 Share of rice-fallow areas (%) in various states of India

Table 6.10 Estimated area under rice-fallows in India

(Area in Mha)

Sl. no.	State	Estimated area by NAAS (2013)	Estimated area by States	Estimated area by MNCFC	Suitable area for pulses & oilseeds by MNCFC
1	Assam	0.54	0.30	1.05	0.67
2	Bihar	2.20	0.05	0.68	0.48
3	Jharkhand		1.50	0.91	0.44
4	Chhattisgarh	4.38	1.56	2.63	0.76
5	Madhya Pradesh		–	–	–
6	West Bengal	1.72	1.15	1.33	0.60
7	Andhra Pradesh	0.310	–	–	–
8	Gujarat	0.08	–	–	–
9	Karnataka	0.18	0.09	–	–
10	Odisha	1.22	1.22	1.72	0.90
11	Maharashtra	0.63	0.90	–	–
12	Tamil Nadu	0.02	0.26	–	–
13	Others	0.37	–	–	–
	Total	**11.65**	**7.04**	**8.34**	**3.86**

Source: National Academy of Agricultural Sciences (NAAS)-2013

These fallow areas are suitable for intensification with a short duration (≤3 months), low water consuming grain legumes, *i.e.* chickpea, lentil, urdbean (blackgram), mungbean (greengram) and lathyrus etc. to improve the smallholder farmers' incomes and the soil health. Their productive utilization can overcome many social and economic problems of the region like unemployment, migration of the labour, and protein malnutrition etc.

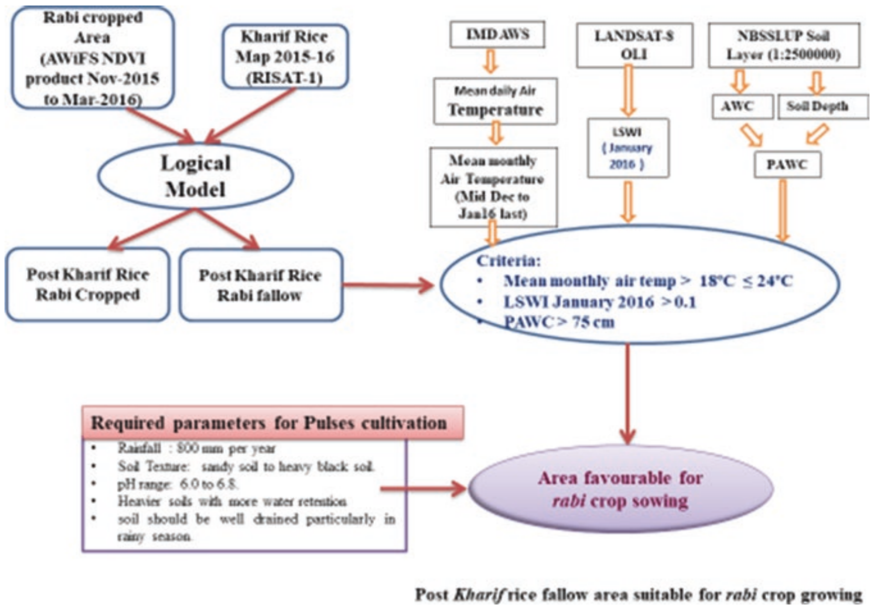

Fig. 6.3 Approach for suitability analysis of rice-fallow areas using remote sensing data

6.5.4 Assessing Suitability of Available Rice-Fallow Areas

The Department of Agriculture, Cooperation and Farmers Welfare (DAC&FW), Government of India initiated suitability assessment in eastern states through Mahalanobis Crop Forecasting Centre, New Delhi. Using remote sensing technique and satellite data with ground validation survey to identified rice fallow areas in Odisha, Chhattisgarh and other states using the following scheme depicted in Fig. 6.3.

6.6 Identification of Crops to be Grown in Rice-Fallow Areas in Different States

For each state the potential crops which can be grown in rice-fallow areas during suitable season were also identified based on the inputs from the earlier studies, on-farm trials and agro-ecoregion by the researchers (Table 6.11). The kind of climate resilient varieties developed in major pulses like chickpea, lentil and; early maturing in chickpea, pea, pigeon pea (including hybrids), and urdbean and matching integrated crop management technologies, the rice fallow area (substantial part of 11.6 m ha) available in different seasons can be brought under pulses. The release of short duration varieties of urdbean and mung bean crop intensification through

Table 6.11 Potential crops which can be cultivated in rice-fallow areas in different states

Crop	State
Lentil	Assam, West Bengal, Bihar, Odisha, Eastern Uttar Pradesh, Chhattisgarh and Jharkhand
Pea	Jharkhand, Chhattisgarh, Eastern Uttar Pradesh and Northern Madhya Pradesh
Chickpea	Chhattisgarh, Bihar and Jharkhand
Greengram	Odisha, Chhattisgarh, Jharkhand, Bihar, Andhra Pradesh, Tamil Nadu and Karnataka
Blackgram	Coastal Andhra Pradesh, Tamil Nadu, Karnataka and Odisha
Grasspea (*Lathyrus*)	Tal area of Bihar, Chhattisgarh and West Bengal
Cluster bean	Andhra Pradesh, Tamil Nadu and Karnataka
Lablab bean	Andhra Pradesh, Tamil Nadu and Karnataka
Mustard	Eastern Uttar Pradesh, Bihar and Jharkhand
Sesame/Linseed	Odisha, Chhattisgarh, West Bengal, Jharkhand
Groundnut	Char area of Bihar, Mahananda of Odisha, Brahmaputra valley of Assam and coastal Andhra Pradesh

Source: NAAS Policy Paper 64 (2013)

promotion of these pulses spring/summer cultivation; heat and drought tolerant varieties chickpea and lentil for rice fallow of Indo-Gangetic plains (IGP) including parts of Chhattisgarh and Madhya Pradesh; and extra-early/early maturing and urdbean varieties for peninsular and coastal belt have open doors for horizontal expansion of pulses.

6.6.1 Interventions to Harness the Potential of Rice-Fallow

It is well established fact that through technology and policy interventions untapped potential of rice-fallows area in India can be tapped. Improved agronomic technologies or technological interventions could possibly help in utilizing untapped potential of rice fallow. To ensure successful cropping system intensification in rice-fallow system, concentrated efforts are needed in the systemic management of the entire rice-based cropping system and promotion of technological interventions for utilization of rice fallows.

Wani and Sawargaonkar (2018) reported steps for improving system productivity in rice-based cropping systems that is affected by climate conditions such as rainfall and minimum daily temperatures. Since rain-fed lowland rice depends on the reliability and amount of rainfall, the growth of subsequent crops can be restricted by low and erratic rainfall. As a result, subsequent crops rely on residual moisture from the wet-season crops. In regions with high rainfall, farmers tend to postpone planting or provide surface drainage to avoid waterlogging. Since planting time is vital for the success of *rabi* crops, targeting the narrow planting window is important, and defined by the interaction between crop growth and environmental conditions. Many studies have shown that good management practices, including planting time adjustment, water management and tillage, could be used to maximize *rabi* season production. However, these practices are time-consuming and expensive. Therefore, Wani and Sawargaonkar (2018) proposed that rice fallow systems in Southeast Asia are intensified with FSF crops (grain legumes/dry season crops).

- The key factors for success in crop intensification is sowing time and the selection of appropriate FSF crops and varieties. The practice of direct seeding of rice helps to overcome the limitation of duration as it reduces the time to maturity and opens the window for the successful introduction of FSF crops during the *rabi* season. Rice varieties with a shorter duration (8–10 days) will also help in the successful utilization of residual soil moisture by *rabi* crops.
- Soil-fertility management must be considered along with water-stress management given the fragile nature of the soil resource base (Wani et al. 2009) particularly in rice fallows. Similarly, on-farm trials conducted in several states of India (Andhra Pradesh, Chhattisgarh, Gujarat, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Nadu and Uttar Pradesh) showed that yields significantly increased (30–120%) in various crops with soil amendments using micro- and secondary nutrients, which resulted in an overall increase in water and nutrient-use efficiencies (Wani et al. 2006, 2009). Similarly, studies on the cultivation of FSF crops in rice fallow revealed that these crops respond positively to balanced nutrient management inclusive of secondary and micronutrients.
- The overriding challenge for intensification in all is the availability of sufficient seed, particularly for short-duration chickpea. Chickpea is a crop that attracts little private-sector involvement because of its low seed-multiplication rate, its production being limited to the *rabi* season, and vulnerability to storage pests throughout the intervening rainy season. In addition, the seeds are bulky and difficult to distribute cheaply. Nevertheless, the current high market price for grain makes it attractive for smallholders if they have access to farm-saved or locally produced seeds. Therefore, the establishment of decentralized but assured quality seed banks, particularly those managed by women's self-help groups at village/block level to help alleviate poverty, needs to be promoted.
- To harness the optimum yield of FSF, crop establishment needs to improve, and the residual soil water after rice must be utilized efficiently. The success of crop establishment can be achieved by rapid germination through seed priming, and seed-soil contact. The strategy would be to develop a sustainable farmers' participatory seed production system for FSF, and promote improved agronomic management practices, such as seed priming, soil-test-based balanced fertilizer that includes micro-and secondary nutrients, biofertilizer, and integrated crop management for better crop establishment in rice fallow.
- Suitable rice cultivars need to be piloted and identified to help make use of residual moisture for the promotion of short-duration pulses during the *rabi* season. Experimental research and farmers' participatory demonstrations made in the

northern states of India (Chhattisgarh, Jharkhand and Orissa) showed that short-duration pulses, such as chickpea and black gram, are suitable for cultivation in rice-fallow areas and can achieve average yields from 700 to 850 kg per hectare, provided that suitable varieties and technologies including mechanization for crop establishment are made available. It is recommended that seed priming, which includes soaking seeds for 4–6 h with the addition of sodium molybdate to the priming water (with further refinement possible), and then sowing with minimum tillage at the optimum seed rate, is used as a simple and effective practice in relay cropping (Harris et al. 2002). Seed priming can enhance seed germination and, therefore, crop growth, plant stand and yield.

- Conservation agriculture/minimum tillage adopting direct seeded rice is recommended for rice cultivated as lowland crop on Vertisols and associated soils as the soil becomes hard, and farmers are facing difficulties with cultivation during the rainy season. During an ICRISAT initiative in central India on *kharif* fallow, it was found that there is a practice of fallowing Vertisols and associated soils in Madhya Pradesh, as well as central India, which accounts for around 2.02 million ha during the *kharif* season (Dwivedi et al. 2003). There is a direct relationship between consumptive water use or evapotranspiration (ET) and crop yield. ET comprises two major processes: non-productive evaporation and productive transpiration. Evaporation cannot be avoided completely but it can be minimized through various field-scale management practices.

- The three basic elements of conservation agriculture are:

  1. zero or minimum tillage without significant soil inversion;
  2. retention of crop residues on the soil surface; and
  3. growing crops in rotations appropriate to the soil-climate environment and socio-economic conditions of the region.

Resource conservation through use of its technology (RCT) could render higher soil moisture conservation, organic matter build-up and improvement in both soil structure and microbial population in these stressed soils. Crop cover, if retained on the soil surface in combination with suitable planting techniques, could alleviate terminal drought condition in pulses by conserving soil moisture and bring overall improvement in resource management. This in combination with minimum soil traffic (no-tillage and minimum soil disturbance) could lead to favourable effects on soil properties that further enhance the overall resource enhancement and productivity capacity in rice-fallows. This will enable reduction in cost of cultivation by resource savings (in terms of labour, time and farm power) besides enhancing input use efficiency and farm income. Rain-fed areas of the country- characterized by its complex nature, diverse and fragile ecosystem and distress prone production system play a key role in country's food production and economy.

On-farm trials on conservation tillage with short-duration soybean in Madhya Pradesh (Guna, Vidisha, and Indore districts) to intensify the *kharif* fallow areas using suitable landform management (broad bed furrow system with zero till planters) to sow the succeeding *rabi* chickpea with minimum tillage enhanced the cropping intensity and increased crop yields (40–200%) and incomes (up to 100%) using landform treatments, new varieties and other best-bet management options (Wani et al. 2008) through crop intensification.

Enhancing water-use efficiency (WUE) in agriculture (rain fed and irrigated) can be doubled from 35–50% to 65–90% with large-scale interventions of scientifically proven management (land, water, crop and pest) options. The *Pradhan Mantri Krishi Sinchayi Yojana* (PMKSY) scheme of the Government of India enabled the handling of green and blue water resources together by adopting holistic and integrated water management approaches (Wani et al. 2012) such as:

1. Efficient use of rainwater stored in soil as soil moisture (green water)
2. Conjunctive use of blue water through rainwater harvesting in farm ponds
3. Improved landform for efficient irrigation and water management
4. Protected cultivation of high-value crops
5. Soil-test-based integrated nutrient management
6. Improved crop management practices
7. Efficient irrigation using micro-irrigation
8. Zero-flood irrigation
9. Water-balance-based irrigation scheduling in place of calendar-based irrigation scheduling
10. Crop rotations and intercrops
11. Improved crop cultivars (drought tolerant and water efficient)
12. Integrated pest and disease management
13. Enabling policies and innovative institutional mechanisms
14. Organic matter amendments through *in situ* generation of green manuring and composting (vermicomposting and aerobic composting)
15. Improved irrigation method is essential as despite water scarcity in most farmers' fields in semi-arid tropic locations, water is carried through unlined open channels causing significant water loss. In India, farmers irrigate land rather than crops. The use of closed conduits (plastic, rubber, metallic, and cement pipes) should be promoted (Pathak et al. 2009) to achieve high WUE. Micro-irrigation, in general, is practiced for high-value and horticulture crops. Similarly, micro-irrigation in field crops, including rice-based cropping systems, should be promoted on a large scale to address the issue of groundwater depletion and water scarcity. Field trials in Raichur, Karnataka revealed that growth parameters improved significantly under sub-surface and surface drip irrigation with laterals spaced 60 cm apart. The highest grain yields of rice of 10.1 and 9.0 tons per hectare were recorded in direct-seeded paddies compared with transplanted rice under surface drip irrigation with laterals placed 80 cm apart and 60 cm, respectively (ICRISAT 2016).
16. Needs-based irrigation scheduling further enhance WUE and crop yields. Farmers, in general, adopt calendar-based irrigation scheduling irrespective of the variability in soil physical parameters (water-holding capacity, soil depth, etc.), resulting in either excess or deficit water application. A simple decision-making tool called the 'water impact calculator' (WIC) for irrigation schedul-

ing that requires simple data on the field and its management is developed that provides an irrigation schedule for the entire season as a per water-balance approach (Garg et al. 2016). An ICRISAT-led consortium with local partners (NGOs) and an irrigation company (Jain Irrigation Ltd.) evaluated WIC in farmer participatory field trials at different sites: Mota Vadala in Jamnagar, Gujarat; Kothapally in Ranga Reddy, Telangana; Parasai-Sindh watershed, Jhansi; Dharola Tonk, Rajasthan, and the ICRISAT research station, Patancheru, Telangana. Deep percolation losses in WIC-managed fields declined by 50–80% compared to calendar-based irrigation. Despite applying 30–40% less water, WIC-managed fields had comparable yields to controls. For example, at Mota Vadala, Gujarat, Jamnagar in 2011–12, the WIC-managed plot yielded 5.8 tons per hectare of wheat compared to 5.9 tons per hectare in the calendar-based irrigation plot; in addition, the drip irrigation plot (guided by WIC) yielded 6.3 tons per hectare. Normalization of micro-irrigation policy incentive

17. Guidelines are needed to reduce considerable time lag between the uptake of the subsidy and actual implementation.
18. Social engineering is critical and awareness raising among farmers that crops can be grown on residual soil moisture after rice was a major factor in promoting crop intensification in rice fallows (Joshi et al. 2002). Along with technology demonstrations, and bringing awareness to all stakeholders and policy makers, social engineering is needed to intensify crop production in these fallows by adopting collective action at the cluster level. For effective implementation and scaling-up of sustainable intensification of rice fallow systems, the development of effective monitoring and evaluation systems is required. These crop intensification technologies should be demonstrated on a pilot basis, followed by a phased-in scale-up to farmers' fields. The anticipated impacts of this initiative would be increased farm incomes and improved rural livelihoods, including enhanced nutritional status. Such initiatives would strengthen environmental benefits/ecosystem services,

In India, it has been estimated that about 11.65 M ha land remains fallow after harvest of rice in various parts of the country which offers huge potential for promotion of pulses (Table 6.10). The central India has maximum rice fallow area followed by eastern, costal and hilly region indicating that during both, rabi and kharif, seasons pulses can be promoted in rice fallows. These areas have a vast potential to cultivate low input and low water requiring upland pulse crops (such as lentil, chickpea, lathyrus and urdbean). However, depletion of soil moisture content following rice harvest affects timely sowing and receiving in of poor returns out of these ecosystems. Conservation agriculture through zero tillage, crop residue retention and crop rotation involving suitable genotypes influence pulses crop in rotation after rice. As per empirical estimates out of 11.65 M ha rice fallow area, about 2 M ha can be brought under various pulses mainly chickpea, lentil, lathyrus, pea, urdbean and mungbean. This area can easily contribute approximately 1.20 Mt of pulses to the total pulses basket of the country besides improving soil fertility and other physical properties of these soils.

In north eastern India in Jharkhand the scaled-up on-farm research showed that short-duration pulses are suitable for cultivation in rice fallow and yield as well, provided that suitable varieties and technologies (including mechanization for crop establishment) are available. Participatory trials in Jharkhand state, with the purpose of demonstrating and evaluating chickpea cultivars (KAK 2 and JG 11) in post-rainy fallow, yielded 1490–1520 kg per hectare for KAK 2 and 1280–1340 kg per hectare for JG 11. This indicates that chickpea is a suitable crop to grow after rice with the benefits of additional income and enhanced rainwater-use efficiency. An economic analysis showed that growing legumes in rice fallows is profitable for farmers, with a benefit-cost ratio of greater than 3.0 for many legumes. Such systems could generate 584 million person-days of employment for South Asia and make the region self-sufficient in pulse production (Wani and Sawargaonkar 2018). In several villages in the states of Jharkhand and Madhya Pradesh in India, on-farm participatory research trials sponsored by the Ministry of Water Resources, Government of India demonstrated enhanced rainfall-use efficiency with rice fallow cultivation, with total production of 5600–8500 kg per hectare for two crops (rice and chickpea). This increased average net income per hectare from INR 51,000 to 84,000 (USD 1130 to 1870) (Singh et al. 2010).

Further, two major cropping systems viz., relay cropping of pulses in standing rice, and crop rotation after harvest of rice have potential for popularization and adoption depending on agro-ecosystem involved. Yet, these constrained areas require an understanding of ecology, constraints analysis and situation specific remedies. Keeping these facts, some potential management considerations involving suitable pulses varieties, zero tillage, relay cropping, residue retention, mulching, seed priming, lifesaving irrigations and foliar sprays of nutrients were suggested that could help in improving pulses productivity under challenging rice fallow conditions. Government of India has targeted about 3.0 M ha rice fallow to bring under pulses cultivation (Table 6.12). This additional area under pulses is likely to contribute about 1.50 Mt of pulses.

With the initiatives of the Government of India, out of the potential total rice fallow area (TRFA) only 10% area could be brought under pulses contributing 4% to the total pulses production of the country. This can be increased substantially by bringing untapped rice fallow and increasing productivity through adoption of high yielding varieties insulated well against major biotic and abiotic stresses besides integrated crops management technologies. In this perspective, intensification of existing agricultural systems is need of the hour to take care of the rising demand of pulses in the country and there is an enormous opportunity to increase the total cropping area through strategic research in rice-fallows. These fallow areas are

Table 6.12 Area and production pulses through targeting rice fallow area (TRFA) scheme

(Area- million ha; Production million t)						
Crop	States/districts/villages	2020–21	2021–22	2022–23	2023–24	2024–25
Pulses						
Area	11 States	2.024	2.226	2.449	2.694	**3.00**
Production		2.024	2.226	2.449	2.694	3.00

suitable for intensification with a short duration (≤3 months), low water consuming grain legumes, *i.e.* chickpea, lentil, urdbean, mung bean, lathyrus etc., to improve the smallholder farmer's incomes and the soil health. The pulse crops are considered as main crop for strengthen of these fallow areas. Their productive utilization can overcome many social and economic problems of the region like unemployment, labour migration etc. At present, because of large gap between supply and demand of pulses, prices of pulse in country had imported a huge quantity. So as to meet up the rising needs of pulses, it should be included as an integral part in rice-fallows with the dual advantage of area expansion and sustainable production. Hence, promotion of pulse crops in these unutilized lands would improve the sustainability of rice cultivation in addition to attractive productivity and augments the incomes of farming community of regions. Rice fallow are widely distributed in rain-fed ecosystem.

6.6.2 Enabling Policies and Institutional Mechanisms for Mission Projects

6.6.2.1 Mechanization of Field Operations

Residual soil moisture in surface layer at the time of planting *rabi* crops is the major constraint in rice fallows. Relay cropping in standing rice is often practiced but with use of combine for rice harvesting, the option is now shifting for direct seeding using zero-till drill or turbo type Happy Seed drill which need to be designed for different situations. For harvesting and threshing, appropriate machines need to be designed and developed.

6.6.2.2 Scaling-Up Crop Management Practices

Tillage and plant population management, application of nutrients and weed management in *rabi* crops pose serious challenges in rice fallows. Early-maturing crop varieties, relay cropping, higher seed rate, seed priming, seed inoculation with rhizobium culture, seed pelleting, mulching, foliar spray of nutrients etc. are recommended practices which need to be further refined and standardized for different ecosystems. Work on development of short-duration, high-yielding varieties, appropriate seeding techniques, water harvesting and recycling, post-emergence herbicides, biotic and abiotic stresses etc. need to be strengthened.

6.6.2.3 Crop-Specific Information on Area Expansion

Based on bio-physical conditions, farm resources and market demand, likely coverage of area under each crop in different states/region need to be estimated. This would facilitate area expansion in phased manner by arranging critical inputs.

6.6.2.4 Periodic GIS Mapping

In order to monitor impact of R&D efforts on area expansion in rice fallows under different crops, cropping systems and soil health, periodic monitoring through GIS is required.

6.6.2.5 Creation of Community Water Reservoirs

Despite heavy rains during kharif season, soil moisture becomes the most critical limiting factor for raising second crop during winter as most of the runoff is wasted. It is, therefore, necessary to create farm pond and community water reservoirs in the area well supported by Government. This will serve as important source for life-saving and supplemental irrigation. Further, the loss of soil and plant nutrients from productive lands will be reduced.

6.6.2.6 Quality Seeds

Timely availability of quality seeds is often a major constraint for delayed planting and poor yields. Hence, community-based seed production programs need to be launched with appropriate processing and storage facilities. The national and state seed Corporations should strengthen their activities in these areas.

6.6.2.7 Ensuring Timely Availability of Other Critical Inputs

Traditionally, the winter crops on residual soil moisture are grown using local varieties without application of plant nutrients, bio-fertilizers, fungicides and other agro-chemicals due to their non-availability. Since crop productivity is the driver for area expansion, which in turn is influenced by better crop management, emphasis needs to be placed on timely availability of all critical inputs.

6.6.2.8 Marketing Infrastructure

Marketing plays a key role in enthusing farmers for crop production. Well organized marketing and processing of farm produce need attention.

6.6.2.9 Protection from Stray Cattle

Blue bull and other stray cattle cause heavy damage to pulses and thus discourage farmers to grow winter crops. Appropriate policies are needed to tackle this menace. To avoid crop damage by stray cattle, open grazing lands at *Panchayat* level should be earmarked. These activities should be the part of state level planning. Social fencing through farmers' participatory approach has been successfully tried in Jharkhand by Tata-ICRISAT initiative at Gumla (Wani and Sawargaonkar 2018) ensuring tangible economic benefit for the farmers.

6.6.3 Short-Term Strategies

- Strengthening seed delivery system by encouraging high-quality seed production of pulses.
- Price structure in the market will have to be derived by the Government much in advance to ensure reasonable profits to the pulse growing farmers to encourage them to take up pulses cultivation on a large scale.
- Easy and timely availability of critical input at nearby market.
- Effective procurement by arranging procurement centers close to producers.
- Skilling of pulse growers on modern production practices with help from KVKs/SAUs/International and National Research Institutes.
- Efficient crop insurance mechanism focused on pulses growers.

6.6.4 Medium-Term Strategies

- Expansion of area under pulses by utilizing fallow lands and reclaimed wastelands for pulses production.
- Forming Farmer-Producer Organizations (FPOs) for value addition through processing of pulses and shortening of the value chain.
- Customization and development of farm equipment, including app-based hiring.
- Setting up of storage and warehousing in rural areas.
- Foresight for international trade, with tools to predict market demand/supply.

6.6.5 Long-Term Strategies

- Developing short-duration and pest- and disease-resistant cultivars.
- Integrating pulses into the public distribution system (PDS) to ensure minimum consumption by poor households even during scarcity.
- Creation of informal seed village system, where farmer to farmer seed production and distribution chain will ensure easy availability of quality seed.
- It would be profitable to have Dal milling industry instituted between groups of villagers so that proper milling is done soon after harvesting and storage is made of split pulses (Dal) rather than whole seed.

- The National Food Security Mission (NFSM) outlines policy packages involving field demonstrations of best farming practices, incentives for adoption of modern technologies, and resource conservation and management practices.
- In the past 6 years, the Government has continued to increase the MSP of kharif pulses by over 45% and that of rabi pulses by 50–60%. However, it will take much more than these incentives for India to achieve self-sufficiency in pulses.

6.7 Journey of Pulses Mission Project

6.7.1 Establishing Seed-Hubs Across the Country

In India, formal and informal both seed systems co-exist, still more than 80% of the farmers rely on farm-saved seed for pulse crops. The informal seed system is mainly based on farm-saved seeds of local or improved varieties. The informal seed system often lacks strict quality control. In the informal seed system, the seed is mainly produced by non-governmental organizations (NGOs), farmers' cooperatives, seed growers' associations, individual progressive farmers, farmer producer organizations (FPOs), farmers' groups etc. This often led in availability of poor quality seeds of pulse crops. Government of India is fully aware of its responsibility to increase quality seed supply in major pulse growing regions therefore established 150 Seed-Hubs with funding support through Department of Agriculture, Cooperation and Farmers Welfare (DAC&FW), Ministry of Agriculture and Farmers Welfare, Government of India. The two schemes namely, *"Creation of seed hubs for increasing indigenous production of pulses in India"* and *"Enhancing breeder seed production for increasing indigenous production of pulses in India"* were launched through Indian Council of Agricultural Research (ICAR) in 2016–17 for increasing supply of quality seeds to boost pulses production and productivity. These schemes helped in ensuring quality seeds (additional breeder seed, foundation and certified seeds) besides training human resources for pulses production sector. Later, several policy initiatives to increase production of pulses emanated through wider consultations and many critical interventions were planned (Table 6.13).

6.7.2 Other Developmental Strategies

The potential also exists for promotion of minor pulses (Table 6.14) in different agro-ecologies and seasons as most of these have inbuilt climate resilience.

- ***Incentives for production and distribution of certified seeds*:** Instrumental both in varietal replacement as well as area expansion.
- ***INM/IPM*:** To ensure availability of quality bio-inputs-rhizobium culture/PSB, micro-nutrients, bio-intensive/bio-pesticides etc.

Table 6.13 Recent policy initiatives/interventions taken (2015–16 to 2017–18)

S. no.	Interventions/initiatives	Year of inception	Remark
1.	Enhanced allocation-NFSM Pulses	2015–16	>50% of total NFSM allocation
2.	Additional Allocation (Spring/ Summer Pulses)	2015–16 2016–17 2017–18	In addition to regular *rabi* programme
3.	Modification in scheme Bringing Green Revolution in Eastern India (BGREI- Pulses) for area expansion under pulses in rice fallow	2015–16	To include cluster demonstration under cropping system approach in rice fallows involving pulses.
4.	Cluster Front Line Demonstrations (CFLDs) through ICAR/KVK	2015–16 2016–17 2017–18	Promotion/adoption of new varieties ICAR-IIPR: 0.98 Crores Since 2016–17
5.	Minimum Support Price (MSP) enhanced substantially	2015–16	(Chickpea, lentil) -Marketing season 2016–17
6.			
(a)	Enhancing Breeder Seed Production (EBSP) (8 states/12 locations)	2016–17 to 2018–19	To increase BSP from 10,000 qtls. to 14,000 qtls. (2016–17), 15,000 qtls. (2017–18) and 16,000 qtls. (2018–19)
(b)	Seed Production Incentives (To increase SRR/VRR)	2016–17 2017–18	@Rs. 2500 per qtls. on <10 years old varieties
(c)	Pulse Seed Hubs (24 states/150 centres)	2016–17 to 2018–19	150 Nos. @ 1000 qtls. per seed hub annum seed production target.
(d)	Pulse Seed Minikits distribution (To ensure varietal Replacement)	2016–17	For 0.4 ha demonstration (Urdbean, Mungbean, Pigeonpea @ 4 kg; Chickpea @ 16 kg; Lentil @ 8 kg)
(e)	Seed Village Programme	2017–18	(29 states, 638 districts) 60,000 villages, 1.955 million farmers
7.			
(a)	Increased Cluster demonstration *(for bridging the yield gaps)*	2015–16 2016–17	2015–16: 0.51 Mha 2016–17: 0.55 Mha
(b)	Promotion of minor pulses (Rajmah, Cowpea, Fieldpea, Horsegram etc.)	2016–17	ICAR to Strengthen breeder seed production and identification of varieties *(for exploiting minor pulses) (for bridging the yield gaps)*
(c)	CDP (Pigeon pea on rice bunds) (Target: 0.02 Mha)	2016–17	Area Expansion
(d)	CDP (demonstrations on Ridge and Furrow cultivation, summer mungbean, pigeon pea transplanting and intercropping)	2016–17	Popularization of Good Agricultural practices (GAP)
(e)	Critical Irrigation (Provision of irrigation under PMKSY, 50% allocation reserved for pulses)	2016–17	Sprinkler sets and water carrying pipes (to Improve Water use efficiency (WUE)

(continued)

Table 6.13 (continued)

S. no.	Interventions/initiatives	Year of inception	Remark
8.			
(a)	Loan against warehouse receipts (Pledge Loan)	2016–17	Interest free loans against warehouse receipts
(b)	MSP and Procurement (Credit guarantee raised from Rs. 9000 Cr to Rs. 19,000 Cr)	2016–17	4.557 Mt. Rs. 10.57 Cr
9.			
(a)	Advisory on pulses (monthly)	2016–17	DPD, Bhopal – IYOP 2016 celebrated with training pamphlets on all pulses in Hindi/English languages
(b)	Creation of IT based information portal (https://dpd.gov.in)		IYOP 2016 round the year trainings/workshops were organized. Pulse Bulletins/pamphlets (bilingual) developed and distributed across the country.
10.	Effective monitoring	2015–16 onwards	Senior Officers Meeting (SOM) under the chairmanship of Secretary, DAC&FW- weekly. Committee for monitoring actions of road map- under the chairmanship of CEO, NRAA, Govt. of India- fortnightly & monthly. Video Conferencing by DAC&FW- weekly. CDDs Review Meeting under the chairmanship of JS (Crops) – bimonthly. National Level Monitoring Team visits in the states under the leadership of Director, CDDs – all crop seasons by CDDs. Monthly field visits by CDDs & consultants. Field visits/monitoring by Director, ATARI; DES (SAUs), Director, IIPR. ICAR-AGM on pulses/interface/seminar/workshop/meetings by Directorate of Pulses Development, Bhopal. Monitoring of seed minikits distribution and FLD/CFLD by CDDs. Monitoring of Seed Hubs, EBSP by CDDs.
11.	Soil test based promotion of INM/IPM	2015–16	2015–16: 2.90 Mha 2016–17: 4.10 Mha
12.	Targeting Rice Fallow Area (TRFA) (Area Expansion)	2016–17	06 eastern states of Assam, Jharkhand, West Bengal, Chhattisgarh, Bihar, Odisha

(continued)

Table 6.13 (continued)

S. no.	Interventions/initiatives	Year of inception	Remark
13.	FPOs – Value Addition Chain Development (Marketing/Value Addition)		11 States (119 FPOs on pulses)
14.	Enhanced MSP of Pulses	2015–16 to 2017–18	The growth rates >4% in all five pulses
15.	EXIM policy	2017–18	Government has imposed import duties on pulses for the first time in this decade. All varieties of pulses, including organic pulses, have been made 'free' for export.
16.	District Agriculture Contingency Plan (DACPs) involving pulses	2016–17	By CRIDA involving 46 SAUs and 8 ICAR institutions. 676 districts.

Source: Pulses in India: Retrospect & Prospects-2018

- ***RCT/CHCs***: To reduce cost of cultivation and timely operations in rain-fed areas where >80% pulses are grown, availability of implements like seed drills, zero-till seed machine/rotavators and ridge-maker etc., ensured through Resource Conservation Technology (RCT) components and Custom Hiring Centres (CHCs).
- ***PMKSY***: In view of favorable response of pulses to 1–2 critical irrigations, priority was given to pulses in tune MIDH/Micro-irrigation scheme under PMKSY.
- ***Value Addition***: For processing and value addition, domestic milling support provided through mini dal mills under local initiative/flexi fund component various states including UP., Gujarat, and Maharashtra.
- ***CSBTs***: To ensure effective transfer of technology, Cropping System Based Trainings (CSBTs) were provided to extension workers. Quality cluster demonstrations, both on sole crop and CSBDs were organized which helped in bridging the yield gaps.
- ***Field days/Kisan Sangosthi***: Strong Interface mechanism between State Department of Agriculture and State Agricultural Universities (SAUs), ICAR and KVKs were developed through seminars/workshops/Annual Group Meetings of ICAR etc.
- ***Effective Monitoring***: Robust monitoring and field visits in all 638 NFSM districts across the country and comprehensive approach in implementation of programme, including all components from seed to post-harvest management, marketing aspects and capacity building etc., yielded wonderful results.
- ***Extension/Publicity***: Dissemination of information through Literature on Pulses (bulletin/leaflet and articles) in both languages by print media as well as digital (dpd.gov.in/Farmers portal/mKisan Portal) including advisories on pulses on monthly basis by the Department including Directorate of Pulses Development, Bhopal.

Table 6.14 Potential minor pulses and their uses ensuring human and animal health

S. no.	Name of the pulse crop	Direct or indirect (whole grain or after processing) uses
1.	Lathyrus (Khesari)	Popularly known as chatri is consumed as dal in eastern and central India. Excessive consumption creates flatulence but is a drought hardy crop. Processing helps in reducing neurotoxins and other antinutritional factors.
2.	Dry bean (Rajmash)	Whole grains are consumed as vegetables and makes good combination with rice. Consumption helps in weight loss, promote heart' health, and maintain blood sugar levels. Immature tender pods are also consumed as vegetables.
3.	Horse gram (Kulthi)	Sprouts, pods and grains are consumed. Consumption as dal or vegetable prevents constipation and eradicates toxins present in gut besides reducing the chances of high blood pressure, heart disease and high cholesterol.
4.	Moth bean (Moth)	Grains contain higher proportion of albumin and glutamine fractions of protein and also good source of lysine and leucine. Roasted grains/flour are used for preparation of a number of delicious confectionary items (papad, mangori, bhujia-salty snacks, etc.).
5.	Cowpea (Lobia)	Whole grains are consumed after cooking and for preparation of salty snacks. Consumption helps in improving digestion, detoxification of the body, managing diabetes, treating insomnia and ensuring better blood circulation.
6.	Broad bean (Bakla/Faba bean)	*Immature tender pods and grains are consumed as vegetables. Grains are* rich in folate and B *vitamins*, thus helps in nerve and blood cell development. Excessive consumption causes flatulence.
7.	Rice bean (Gahad)	Whole grains or splits are consumed with rice or chapati/roti in our country. Grains have high quality protein with all essential amino acid in balance manner. Among the minerals, it contains calcium, iron, zinc and potassium with high bio-availability of calcium
8.	Adzuki bean	Consumption of grains after soaking, sprouting and fermenting is linked to several health benefits, like improving heart health, digestion, weight loss, lowering risk of diabetes. Grains are rich in protein, fiber, vitamins, minerals etc.
9.	Winged bean	All plant parts like leaves, stems, flowers, seeds, tubers, etc. are edible in one or other form. Grains have large amount of essential nutrients, protein, complex carbohydrates, B vitamins, calcium, iron and fiber. The high dose of antioxidant present in grains helps in maintaining elasticity of the skin and keeps it looking young.
10.	Hyacinth bean	The grains, tender pods, leaves, flowers, and roots are eaten in different ways. The grains are used as medicine to prevent pregnancy, and consumption helps in preventing diarrhea and stomach disorders.
11.	Jack bean	The beans are mildly toxic, and copious consumption is harmful and must be avoided. Boiling of grains in water reduced toxicity. Young foliage is also consumed as green vegetable and entire plant is good source of nutritious.
12.	Sword bean	The young green pods and immature grains are consumed after cooking as vegetable.
13.	Zombi pea	Mature grains boiled and consumed by the tribal people living in the hilly region of Maharashtra. L-Dopa, present in grains used as *medicine* to parkinsons disease. Consumption helps in preventing liver disorders, rheumatisim, infection of nervous system, etc.

- ***CFLDs*****:** In 2015–16, All XI – ATARI's/578 KVKs were involved in conducting of Cluster Front Line Demonstrations (CFLDs) of pulses with need based thematic areas on farmers' field.
- ***Seed Minikit*****:** In 2016–17 Seed minikits programme of newer varieties of pulses was initiated to popularize improved varieties of pulses.
- ***Research & Development*****:** Applied and Action-Research Projects to ICRISAT, ICARDA, ICAR/SAUs to address biotic and abiotic stress/assessment and providing varieties /recommendations.

6.8 Way Forward

Government of India was fully aware of its responsibility, therefore launched several schemes for the promotion of pulses cultivation to arrest protein malnutrition among largely vegetarians. The role of pulses in agrarian economy is vital as >40 *per cent* human population and 2/3rd live-stock come from the rain-fed regions of the country. It has been noticed that still pulses are generally produced on poor soils that is not suited to other crops with seldom use of agro-chemicals including fertilizers in major growing areas. Pulses are vital constituent of cropping systems under rain-fed ecologies and consumption pattern for different pulses is uncommon from one to other states. Of the total net sown area of 141.40 Mha, 73.20 Mha is rain-fed where as high as 90% of nutri-cereals (millets), 80% pulses, 74% oilseeds, 65% cotton and 48% rice crops are grown. It is a challenge for the researchers and policy makers to meet demand of pulses for domestic consumption as these crops are primarily cultivated under rain-fed condition in poor soils and are prone to soil moisture stress and other abiotic stresses. To meet the domestic demand of pulse requirement and ensure self-sufficiency in pulses, a sustainable production and productivity has to be maintained with the multi-pronged short-term and long-term strategies. As agriculture growth is limited, imports may help to improve the supply situation in the short-term whereas, the long-term measures would need to focus on sustainable production system with increased productivity envisaging public capital formation in irrigation, enhancing availability of quality seeds of promising varieties, investment in research in targeted areas improving water productivity and nutrient use efficiency besides bringing down cost of cultivation through development of machine harvestable varieties and other cost cutting technologies. On research front efforts will be required for enhancing genetic gain and reduced vulnerability to pests, diseases and weather vagaries so that climate resilient varieties can ensure stable yields under unfavorable situations with suitable management options. Huge potential for area expansion under pulses through cultivating rice-fallows must be harnessed through innovative scaling-up of integrated approach as adopted by the government.

The other important strategy need focus is investment in farm mechanization, especially for planting and harvesting of the crop to reduce cost of cultivation. Further, restructuring plant types for combine harvesting, enhancing photosynthetic efficiency, and ease in application of plant protection chemicals, and enhanced nutrients acquisition and use efficiency will help in increasing income from per unit area of cultivation. Government is investing in farm mechanization and promoting line sowing for maintaining optimum plant population, strengthening micro-irrigation (drip/sprinkler/water carrying pipes) etc., for improving yields. Further, critical irrigation support has been provided through National Food Security Mission (NFSM) and Pradhan Mantri Krishi Sinchayee Yojna (PMKSY-a scheme for ensuring water for irrigation) to cover 20% of total pulse area under irrigation.

The major social issue is very peculiar and specific to the Indo Gangetic plains (IGP) in *rabi* and Bundelkhand region of the Uttar Pradesh and Madhya Pradesh during *kharif* is the menace of large scale grazing by the blue bulls and stray cattle. There is need to change the policies and provisions regarding protection of wild life where Acts are prohibiting killing of these animals. Thus, there is a huge possibility and potential of bringing innovative solutions to save the pulses crops and encourage more intensive promotion of production technologies.

The achievements not with-standing, there still remain a large untapped yield potential reservoir for the exploitation of which mission has to step-up its efforts further. A gap between the potential yield that can be achieved at farmer's field level and what they actually get is very wide. Bridging this yield gap offers an opportunity to produce more even by using the available technologies. To meet the challenges faced by the pulses sector, government has given emphasis on research efforts for developing biotic stress resistant and stress tolerant varieties, to be encouraged along with public-private initiatives for better logistics planning and handling of pulses. Newer varieties of pulses need to be developed so that the crop cycle fits well into cropping systems that the farmers adopt and takes during the year.

It is learnt that the success is likely to remain sustainable owing to 100% implementation of Direct Benefit Transfer Mode (DBT) under Crops Development Programme (NFSM-Pulses). The assistance towards critical inputs has been ensured in the accounts of the beneficiaries through various social schemes (SCP/TSP/Woman/SMF categories). A large section of farmers'/pulse growers are happy with the DBT and the assistance provided is being utilized in real sense. These efforts and positive policy support will certainly boost pulses production in rice fallow areas and in other parts of the country.

6.8.1 Required Policy Support

Policy support is required in terms of investment in research and development in making market available for pulses. Reducing post-harvest losses through refinement and popularization of combines, harvesters, threshers and graders; development of stored grain pest resistant varieties; popularization low cost safe storage bins/structures/processing units; strengthening of FPOs will be rewarding. Similarly, announcement of remunerative MSP well in advance before sowing; assured procurement and creation of procurement centres in production zones; development of organized markets for pulses; linking farmers with FPOs, aggregations and e-NAM (markets); promotion of export of pulses like lentil and kabuli chickpea and arid legumes; production of value added products and use of by-products; branding of produce and promotion of organic pulse production are likely to promote pulses industry.

At the same time efforts towards ensuring timely availability of quality bio-pesticides; creation and sustaining production units of quality seed, bio-fertilizers and bio-pesticides; fortification of fertilizers with specific nutrients like S, Fe, Zn, B etc.; popularization of sprinklers and micro irrigation techniques in rain-fed areas; establishment of single window input supply centres for cluster of villages; advanced forewarning and forecasting systems for pest and disease outbreaks; creation of processing and storage facilities, organizing massive stakeholders trainings, exposure visits and close interaction with research organizations, SDAs and private agencies; branding of local germplasm e.g. in case of pigeonpea, Kalburgi Tur dal in Karnataka and Baigani Arhar in tribal belts of Madhya Pradesh are likely to add more pulses in food basket.

It is expected that additional 2 m t of pulses can be added to Indian pulses basket from rice fallows of IGP and peninsular India. In addition, development and popularization of improved varieties of pulses and oilseeds suiting to rice fallows of different agro-ecological regions coupled with improved agro-technology will boost production, and thus improve income and livelihood security of farming community. Further, introduction of legumes can provide a sustainable production base to the continued rice mono-cropped system leading to decline in total factor productivity and also provide much needed nutritional security. The status, strength and strategies to promote pulses cultivation in rice fallow of Indo-Gangetic plains, peninsular and central India has been discussed here. Efforts have been made to discuss about the policy support from the government in terms of declaring remunerative minimum support price (MSP), and procurement at MSP, strengthening seed chain and creation of 150 Seed-Hubs to ensure quality seed supply locally and develop human resources, etc. in present article.

6.9 Summary

Eradicating hunger and malnutrition is one of the great challenges of our time. Almost 1/3rd population suffer from malnutrition. As the 17 global goals of the world Food Program 2015, SDG2: Zero Hunger-pledges to end hunger, achieve food security, improve nutrition and promote sustainable agriculture. The current population (2018) of the country is 1.36 billion which is expected to be 1.51 billion by 2030. To feed 1.51 billion population, the projected demand of pulses by 2030 is likely to be 35 Mt as per the behaviouristic approach (consumption: 28.70 Mt + seed post-harvest losses: 5.72 Mt) which will require an annual growth rate of 3.57 *per cent*. To meet the projected demand of 35 Mt of pulses by 2030 the existing (2017–18) productivity (835 kg/ha) shall have to be raised to 1030 kg/ha in addition bringing additional area under pulses (5–6 M ha) over the existing normal area (27 M ha). It indicates that there is need to have average growth in area and productivity to the tune of 1.7% and 1.95%, respectively. At the same time efforts are required to bridge yield gaps existing between the present level of productivity and potential harvestable yields as demonstrated through FLDs.

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Chapter 7
Sustainable Intensification and Diversification of Cropping and Food Systems Through Lentil and Grass Peas in South Asia

Ashutosh Sarker, Nigamananda Swain, Rajib Nath, Rajendra Darai, and M. Omar Ali

Abstract Increase in agricultural production can be achieved through higher productivity and intensification through potential use of 4–5 million ha (out of 15 million ha) rice-fallows in Bangladesh, India and Nepal. Pulse crops, like lentil, grass pea, chickpea, pea, mung bean and black gram were successfully grown on residual soil moisture after rice crop. Growing pulses in this mono-cropping system increased cropping intensity, additional income, and contributed to nutritional support. ICARDA and its South Asian partners developed and deployed technologies such as short duration lentil to avoid terminal drought (Moitree, HUL 57, KLS 218 and L4717 in India; BARI Masur 5, BARI Masur 6 and BARI Masur 7, BINA Masur 7, BINA Masur 10 in Bangladesh; and Shital, Simal, Khajurah 3 and ILL 7723 in Nepal with 560–1322 kgha^{-1} yield), and low-toxin grass pea cultivars (Ratan, Prateek, Mahatiwara Nirmal and Bidhan Khesari 1 in India, and BARI Khesari 2, BARI Khesari-3 in Bangladesh) benefitting >550,000 farmers from 85,000 ha fallow lands.

Keywords Rice-fallow · Pulses · Cropping intensity · Nutrition security

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7.1 Neglected and Under-Utilized Legumes (Lentil and Grass Peas)

Food legumes play an important role in farming and food systems in South Asia since time immemorial. They provide an important opportunity to contribute to food and nutrition security in a sustainable way through intensification and diversification of agricultural production systems. This group of food crops is an integral part of the daily diet of the people in the region. Despite their contribution to human and animal health, and in improving soil health for sustainable cereal-based systems, little attention has been paid to improve grass pea and lentil crops. Generally, research for development on rice, wheat, maize, potato and a few major food legumes received attention by policy makers and scientists. The era of green revolution virtually addressed higher productivity, modified plant architecture, resistance to key biotic and abiotic stresses for rice and wheat as high-input agriculture to attain food security at the cost of other crops in cropping systems. Among food legumes, chickpea, pigeon pea and mungbean received due attention in technology development and delivery. However, the potential of lentil (*Lens culinaris* Medikus subsp. *culinaris*) and grass pea (*Lathyrus sativus* L.) has not been exploited to a greater extent, although research is underway at national systems in the region and at the International Center for Agricultural Research in the Dry Areas (ICARDA).

Grass pea and lentil are regarded as neglected, unattended and orphan pulse crops, but important for small farmers and low-income consumers in South Asia. They are domesticated for human needs along with other legumes since Neolithic agriculture in the Fertile Crescent of Near-East (Cubero 1981).Grass pea has multifarious uses—seeds and tender twigs for human food, green fodder and residues for animal feed, and it improves soil heath by incorporating nitrogen, carbon and organic matter. Grass pea can be grown on a wide range of soil types, tolerates moderate salinity and is highly resilient to drought, water logging, diseases and insect-pest attacks. When other crops fail due to adverse edapho-climatic conditions, grass pea can be the only available survival crop during food crisis/famines (Mehra et al. 1993). Lentil and grass pea are excellent source of protein (up to 35%) and other essential nutrients to support human health. In South Asia, they are eaten mainly as Dahl (concentrated soup) in rice-grass pea, rice-lentil popular dish, and in preparation of various snacks from flour. Grass pea twigs are palatable leafy vegetables, promotes cash earnings by farmers.

Lentil and grass pea require less inputs to cultivate, and many a times input is only the seed, thus their cultivation cost is low. Grass pea is mainly cultivated as a relay crop in rice field without any tillage operations. However, despite many desirable attributes/facts, the crop has an ambivalent reputation. Its plant parts including seeds contain a neurotoxin, β-N-oxalyl-L-2,3 diamino-propionic acid (ODAP), excessive consumption of which causes neuro-lathyrism, particularly to young males (Haque et al. 1993). Therefore, cultivation of low-ODAP/ODAP-free varieties and their consumption is recommended.

With shortening of growing period in the region due to climate change effects, both lentil and grass pea require early maturing varieties (<110 days for lentil and <120 days for grass pea). Research efforts are underway at national and international levels to develop phenologically adapted varieties for short-season environments without yield penalty. In this context, several early maturing lentil varieties with resistance to key diseases and grass pea varieties with high biomass and low-ODAP contents have been released in Bangladesh, India and Nepal. Many of such farmer-preferred varieties are under scaling-up programs to reduce yield gap in traditional cropping systems to enhance productivity, and for rice-fallow systems to increase cropping intensity in rice mono-cropping. About 15 million ha have been identified as rice-fallow systems in South Asia (NAAS 2013), of which about 4.5–5.0 million ha can be brought under pulses cultivation. Presently, lentil is grown in about 2.1 million ha and grass pea in 0.75 million ha in Bangladesh, India and Nepal, and the productions are used to meet domestic demands except in Nepal which exports small-seeded lentils to Bangladesh and the Middle-East countries. Considering nutritional, economic and cultural benefits, large-scale cultivation of lentil and grasspea are warranted.

7.2 Role of Lentils and Grass Peas in Sustainable Food Systems

Lentil is a popular and staple food legume crop in eastern Indian states (eastern UP, Bihar, MP, West Bengal, Assam, Tripura, Meghalaya, Manipur, Arunachal states in India), Bangladesh and Nepal, predominantly eaten in rice-lentil dish. It is also used in '*Bori'* making which can be stored for a year to use for preparation with vegetables. The whole lentil is used to prepare popular snack like '*Dal-mooth*'. Similarly grasspea is mainly used as '*Besan*' to prepare various delicious snacks besides split dahl which is used in rice-grasspea dahl dish. Generally, tribal, small and marginal farmers with less land holdings grow grass pea for family consumption and used by low-income consumers for its low price compared to other pulses in markets**.**

When we talk about food security, it is the nutritional security to maintain good health. Food legumes in general are known as "poor man's meat" because of their high protein content (up to 35%) and regarded as 'house of nutrients'. In general, the poorer and vegetarian segment of society in South Asian countries cannot afford animal products for nutritional requirements due to their high price. These crops also contain a high proportion of macronutrients and micronutrients (Ca, P, K, Fe, Zn), vitamins (niacin, Vitamin A, ascorbic acid, Inositol), fiber, and carbohydrates for balanced nutrition (Grusak 2002). Pulse crops are rich in lysine, an essential amino acid, which is low in cereal protein. On the contrary, Sulphur-containing essential amino acids (methionine, cystine, and tryptophan) are high in cereals and low in legumes. Therefore, the intake of cereal and legumes (which are traditional foods in South Asian countries) together give complementarities in amino acid balance in foods. Nutrition from pulses also lowers cholesterol level, and their carbohydrates are good for diabetes. Among food legumes, lentil and grass pea are contributors to nutritional security in South Asia.

7.2.1 Identification and Genetic Improvement

Lentil and grass pea germplasm prevailing in South Asia have inherently narrow genetic base with respect to yield contributing, agro-morphological traits, and resistance to prevailing biotic and abiotic stresses (Sarker and Erskine 2006).The genebanks in Bangladesh (Bangladesh Agricultural Research Institute), Nepal (Nepal Agricultural Research Institute) and India (National Bureau of Plant Genetic Resources) have about 6400 lentil and 4210 grasspea indigenous accessions. About 13,550 lentil accessions and 3400 grass pea accessions are in repository of ICARDA gene-bank, collected from global sources including the Center of Origin and Primary diversity of lentil and grass pea containing precious genes/alleles/QTLs to use by breeders globally. They are the building blocks of genetic enhancement of these crops using conventional breeding methods. Relevant germplasm and breeding lines from ICARDA with exotic genetic make-up are shared with the breeding programs in the region through international nursery network.

In early days, varieties were developed mainly by selection from landraces, adapted to site-specific agro-ecologies. Cross-breeding programs are underway using local and exotic genetic materials to develop stable and high yielding varieties of lentil and grass pea. To date, several dozens of lentil varieties have been released for commercial cultivation in Bangladesh, India and Nepal of which 11 varieties in Bangladesh; 15 varieties in India and 11 varieties in Nepal have emanated from ICARDA-supplied exotic genetic materials. Besides, five low-toxin grass pea varieties in Bangladesh, 5 in India and 2 in Nepal have been developed using combinations of local and exotic germplasm. Many of the farmer-preferred varieties are in up-scaling programs across the countries for intensification and diversification of rice-based production systems. For example, BARI Masur-4, BARI Masur-5, BARI Masur-6, BARI Masur-7, BARI Masur-8,BINAMasur-7, BINAMasur-10 lentil varieties and Barikhesari-2, Barikhesari-3, Barikhesari-4 and Barikhesari-5 in Bangladesh; HUL-57, KLS-218, IPL-81, NDL-1, IPL-316, IPL-220, PL-6, PL-8, Moitree, Subrata, RVL-31, JL-3, IPL-406 lentil varieties and Ratan, Prateek, Mahatiwara, Nirmal and Bidhankhesari-1 in India; and Simal, Shekhar, Shital, Khajurah masuro-2, Khajurah masuro-3, Khajurah masuro-4, kalomasuro, ILL 7723 lentil and CLIMA-Pink grasspea varieties in Nepal are in up-scaling programs. Some of the lentil varieties are biofortified with Fe and Zn and performing well under rice-fallow cultivation having desired root traits and matching phenological adaptation.

7.2.2 Gaps and Development of Technologies for Sustainable Production

Although several varieties of lentil and grasspea along with their matching production technologies have been recommended, there still lies gaps in technology generation. Some of the previously varieties could not fit in short-season environments due to delay in maturity, were subjected to terminal heat and drought stresses. In vast majority pulse-growing areas, late-maturing rice varieties as preceding crop are still grown by farmers, where late-planting potential lentil and grasspea varieties are required. Such lentil and grass pea varieties along with production package are very limited in the hands of farmers which need attention of researchers. In many instances, farmers are unable to adopt recommended package due to their economic situation and unavailability of required inputs in time.

Treated as "orphan crops", pulse production is also constrained by less availability of good quality seeds of improved cultivars. This situation is mainly due to the lack of a formal seed multiplication system. The current Varietal Replacement Rate (VRR) and Seed Replacement Rate (SRR) are negligible. Therefore, the need for improved and high-quality seed is essential for their adoption and yield improvement at the farmer's level. Likewise, in the absence of formal seed delivery systems, non-governmental organizations and local farmer associations should play a significant role in seed production and distribution. At present, the use of improved varieties is not extensive, but there is plenty of scope, because farmers are quite responsive to the new varieties. In a recent study it has been reported that farmers in the region are less aware of improved pulse technologies, as mostly they concentrate on major cereal crops. Participatory Rural Appraisal (PRA) reveals that farmers do not practice improved production technologies, make negligible use of essential inputs, and are unaware of post-harvest processing and storage. Therefore, empowering farmers with new knowledge/information and skills is essential.

One of the major constraints in expanding pulse cultivation is the low degree of mechanization of these crops. The whole process of pulse production is labour-intensive. Therefore, mechanization of field and post-harvest operations are needed. The use of appropriate farm machinery in production will make farming more efficient and enable farmers to diversify cropping by growing more crops. Through working with national partners, it has been documented that the use of Conservation Agriculture (CA) technology (zero-tillage, reduced-tillage) is very much applicable in pulse crops in the region. Farmers are keen to use the technology as it substantially reduces cost of cultivation.

Production systems need to be diversified with lentil and grass pea among other pulse crops, instead of the rice-rice and rice-wheat systems, which have been operating in the region for the last few decades. Indiscriminate use of fertilizers (mostly N-fertilizer) and insecticide has led to poor soil health, stagnancy in yield, high cost of production, and low return from the above systems. Farmers and governments in the region have recently shifted to the concept of crop diversification and intensification based on the principles of integrated crop management practices, where lentil and grass pea have inherent advantages.

Overall, R & D gaps can be addressed through dissemination of information on appropriate crops and varieties, soil health, water management, agro-techniques, pest management, mechanization, quality seed production and distribution, etc. Furthermore, there is a need to identify major research gaps for each intervention at farmer level and the proven results will kelp in refining the need-based technologies for diverse ecosystems.

7.2.3 Building Partnerships for Popularizing

Research and development partnerships are key to develop, delivery and popularization of innovations/technologies to realize higher productivity and production of lentil and grasspea. Beside available technologies for scaling, there should be continuous flow of new technologies for sustainable production. Research partnership on lentil and grasspea improvement has been established with the Bangladesh Agricultural Research Institute (BARI), Bangladesh Institute of Nuclear Agriculture (BINA) and Bangladesh Agricultural University (BAU) in Bangladesh; Indian Institute of Pulses Research (IIPR), Indian Agricultural Research Institute (IARI), *Bidhan Chandra Krishi Vishwavidyalaya* (BCKV),*Indira Gandhi Krishi Vishwavidyalaya (IGKV),* Odisha University of Agriculture and Technology (OUAT) in India; and National Grain Research Program (NGRP) of Nepal Agricultural Research Council (NARC) in Nepal. Besides, advanced research institutes like Washington State University, Pullman and North Dakota State University, Fargo, USA; University of Saskatchewan, Canada contributes to basic research towards developing pertinent lentil technologies for South Asia.

On technology delivery, the above national public sector institutions, national/state extension systems, NGOs, farmer associations, public seed sectors are involved in technology dissemination and popularization. For example, BARI, BINA, directorate of agricultural extension, BIVA, PROVA (NGOs) and Bangladesh Agricultural Development Corporation in Bangladesh are engaged in technology demonstrations and quality seed production. In India, state Govts of Madhya Pradesh, Odisha, West Bengal, Bihar, Uttar Pradesh, Chhattisgarh, Assam, Tripura, Manipur, Meghalaya; several state Agricultural Universities; National Seed Corporation (NSC); and NIRMAN and TSRD (NGOs) in India; and NGRP and FORWARD (NGO) in Nepal. In this endeavor, The National Food Security Mission of the Govt. of India; Rastriya Krishi Vikash Yojona (RKVY) Govt. of India; OPEC Fund for International Development (OFID), Austria; OCP-Foundation, Morocco; HarvestPlus of CGIAR; Australian Center for International Agricultural Research (ACIAR); Australia; International Fund for Agricultural Development (IFAD) operated up-scaling projects in the region to popularize lentil and grass pea technologies in partnership with ICARDA and national partners.

7.2.3.1 Researchers and Policy Makers

With rapid population growth in countries such as Bangladesh, India and Nepal as well as climate variability and changes, the pace of pulses production is lagging, relying on imports for meeting domestic demand. For example, India itself is facing a deficit of 4-5 million tons, and 70% of pulses requirement in Bangladesh are imported at the cost of hard–earned foreign currency where in some years the produce is not available in the world market. During the last few decades, per capita availability of pulses has diminished threefolds in the region. Therefore, to keep rice or wheat-based production systems sustainable, and to meet internal demands, these countries need to boost up pulse production, where lentil and grass pea can substantially contribute to overall national production. Considering these facts, it is essential to divert attention to research for development of these crops in a farming system approach. Researchers are engaged in developing new technologies suitable for changing cropping systems; consumers, market and industrial requirements; and addressing sustainability of production systems. However, it is evident that govt. policy interventions have greater impact on technology dissemination, adoption and impact at the farm level. Policies on public sector quality seed production and distribution, ensuring timely availability of critical inputs, rural credit, marketing infrastructure, providing minimum support price to farmers, subsidies on farm implements, etc. can help small and marginal farmers.

7.2.3.2 Consumers, and Development Agencies

Lentil and grass pea have enormous demand in farming and food systems in South Asia. They are usually consumed as a natural food product in the form of decorticated seeds, flour for various preparations which are served with other staple foods based on rice, wheat and other major cereal grains. As in the case of other pulse crops, consumers' preferences are very specific in terms of seed size and shape, seed-coat appearance and colour, cotyledon colour and uniformity of appearance. In case of grass pea, physico-chemical detoxification of splitted seeds significantly reduces ODAP content are safer for consumption (Bell 1993).

Several development agencies are involved in the entire chain of production, storage, post-harvest processing, etc. Development agencies related to technology dissemination are extension departments of public sectors and NGOs, quality seed production corporations, suppliers of inputs, custom hiring centers for farm machineries. Large-scale storage facilities are provided by private warehouses, marketing of whole or processed products are done by marketing agencies. For example, lentil products are linked with "*Sufal Bangla*" in West Bengal state, and woman self-help group developed value-added products are packaged and linked to local markets. Large-scale processing industries (dal mills) to cover whole-sale and retail markets have two components. Primary processing consists of cleaning and delivery of whole seeds to consumers. The secondary processing component mostly involved decortication, splitting, sorting and polishing. These developmental agencies are directly or indirectly involved in production and creating demands for lentil and grass pea which encourage farmers to grow these crops in traditional as well as and rice-fallow cropping systems.

7.2.4 Development and Demonstration Strategy

Research on technology generation is targeted in enhancing productivity of lentil and grass pea in traditional growing areas and for rice-fallow cultivation which spans from varietal development to appropriate crop management practices. Large-scale cluster demonstrations (4–5 ha per cluster) were conducted with site-specific technologies across the countries where a number of farmers were associated in these cluster demonstrations per village. A holistic approach involving farmers, local governments, extension departments, public sector institutions, NGOs with multi-disciplinary team of researchers has been adopted to disseminate the technologies. The scaling activities were farmer-centric with their active involvement in the selection of varieties and site-specific technologies, capitalizing on the already existing technologies. Farmers were empowered in taking decision on selection of appropriate technologies and make them self-reliant in seed production of improved varieties. Wherever necessary, technical back stopping were provided by the participating institutions on the basis of feedback from the farming community. The research and development process aimed to integrate local knowledge and integrated crop management practices (IPM, IDM, and INM), which were farmer-friendly and compatible with local situations and socio-economic conditions. Equal weightage was put forward to strengthen partner's capacities on one hand and to the availability of better-adapted cultivars and site-specific improved production technologies on the other.

7.3 Implementation of Scaling-up with Examples

During last decade, several initiatives were undertaken in the region to incorporate pulse crops in rice-fallows to break mono-cropping involving small and marginal farmers, and in this case lentil and grass pea are the best fit. This also provided sustainability to rice-based production systems and use of plant residues for animal feed. A system approach was undertaken where short or medium duration preceding rice crop, appropriate lentil and grass pea varieties to grow with expression of full genetic potential. Appropriate varieties, seed priming, optimum seed rate, application of foliar nutrition, seed treatment, disease and pest management were followed. Thus, the cropping system transformed from rice-fallow-rice to rice-lentil/grass pea-rice. A systemic transformation has taken place in the intervention sites and farmers are keen to grow an extra-crop in fallow lands.

Bangladesh

With support from policy makers and researchers, Bangladesh has taken up the rice-fallow intensification program under several initiatives. The program was implemented in high Barind tract of north-western Bangladesh, where the govt. banned spring rice cultivation at the cost of precious groundwater, river basin of northern Bangladesh and in southern saline regions. Lentil is promoted as pure-cropping, zero-tillage and surface seeding, and grass pea under surface seeding only. The directorate of agricultural extension, the Pulses Research Center of BARI, BINA and BIVA played a major role in implementation of the program with financial support from the Govt. of Bangladesh, ACIAR, OFID, HarvestPlus, IFAD and OCP Foundation. Performance of varieties and beneficiary farmers are shown in Table 7.1.

India

Lentil and grass pea are among important winter pulse crops, contributing to nutritional security to low-income people. Where lentil is grown in entire eastern states, however, grass pea production is mainly concentrated in Chhattisgarh, West Bengal and Bihar. It has been estimated that about 11.65 m ha are under rice-fallows in India, which is concentrated in 12 states of southern and eastern regions of which about 3.0 m ha can be brought under pulse cultivation with appropriate varieties and improved production packages. (NAAS 2013). In this endeavor, Government of India and state governments, Indian Institute of Pulses Research (IIPR), all India Coordinated Research Projects (AICRPs), International Centre for Agricultural Research for Dryland Areas (ICARDA), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and International Rice Research Institute (IRRI) are engaged in bringing pulses technologies in rice fallow lands. ICARDA in partnership with public sector organizations, SAUs and NGOs have been involved with funding support from National Food Security Mission (NFSM), Rastriya Krishi Vikas Yojona (RNVY), Odisha Pulse Mission (OPM), OCPF, IFAD, HarvestPlus, etc. have successfully introduced lentil and grass pea technologies. Appropriate varieties have been identified and recommended production technologies have been provided to farmers. Performance of varieties is presented in Table 7.2.

Table 7.1 Performance of improved varieties and technologies in rice fallow in Bangladesh

Crop	Varieties	Districts	Beneficiary farmers (Nos)	Area covered (ha)	Yield range (kg)
Lentil	BARI Masur-4, BARI Masur-5, BARI Masur-6, BARI Masur-7[a], BARI Masur-8[a], BINA Masur-7, BINA Masur-10[a]	Natore, Kurigram, Rajshahi, Chapai, Rajbari, Faridpur, Pabna	132,566	31,762	578–1322
Grass pea	BARI Khesari-2[a], BARI Khesari-3	Rajshahi, Madaripur, Sathkhira, Bagerhat, Gopalganj	34,221	8050	654–1688

[a]Are best performing varieties

Table 7.2 Performance of promising varieties, farmers and yield of lentil and grass pea in India

Crop	Best performing varieties	States	Beneficiary. of farmers	Area covered (ha)	Yield range (kg/ha)
Lentil	Subrata, Moitree, HUL-57, KLS-218, L-4717, IPL-81	UP, Bihar, West Bengal, Assam, Tripura, Odisha, Manipur, Meghalaya, Chhattisgarh	243,504	41,422	560–1225
Grass pea	Ratan, Prateek, Nirmal	Assam, West Bengal, Odisha, Chhattisgarh, Bihar	35,766	8622	349–1553

Nepal

Lentil is the major pulse crop of Nepal which constitutes 67% of production among pulse crops. Lentil is mainly grown in the lowland Terai region of Nepal as sole, relay and intercrop of which about 75% area in rotation with cereals based on the availability of residual soil moisture. Fourteen high-yielding varieties have been released in Nepal so far and used for rice fallow cultivation, and CLIMA pink and Ratan grass pea varieties are being promoted. There is a potential of growing lentil in about 240,000 ha rice-fallow lands. In scaling-up of lentil and grass pea technologies, several initiatives operated/underway in Nepal. In addition to govt. programs, HarvestPlus, OFID, Australian Centre for International Agricultural Research (ACIAR), IFAD, Agriculture and Food Security Project (AFSP), National Seed and Fertilizer project (CIMMYT-NSAF), Raising Incomes of Small and Medium Farmers Project (RISMFP), Knowledge-based Integrated Sustainable Agriculture and Nutrition (KISAN) project and Prime Minister Agriculture Modernization Project (PMAMP) are involved to in improved technology deployment in traditional and rice fallow areas. It is estimated that >125,000 farmers are benefitted from improved lentil and grass pea technologies.

Overall, the improved technologies of lentil and grass pea have been adopted by >550,000 farmers, covering >85,000 ha rice fallow lands in Bangladesh, India and Nepal. Besides, the technologies have also been promoted to traditional growing areas to reduce yield gap by enhancing productivity and yield stability.

Few Examples of Successes Above achievements have been recorded which have a great significance in improving livelihoods of farmers by exploitation of fallow lands where no crops were grown. Some specific cases are mentioned below:

Livelihood Enhancement and Women Empowerment A Woman farmer Mrs Firoza Begum, a widow from Bangladesh cultivated grass pea variety 'Barikhesari-3' in her 1.34 ha of rice-fallow land and harvested 2.51 tons of grass pea worth $ 717 (grain & residue). The land was virtually kept fallow as a traditional practice after harvest of deep-water monsoon rice crop. The extra-income from grasspea was used to purchase inputs for next crop, purchase of medicine, school fees for her grandchildren and building brickhouse.

Mr. Bishwanath Chaudhary, lives with his family of 5 in the village Motipur of Siraha district in Nepal. Mr Chaudhary was a wheat farmer and used to obtain 1300 kg wheat from his 0.75 ha and could hardly earn NPR 28,600 from its sale. He planted lentil variety Sital and was able to harvest 1050 kg per ha. By switching over to lentil farming, he was able generate a net income of NPR 72,654. Thus the farmer could earn an additional NPR 43,946 ($ 380)

Mr. Bibhishan Bairagi, a farmer from Manbazar, Purulia, West Bengal. He has 2 ha land where he used to grow rice in monsoon season and keeps fallow in winter. After receiving quality seed and other inputs, he grew grass pea in 0.13 ha land with improved production technology and harvested 150 kg grain. His own produce met his 1-year family consumption and he marketed the surplus production. Additionally, the Stover was fed to his animal.

Fulkumari Mahato, a woman farmer from Dumurdih, Purulia II block, Purulia, West Bengal**.** She grew lentil and chickpea in 0.06 ha land each after monsoon rice and harvested 70 kg lentil & 80 kg chickpea. She fed Stover to her cattle and goat. Earlier, after harvesting of paddy, the land used to keep fallow, but since getting help from BCKV-ICARDA project, her self-produced pulse has been used for family requirements. She is happy getting extra pulse production/income and keen to continue pulse cultivation with improved package and practices in fallow lands.

7.4 Challenges and Opportunities in Asia

Challenges Narrow genetic base of lentil and grass pea germ plasm in South Asia limits breeders progress in constructing new genetic variants with desirable traits. This can be addressed through employing pre-breeding approach to broaden the genetic base with respect to yield contributing traits and resistance to biotic and abiotic stresses. Limited availability of quality seeds of site-specific improved varieties is one of the major factors of spread and adoption. With shortening of growing season, resurgence of new diseases and pests, occurrence of frequent drought, water logging, heat, salinity, etc. due to climate vagaries have direct implication on yield and stability. Poor plant stands due to the effect of various biotic and abiotic stresses have been identified as the cause of lower yield. Lentil and grass pea are weak competitors to weeds where about 50% yield reduction is faced by these crops due to weed menace. There is tough competition among a range of winter crops and also growing spring rice (boro rice) overlaps planting of pulse crops which hinders scope of cultivating remunerative pulse crops. In many areas, farmers are still growing late-monsoon rice varieties as preceding crop which are harvested in late-Nov to mid-Dec, prevents to grow pulse and other winter crops. In rice-fallow areas restricting of stray animal from free grazing after rice harvest is one of major hurdles to bring second crop in cultivation. Farmers need to be acquainted with improved technologies

Opportunities Variable gene-pools of lentil and grass pea comprising of landraces and wild species have recently been introduced from ICARDA gene bank to South Asia. These can be judiciously utilized in pre-breeding activities to develop new varieties with multiple desirable traits. Cultivation of new varieties following improved production technologies will certainly reduce yield gaps which can make the crops profitable to farmers. In the past, we have observed that farmers are keen to grow lentil and grass pea in rice-fallows, thus may widen the opportunities to increase cropping intensity, generating extra-income by farmers and attain nutritional security. There is ample scope for horizontal expansion of pulse crops more specifically lentil and grass pea as they are most suitable to grow in those agro-ecologies and cropping systems. With adoption of Conservation Agriculture technology using farm machineries farmers can grow lentil and grass pea with low cost. Value-addition by women groups can be expanded in newer areas.

7.5 Lessons Learnt and Way Forward

7.5.1 Lessons Learnt

- It has been observed that if crops are remunerative, farmers are willing to adopt the technologies.
- For better crop establishment in achieving and sustaining higher yield, conservation agriculture practices, integrated crop management including seed priming are rewarding.
- Short duration varieties without yield penalty, late planting potential and deep rooted varieties are to be developed and deployed for better utilization of rice fallows.
- Time of sowing is critical for proper crop growth, avoidance of disease incidence and terminal heat and drought stresses. First fortnight of November is the optimum time for sowing lentil and grasspea in the region.
- Creating awareness and capacity development of farmers are crucial for adoption of technologies.
- Effort should be made to supply good quality seed and inputs in time at farmers' doorstep.
- Close monitoring and supervision are the key factors for a successful demonstration.

7.5.2 Way Forward

- Periodic real-time and disaggregated mapping of rice fallows to be conducted to understand changes in cropping systems, crop productivity, stability and production constraints, duration of fallow period, status of soil moisture, etc.
- Flow of new technologies at farmers' level, and consolidation of research and development activities to be ensured.
- Large-scale cluster demonstrations of improved technologies to be intensified in remote areas. Scaling-up of farmer-preferred varieties with all components of crop management practices to be conducted.
- Informal seed system to be strengthened with the formation of Village Seed Hubs involving farmers' groups.
- Pro-farmer policies to be in place with respect to development and use of community watersheds, timely availability of seeds and inputs, rural credit marketing infrastructure and containing of stray animal.
- Independent team consisting of scientists, development personnel and farmers' representative to be formed to review the progress and bring out document on future strategies.
- Value-addition by women self-help group to be expanded and establish linkage with local markets.
- Successful farmers to be rewarded which will encourage others to adopt new technologies.

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Chapter 8
Environment-Friendly Direct Seeding Rice Technology to Foster Sustainable Rice Production

Nitika Sandhu, Deepti Baburao Sagare, Vikas Kumar Singh, Shailesh Yadav, and Arvind Kumar

Abstract Rice, a staple food for majority of the world's population consumes about 50% of fresh water in Asia. Demand for food is likely to increase by as much as 60% between 2010 and 2050 in many developing countries. Future food production will be limited by availability of land, water, labor and energy. Agricultural transformation, as a cornerstone of the new sustainable development agenda, must therefore be an eco-efficient revolution in the next few decades. The direct seeded rice (DSR) technology has potential to effectively address the problem of labor-water scarcity and is emerging as an environment-friendly system due to higher water productivity, and lower global warming potential. Keeping this in mind, the chapter discusses the importance of rice, emerging climate-and workforce-related challenges, introduction of climate-smart agricultural practices, transformation of rice-based food systems, constraints and policy issues in adoption of DSR and national-level initiative to scale-up the adoption of DSR.

Keywords Direct seeded rice · Environment-friendly system · Water productivity · Policy issues

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8.1 Importance of Rice in Global Food Systems

Rice, one of the most important staple food crops has always been important to the worldwide food security and socioeconomic stability (Zeigler and Barclay 2008). It is a vital strategic commodity for the whole world, intensively connected with food security and economic growth. It is being cultivated in more than 100 countries. In every aspect such as nutritional importance, productivity, production, quality, number of farmers/consumers, affordability to poor, rice will remain the leading feature of the agricultural and nutritional security in the developing and developed countries. More than 3.5 billion people around the world depend largely on rice for 20% of their dietary caloric supply (IRRI 2013).

Rice has been domesticated from *Oryza rufipogon*, the wild grass about 8–10 k years ago (Greenland 1997). In the developing countries, rice is the main food for most of the poorest people. Asia represents about 90% (640 million tons) of the total rice production (Khush 2005) and consumption. The worldwide demand of rice is predicted to rise from 439 million tons (milled rice) to 496 million tons to 555 million tons in 2010, 2020 and 2035, respectively (Seck et al. 2012). Rice yields ranged from less than 1 t ha^{-1} to more than 10 t ha^{-1} under poor rain-fed and intensive irrigated areas, respectively.

Rice is being cultivated in a wide range of agro-climatic conditions (Gill et al. 2006a, b). The small-scale farmers contributed to the four-fifths of the world's rice production which is being consumed locally. The rice cultivation is the primary source of income for approximately 100 million households in the Asia and Africa. The increase in the rice production was attributed to various factors such as semi-dwarf, high-yielding rice varieties (IR 8, released in 1966; Mackill 2018), increase in the irrigated area, and the use of agrochemicals. The adoption of high-yielding rice varieties was so fast in Asia that 40% of the total crop area was planted with modern varieties by the 1980 (World Bank 2007). However, the growth rate sustainability of rice sector is a key concern for the rapid growing population to maintain economic growth, food security and social stability. Traditional method of rice cultivation due to its heavy water and environmental footprints cannot be continued in many parts of Asia and South-east Asia where water and labor scarcity are main drivers of change.

8.2 How Rice Has Been Moved to New Areas Due to Policies During the Green Revolution

The developing countries witnessed a significant period of growth in rice productivity over past 50 years, regardless of the increasing land scarcity in addition to the rising values of land (Pingali 2012). Although, the population growth was double, the cereal crops production was tripled during this period; with approximately 30% more cultivated land (Wik et al. 2008). The Green revolution in Asia was principally led by technology and supported by policy, rather than only policy driven as it is mostly assumed. Green revolution is generally characterized by the development and dissemination of high-yielding and fertilizer responsive rice varieties (Otsuka and Kalirajan 2010).

During green revolution time, the policy makers strongly promoted new high-yielding varieties of rice with high-input technologies with a focus on smallholder farms. The adoption of improved seed varieties and better crop technologies became the key source of development. The strategies of seed import, distribution, use of fertilizers, irrigation, agrochemicals and the expansion of extension services were adopted. Various institutions such as the State Agricultural Universities (SAUs), Commission for Agricultural Costs and Prices (CACP), the Central Warehousing Corporation (CWC), and the Food Corporation of India (FCI) were set up during 1960s–1970s. In 1970s, the irrigation investments were accelerated. Various government-supported credit programs and national research and extension system were strengthened (Barker and Rose 1985). Furthermore, the credit contracts between the farmers-fertilizer dealers, irrigation systems management at community level (Hayami and Kikuchi 1932), markets and the supporting institutions were developed to take advantage of the opportunities generated by the Green revolution.

Another important policy decision was the nationalization of main commercial banks; establishment of NABARD (National Bank for Agriculture and Rural Development) and RRBs (Regional Rural Banks); strengthening of agricultural research-extension system, cooperative credit societies and marketing of agricultural supplies (Arora 2013). Since 1991, the emphasis of agricultural policy has moved towards reducing unnecessary legislation, improving the functioning of markets, and liberalizing the import and export of agricultural goods. There was significant increase in the funding of, and provision of credit to farmers. The replacement of the traditional low-yielding rice varieties by the high-yielding rice varieties resulted in a quantum jump in rice crop yields. Over the past decades, there is a sharp increase in the use of chemical fertilizers. Till 1990, the use of chemical pesticides and herbicides was higher, but then dropped steadily. Although, application of heavy fertilizer is needed to maintain and achieve high rice yields but from the environmental point of view, it is much more undesirable. To reduce the use of more and more fertilizers and pesticides, however, every single effort has been made to develop and disseminate nutrient-efficient and pest/disease-tolerant mega varieties. On the other hand, focus of the green revolution was based on the strengthening of favorable areas; its role in the reduction of poverty in marginal environments was comparatively lower.

8.3 Impacts of Climate Change and Cry for Shifting from Water Guzzling Rice

The climate change has become a worldwide concern and plugged in the globe to pursue environment-friendly strategies to cope-up. A continuous emission of greenhouse gases (GHGs) causes warming and long-lasting changes in all components of the climate system. The global temperature has increased by 0.6–0.8 °C over the past century (IPCC 2014) which is the most conspicuous temperature rise over the past 1000 years (Meshram et al. 2020). There is a clear trend in temperature rise due to climate change, but trends in annual precipitation volume shows uncertainty in many regions (Fig. 8.1a, b). According to the United Nations Intergovernmental Panel on Climate Change (IPCC) and Food and Agriculture Organization (FAO), agriculture industry in developing countries is most vulnerable to climatic changes (Parker et al. 2019). Under arid and semi-arid areas, the impact of climate change on precipitation pattern is much higher than the combined effect of CO_2

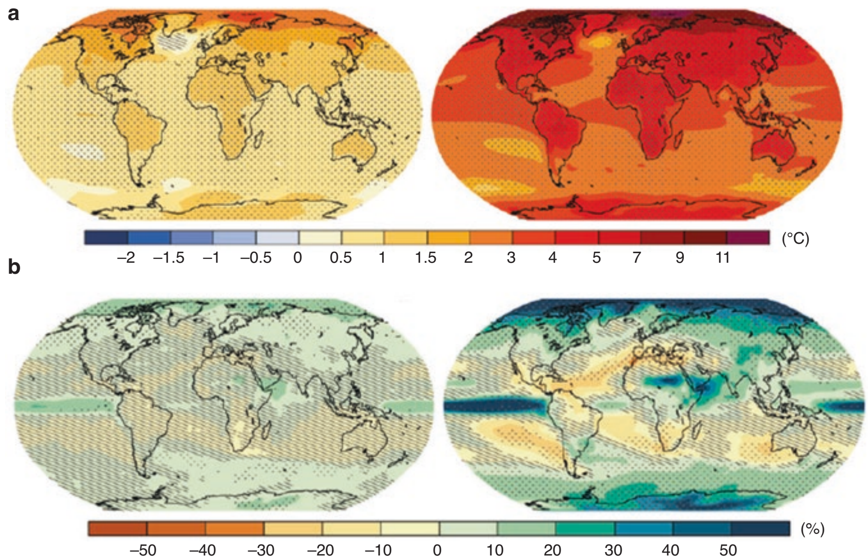

Fig. 8.1 (**a**) Change in average surface temperature (1986–2005 to 2081–2100). (**b**) Change in average precipitation (1986–2005 to 2081–2100). (**Note:** The average of the CMIP5 model (Coupled Model Intercomparison Project Phase 5) projections available for the 2081–2100 period under the Representative GHG Concentration Pathway 2.6 – RCP2.6 (left) and RCP8.5 (right) scenarios for (**a**) change in annual mean surface temperature and (**b**) change in annual mean precipitation, in percentages. Changes are shown relative to the 1986–2005 period. Stippling dots on indicates regions where the projected change is large compared to natural internal variability (i.e., greater than two standard deviations of internal variability in 20 year means) and where 90% of the models agree on the sign of change. Hatching (diagonal lines) on and shows regions where the projected change is less than one standard deviation of natural internal variability in 20 year means. Source: UN world water development report, 2020)

concentration and temperature rise (Huang et al. 2016), and thus, water resources and grain production are affected severely (Lu et al. 2019). Temperature rise leads to increase in evapotranspiration and reduces the soil moisture, resulting in drought and yield decline (Lu et al. 2019). The temperature rise rate in India since 1901–2007 was observed around 0.51 °C, and its negative effects on the rice yield in some parts of India are notable (Meshram et al. 2020). There is a very close and complex relationship between the earth's climate and the terrestrial water cycle (Abbott et al. 2019). The climate variability and change therefore, propagate and affect global water resources in various ways such as, with complex spatio-temporal patterns, adverse reactions, and interactions between physical and anthropogenic activities (UN world water development report 2020). Climatic changes are presumed to intensify the water stress, which is one of the major problems to be faced by every continent in the twenty-first century (Fig. 8.2).

Rice production is a victim as well as a contributor to climate change. The conventional puddled transplanted rice production contributes 55% of agricultural GHG emissions, particularly methane (IPCC 2014). In rice fields the factors controlling gas exchange between rice and the atmosphere are very much different than those in upland agriculture, because rice field remains flooded during cultivation period (Alam et al. 2016). Conventional rice production ecosystem such as puddled transplanted (PTR), requires up to 5000 liters of the water to produce 1 kg of rough rice (Bouman 2009), and being water-guzzling crop rice consumes about 50% of total irrigation water used in Asia (Chauhan et al. 2017). In Asia, more than 80% of the freshwater resources (ground and surface water) are used for irrigation in agriculture sector, and about half of those are used for rice production (Farooq et al. 2009). The water inputs required in PTR depends on several factors such as, growing season, climatic fluctuations, soil paradigm, and hydrological pattern. The seasonal water input for PTR varies from 660 to 5280 mm: 160–1580 mm for land preparation (puddling operations), 400–700 mm for evapotranspiration (ET), and 1500–3000 mm (for loamy/sandy soils) or 100–500 mm (for heavy soils) of

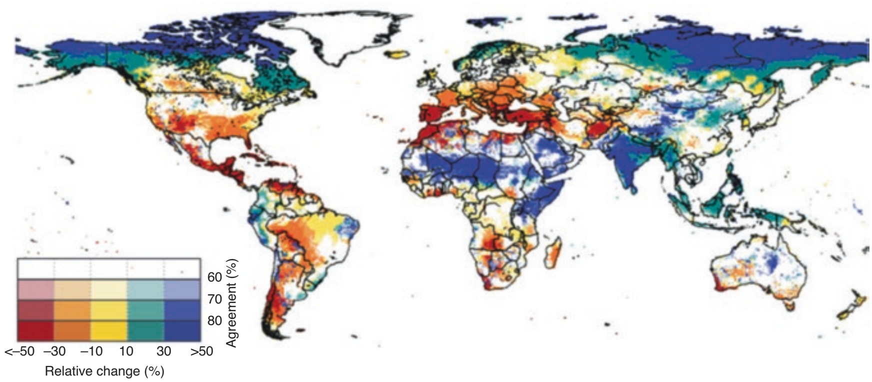

Fig. 8.2 Climate change scenario trends in water availability. (Note: This figure depicts the relative change in annual discharge at 2 °C temperature increase compared with present day)

inexorable water losses resulted by percolation and seepage (Tuong and Bouman 2003). The water use for rice estimated in Indo-Gangetic Plains Bihar (wetter region) and Haryana (drier region) by Gupta et al. (2002) were varied from 1144 to 1560 mm, respectively. A total water use of 790–1430 mm for aerobic fields, and 1240–1880 mm for flooded fields was estimated in the Philippines (Bouman et al. 2005). Whereas, in Pakistan, water input was estimated as 2190–2445 mm, 1793–1935 mm, and 1573–1635 mm for flooded rice, alternate wetting and drying, and direct-seeded rice, respectively (Jabran et al. 2015). Over consumption of irrigation water in agricultural, industrial and domestic sectors leads to irrigation water scarcity, and is a startle issue for sustained rice productivity in the future (Mahajan et al. 2018). In Asia, 17 and 22 million ha of irrigated rice areas may experience 'physical water scarcity' and 'economic water scarcity', respectively by 2025 (Tuong and Bouman 2003). Since 2000–2010, the depletion of groundwater increased by 23%, and is a major concern for production and self-sufficiency of important cereals, rice and wheat (Dalin et al. 2017; Barik et al. 2017).

According to several reports, by 2025, about 15 million ha flood irrigated rice area in Asia is likely to suffer with water shortage (GRISP 2013). In major rice-growing Asian countries, during 1950–2005 per capita water availability has been decreased by up to 76%, and by 2050 it is expected to decline further up to 88% (Ercin and Hoekstra 2014). According to the satellite survey by NASA, in the north-west India the groundwater table has been declined at a rate of 0.33 m per year, causing a net loss of 109 km^3 of groundwater during 2002–2008 (Rodell et al. 2018). The continuous use of groundwater for rice cultivation is menacing the water table, and in some regions, it has created alarming situation. For instance, in the Indo-Gangetic plain of India water table is declining by 0.5–1.0 m every year (Carriger and Vallee 2007; Hira 2009), while in north China plain, it is declining by 1.0–3.0 m every year (Shah and Ross 2009). Thus, under the emerging scenario of water scarcity, sustainability of rice cultivation is threatened (Mahajan et al. 2018). From 2000 to 2010, a 23% increase in the groundwater depletion is reported and is a major concern for rice production (Dalin et al. 2017). Drastic changes to local and regional hydrology and weather patterns due to agricultural conversion and expanded crop irrigation have been identified (Ghosh and Misra 2010). Moreover, changing climatic conditions (specifically warming) is expected to cause about 13–23% rise in irrigation water requirement for the rice cultivation (De Silva et al. 2007; Thomas 2008; Chung et al. 2011). Considering the impacts of climate change scenario, precipitation patterns, water scarcity etc., on rice production, it is much needed to replace water guzzling conventional rice production system with novel environment-friendly technologies to reduce water loss and to increase the water productivity of the crop.

8.3.1 Less Water More Rice Policies and Greed Made It Water Guzzler

The rice growing areas are already facing water scarcity. To reduce pressure on freshwater resources and alleviating unsustainable groundwater use, climate smart technologies to cope with water scarcity and ways to secure rice production with less amount of available water are necessary (Farooq et al. 2009; Chauhan et al. 2017; Mahajan et al. 2018). The water crisis threatens the rice productivity; thus, less water and more rice policies are much needed to cope with climatic change and to conserve current water resources. More rice with less water can be achieved by integration of water management and employment of water-saving technologies with, (a) appropriate germplasm selection, (b) resource management practices to achieve higher yields, and (c) system level management such as, a high degree of recycling and conjunctive use of water (Tuong et al. 2005).

Rice is very sensitive to water stress and ways must be sought to reduce water inputs, and to enhance water productivity (Kumar and Ladha 2011). It is very challenging to develop novel technologies and production systems that can either maintain or enhance rice production under limited water availability (Farooq et al. 2009). Shifting from conventional flooded rice system to cultivating rice aerobically and, developing high-yielding varieties that can perform better under aerobic conditions without yield penalty, seems to be most viable solution for sustainable rice production with less water (Chauhan et al. 2014, 2017; Khush 2015). Several strategies viz., saturated soil culture, system of rice intensification (SRI), a ground-cover system, alternate wetting and drying (AWD), raised beds, aerobic rice etc., are in vogue to reduce water requirement for rice production (Stoop et al. 2002; Bouman et al. 2005; Farooq et al. 2009; Kumar and Ladha 2011). The AWD and aerobic rice provides about 38% and 40%, respective reduction in water input over the conventional PTR system (Lampayan et al. 2015); however, the farmers are not willing to adopt these practices because of possible yield penalty and few information gaps about these systems. The conventional puddled transplanted practice of rice cultivation where fields are kept continuously flooded is more popular among farmers because of weed suppression and higher yield (Grassi et al. 2009).

Although, under more rice with less water policies several novel strategies have been implemented, the impact of reducing water inputs on weed infestation, soil nutrient mobility and uptake by crop, sustainability and environmental services of rice ecosystem warrants further research (Chauhan et al. 2017). On one hand, world rice demand is projected to increase from 496.1 million metric tons (milled rice) in 2019–2020 to 555 million metric tons in 2035 from the population prediction made by the United Nations (UN) and income estimations from the Food and Agricultural Policy Research Institute (FAPRI). Climate change is threating the sustainability of rice production on other hand. Moreover, area expansion is predicted to be slower in future, and therefore, global rice production needs rapid increase compared to recent past to keep global market prices at affordable levels and to ensure sustainable food security. To meet the global rice demand, the more rice with less water policies were disregarded and conventional PTR system was followed. Thus, the global greed for more rice made it more water guzzler. The global production volume of milled rice (million metric tons) and rice acreage (million hectares) from 2010–2011 to 2018–2019 depicted in Fig. 8.3 and arable land (ha/person) in Asian countries is presented in Fig. 8.4. The arable land per person in Asia is quite small compared to developed countries like USA. Also, the arable land is being diverted

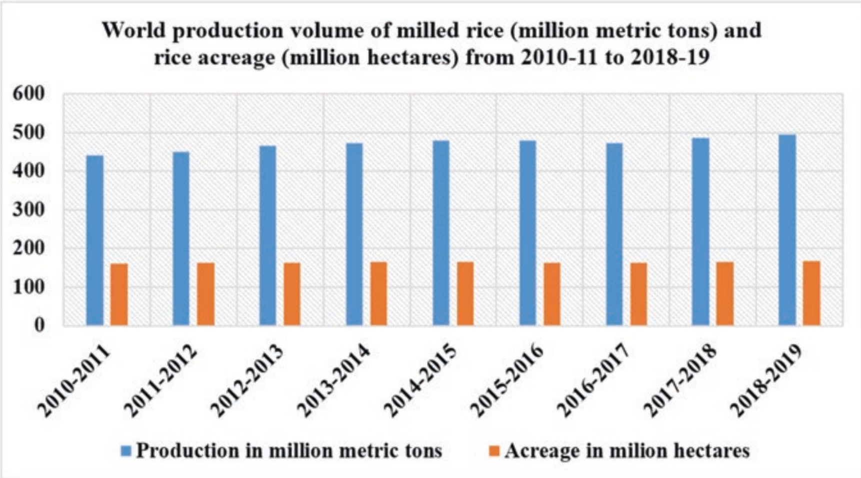

Fig. 8.3 World production volume of milled rice (million metric tons) and rice acreage (million hectares) from 2010–2011 to 2018–2019. (Source: Statistica 2020)

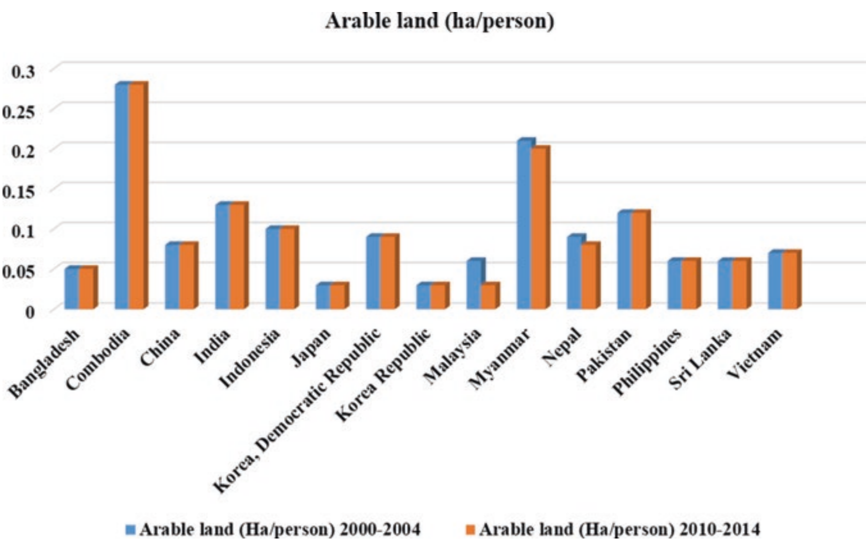

Fig. 8.4 Arable land (ha/person) in Asian countries. (Source: World Bank – IDA 2015)

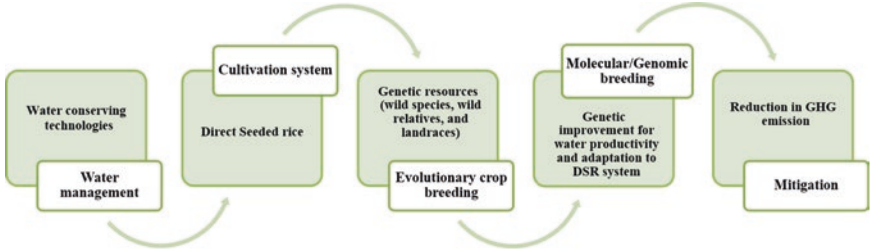

Fig. 8.5 Producing more rice with less water

Table 8.1 List of varieties recommended for aerobic direct seeded cultivation conditions

Country	Varieties
Philippines	Apo, Sahod Ulan 1, Katihan 1, Sahod Ulan 12, Katihan 2, Katihan 3, Katihan 4
India	Shabhagi Dhan, CR Dhan 200 (Pyari), CR Dhan 201, CR Dhan 202, CR Dhan 204, CR Dhan 205, MAS 26, MAS 946-1, MAS 26, PR126
Nepal	Sookhadhan 1, Sookhadhan 2, Sookhadhan 3, Hardinath 2, Tarharra
Pakistan	IR 79597-56-1-2-1, IR 80416-B-32-3
Cambodia	CAR 14, PhkaRumduol

for road constructions, industrial development and dwellings etc., arable land. Therefore, considering the increasing global demand for rice with increasing population, while arable land and water resources are becoming scarce, it is prudent to adapt water management and rice growing practices requiring less water inputs along with appropriate varieties/germplasm to achieve sustainable rice production with less water and resource inputs (Fig. 8.5) (Wang et al. 2002; Tuong et al. 2005; Kato et al. 2009) (Table 8.1).

8.3.2 Direct Seeded Rice with Less Water

The direct seeded rice (DSR) cultivation system is considered as water and resource conserving technology as it effectively addresses the problem of water and labor shortage in both irrigated and rain-fed areas through reduced utilization of water for land preparation as well as water saving through better irrigation management and introduction of mechanized practices for sowing, weed control and harvesting (Liu et al. 2015). The differences among direct seeded and puddled system of rice cultivation are presented in Table 8.2. In DSR system, seeding is done in unpuddled fields with well-tilled leveled and uniform slope, further the aerobic condition is maintained with no standing water throughout the season for crop cultivation. In DSR system, crop establishment can be achieved employing different methods, (i) seeding (broadcasting, drilling, dibbling) in a well-tilled field, (ii) direct seeding (mechanical seed drill) in a field with zero tillage, and (iii) seeding on raised beds

Table 8.2 Difference between the direct-seeded aerobic rice and conventional puddled transplanted rice

Eco-friendly direct-seeded rice	Conventional puddled transplanted rice
1. Precise land levelling is required	Land should be normally levelled
2. Direct sowing in wet/dry soil is done	Nursery raising is needed
3. Puddling, nursery raising and transplanting, not required	Puddling, nursery raising and transplanting are required
4. It matures 7–10 days earlier, harvest early	Matures later than direct seeded rice
5. Water-labor-energy use is less 6. 30–40% water savings, constant maintenance of water in the field is not needed	Water-labor-energy use is higher Constant maintenance of water in the field is required
7. Weeding can be mechanized	Mechanized weeding is not possible
8. Trimming bunds and plugging holes is not required	Constant attention by way of plugging holes and trimming bunds is required
9. Intercropping of any other arable crop is possible	Intercropping of any other arable crop is not possible
10.Crop rotation can be practiced in both rain-fed and irrigated ecosystems	Crop rotation practice is not common in rain-fed ecosystem
11. Aerobic conditions is well maintained in the direct seeded system of rice cultivation	Anaerobic conditions prevail in the puddled system of rice cultivation
12. Soil structure is maintained	Soil structure is destroyed. Subsurface hard pan is made by repeated plowing
14. Oxygenated rhizosphere is found	Oxygenated rhizosphere is not found
15. Water-use efficiency is higher	Water-use efficiency is low
16. Efficient use of rain water	Use of rain water is not efficient
17. Methanogenesisis zero or low	Methanogenesisis higher
18. Nutrient uptake is less	Nutrient uptake is higher
19. Production of toxins such as ethanol and lactate are absent	Toxins are produced
20. Reduced humidity in microclimate	Humidity is high
21. Incidence of diseases and pests is significantly low	High incidence of diseases and pests
22. Cost of cultivation is significantly low	Cost of cultivation is significantly high

Source: Modified from Parthasarathi et al. (2012) and Kumar and Katagami (2016)

(Kumar and Ladha 2011). In Asia, the DSR method has been practiced conventionally in rain-fed upland and rain-fed shallow lowland areas, and is sought after in irrigated areas facing water scarcity (Rao et al. 2017). DSR is classified as; dry DSR (seeds are sown into the soil which is not puddled but may be either zero-till or dry till conventional tillage, and seed environment is aerobic), wet DSR (seeds are broadcasted on wet soil which is puddled and seed environment can be aerobic or anaerobic), water DSR (pre-germinated seeds are broadcasted in standing water and seed environment is anaerobic) (Datta et al. 2017; Kaur and Singh 2017). Dry and wet seeding methods require less labor and time than transplanting (Sarkar and Das 2003). Dry seeding is preferred in the areas where water supply is unpredictable (Gathala et al. 2011).

The DSR is more advantageous compared to conventional PTR system in many situations therefore; farmers tend to shift the crop establishment methods for lowland rice from transplanting to the direct seeding system (Farooq et al. 2011). Higher economic returns are the major advantage of direct-seeding methods; DSR crops are faster and easier to plant, less labor intensive (Bhushan et al. 2007), consumes less water – more efficient water use and higher tolerance of water deficit (Bouman and Tuong 2001; Chauhan et al. 2017). DSR crops are conducive to mechanization, establishes early and thus hastens physiological maturity and reduces vulnerability to late-season drought, mature 7–10 days earlier making shorter crop duration (Farooq et al. 2006, 2008) and have less methane emissions (Chauhan et al. 2014) than transplanted puddled rice. Direct seeding has resolved edaphic conflicts (between rice and the subsequent non-rice crop) (Farooq et al. 2008).

The dry-seeding on raised beds or flat land with saturated soil conditions reduces the water requirement for land preparation and crop irrigation (Kumar and Ladha 2011). In recent past several researchers globally have dealt with water use efficiency and yield performance of DSR. Compared with PTR system, a total of 11–57% input water savings was reported for direct seeding into non-puddled soil (Gathala et al. 2013; Liu et al. 2014, 2015; Jabran et al. 2015; Tao et al. 2016; Mahajan et al. 2018). The more efficient water use in DSR (0.59–1.37 kg grain m^{-3} water) across locations and irrigation schedules was observed by Kato and Katsura (2014). Liu et al. (2014) reported 15.3% less water use in DSR than PTR with similar grain yield (9.01 Mg/ha), and enhanced grain nitrogen use efficiency (11–20%). Higher water productivity in DSR (11.6 in dry-DSR and 13.4 on wet-DSR) than that of conventional PTR was reported by Tao et al. (2016). A total of 517 mm irrigation water savings was observed under DSR compared to PTR in the North-western Indo-Gangetic Plains of India (Mohammad et al. 2018). Under DSR situation high-yielding, lowland rice varieties showed a great potential to enhance water productivity/water use efficiency in the field experiments (Mahajan et al. 2013, 2018). Further, the extent of water saving also depends upon irrigation scheduling (Humphreys et al. 2012). Total labor requirement for field operations (puddling) and various practices (nursery raising, seedling uprooting, transplanting) in PTR is much higher (~37%) than DSR (Mahajan et al. 2013; Kato and Katsura2014). The 30–45% savings in labor requirement in DSR is reported (Kumar and Ladha 2011). Though the labor required for weed control in DSR is much higher (~12–200%) than PTR; use of varieties with weed competitiveness traits, effective herbicide application, and herbicide-tolerant rice mutant, the labor use can be sized (Yamano et al. 2013; Rao et al. 2017).

Besides the savings of scare resources, edaphic conflicts (between rice and subsequent non-rice crop) can be resolved upon adoption of dry DSR (Gathala et al. 2013; Ladha et al. 2016; Padre et al. 2016). Direct seeding helps to improve the soil structure and overall properties that provides a congenial environment for succeeding crops. In wheat, yield was increased by 8–18% when grown after DSR compared with PTR, and the net economic returns were increased up to 79% when maize was grown after ZT-DSR than CT-PTR (Gathala et al. 2013). Higher system productivity of DSR-wheat, DSR-chickpea and DSR-mustard (14.96 t ha^{-1}, 14.48 t ha^{-1} and 13.48 t ha^{-1}, respectively) than the PTR (13.53 t ha^{-1}, 12.12 t ha^{-1} and 11.81 t ha^{-1}, respectively) was observed (Gangwar et al. 2008). In ZT-DSR-wheat rotations, 54% higher grain yields with a 104% increase in economic returns were observed (Ladha et al. 2016).

Wetland rice production is a major contributor of GHGs (CH_4 and N_2O) from agriculture (IPCC 2014). Emission of GHG from rice fields is very sensitive to crop establishment techniques and management practices (Wassmann and Vlek 2004; Smith et al. 2007). In conventional puddled transplanted system, puddling operation and continuous standing water leads to lower soil oxygen content and soil redox potential, which in turn increases the activity of methanogens increasing CH_4 emission (Pathak et al. 2013). Flooded rice accounts for 10–20% (50–100 Tg/year) of total global annual CH_4 emissions (Reiner and Milkha 2000). The aerobic condition in dry DSR during the early growth stages and until seedling establishment in wet DSR is the prime reason for less CH_4 emissions (Alam et al. 2016). Cumulative CH_4emission reduction by DSR over PTR were reported between 60% and 80% (Liu et al. 2015; Weller et al. 2016; Gupta et al. 2016). But, N_2O emissions are higher in DSR than PTR system (Shang et al. 2011). Though the relatively higher N_2O emissions are reported in in DSR system, global warming potential ($CH_4 \times 25 + N_2O \times 298$) of DSR is lower than that of PTR because of substantially low CH_4 emissions in DSR. From a comparative study for global warming potential of DSR and PTR system, a lower global warming potential of 76.2% under dry-DSR was observed (Tao et al. 2016).

More than 11.2 t ha^{-1} grain yield under DSR is reported in few studies (Dong et al. 2004; Kato et al. 2009). A study conducted in Mossouri, USA, reported a 10.3 Mg ha^{-1} grain yield with only a 750 mm water input in DSR (Stevens et al. 2012). Across different cultivars and locations, the average grain yield of dry-DSR in Japan was about 9.6 t ha^{-1} (Matsunami et al. 2009; Katsura and Nakaide 2011). In China, few studies reported 5.33–22% higher grain yields and about 25–50% lower water use in DSR than PTR (Zhao et al. 2007; Zhu 2008); whereas, Liu et al. (2015) observed on par grain yield under DSR and PTR. In India, a significantly higher grain yield (3.74–6.79%) in DSR was observed as compared to PTR (Gill et al. 2006a, b; Mishra et al. 2017). There are several reports on significant reduction in production costs for DSR adopters compared to costs for non-adopters (Johnkutty et al. 2006; Kumar and Ladha 2011; Yadav et al. 2011; Mishra et al. 2017).

The rice varieties bred for the PTR system are currently been used in DSR system, and as these varieties does not possesses traits required to withstand DSR conditions and without yield penalty, they are either fairly promising or failed to achieve their potential yield productivity under DSR system. High-yielding, lowland rice varieties were found to perform well at water saving potential under DSR, but with a severe yield penalty in the field experiments (Peng et al. 2006). The poor understanding of favorable traits for DSR adoption was one of the major hurdles while breeding. Recently several studies reported potential traits for DSR to achieve higher yield and the information of DSR suitable traits along with novel molecular and genomic techniques can pave the way for DSR specific varietal development.

Recent progress made in molecular and genomics research has provided progressive understanding about the novel traits, donors, QTLs and genes that can contribute to the future transformation of existing PTR system.

8.3.3 Technologies for DSR and Sustainable Intensification

DSR cultivation is nowadays becoming more popular day by day among rice farmer due to less cost of cultivation and yields are also comparable with transplanted rice if good management and deployment of correct technologies has been adapted suitable for DSR cultivation. Wider adoption of can be enhanced by prioritizing the viable resources and holding the key to public – private -partnership (PPP). Precise use of available DSR technologies is helpful in raising the crops with less water, energy and timely seeding through mechanization. Water-use efficiency (WUE) can be enhanced significantly by adopting alternate wetting and drying technology or aerobic cultivation. A complete DSR package including better field levelling through laser leveller, and the integrated approach for weed, nutrient and pest management can help in improving the water-use efficiency. To increase the farm income and sustainability of the system, diversification of DSR technology has been recommended.

8.3.3.1 Laser Levelling

Land leveling through laser leveler is one such proven technology in cultivation of direct seeded rice that can conserve water judiciously (Jat et al. 2006). Variability in the soil and unevenness soil surface has proven a negative impact on the faster germination, uniform crop stands and ultimate yield of crops through uneven distribution of water, nutrient and salt interaction. Land levelling can improve the efficiency of water, labor and energy and have the following advantages (Naresh et al. 2014)

(i) More levelled and smooth soil surface
(ii) Equal and uniform distribution of water across the field
(iii) Saving in time and total water required to irrigate the entire field
(iv) Higher and uniform germination and growth of crops
(v) Less inputs such as seeds, fertilizer, chemicals, and fuel required in cultivation and cultural operations

The limitations include the following:

(i) The cost of laser leveler is high
(ii) Highly skilled operators needed to operate laser operations efficiently

8.3.3.2 Integrated Nutrient Management

Nutrient dynamics, especially of limited nutrient uptake of nitrogen and phosphorus under direct-seeded cultivation conditions compared to transplanted conditions playing a significant role for lower yield in direct-seeded systems compared to transplanted rice cultivation (Kumar and Ladha 2011). Water management and land preparation are crucial factors in governing nutrient flow both in direct seeded as well as transplanted rice cultivation. In case of DSR, increased oxygen in the rhizosphere due to dry land preparation favors oxidation of NH_4^+ to NO_3^- and thereby more losses of Nitrogen via leaching. Application of nitrification inhibitors along with fertilizer can maintain soil N as NH_4^+, which also increase nutrient use efficiency (NUE) and crop yield. Deficiencies of micronutrients are also a major concern in DSR cultivation. Zn availability in soil becomes very limited due to slow release of Zn from the highly insoluble fractions in aerobic rice fields. DSR cultivation under unsaturated soil conditions can lead to iron deficiency and plants show chlorosis significantly. Iron deficiency for prolonged period may result in severe yield losses in DSR cultivation, hence effective management of Fe deficiency and other micronutrients are essential to achieve expected grain yield under DSR condition.

8.3.3.3 Integrated Weed Management

Weeds are the most important constraint in wider adoption of direct seeded rice cultivation in farmers' field on a large scale. Weeds are more problematic in DSR compared to transplanted rice because (a) the emerging weeds are highly competitive as compared to the DSR seedlings simultaneously and (b) lack of saturated water layer in DSR system make rice crop more prone to initial weed infestation compared to transplanting (Kumar and Ladha 2011). Some much higher yield losses up to 30–80% in the absence of effective weed control under DSR cultivation has been reported compared to transplanted rice (Rao et al. 2007). Hence, an integrated approach, such as cultivation of weed competitive rice variety, early in vigor, having robust root system, crop rotation, water and nutrient management along with rotation of herbicides with different mode of actions followed by manual weeding are suggested for sustainable weed control in DSR.

8.3.3.4 Integrated Pest Management

DSR cultivation is highly susceptible to a range of diseases, however, blast is one of the severe diseases among them (Bonman 1992). Under limited water, damage due to rice blast increases as the water level affects several physiological and biochemical processes such as the liberation and germination of spores and the infection in rice causing blast (Kim 1987). In DSR, the other disease and insect significantly reported as brown spot disease, sheath blight and dirty panicle and plant hoppers and soil borne fungus (Prabhu et al. 2002; Savary et al. 2005). An integrated management including judicious use of insecticide, biological control as well as biotechnological and the genetic approaches may help to control issues of insect/pest/disease sustainably.

8.3.3.5 Alternate Wetting and Drying

Alternate wetting and drying (AWD) is a technology, where, the field is alternatively kept flooded and non-flooded. This technology help in reducing the water use as per the requirement of actual amount of water needed to produce rice and suitable for dissemination in water limited rice growing areas. AWD was successfully implemented and introduce to farmer-co-operators and it saved 16–24% of irrigation water without any yield penalty. In AWD, soil is dried for some days after the disappearance of ponded water before its reflooding again, during dry period seepage and percolation losses diminished to nearly zero (Bouman 2007).

The other possible solutions can be implemented for DSR cultivation sustainably and efficiently mentioned as (Kaur and Singh 2017)-

- Slow release N fertilizers and nitrification inhibitors may apply to minimize the volatile losses of fertilizers
- Soil application of biocide particularly neemicide for effective nematode control
- Foliar application of Fe and soil application of Zn for better nutrient management
- Seed priming practises for better crop establishment
- Integrated approach blended with genetics and genomics approaches in reducing the damage from insect, pest, and diseases
- Lodging resistant cultivars, optimum seeding rate, hill seeding, optimum depth and mechanized methods to overcome lodging

8.3.4 Scaling-Up of DSR Initiative in India

Direct Seeded Rice (DSR) is the eco-friendly rice cultivation technology with judicious use of water, labour, and energy. DSR saves 30% of production cost (Alam et al. 2018) and 30–50% irrigation water (Yadav et al. 2011) compared to transplanted rice and reduces women drudgery, labor, production costs, and energy through mechanization. DSR cultivation is also good potential to mitigate and well adapted under ongoing climate change. The enormous benefits of DSR over transplanted rice cultivation make it more popular day by day among the farmers. The scaling of DSR cultivation on larger scale is hours need and by adopting the following strategies DSR cultivation can reach to marginal farmers' field faster and conveniently.

8.3.4.1 Extension Strategies for DSR

Extension activities by including training, village fair, capacity building, field demonstration of DSR in farmer's field, exhibition of on farm trials including various mechanized method of seeding and exposure of farmers to innovations and technologies related to DSR.

8.3.4.2 Technology Adoption

At Technical level, intensive research and development is essential to solve the problem of water, nutrient and weed management, develop the rice varieties suitable for wider adaptability and better crop establishment under direct seeded condition.

8.3.4.3 Linkages and Participation for Popularisation

The two-way link and interactions must be established between both farmers and extension officers as well as between farmers and research scientists of state agricultural university (SAUs), *krishi Vigyan Kendra* (KVKs), and zonal research stations (ZRS) which can play a significant role in transfer of DSR technology and better understanding of the correct management practised required for DSR cultivation.

8.3.4.4 Awareness Creation

Village-level integration and awareness would aim to, improve farmers' skill, decision-making abilities and to educate them for development and incorporation of DSR technologies at their own farm. The economic aspects of DSR technology, through both ways, (i) increased productivity per hectare and (ii) by reducing cost of cultivation is essential for wider adoption. Singh and Shahi (2015) suggested some closely linked activities should be implemented for scaling up DSR technology among the farmers:

(i) Capacity building through farmer's field schools and trainings.
(ii) By conducting on farm trials and involving the farmers through participatory technology.
(iii) Communication support by providing the complete information to farmers through the use of newsletters, posters, and pamphlets.
(iv) New and traditional knowledge of farmers mixed together to form an integrated weed nutrient management -DSR technology.

8.3.4.5 Government Policy

DSR can be popularised through policy level by adopting the following measures (Singh and Shahi 2015):

(i) Providing more fund for DSR research and with special focus on Eastern India rice cultivation suitable for DSR
(ii) A task force involving the experts and to oversee the progress on DSR,
(iii) Funding for research and development from the central government agencies
(iv) Creating public-private partnership for mechanization and seed multiplication at larger scale
(v) Involvement of food corporation of India (FCI) and other government agencies for procurement of DSR suitable rice varieties

In countries like Cambodia, Malaysia, and Sri Lanka, more than 90% of the rice has been now cultivating through direct seeded method and the case studies can provide an important lesson for the countries that are shifting towards DSR (Kumar and Ladha 2011). In conclusion, precise land levelling, suitable DSR cultivars, good crop establishment, precise water management, integrated weed and nutrient management, efficient extension strategies in popularization, institutional linkages and favourable government policies are keys to the success and wider adoption of DSR.

8.4 Rice-Based Food Systems Using Innovations

Agricultural growth, poverty reduction and food security are at higher risk and impact on crop yield particularly in food insecure regions of the world under the ongoing climate change has worsened the situation. Raising of farmers' net income and developing resilience in rice-based food system can be enhanced by increase in crop productivity in a sustainable way, easy access to markets, and by providing the financial security and crop insurance through governments, NGOs, research partners and private sector. Diversification of rice-based farming system has been facilitated higher-value commodities and overall farm stability and minimizes risk, increase income and overall growth of marginal farmers. Raising productivity, profitability, and resource-use efficiencies of rice-based food systems for poor and marginal farmers can be improved by adopting the new innovative technologies. The major innovations to achieve this are listed below:

8.4.1 Strengthening Seed Systems and Adoption of High-Yielding Stress-Tolerant Rice Varieties

Non-accessibility of quality seed is a serious problem in achieving the goal of food security. The seed quality of improved varieties plays a crucial role in increasing the overall crop productivity and net income of marginal farmer. Crop yields can be increased by 20–25% by providing the sufficient quantity of quality seeds in timely manner and yield can be further raised up to 45% with good management and timely application of right quantity of other inputs such as chemicals, fertilizers, insecticide/pesticides and irrigation. Most of the rice growing farmers have small and marginal lands with low yield potential. The farmers in these areas routinely use the seeds saved in their farms from last year harvest and due to lack of proper training on quality seed production and storage, the quality of the farmers' saved seed is often below standard, thus affecting the crop yield. Interventions to strengthen the informal, semi-formal, and formal seed systems in the marginal areas by enhancing the capacity of farmers, seed growers, extension workers, sufficient seed production and storage, ensuring the availability of quality foundation seed for multiplication, promoting seed entrepreneurship to increase the profitability of farmers and ensure a local supply of quality seed, establishing community seed banks, multiplying seeds, and evaluating new varieties in a participatory mode are very much needed with the help of public-sector institutions and to build the resilience of poor rice-farming families in these areas. IRRI has played a crucial role in developing the climate resilient high yielding rice varieties as STRVs under the STRASA project. In this context, more than 15 STRVs were grown on about 20,000 ha by 82,000 farmers through head-to-head trials, cluster demonstrations, and dealer-linked mini kits during 2016–2019. Some of these varieties such as CR 1009-Sub 1 and Swarna-Sub 1 are now growing on larger scale in coastal areas resulting in faster replacement of popular varieties such as Swarna. Similarly, DRR 44 is getting popular among farmers for its drought tolerance, higher yield, and grain type in drought prone areas of Eastern India. For DSR, there is a need to select a variety with faster initial growth, high early vegetative vigor, and early canopy cover ability. Table 8.1 showed list of varieties recommended for aerobic direct seeded cultivation conditions.

8.4.2 Inclusive Development Through Knowledge, Innovative Extension Methods, Networks, and Capacity Building

8.4.2.1 Delivery Through Demonstrations

Progressive farmers will work as Community Resource Persons (CRP) and would coordinate with the participating farmers. These progressive farmers will be a focal point at cluster level to guide and help building up the technical capacity of these farmers. These demonstrations will be organized by NGOs/SAUs/ICAR/KVKs/ Private seeds and other institutes.

8.4.2.2 Head to Head (H2H) Trials

To compare the farmers' varieties with the new stress tolerant varieties, the new stress-tolerant varieties are grown in the same plots next to the farmers' varieties. H2H trials are an effective way for improving adoption and varietal replacement through informal seed diffusion. Through these trials, various stress-tolerant rice varieties (STRVs) are becoming more popular among farmers in Eastern India and other countries in South Asia.

8.4.2.3 Cluster Demonstrations

Instead of going to varietal demonstrations on several hectares in one place, conducting the varietal demonstrations in 5-hectare patches located at several focal points to ensure that these are accessible to more stakeholders will help in faster replacement of local varieties.

8.4.2.4 Crop Cafeteria

STRVs and other popular varieties are grown on a large tract of land where multiple stakeholders such as seed dealers, producers, district agriculture officials, scientists, and progressive farmers invited to learn about the varieties and evaluate their performance.

8.4.2.5 Organizing Seed Fairs

After the demonstrations are conducted in the districts, it is believed that farmers will learn from these demonstrations and will try and test the new varieties in their fields through informal seed exchange system, however, it has been observed that unavailability of seed is a limiting factor in the faster adoption of new technologies like rice varieties. To address this bottleneck, seed fairs will be organized at block level in all the districts where demonstrations are carried out to make seed locally available for sale. Farmers will be informed about this sale well in advance.

8.4.2.6 Evidence Hubs'

IRRI and the State Government of Odisha are promoting 'Evidence Hubs'. The hubs are organized at district levels to involve different stakeholders of the seed value chain in evaluating released rice varieties and those in the breeding pipeline.

8.4.2.7 Development & Validation of Extension Models for Faster Dissemination

Organization of client-oriented seed/varietal exhibitions to create awareness among dealers, distributors, and other potential stakeholders to facilitate the take up of new STRVs in the sustainable seed chain.

8.4.3 Empowering Women and Youth

The majority of the rice-farming households, women are actively involved in most of the rice production operations, such as, applying farmyard manure, weeding, postharvest operations such as threshing, and winnowing, drying, parboiling, selecting and storing seeds for the next season. However, despite their active labor participation in rice production and postharvest operations, women have relatively poor access to appropriate seeds and training on improved farming methods compared with men. To build the resilience of poor rice-farming families, both men and women should equally share of improved farm practices.

Youth finds agricultural work unattractive due to drudgery in farm operations, low farming profits, uncertainty, and lack of adequate finance/credit facilities. Youth engagement in agriculture can be enhanced by taking certain initiatives as mentioned below:

(i) Provide more opportunities for on-farm training for youth at primary and secondary school level
(ii) Organize trade fairs, exhibition, competition on farming techniques among the youths
(iii) Develop and expand the business based on agriculture
(iv) Provide motivation, financial security, update the ongoing policies and programs
(v) Develop the capacity building
(vi) Upgrade the skills and knowledge of local agricultural extension workers

8.4.4 Raising Productivity and Profitability of Rice-Based Food Systems Through the Rice Crop Manager (RCM)

The Rice Crop Manager is a web- and mobile phone-based application/software based on the principle of site-specific nutrient Management developed by IRRI in 2013. The rice crop manager tools included web-based as well as on mobile android platform in easy and user-friendly interface provides recommendations and guidance to small scale farmers on fertilizers and nutrient management practised to be adopted for their field. To get the precise recommendations from this tool, farmer needs to provide the information about their field location, seed variety, planting method, fertilizers used, yield, method of harvesting and other factors.

For example, IRRI had successfully demonstrated the use and benefits of RCM in rice cultivation of Odisha during 2012–2015 through collaboration with the Odisha University of Agriculture and Technology (OUAT) and National Rice Research Institute (NRRI). The benefits of using RCM includes either due to increase in yield (~4 t ha^{-1}), or decrease in fertilizer added with benefit of 10,107 Rs ha^{-1} for the fertilizer applied in the field (IRRI newsletter 2018).

8.4.5 Improved Post-harvest Technologies and Mechanization

Improved post -harvest technologies including proper storage and easy threshing and by use of different seed driller, laser land leveller can be deployed to empower farmers cultivating DSR and their linkages with traders and millers.

8.4.6 Targeting Rice Fallows for Increased Productivity by Promoting Pulses and Other Crops

Short duration drought-tolerant rice varieties with fertilizer responsiveness have increased the prospects for crop diversification in upland areas. Crop diversification through intercropping can increased productivity. For example, a short-duration legume (60–65 days varieties of cowpea) can be grown with the residual moisture after the harvest of the main rice crop. The most important criterion for intercropping upland rice is to maintain rice yield while obtaining additional yield from grain legumes. Farmers grow rice during the rainy season and the land remains fallow after the rice harvest in the post-rainy season because of a lack of sufficient rainfall or irrigation facilities. A crop maturing in September/October leaves sufficient carryover residual soil moisture available in the rice fallow in the post-rainy season, which can be used for growing second crops in the region, particularly short duration legumes.

8.4.7 Developing Web-Based GIS Based Rice Monitoring System

A dynamic assessment of rice crop, showing the status of the crop at different stages of the crop cycle in combination with a using various satellite systems. A rice monitoring system will strongly support an insurance program for the rice ecosystem, and it can provide updated information on cultivated area during the cropping season. Through GIS-based monitoring system, detailed and accurate information on total rice area planted in a particular area, and timely information of extreme weather events such as flood, drought, and tropical cyclones throughout the cropping season is possible. This information's are useful and critical for policy makers and government agencies for effective disaster management, ensuring food security and in providing crop insurance to farmers.

8.5 Lessons Learnt and a Way Forward

Dynamic socioeconomic and agro-ecological changes in Asia require the development and dissemination of direct seeded adapted rice varieties and technologies in addition to their adoption. In many countries such as Sri Lanka, Malaysia, and the United States, dissemination of varieties with complete package, including laser land leveling, mechanized seeding-harvesting-threshing, proper water-nutrient-weed management enabled the successful expansion of direct seeded rice cultivation system. The diverse environment, climatic variability and season specific availability of water in the Asian countries necessitate massive research to solve every challenge to develop and disseminate DSR varieties and technologies suited to all ecosystems. For large scale dissemination and adoption of these technologies, it is very important to take advantage of combinations of precise technologies and suitable direct seeded adapted varieties that allow farmers to realize the benefits of DSR cultivation with less water, labor and energy. There is strong need to identify the constraints, policy issues, institutional support; logistics need to scale up the adoption of DSR varieties and climate smart agricultural practices that will ensure food security for marginal and smallholder farmers under the changing climatic situations. Developing and distributing improved high yielding DSR adapted rice varieties that are suitable to the local conditions are important to save the natural resources as well as to tone down the existing crop yield gaps. The lack of knowledge about mechanized technologies, mind-set of farmers', traditional way of cultivation rice, poor linkages among the stakeholders, and very less or zero government support are the important constrains in adoption of DSR rice varieties and technologies. Involvement of research and extension agencies, government support, public infrastructure investments, and dissemination of DSR adapted rice varieties with complete water-nutrient-weed management package is required for the effective scaling up of DSR varieties and technologies among farmers in the Asian countries.

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Chapter 9
Sustainable Intensification of Potato Cultivation in Asia

Sampriti Baruah and Samarendu Mohanty

Abstract Potato consumption in Asia will continue to rise in future due to a combined influence of rise in income and population growth. In addition, potato will continue to remain as an important staple for millions of poor people along the Indo Gangetic Plains of India, Bangladesh, Nepal and in the improvised mountainous regions of China. Thus, potato production in these cropping systems need to increase in the face of declining arable land due to urbanization and rising frequency of extreme weather events such as flood, drought and unseasonal rain due to climate change. For sustainable intensification to happen, several constraints need to be addressed like availability of quality seed at affordable price, various socioeconomic factors like poor market linkages, high year-to-year price fluctuation and disadvantages of small farm size.

Keywords Potato · Sustainable intensification · Asia · Potato cultivation · Apical rooted-cuttings

9.1 Sustainable Intensification of Potato Cultivation in Asia

Potato is the third most important food crop behind rice and wheat and a staple for 1.3 billion people, including millions of poor people in Asia (Devaux et al. 2020). The importance of potato has been on the rise in Asia with its production rising from 23 million tons in 1961 to 189 million tons in 2018 (Fig. 9.1). During the same period, potato production in the rest of the world has declined from 247 million tons to 189 million tons. Asia now accounts for more than half of the global production. Within Asia, both China and India are the top two producer and consumer of potato in the world accounting for 75% of Asian production and 38% of the global production in 2017 (FAOSTAT).

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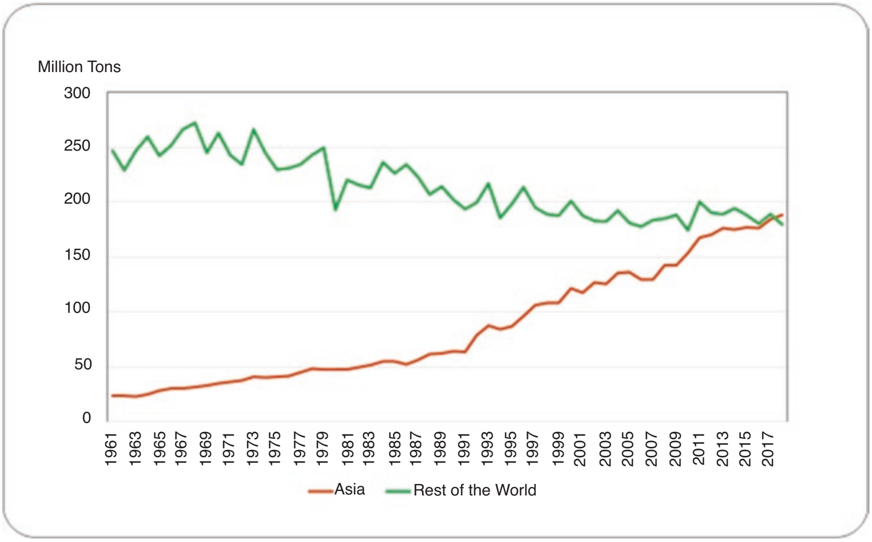

Fig. 9.1 Asia vs. rest of the world potato production during 1961–2018. (Data source: FAOSTAT accessed on October 31, 2020. http://www.fao.org/faostat/en/#data/QC)

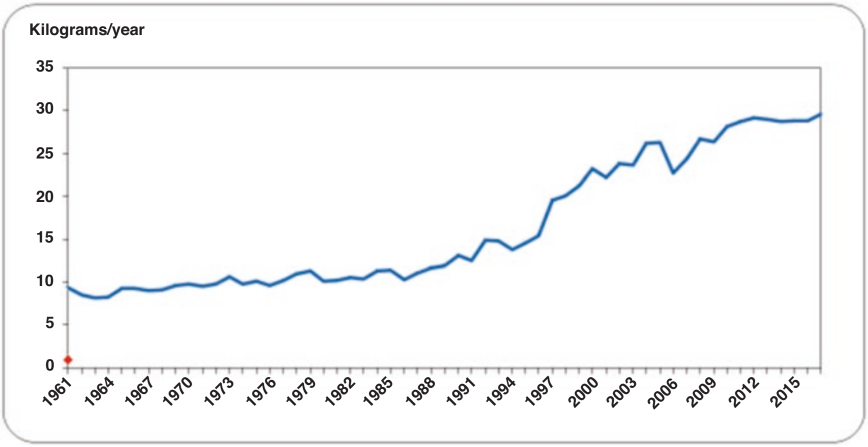

Fig. 9.2 Per capita utilization of potato in Asia. (http://www.fao.org/faostat/en/#data/FBSH)

Tracking production trend, per capita utilization of potato has been on a steep rise since late 80s from 11 kilograms to close to 30 kilograms in recent years (Fig. 9.2). However, majority of the increase has come from South and East-Asia whereas potato remains a very minor food crop in Southeast Asia with per capita utilization stagnant at 5 kilograms in the past decade (Fig. 9.3). For decades, the Chinese government has been trying to encourage potato consumption in the

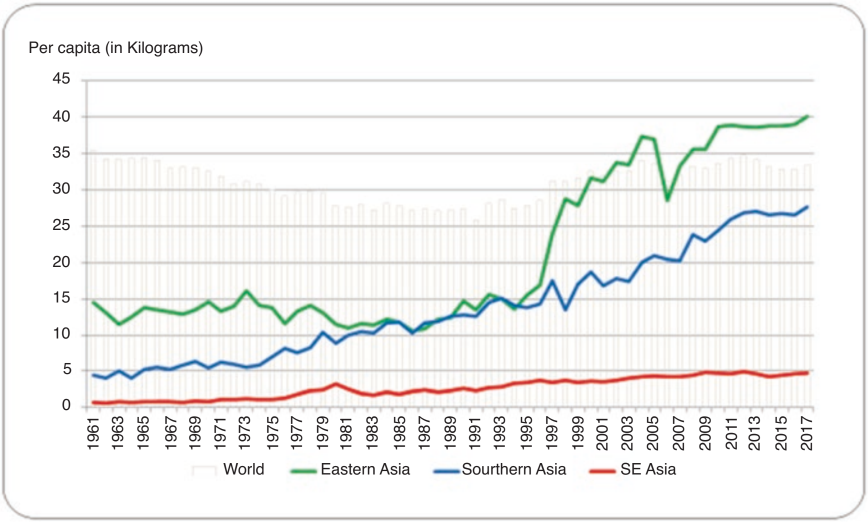

Fig. 9.3 Wide variation of potato consumption within Asia. (Data source: FAOSTAT)

country as an alternate to cereal as a food security crop (Su and Wang 2019). Since potatoes haven't been large part of Chinese diets, more than 200 potato products including potato steamed bread, potato noodles, flour, potato cakes and others have been developed keeping in mind the preference of Chinese consumers (Su and Wang 2019). The end results have been encouraging with per capita consumption increasing from 30 kilograms in 2007 to 52 kilograms in 2016.

With rise in income and urbanization, potato consumption in urban Asia will continue to rise in the future as a combination of both rise in per capita consumption and population growth. In addition, potato will continue to remain as an important staple for millions of poor people along the Indo Gangetic Plains (IGPs) of India, Bangladesh, Nepal and in the improvised mountainous regions of China. Overall, the total potato consumption is expected to rise in the future. As shown in Fig. 9.4, an extrapolation of total potato consumption in Asia by fitting a trend line indicate that the total consumption is likely to rise by another 70 million tons by 2030.

9.2 Key Constraints Faced by the Potato Production System

In Asia, potato production system can be broadly grouped into four cropping systems based on latitude (Ezeta 2008). It includes single cropping system of the northern latitudes, the double cropping system in the central part of China, the mixed cropping in the southwest of China and the winter crop of the extreme southern part of China, the Indo-Gangetic Plains, Bangladesh, and northern Vietnam where

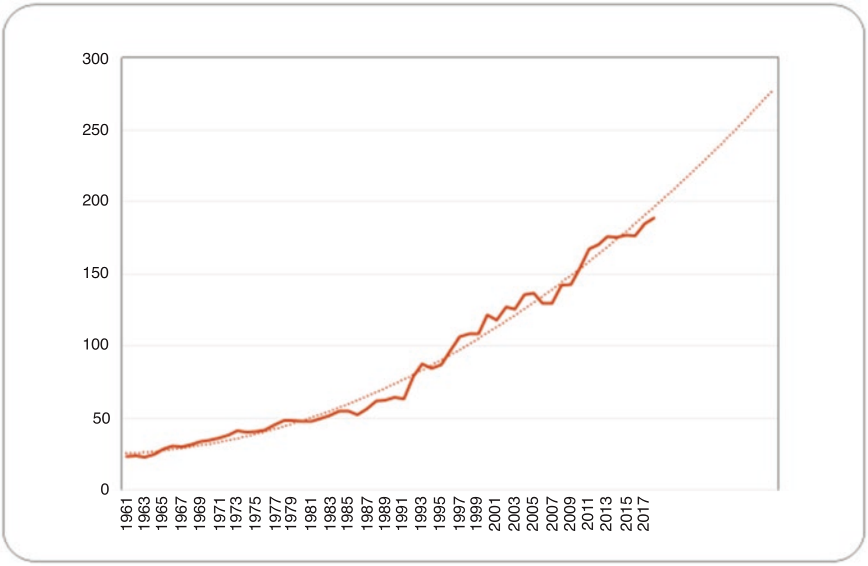

Fig. 9.4 Projected potato consumption in Asia

potatoes are planted in the winter after rice but in some areas, it is planted after maize and competes with wheat and other vegetables in South Asia and rice in Southeast Asia (Ezeta 2008). The potato production in these cropping systems need to increase with declining arable land due to urbanization and rising frequency of extreme weather events such as flood, drought and unseasonal rains due to climate change adding to the situation of the existing land degradation due to the excessive use of pesticides and fertilizers (Liu et al. 2015).

All potato growing regions are faced with different set of production constraints like set of biotic and abiotic stresses including aphid, late blight and drought in the single cropping system (Ezeta 2008). Similarly, in the double cropping system where potato is cultivated as a monocrop and then as an intercrop with maize is faced with serious virus and bacterial wilt. The southwest of China and northern Myanmar where potato is cultivated in a mixed cropping system, late blight, bacterial wilt and wart are the main problems. The winter potato is grown in all regions that extends from Southern China to India and Bangladesh. It is also grown in the Red River Delta in northern Vietnam, parts of Myanmar and northern Thailand, Indonesia and the northern tip of Luzon in the Philippines. In this production system, potato is planted in intensive cropping system where productivity is impacted by different pest and diseases including late blight, bacterial wilt, viruses, and various pests (Ezeta 2008).

Apart from various biotic and abiotic stresses, the potato production in the region is also impacted by the non-availability of quality planting materials and different socioeconomic factors. The non-availability of reliable and affordable planting material is a major problem in all potato growing regions in Asia. The high cost of seed has led to the use of discarded, small-sized potato as seed for most small farmholders in the region. For example, in India, potato seed used by farmers comes from the seed-producing region in the north of India – more than 2000 kilometers from the potato growing regions in the east. This high transportation cost is borne by the poor farmers who pay high seed prices. To make matters worse, the high price does not guarantee high quality, thus making it difficult for small and marginal farmers to invest such a large sum in seed purchases which accounts for nearly half of the total cost of production. This has led to low seed replacement, which was 8.5% in 2013, according to a workshop report published by the Central Potato Research Institute (CPRI) (https://www.researchgate.net/publication/321996825_Problems_and_Prospects_of_Seed_PotatoProduction_Systems_in_India_Souvenir)

The seed situation is equally problematic in Bangladesh where formal seed sector accounts for 5% of the seed requirement and the remaining 95% is low quality seed produced by the farmers themselves (Shaheb et al. 2015). Despite high cost, some Asian countries including Indonesia, Thailand, Vietnam and Pakistan import certified seed from the Netherlands and other countries (Ezeta 2008).

Among various socioeconomic factors that limit potato production in the region are poor market linkages and high year-to-year price fluctuation with price crash after harvest. The risk of losing money due to high price fluctuations has been a key deterrent for small farmers to take up potato production. Unlike cereal and pulses, the absence of government procurement and minimum guaranteed price expose potato farmers to all downside price risk in case there is a glut in the market. This has been a key deterrent for small farmers to take up potato production.

9.3 Sustainable Intensification of Potato Farming Systems

To meet rising demand for potato in the region, the additional production will have to come from raising productivity and increasing cropping intensity on cultivated land in a sustainable manner. This will have to happen in the face of declining arable land due to urbanization and induced negative effect on productivity due to climate change. Incessant unseasonal rain during the harvest time of March/April 2020 in key potato growing states in India is an example of how climate change has been negatively affecting potato yield in the region. In addition, sustainable production practices including conservation agriculture will have to be adopted by potato farmers to offset the negative impacts of excessive use of pesticides and fertilizers on soil degradation and contamination of water resources (Liu et al. 2015; Ezeta 2008). But more importantly, availability of quality seed at affordable price in a timely manner and strong market linkage and cold storage facilities to minimize price crash after the harvest need to be developed to encourage farmers to intensify potato production.

9.3.1 Sustainable Productivity Improvement

As mentioned earlier, the availability of quality seed at affordable price in a timely manner is a pre-requisite for improving productivity in a sustainable manner. This is possible with availability of a low-cost seed multiplication technology such as apical rooted cutting (APC) instead of aeroponic technology, which has a high capital requirement and a long gestation period. The low-cost technology needs to be popularized in the potato production belts so that progressive farmers, farmer producer organizations (FPOs), and other small entrepreneurs from potato-growing regions can take up seed potato production.

The apical rooted cuttings (ARC) like current aeroponic seed production system involves tissue culture plantlets. It uses tissue culture plantlets as mother plants in coco pits for producing cuttings where each mother plant can be multiplied to produce 8 plants in 6 weeks and the number goes to more than 15 in 12 weeks (Fig. 9.5). These cuttings are transplanted on the seed bed and once rooted, are moved to net houses or open field for producing first generation seed tubers. In the last couple of years, CIP in partnership with national partners in India, piloted ARC in several Indian states including Karnataka, Haryana, Odisha and Assam to assess the performance of ARC in Indian conditions. Based on our pilots in different India states, the average number of first-generation tubers from cutting has been estimated to be around 10.

In Karnataka and Haryana, we have seen overwhelming interest from progressive farmers and farmers' groups in taking up seed production from ARC enabling scaling-up sustainably (Fig. 9.6). So far, 19 nurseries in Hassan, Karnataka and a few large potato farmers in Haryana have taken up producing ARCs from tissue culture plantlets. The numbers in Karnataka and Haryana are expected to rise significantly in the next few years. Recently, we provided training to two nurseries with tissue culture facilities in Odisha to start producing ARCs in the coming seasons. The International Potato Center (CIP) is partnering with the Central Potato Research

Fig. 9.5 Apical Rooted Cutting Seed Production in Open Field, Bengaluru, Karnataka. (Source: Mohanty et al. 2020)

Fig. 9.6 Farmer carrying beautifully Packed apical rooted cuttings to field for planting in Karnataka. (Source: Mohanty et al. 2020)

Institute (CPRI) and horticulture departments in other states such as Bihar, Assam and Meghalaya to pilot and demonstrate the ARC technology to larger group of farmers and other organizations, interested in taking up cutting production and seed tuber multiplication. We expect that in the coming seasons, there will be increased demand for cuttings and first-generation seeds from farmers, FPOs, and other entrepreneurs. The scaling up of this technology as initiated through building partnerships can also be accelerated with proper enabling policy support and some subsidy for setting up tissue culture laboratory and poly house to interested individuals or organizations as is the case for horticulture by the government.

From private entrepreneurship perspective, the entire ARC supply chain can be taken up by one entity or can be broken up into two components and can be taken up by different entities (Mohanty et al. 2020). As explained by the authors, the first component includes setting up a tissue culture laboratory and producing cuttings from tissue culture plantlets. Table 9.1 provides the fixed and operating cost and returns of producing cuttings from tissue culture plantlets. The investment in infrastructure, which includes a tissue culture laboratory and two 500-square-meter polyhouses, is around INR 3.5 million (US $ 48,300), with INR 1.5 million (US $ 20,718) for the tissue culture laboratory and INR 2.0 million (US $ 27,624) for two polyhouses. Assuming a 10-year useful life for the tissue culture laboratory and polyhouses, the annual amortized amount is estimated to be INR 0.35 million (US $ 4834). The cost of producing 2.0 million ARCs from tissue culture plantlets is estimated to be INR 1.41 million (US $ 19,475). Reasonably pricing each cutting at INR 1 (US penny 1.4), the profit is found to be INR 0.59 million (US $ 676).

The above operation of the tissue culture laboratory for producing tissue culture plantlets and of the polyhouses for producing cuttings, which requires an upfront investment of INR 3.5 million (US $ 48,300) and operating budget of INR 1.4 million (US $ 19,337), could be expensive for small entrepreneurs. In that case, an

Table 9.1 Cost and returns of producing apical rooted cuttings from tissue culture plantlets

Infrastructure development cost	**One-time investment for 10 years (in INR)**		**Annual amortization cost (in INR)**
Tissue culture laboratory	1,500,000		
Two polyhouses of 500-sq.-meter size	2000,000		
Total upfront investment	3,500,000		350,000
Operating cost	**Number**	**Unit cost (in INR)**	**Cost/revenue/profit (in INR)**
Tissue culture plantlet production	20,000	3	60,000
Production of cuttings (including labor, coir pith, and tray)	2000,000	0.50	1,000,000
Total cost			1,410,000
Gross revenue by selling cuttings	2000,000	1.00	2000,000
Net profit			590,000

Source: Mohanty et al. (2020)

Table 9.2 Cost and returns of producing apical rooted cuttings by Purchasing Tissue Culture Plantlets

Infrastructure development cost	**One-time investment for 10 years (in INR)**		**Annual amortization cost (in INR)**
One polyhouse of 500-sq.-meter size	1,000,000		
Total upfront investment	1,000,000		100,000
Operating cost	**Number**	**Unit cost (in INR)**	**Cost/revenue/profit (in INR)**
Tissue culture plantlet production	10,000	3	30,000
Production of cuttings (including labor, coir pith, and tray)	1,000,000	0.50	500,000
Total cost			630,000
Gross revenue by selling cuttings	1,000,000	1.00	1,000,000
Net profit			370,000

Source: Mohanty et al. (2020)

entrepreneur/nursery/farmer can take up ARCs by purchasing tissue culture plantlets from a tissue culture laboratory and operate on a smaller scale. As shown in Table 9.2, the upfront cost of setting up one polyhouse will be INR 1.0 million (US $ 13812) and the operating budget for producing 1.0 million cuttings will be approximately INR 0.53 million (US $ 7320). Selling at INR 1(US penny 1.4) per cutting, the operation will generate a net profit of INR 0.37 million (US $ 5110) within a period of 4–6 months.

The second component includes production of first-generation seed either in net house or open field and production of second-generation seed tubers from first generation seeds in open field. The cuttings planted in the open field can be sold to farmers after the second generation, whereas cuttings planted in the net house can be multiplied one more round before selling to farmers to make them economically viable.

Table 9.3 provides the cost and returns of producing first- and second-generation seeds from ARCs in an open field and selling it to farmers as seeds. As shown in Table 9.3, one acre will require 40,000 cuttings that will produce around 4 lakhs seed tubers with an average of 10 tubers per cutting. These four lakhs first generation tubers can be planted in 10 acres in the next season to produce 80 tons of second-generations seeds which can be sold to farmers in the following season at Rs. 20 per kilogram to generate a net profit of Rs. 0.74 million (US $ 10,220).

9.3.2 Overcoming the Disadvantages of Small Farm Size of for Sustainable Intensification

The small size of potato farmers in the region is another constraint for intensifying potato production because of diseconomy of scale in mechanization and lack of bargaining power both in the input and output markets. As we know, the average size of farmers in Asia is around one hectare but these small farmers only plant a fraction of land for potato because of high price fluctuation in the produce market after harvest making them vulnerable to loss. To overcome these adversities, the small farmers need to come together either through Farmers Producers Organizations (FPOs), Self-Help groups (SHGs) or any other informal models such as the Small Farmers Large Field (SFLF) farming started in Vietnam. SFLF is a participatory and innovative bottoms up informal model where the farmers organize themselves into groups and synchronize their operations by virtually converting their small landholdings into a large field (Baruah 2020). The SFLF model is founded upon the

Table 9.3 Cost and returns of producing first-generation seed potato from apical rooted cuttings

Operating cost	Number	Unit cost (in INR)	Cost (in INR)
Apical rooted cuttings	1 acre (40,000 cuttings)	1	40,000
Cost of production	1 acre	60,000	60,000
Cold storage	4 lakhs	5000	20,000
Multiplication from first- to second-generation seeds			
Cost of production	10 acres	60,000	600,000
Cold storage	80 tons	2000	160,000
Total cost			880,000
Gross revenue	80 tons	20,000	1,600,000
Net profit			740,000

Source: Mohanty et al. (2020)

principle of aggregating small and marginal farmers to achieve bargaining power by strengthening backward and forward integration along the supply chain, reducing per unit cost of production, improve yields, improve efficiency by synchronizing selected key operations (Baruah 2020). It has also been successfully piloted for both rice and potato farmers in India. In case of rice, it was piloted in Taraboisasan village near Bhubaneswar, 54 farmers with about 36 hectares participated in the 2016/17 *rabi* season (Mohanty et al. 2018).

At the end of the season, the average per hectare profit was more than doubled from INR 29,973 (US $ 414) to INR 61,355 (US$ 847). Apart from the monetary benefits, the farmers saved time and energy in each of the farming activities performed together. The participating farmers also mentioned the time and money they saved because the fertilizer was delivered to them. Organizing themselves into a group also helped the participating farmers to obtain interest-free credit from each other under group solidarity rather than from micro-finance loans at an average 26% interest rate. The same approach can be used for potato farmers to harmonize and synchronize selected operations and activities to achieve bargaining power and economy of scale. Bizikova et al. (2020) also have reported based on the meta-analysis that farmers' organizations helped the small farm-holders through collectivization which enabled them to exert power of collectivization for bargaining with service/inputs providers.

In 2019/20 dry season, the SFLF model was piloted by CIP with more than 800 small potato farmers in 13 villages of Odisha and Assam covering more than 300 acres. On learning that growing a single variety would benefit them from economies of scale when selling there produce as a group, all the farmers participating unanimously decided to grow Kufri Jyoti a popular table variety in Odisha and both Kufri Jyoti and Lady Rosetta a processing variety in Assam.

In Odisha, the participating farmers attained an average yield of around 25 tons per hectare for as compared to 12 tons per hectare in the previous seasons and net profit increased by 3 times compared to previous seasons. Farmers received an average price of Rs. 14 per kg for table variety Kufri Jyoti. In Assam also the average yield was around 25 tons per hectare and net profit doubled compared to the previous season. Farmers received an average price of Rs. 12 per kg for table variety Kufri Jyoti and an average of Rs. 13 per kg for processing variety Lady Rosetta (LR). Through backward linkage the farmers were connected to input suppliers like Indian Farmers' Fertilizer Cooperative Limited (IFFCO), Syngenta, Bayer, DuPont, Mahindra, Jalpo etc. The suppliers were also happy to supply required inputs (seeds, fertilizer & pesticides) as they received bulk order at one time from a single place/village. Since it was bulk purchase, it was also possible to convince input dealers, to supply inputs at doorstep of farmers and at a price which was lower than the prevailing retail price. As a result, a good amount of discount could also be availed in terms of transportation cost of the inputs. The increase in profitability was attributed to the cost reduction in farm operations due to synchronization and mechanization by adopting collectivization and higher gross revenue due to greater bargaining power input and output markets through suitable market linkages and higher yield due to better seed and improved crop management practices suggesting that holistic

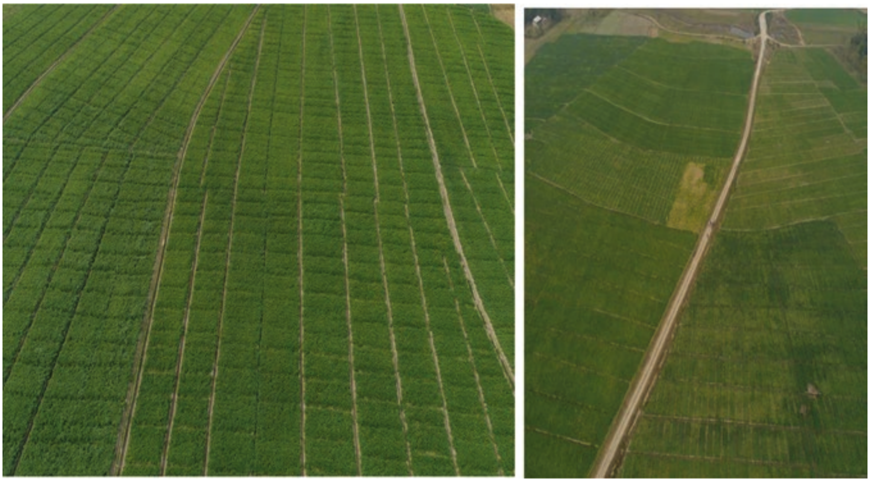

Fig. 9.7 About 30-hectare land under SFLF potato plantation as patches in Gingia Village, Biswanath district, Assam. 2019–2020 dry season

Fig. 9.8 Three hectares of land under SFLF potato plantation Chhenua Village, Puri district, Odisha. 2019–2020 dry season

integrated approach through building partnerships benefitted small far-holders as indicated by Wani et al. (2003) and Wani 2021, Chap. 1) Figs. 9.7 and 9.8.

Apart from the availability of quality seed at affordable price and achieving economy of scale and bargaining power through group farming like SFLF, the intensification of potato in the Asian cropping system will have to be achieved with lesser environmental impact. First of all, intensification requires more labor which is good for rural employment, but the present situation is posing labor shortage because of rural outmigration and rising wage rates especially during the peak season as an important stumbling block for intensification. Secondly, potato cultivation requires higher fertilizer (usually at a rate of NPK 200–43-125 kg ha^{-1}) and pesticide use (Gatto et al. 2020) as compared to cereal crops. The intensification will increase the use of fertilizer and pesticide causing more damage to the environment (Biswas et al. 2006). Finally, the water availability which is the key determining factor for the extent of intensification in Asia. For example, many governments in the regions such as Bangladesh, India and others are discouraging farmers to grow dry season (boro) rice. According to Rabbani and Rahman (2015), upland boro rice in Bangladesh is discouraged by the government. Similarly, Haryana government has started paying Rs. 7000 (US $ 97) per acre to its farmers not to grow rice. Instead, they can grow any non-rice crops including maize and pulses. Although, the water requirement for potato is significantly lower than dry season (boro) rice there is still need for water use efficiency to conserve groundwater in many parts of Asia.

The above-mentioned problems need to be resolved for sustainable intensification of potato in Asia. The labour shortage and high wage rate can be addressed by planting early maturing rice variety that will shift harvest by 2–4 weeks and timely planting of potato (Gatto et al. 2020). This will shift the labour requirement to a lean period where labour is readily available and costs are lower (Gatto et al. 2020). The timely planting of potato will also reduce the irrigation requirement because of residual moisture in the soil. Combining early maturing paddy with early maturing or short duration potato of 70–75 days can have double beneficial effects with reduced irrigation requirements by proper utilization of soil moisture and the number of irrigations. Apart from efficient utilization of water, the early harvest of potato also solves another big constraint, i.e., low price for the produce. Normally, in Asian countries, the farm gate price drops after the harvest because of glut in the market. If farmers can sell their potato 2–4 weeks earlier before the normal harvest enters the market then they can receive much higher price for their produce, making it attractive for farmers to intensify potato cultivation. Small scale mechanization of planting and harvesting is another way to reduce labour requirement and cost of cultivation. But the small size of potato farmers makes the mechanization economically unviable. To achieve the scale effect, group farming model such as SFLF could be promoted. The availability of machinery rental through Farmers Producers Organizations (FPOs) and service providers through custom hiring centers (CHCs) which are promoted by the government of India (GoI) are other ways to make it viable for small farmers to adopt machine planting and digging.

Although intensification increase fertilizer usage, there is evidence in the literature that the succeeding crop after potato in the rice and maize cropping systems will require less fertilizer application (Gatto et al. 2020). According to Singh et al. (2007), the fertilizer requirement is reduced by half for succeeding wheat and sunflower crops after potato. Similarly, the pesticide application can be reduced by developing and disseminating biotic stress tolerant varieties for late blight. In addition, the introduction of short duration and early maturing varieties will reduce the exposure of the crop to disease pressure and will reduce pesticide application.

9.3.3 Zero Tillage Potato Cultivation

Many negative environmental footprints of potato intensification can be minimized by zero tillage (ZT) cultivation using paddy straw mulching. It involves treating potato seeds with Dithane-M-45 on the top soil at 60 × 25 cm inter and intra row distance immediately after the paddy harvest (Ali and Raut 2020). In the next step, the seed tubers are covered with well decomposed farmyard manure at the rate of two tons per acre and basal dose of chemical fertilizer around the seed tubers (Ali and Raut 2020). Finally, the field is covered with thick rice straw at the rate of two kilograms per square meter (Fig. 9.9). More detailed information of the crop management under zero tillage cultivation can be found in Ali and Raut (2020). After 90 days, tubers can simply be picked from the ground after removing straw mulch.

ZT potato cultivation leads to significant water saving with 50–60% less water requirement than traditional practice. It also saves labour expenses for farmers as it needs no ploughing, planting & digging. Straw coverage also reduces weed infestation saving herbicide application and labor cost for weeding. The no tillage of soil also improves the soil health by enhancing normal biological process (Ali and Raut 2020). ZT also can be promoted as a women-friendly potato production technique: no ploughing, no planting seeds by making ridge and furrow and no digging to harvest tubers. One only needs to place the seeds on the topsoil (Fig. 9.9) after paddy harvest, cover it with straw and pick up the tubers by removing the straw (Fig. 9.10).

Fig. 9.9 Zero Tillage Potato plantation at Resinga Village, Puri district, Odisha. 2019–2020 *rabi* season

Fig. 9.10 Zero Tillage potato plantation at Assam and Odisha. 2019–2020 *rabi* season

9.4 Potato Supply Chain Improvement

For sustainable intensification to happen, it is essential to have a well-developed supply chain to properly handle expanding production. At present, high price fluctuation in the potato market makes it risky for farmers to grow potato. Small potato farmers are forced to sell their produce after harvest at a throwaway price because of need for cash to pay off debt and household expenses. In years of bumper harvest, farmers lose money because market price falls below the cost of cultivation. Farmers can get attracted to potato cultivation if potato value chain is improved with adequate cold storage facilities and market linkage information. Farmers (specially the small holders) need to be well acquainted to the various channels of potato marketing in order to improve their price realization. By promoting medium and small micro-enterprises in rural areas through FPOs and young entrepreneurs will benefit small farm-holders by using warehouse and cold storage facilities as well as enable them to get loan using warehouse/cold storage depository receipts.

9.5 Way Forward

Potato consumption in Asia will continue to rise in the future as a combination of both increase in per capita consumption and population growth and is expected to rise by another 50 million tons in the next decade. In the face of growing land degradation and water scarcity, climate change, competition for agricultural land from urbanization, as major challenges, the future growth will have to come from the existing land and in a sustainable manner with minimum environmental footprint. Sustainable intensification can happen by adopting low-cost ARC seed supply system for ensuring quality seed supply at low price in a timely manner. Farmer led low-cost technology like ARC can be scaled up through FPOs and young entrepreneurs so that farmers can get quality seeds at affordable price. This farmer-led approach can decentralize seed production system and significantly improve the quality and price of seed.

Apart from seed, the small size of potato farmers in the region is also another constraint for intensifying potato production because of diseconomy of scale in mechanization and lack of bargaining power both in the input and output markets. This adversity can be overcome by bringing farmers together either through Farmers Producers Organizations (FPOs) in India, Self-Help groups or any other informal models such as SFLF farming model. It has been successfully implemented in two Indian states where farmers have significantly benefitted with this synchronized collective farming model which led to lower cost cost and higher quality produce. The combination of early planting with short duration or early maturing varieties can address several emerging issues including labour shortage, water efficiency and irrigation requirement and less environmental footprint. Similarly, zero tillage potato cultivation with paddy straw mulching can minimize several negative environmental footprints of potato intensification. Finally, it is essential to have a well-developed supply chain to properly handle expanding production due to intensification. In brief, for sustainable intensification of potato cultivation farmers need to receive improved knowledge/technologies such as zero tillage potato cultivation, improved stress-tolerant cultivars and holistic integrated solutions including backward and forward market linkages as well as collectivization for promoting micro-enterprises and achieving scale for operations are must.

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Chapter 10
Scaling-up Technology Adoption for Enhancing Water Use Efficiency in India

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Abstract Large yield gaps are existing on farmers' fields in India in spite of several islands of successful pilots conducted by several institutions. In recent years Science of Delivery has received the attention of the international and national research institutions but the success rate is rather very low. There is an urgent need to strengthen the science of delivery and scaling-up the impacts to develop sustainable food systems for achieving food, nutrition and income security for the small farm holders as well as for the countries. Keeping this in mind, a pan- India study on farmers' participatory action research program (FPARP) covering 5000 locations spread out in 21 states of India was initiated by the Ministry of Water Resources, Government of India during 2007–2009 and evaluation of the program was done in the subsequent years. The results indicated increased water productivity, income and water saving in several crops due to technology adoption with farmers' participation. However, adoption of the improved technologies has ranged only from 12 to 15%. Hence, the existing two technology adoption level gaps, viz., technology transfer gap and the technology performance gaps should be properly addressed in the future agriculture development programs. Piloting of location specific technology packages in a cluster of villages through farmer participatory action research-cum-capacity building programs and initiating public private partnership in technology transfer and uptake will have a higher pay off. Convergence of the government programs in technology transfer should be made through involvement of different stakeholders such as government departments, NGOs, private sectors and farmers.

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10.1 Status of Water Resources in India

10.1.1 Challenges in Managing Water in Agriculture

India has made a significant progress in developing its water resources over the past six decades (Palanisami et al. 2015). However, demand for water has been increasing due to rapid economic development (Björklund 2001; Gurría 2009; Brauman et al. 2013; Palanisami et al. 2015; Suresh Kumar and Palanisami 2019). In the agriculture sector, irrigation is considered important to ensure food security and also to sustain economic growth. Indeed, managing water for agriculture has been emphasized by researchers owing to its potential in reducing poverty, and achieving food sufficiency (Chaturvedi 2000). By 2030, about 1 billion more people will be living under severe water stress and the majority of them will be in emerging economies (Gurría 2009). The major challenges that India has experienced in irrigation water management are:

(i) **Water scarcity:** Significant gap has been observed between supply and demand for water (Chaturvedi 2000). Fresh water resources are finite, not less than 90% were accounted for agriculture (Davies and Bennett 2015), of which one-third is groundwater. Growing demand for water coupled with constraints in exploring new water resources results in water scarcity. This increasing water scarcity would be a major challenge in allocation of water resources between sectors, which may influence the growth process of those sectors.

(ii) **Food security:** Ensuring food security of the huge population is certainly a noteworthy task with water as a major factor (Leisinger 1996; Chaturvedi 2000; Björklund 2001; Ahmed et al. 2014). To be self-sufficient in food, India need to grow sufficient food within the country (Kumar 2001). Though demand for water has significantly increased across sectors, concerning food security issues, huge amount of water has been diverted to agriculture. Conversely, to sustain economic growth, increased demand for water in other sectors poses a significant challenge.

(iii) **Water use efficiency:** In India, the water use efficiency in irrigation has been very poor due to field evaporation, evapotranspiration, percolation, and poor on-farm water management practices (Kumar 2001). Overuse of water for irrigation has already resulted in serious groundwater depletion (Davies and Bennett 2015). Efficient use of irrigation water would be a potential option, and likely to be achieved by raising crop water productivity.

(iv) **Climate change:** Climate change is a potential threat in irrigation management (Kundzewicz et al. 2007; Hanjra and Qureshi 2010; Turral et al. 2011). Increased variability of rainfall includes longer drought periods resulting in an increase in irrigation requirements (Eheart and Tornil 1999). The implications of water allocation for agriculture are significant, where runoff is predicted to decline under climate change. Hence, the allocation decisions and associated trade-offs between ecosystems and agriculture will be really challenging (UN-Water 2007).

(v) **Groundwater depletion:** In India, wells are the predominant source for irrigation and about 60% of the irrigated land is supported by groundwater supply. More than 80% of the addition to net irrigated area since green revolution has been supported by groundwater use (Chindarker and Grafton 2019). Excessive withdrawal of groundwater is the major concern for lowering of water levels. This would result a significant stress to irrigation potential affecting food security (Suresh Kumar and Palanisami 2019).

10.1.2 Low Water Use Efficiency in Irrigated as Well as Rain-Fed Agriculture in India

Increasing water productivity is particularly appropriate where water is scarce (Sharma et al. 2015), and it needs to be improved to meeting out the rising demand for food, as a measure of climate change adoption, and to meet out the demand of different sectors of the economy (Molden et al. 2010). Existing water use efficiency is significantly low (Chaturvedi 2000; Palanisami et al. 2012) for both irrigated as well as rain-fed farming systems. Crops are predominantly cultivated using flood and furrow irrigation, triggering evaporation losses and deep percolation (Frenken 2012). Thus, lack in adoption of modern technologies could be a prime reason for lesser water use efficiency; however, institutional failure is also another important factor. Under rain-fed condition, not only modern cultivation practices were properly adopted, most of the intercultural operations may also not been practiced predominantly, which would result significant yield loss, and thus lower water use efficiency. Hence, in the future, water productivity increases are highly warranted. The term water productivity refers to the ratio of physical production (in terms of biomass or crop yield) or, in some instances, 'economic value' of production (in terms of gross or net value of product) relative to water use (in terms of water withdrawn, applied or consumed). It is, therefore, expressed in kilograms per cubic meter (kg/m^3) or rupees per cubic meter (Rs/m^3). Alternatively, the water foot print which is reciprocal of the water productivity can also be used where the aim will be to minimize the water foot print of the products at different levels.

10.1.3 Why "More Crop Per Drop of Water" Initiative is Important?

Food security is becoming an acute problem (FAO 2013), and therefore more food needs to be produced to feed. Nevertheless, water availability has been a prime factor that likely to limit future food production. Besides, climate change poses a further threat to food production by limiting water availability, and crop productivity (Hanjra and Qureshi 2010; Turral et al. 2011). Hence, food production must be increased within limited water resources (Ahmed et al. 2014), and thus maximizing food production whilst minimizing water usage is the key to addressing water scarcity and food insecurity (Molden 2007) and this is being referred to as more crop per drop of water.

The overarching objectives of enhancing water productivity are increasing agricultural production to meet rising food demands and reducing agricultural water use to facilitate reallocations to other sectors. The others are raising farm-level income, and alleviating poverty and inequity in the agriculture sector. Thus, in many instances, water productivity interventions have embraced more than one development objective (Giordano et al. 2019).

The water productivity ratios are often used for making comparisons across users, sectors and over time for fulfilling the above objectives. Consequently, at macro level, estimates of changes in water productivity will be useful to assess policy interventions by incorporating the possible trade-offs—such as effects on downstream users, increased risk and uncertainty, and rising inequities—into the assessments (Barker et al. 2003; Kijne et al. 2003; Wichelns 2014). In the "widest possible sense" water productivity can also incorporate the ultimate objective of increasing yields, fisheries, ecosystem services and direct social benefits at less cost (social, ecological) per unit of water consumed (Rijsberman 2006; Molden et al. 2010). Keeping the water productivity increases as a priority strategy, water management research works in India have been initiated at regional level to account for different agro-climatic variations.

10.1.4 Water Management Research in India

Since independence, significant efforts are made by the researchers related to water management studies such as implications of conventional irrigation practices, water conservation measures under rain-fed conditions, adoption of modern technologies (i.e. drip and sprinkler irrigation systems), climate change, and food security. Expanding water planning and management research against a backdrop of rapid change and growing complexity is important as the world needs more modern and integrated information platforms. Multi-purpose water planning, and adaptive research and management institutions, which together enable and deliver technical and policy related solutions that work across a wide range of agro-climatic regions and irrigation typologies are also increasingly important. All India coordinated water management research is being carried out in several regions involving state agricultural universities and research stations where, the Indian Institute of Water Management (IIWM) at Bhubaneswar is coordinating the all India level water management research. In addition, several institutions such Indian Institute of Technologies (IITs), Indian Institute of Hydrology (IIH), National Institute of Technologies (NITs), State Agriculture Universities (SAUs), and Water Technology Centres in different parts of the country are concentrating on research on improving the water productivity.

10.1.5 Impact and Adoption Level of Technologies in India

The India water vision aims for a technology based improved water use. Technology adoption in water management in the future is expected to increase significantly from the current level of less than 15% (Palanisami et al. 2015). This will result in increase in crop yield and water saving, and decrease in water footprint thus contributing for more crop output and income per unit of water consumed by the crops.

The water mission will therefore be to provide the affordable, appropriate and accessible water management technologies at all levels (i.e., farmer, project and basin). This can be possible through scientific research programs, farmers' local knowledge-based practices/innovations, outreach activities including capacity building activities, institutional support and governments policy initiatives in promoting the spread and adoption of these technologies. Besides, new business models need to be introduced to promote the technologies with public private partnerships. Future water research should focus on solutions in water management that coupled with better policies, innovations, changes in practice, and accelerate impact.

The IMPACT-WATER model (combining the International Model for Policy Analysis of Agricultural Commodities and Trade [IMPACT] model with a water simulation model) was used to estimate various water productivity scenarios for irrigated rice at global and regional levels. The projections were estimated while taking into account possible impacts from technology and management improvements, investments in agricultural infrastructure and research, and increased environmental flow requirements. The results indicated that developed countries have higher water productivity values than developing countries. However, the values converge over time due to a projected higher rate of increase in irrigated yield and increase in water-use efficiency for irrigated crops in developing countries (Cai and Rosegrant 2003). The trigger to increase productivity per unit of water is the technology, which will help in achieving increased water use efficiency.

10.1.6 Returns to Water Management Research

Evaluating returns to research investment has been the main research agenda among agricultural economists since long period and the importance of assessing the impact of agricultural research is not something new. However, returns to research investment are very crucial because these returns benefit not only farmers but also the food industry and consumers, who gain from more abundance and lower cost of commodities. Economic studies that have estimated returns to research investment on the particular crop or livestock commodities, have usually found evidence of high returns, although returns do vary by commodity and over time. In India, many researchers have attempted to evaluate the returns to research investment in the agriculture and livestock sector. But, there is no clear evidence on returns to research investment on water management technologies in the country. Water research managers and policy makers are often interested in the returns to research investment in water management technologies. As millions of rupees are being spent on water research in general and on developing water management technologies in particular, these investments essentially generate adequate benefits and yield sufficient returns. The analysis of returns to research investment informs the researchers and policy makers about the economic viability of research and various technologies developed. It is essential to assess the contribution of the technologies to generation of adequate returns. The results of econometric analysis on the impact evaluation of the returns to water management research have yielded varying returns depending upon the nature of technology (Palanisami et al. 2012). It is important to see that the alternate wetting and drying technology yields higher rate of return and this might be due to the fact that this technology has only management cost (i.e., guiding water to the fields) as compared to drip irrigation, which needs capital cost towards drip materials, on drum seeding technology, which has a cost towards the seeder. Also, drip irrigation needs additional costs towards the fertigation compared to the drum seeder, which needs only the machine or bullock labour. Thus, this type of technology influences the quantum of costs involved and therefore costs and benefits vary according to the quantum of research activities involved. Also, some technologies are labor-saving while some are labour-augmenting. Most of the new technologies aim at labour-saving, which is also considered a benefit. Hence, future water management technologies should aim for both resource saving (water and labour) and yield increasing.

10.2 Farmers Participatory Action Research Programme (FPARP)

Given the need for the efficient use of scarce water resources in the country, several programs have been initiated from time to time and implemented by various departments and institutions. The Farmer Participatory Action Research Program (FPARP) was initiated throughout the country with a total of 5000 action research trials, while taking into account all the proven water management technologies with farmers' participation in implementation in order to produce more crop and income per drop of water (GOI 2006). The total cost of the Program (with 5000 trails) was around Rs.250 million. State Agricultural Universities (SAUs), ICAR Research Institutes, International Crops Research Institute for Semi-Arid Tropics (ICRISAT) and Water and Land Management Institutes (WALMIs) were the implementing agencies of this programme.

Each action research trial covered a minimum of one hectare and it was implemented in a participatory mode, with the farm family having a sense of ownership of the program. A well planned Water Literacy Drive, together with the revitalization of traditional systems of water conservation was also undertaken as a part of this program. Also, aimed phasing out offlood irrigation in irrigated areas by the end of the 11th Plan. As such 63 institutes in 21 states covering 2001 villages conducted this action research program (Table 10.1). This paper analyzed the results obtained from 2512 action research trials during 2012.

Table 10.1 State wise number of action research programmes

S no.	State	Number of action research trials allotted	Number of action research evaluated
1.	Andhra Pradesh	500	350
2.	North East states	250	166
3.	Gujarat	280	212
4.	Haryana	270	5
5.	Himachal Pradesh	400	23
6.	Jammu & Kashmir	260	223
7.	Jharkhand	50	11
8.	Karnataka	380	380
9.	Kerala	90	63
10.	Madhya Pradesh	270	118
11.	Maharashtra	360	53
12.	Orissa	100	8
13.	Punjab	60	94
14.	Rajasthan	300	142
15.	Tamil Nadu	418	90
16.	Uttar Pradesh	450	144
17.	Uttarakhand	175	170
18.	Andaman & Nicobar	98	30
19.	Bihar	100	60
20.	Chhattisgarh	30	10
21.	West Bengal	200	160
	Total	5000	2512

10.2.1 Viable Technologies for Enhancing Productivity and Income

Saving a drop of water would mean earning a drop of water. All possible rainwater harvesting techniques with striking balance between watershed management and prevention of sea water intrusion along with the coastal belts shall be given the onus. The needed interventions will be through both supply augmentation and demand management. The demand management offers comparatively more scope in increasing the yield and income both in the short run and long run. The major demand management interventions include the following:

10.2.1.1 System of Rice Intensification (SRI)

"System of Rice Intensification (SRI)" involves the use of certain management practices, which together provides better growing conditions for rice plants, particularly in the root zone, than those plants grown under traditional practices. The main components of SRI include early planting (14 days' old single seedlings, wider spacing), limited irrigation (2–3 cm depth after the appearance of hairline cracks), weeding and application of more compost, and building soil organic matter content. The benefits of SRI include less seed rate, less nursery area, labour saving, water saving, aeration, enhanced yield, and control of malaria.

10.2.1.2 Micro-Irrigation with Fertigation

Fertilizers applied under traditional method of irrigation are not efficiently utilized by the crops. Fertigation refers to the addition of fertilizers to irrigation water and application via micro-irrigation systems to improve the efficiency of water and fertilizer. Several success stories have been reported in different crops.

10.2.1.3 Soil Health

Declining soil health is closely linked through unfavorable alterations in physical, chemical, biological and hydrological activities and mismanagement by human. If the consequences of these activities are not adequately managed, the stability of soil's ecosystem for the next generations will be jeopardized. The decline in soil productivity is primarily due to adverse changes in nutrient status, soil organic matter, structural attributes and toxic chemicals. It is necessary to draw action plan to supply sufficient and balanced nutrients to the crops through Integrated Nutrient Management (INM), which will enhance the yield of crops to the desired level besides ensuring sustained soil fertility and soil health.

10.2.1.4 Promotion of Integrated Farming System

This aims to integrate farming activities, animal, poultry and fisheries production in such a way that the crop and animal residues are recycled to the soil. Inclusion of animal component in the farm system brings additional income to the farmers in addition to nutrient recycling into the lands. Standard integrated farming system(IFS) models suitable to dry land, garden land and wetland conditions can be popularized. The system also ensures that the production of at least 5 tons of organic matter in one acre of land, which can supplement for the soil health sustenance by setting up seven model units at regional stations of agricultural universities. These units can offer training to the farmers of the region, school teachers and children on IFS, benefits of nutrient recycling and ways of additional income generation.

10.2.1.5 Crop Diversification and Multiple Uses of Water

The return per unit of water is varying across the regions and crops. In the high rainfall regions of eastern India, there is scope to increase the income through crop and fish activities. In the hard rock regions of south India, there is scope for increasing the income through farming systems approach. Successful experiences of the rice and fish cultures should be explored.

10.2.1.6 Weather-Based Crop Insurance Programs

Weather-based crop insurance is a protection for losses that may arise due to abnormal weather conditions. These abnormal weather conditions can be events such as excess rainfall, shortfall in rainfall or variations in temperature, wind speed and humidity. What is now important is to convert generic information into location-specific land use advice, based on cropping patterns and water availability. The Agro-meteorological Advisories issued by Indian Agro-met Advisory Service Centre, Pune, can be used by Panchayat Level Farm Science Managers, trained to give appropriate land use suggestions.

10.2.1.7 Credit, Insurance and Market Reforms

Institutional agricultural credit is a vital input required for capital formation and adoption of new agricultural technologies and in turn for enhancing crop productivity, income, and employment. The Self Help Group – Bank linkage approach was introduced by the National Bank for Agricultural and Rural Development(NABARD) in February 1992 as a pilot project. The economic viability of farming depends heavily on assured markets and remunerative prices. Direct sale by farmers and absence of farmers' organizations to reach volumes and protect the interests of the small producers had resulted in reduced income to the farmers. Organized marketing was promoted through a network of regulated markets. A massive program for creation of the marketing network was taken up. Fair play and transparency in transactions was aimed at. Most of the State Governments and the Union Territories enacted legislations (APMC Act) to provide measures for development of agriculture produce markets.

Due to focusing more on the crop water interventions during the first phase of the FPARP, some of the interventions like weather-based crop insurance programs and credit, insurance and market reforms were not undertaken in the FPARP program implemented.

10.2.2 Impacts of Action Research Program

An evaluation of the program was conducted using a questionnaire that covered the beneficiaries profile and the benefits realized by them due to the interventions of the FPARP. The impact analysis of the program was done using 2512 respondents who were successful in completing the action research with the participating research institutions (Table 10.1). The remaining responded were either not successful in completion of the research trials or not able to record the crop related field data in time.

10.2.2.1 Yield Increase and Productivity Per Unit of Water

Table 10.2 indicates that all the action research programmes conducted under irrigated situations had resulted in more yield and income. In the case of SRI (System of Rice Intensification), yield increase was 14.8% with an income of Rs.329 per cm of water under conventional and Rs.453 per cm under action research trial. Among the other action research trials on paddy crop, drum seeded paddy resulted in highest income per cm of water i.e., Rs. 3006 per cm of water used. Among the drip irrigation action research trials, tomato, beetroot, and brinjal crops resulted in an income of Rs. 3141, Rs. 1428, and Rs. 3333 per cm of water used respectively. Zero tillage trial with wheat crop resulted in a yield increase of 39.6% and Rs. 5025 per cm of water used. Critical state irrigation in maize resulted in 29.1% increase in yield with an income of Rs. 3942 per cm of water used.

Organic mulching was the other important action research trials conducted. Among all the crops with organic mulching, pointed guard(cucumber) gave 20% yield increase and Rs. 5250 per cm of water used, followed by banana with 51.5% yield increase and Rs. 1500 per cm of water used. Precision land leveling in wheat resulted in 8% increase in yield with an income of Rs.667.2 per cm of water.

Table 10.3 shows the results of action research trials conducted under rain-fed conditions. Among the technologies demonstrated via. Micro nutrients, improved variety and balanced nutrition in chick pea varieties and integrated nutrients management in wheat, chick pea, groundnut and mustard showed increase yield over

Table 10.2 Yield and income due to FPARP (Irrigated)

Technology	Crop	Additional yield due to FPARP		Yield and income per drop of water			
				Conventional		Action research	
		Additional yield (kg/ha)	% increase in yield	Yield (kg/cm)	Income (Rs/cm)	Yield (kg/cm)	Income (Rs/cm)
SRI (System of Rice Intensification)	Paddy	830.0	14.8	33.0	329.53	45.3	453.0
Alternate wetting and Drying	Paddy	355.0	6.0	3.9	38.88	5.5	54.8
Direct sown paddy	Paddy	1067.0	18.2	54.3	543.15	77.9	779.0
Rotational Irrigation	Paddy	458.0	8.1	29.1	291.30	45.4	453.7
Sprinkler Irrigation	Maize	1300.0	21.0	51.7	465.00	75.0	675.0
	Groundnut	373.0	18.3	6.0	120.35	8.6	171.7
Critical stage irrigation	Maize	6425.0	29.1	225.0	2025.00	438.1	3942.7
Integrated Nutrient management	Cotton	292.0	13.8	42.28	1138.54	68.74	1837.49
Drum seeded paddy	Paddy	909.0	13.8	122.35	1223.52	300.64	3006.40
Drip Irrigation	Tomato	6920.0	17.2	335.00	1675.00	628.27	3141.33
	Beetroot	2937.0	17.2	189.59	947.94	285.71	1428.57
	Brinjal	34500.0	1150.0	22.73	181.82	416.67	3333.33
Zero Tillage	Wheat	1140.0	39.6	160.00	1600.00	502.50	5025.00
Organic mulching	Brinjal	3160.0	15.6	289.29	2314.29	585.25	4682.00
	Pointed guard (cucumber)	3750.0	20.0	267.86	1875.00	750.00	5250.00
	Garlic	450.0	12.0	46.88	843.75	105.00	1890.00
	Potato	1905.0	10.2	468.75	3281.25	1032.75	7229.25
	Banana	1275.0	51.5	30.94	371.25	125.00	1500.00
	Tomato	750.0	3.5	358.33	1433.33	741.67	2966.67
	Cauliflower	620.0	5.0	154.63	1391.63	324.75	2922.75
Short duration and HYV	Wheat	800.0	16.7	114.29	1028.57	373.33	3360.00
Critical state irrigation	Groundnut	302.0	12.0	53.45	801.70	63.95	959.32
Raingun	Wheat	1799.0	66.4	56.48	508.31	140.94	1268.44
	Soya bean	763.0	55.5	40.44	404.41	85.52	855.20
Precision land levelling	Wheat	410.0	8.0	46.82	421.36	74.13	667.20

Table 10.3 Yield and income due to FPARP (Rain-fed)

Technology	Crop	Yield (kg/ha)		Impact on yield	
		Farmers practise	Farmers practice + technology	Additional yield (kg/ha)	% increase in yield
Micro-nutrients	Wheat	2990	3708	718	24.01
	Mustard	922	1456	534	57.92
	Chickpea	2500	3700	1200	48.00
Improved variety and balanced nutrition in chickpea varieties	Chickpea	956	1594	638	66.74
INM	Chickpea	1650	2090	440	26.67
	Groundnut	3230	3740	510	15.79

conventional methods. Chickpea with improved variety and balanced nutrition resulted in 66.74% increase in yield.

10.2.2.2 Water Savings Due to the Adoption of New Technologies

The performance of water saving technologies under FPARP was compared with the conventional method of irrigation in terms of percentage increase in water saving. Crop wise and technology wise water saving results are presented in Table 10.4. It was observed that due to the FPARP interventions, there was appreciable enhancement in water saving at farm level in various crops ranging between 6.5 and 89.45%. Maximum water savings was recorded in okra (84%), floriculture (89.4%) and groundnut (86.9%) crops with sprinkler irrigation in Tamil Nadu. Trials in Himachal Pradesh also showed a water saving of about 60% due to the integrated nutrient management and farming systems in vegetable crops. Likewise, considerable proportion of water savings under FPARP was recorded in Apple (45.28%) due to water harvesting tanks and pipe line water supply, drip with gravity fed micro irrigation and black plastic mulching.

In case of West Bengal, water saving of about 51% was seen due to SRI practice in paddy and in Tamil Nadu, Assam, and Andhra Pradesh states, it ranged from 25 to 30% along with INM. Critical stage irrigation in pearl millet saved 69% of water in Rajasthan. INM, precision land levelling and zero tillage in wheat cultivation has reduced the water use by 30–35% in Gujarat, Punjab and West Bengal. Sprinkler irrigation in wheat was also demonstrated in Madhya Pradesh and reduced the water consumption by 47% even though the number of irrigations has increased by 33%. The higher level of water saving achieved under FPARP was mainly due to the reduction in depth of water applied as well as reduction in the frequency of irrigation given to the crops.

It is also interesting to note that the reported increased crop yield and reduced water use at farm level due to technology adoption under FPARP can be still high if the gap in performance of the technologies between the research stations and

Table 10.4 Water use and savings due to FPARP

S. No.	State	Crop	Water use depth (cm)		% water saving by depth	% change in no. of irrigations
			Conventional	FPARP		
1.	Tamil Nadu	Paddy – SRI	3.63	2.54	30.02	−18.13
		Sugarcane – INM	5.90	5.20	11.86	−18.11
		Ground nut – Sprinkler	7.38	0.96	86.99	–
		Okra – Sprinkler	6.40	1.02	84.06	–
		Floriculture – Sprinkler	7.11	0.75	89.45	–
2.	Gujarat	Wheat – INM	6	4	33.3	−12.50
		Vegetables – INM	6	4	33.3	–
3.	Uttarakhand	Wheat – INM	9.86	7.83	20.58	−42.97
		Onion – INM	2	2	0	0
		Rice – INM	8	7	12.5	−16.66
4.	Karnataka	Rice	7	5	28.57	–
5.	Assam	Rice – INM	6.90	5.00	27.53	−30.73
6.	Haryana	Wheat	7.50	5.00	33.33	−40.0
7.	Punjab	Rice –PLL	7.50	5.87	21.73	–
		Rice- PQW	7.50	7.50	0	0
		Rice- INM	7.50	7.50	0	0
		Wheat- INM	7.50	7.50	0	0
		Wheat- PLL	7.50	5.0	33.33	0
8.	Himachal Pradesh	Vegetables –INM & Farming system	5.0	2.0	60.00	−22.2

(continued)

Table 10.4 (continued)

S. No.	State	Crop	Water use depth (cm)		% water saving by depth	% change in no. of irrigations
			Conventional	FPARP		
9.	Orissa	Vegetables-MC	–	16.37	–	–
10.	Madhya Pradesh	Wheat – Sprinkler	16.70	8.80	47.30	+33.33
11.	Jammu & Kashmir	Apple (Water harvesting tank & pipe line)	74.31	40.66	45.28	−1.09
12.	Andhra Pradesh	Rice – SRI	90.06	65.10	27.71	−5.65
		Rice – RI	133.26	101.70	23.68	−32.51
		Cotton	5.0	2.04	59.2	−40.00
13.	Uttar Pradesh	Rice – SD & HYV	7.05	4.44	37.02	−59.25
14.	Rajasthan	Ground nut – CSI	47.25	44.06	6.75	−8.12
		Pearl millet – CSI	11.65	3.60	69.09	−14.28
15.	Jharkhand	Wheat	2.0	1.4	30.00	–
16.	West Bengal	Rice – SRI	5.0	2.42	51.6	−26.53
		Wheat -Zero tillage	5.54	3.73	32.67	−6.11

PLL Precision land leveling, *PQW* Poor quality water, *INM* Integrated nutrient management, *SD & HYV* Short duration & High yielding Variety, *SRI* System of rice Intensification, *MC* Mixed cropping, *CSI* Critical stage irrigation, *RI* Rotational Irrigation farmers' fields is reduced. In order to get an idea about the gap in yield and water use between regions, the states covered under FPARP have been grouped in to south, east, west, north and north eastern regions according to their geographical locations and the farmers' field level (action research) data with the given technology attributes were computed with the same technologies used in the nearby research stations. Considering all the adopted technologies by the farmers, the region-wise technology performance gap was calculated. The percent gap in water saving is comparatively lower (32%) in southern region whereas the percent gap in yield is lower in northern region (48%) (Figs. 10.1, 10.2 and 10.3, Table 10.5).

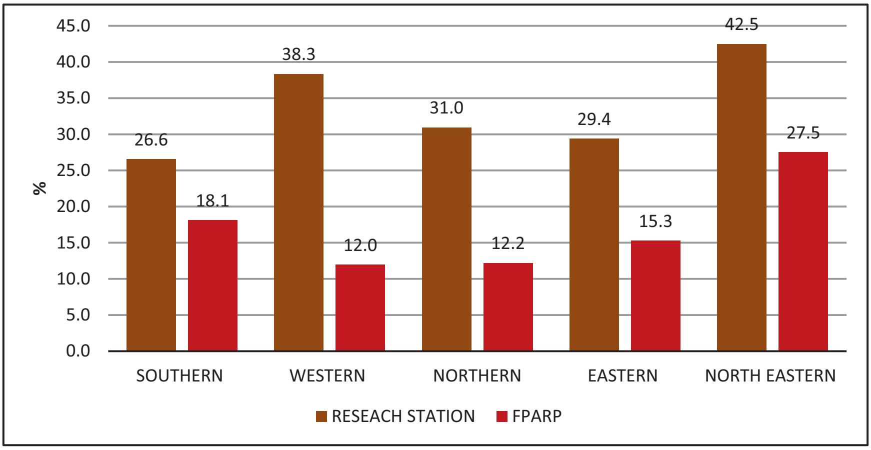

Fig. 10.1 Water saving at research station and farm level (FPARP) due to water management technologies

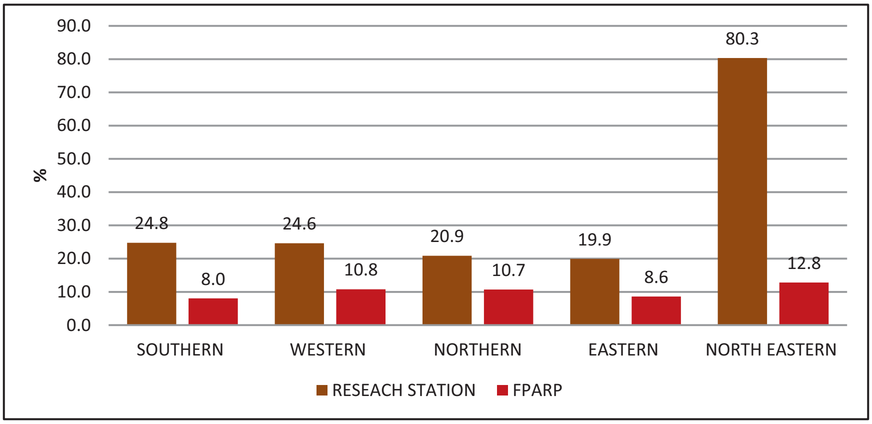

Fig. 10.2 Yield increase at research station and farm level (FPARP) due to water management technologies

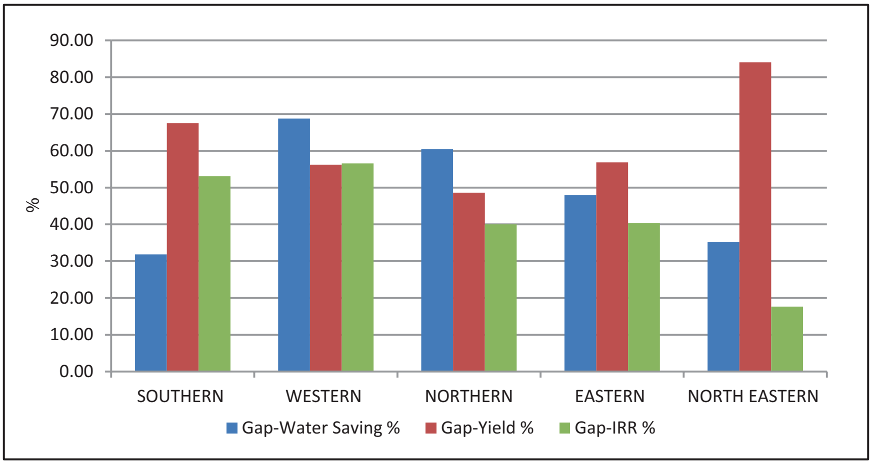

Fig. 10.3 Gap in water saving, yield increase and IRR between research station and farm level

Table 10.5 Comparison of technologies at research station and farmers' fields

Regions	Increase in water saving (%)			Increase in yield (%)			Internal rate of return (%)		
	Research station	FPARP	Gap (%)	Research station	FPARP	Gap (%)	Research station	FPARP	Gap (%)
Southern	26.58	18.12	31.84	24.75	8.03	67.54	22.25	10.44	53.06
Western	38.34	11.98	68.75	24.63	10.79	56.21	25.00	10.86	56.57
Northern	30.95	12.23	60.49	20.86	10.72	48.60	19.08	11.44	40.01
Eastern	29.40	15.29	48.00	19.93	8.60	56.85	15.50	9.25	40.32
North eastern	42.50	27.53	35.22	80.33	12.80	84.07	17.00	14.00	17.65
Average	32.73	14.85	54.61	26.21	9.72	62.92	20.96	10.8	48.48

This gives the signal that crop productivity per unit of water applied can still be increased by adopting the technologies at farm level. Hence, the two possible ways to increase the productivity per unit of water will be: (i) bridging the Technology gap1 by adopting the appropriate technologies/practices for different crops in those areas where traditional practices are followed, and (ii) bridging the Technology gap2 by effectively adopting the technologies for different crops and soils in farmers' fields as per research station guidelines (Fig. 10.4). This will be the stage of complete technology adoption which will help for up-scaling the technologies in a faster way.

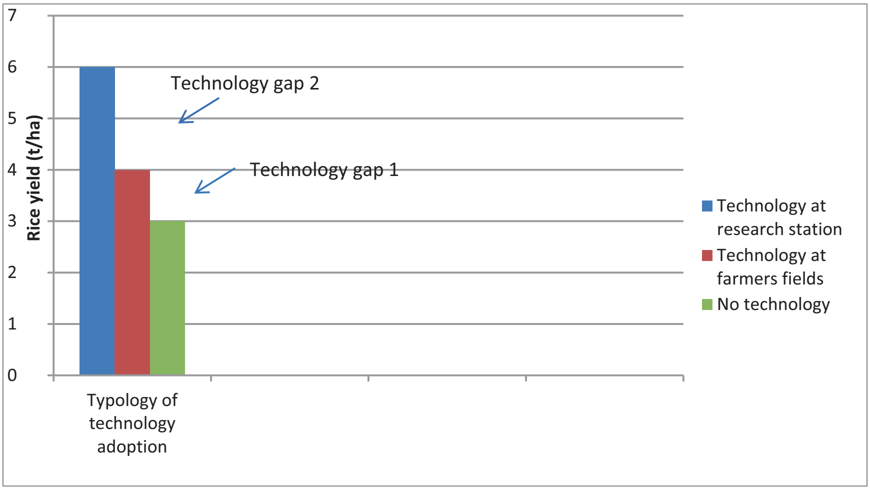

Fig. 10.4 Yield gaps between research station and farmers' field trials as well as current farmers' practice

10.3 Feedback from Action Research

10.3.1 Adoption of New Technology and Lessons Learnt

More number of farmers from Assam, Maharashtra and Karnataka had visited the action research sites to gain firsthand information about the technologies demonstrated in the respective states for adoption (Table 10.6). However, there is no such visit recorded in the states of Haryana and Uttarakhand. Table 10.6 also shows that in most of the states the farmers had felt that they had learnt new irrigation technologies and improved the existing method of irrigation to various crops. Similar observations were noticed in the case of Orissa (Odisha), Kerala, Madhya Pradesh, Karnataka, Tamil Nadu, Uttarakhand, Punjab, Assam, and Maharashtra. It can be further inferred that the farmers across the states stand benefited through the action research program by way of either learning a new technology or improving the existing method. In a very few cases, farmers in Uttarakhand, West Bengal, Punjab and Himachal Pradesh felt that there is no additional information available regarding the technologies learnt. The results on the follow up of the technologies revealed that almost all the farmers benefited directly through the FPARP would follow the technologies in future also. This result was recorded uniformly across the states. However, the assured water supply remains as one of the factors influencing the better adoption of these technologies by the farmers. Consequently, very few farmers have responded they have problems in adopting the technology and may not follow it in the future (Table 10.7).

Table 10.6 Lessons learnt from the FPARP

S. No.	State	No. of farmers surveyed	Farmers visiting the action research	Farmers willing to adopt the technology	Learned the new technology	Improved the existing method	No additional information available
			No. of farmers reported				
1.	Tamil Nadu	90	76	14	54	56	–
2.	Gujarat	212	66	36	50	54	–
3.	Uttarakhand	198	–	76	133	61	7
4.	Karnataka	480	231	203	364	99	–
5.	Assam	66	34	14	40	20	–
6.	Haryana	5	–	–	–	5	–
7.	Punjab	94	26	18	78	57	1
8.	Himachal Pradesh	23	6	7	15	17	1
9.	Maharashtra	53	70	35	2	51	–
10.	Orissa	8	1	2	8	–	–
11.	Kerala	63	10	17	63	48	–
12.	Madhya Pradesh	18	5	6	18	–	–
13.	Jammu & Kashmir	139	30	55	73	58	–
14.	Andhra Pradesh	156	40	46	91	61	–
15.	Uttar Pradesh	144	11	15	19	–	–
16.	Rajasthan	142	39	17	35	5	–
17.	Jharkhand	11	2	4	10	10	–
18.	West Bengal	464	135	101	257	188	6
19.	Andaman	5	1	2	–	5	–

10.3.2 Constraints in Adopting the Technology

The major constraint faced by the farmers in adopting the technological interventions was high capital or initial cost. More than 30% of the farmers reported for the high initial cost except in case of Rajasthan and West Bengal. The other important issues faced by the farmers were requirement of more labour followed by the need for technical expertise and lack of assured and timely water release from canals to adopt the recommended technologies (Table 10.8).

Table 10.7 Follow up on the technology in future

S. No.	State	No. of farmers surveyed	Will follow in future	Will follow depending on water supply	May not follow it
			No. of farmers reported		
1.	Tamil Nadu	90	67	24	0
2.	Gujarat	212	51	–	–
3.	Uttarakhand	198	185	9	3
4.	Karnataka	480	389	72	17
5.	Assam	66	58	2	–
6.	Haryana	5	–	5	–
7.	Punjab	94	76	16	1
8.	Himachal Pradesh	23	20	4	–
9.	Maharashtra	53	53	–	–
10.	Orissa	8	8	–	–
11.	Kerala	63	62	2	–
12.	Madhya Pradesh	18	18	–	–
13.	Jammu & Kashmir	139	107	6	–
14.	Andhra Pradesh	156	112	16	2
15.	Uttar Pradesh	144	136	1	–
16.	Rajasthan	142	25	14	–
17.	Jharkhand	11	10	2	–
18.	West Bengal	464	420	21	–
19.	Andaman	5	5	–	–

10.4 Up-Scaling the FPARP- Lessons Learned

In all the states, technologies based on action research trails had resulted in higher yield and water saving compared to conventional practices particularly in terms of reduced depth as well as number of irrigations. Additional income from water used was also high under the field tested technologies thus showing the need for technology up-scaling at a larger scale.

Efforts were also made to create awareness among the villagers about the FPARP trials demonstrated in the selected farmers' fields in the villages. Regarding the responses of other farmers in the villages to FPARP sites, relatively more number of farmers from Assam, Maharashtra and Karnataka had visited the action research sites to gain firsthand information about the technologies demonstrated in the respective states for adoption. However, there is no such visit recorded in the states of Haryana and Uttarakhand and this might be due to poor extension efforts. In several states Orissa (Odisha), Kerala, Madhya Pradesh, Karnataka, Tamil Nadu, Uttarakhand, Punjab, Assam, and Maharashtra), farmers felt that they had learnt new irrigation technologies and improved the existing method of irrigation to

Table 10.8 Constraints faced by the farmers in adopting the technology

S. No.	State	No. of farmers surveyed	High capital or initial cost	Too technical to adopt	Need technical support	Maintenance problem	Need more labour	Not matching with water supply
			No. of farmers reported					
1.	Tamil Nadu	90	29	16	19	18	16	0
2.	Gujarat	212	–	–	–	–	–	22
3.	Uttarakhand	198	63	9	59	135	28	8
4.	Karnataka	480	197	21	75	14	115	48
5.	Assam	66	37	–	6	3	5	–
6.	Haryana	5	–	–	–	–	–	–
7.	Punjab	94	28	7	1	4	16	15
8.	Himachal Pradesh	23	16	–	6	7	3	–
9.	Maharashtra	53	43	–	–	–	10	–
10.	Orissa	8	–	–	8	–	–	–
11.	Kerala	63	36	15	34	9	14	–
12.	Madhya Pradesh	18	–	–	–	–	–	–
13.	Jammu & Kashmir	139	84	10	2	16	–	2
14.	Andhra Pradesh	156	70	9	24	22	50	17
15.	Uttar Pradesh	144	–	–	–	–	–	–
16.	Rajasthan	142	13	1	2	1	18	–
17.	Jharkhand	11	8	1	7	7	6	1
18.	West Bengal	464	48	35	11	100	21	–
19.	Andaman	5	–	–	–	–	–	–

various crops. In few states (Uttarakhand, West Bengal, Punjab and Himachal Pradesh), farmers had not responded well to new technologies and their adoption for want of more information on the success of the technologies including their cost and returns.

10.5 Way Forward

10.5.1 Raising Farm-Level Water Productivity

Increased agricultural production to meet the rising food demands should be the main vision. The key to mitigating the emerging water crisis and establishing long-term sustainable water use for agriculture is increasing water productivity, that is, the crop yield per unit of water consumptively used in evapotranspiration (Kassam and Smith 2001). The vision, strategies and the expected outcome are shown in Fig. 10.5.

In India, food security was “crucially” dependent on the development of additional irrigated lands (Seckler 1996). These impressions were given in the context of declining irrigation development investments, and growing competition for water from other sectors (mainly urban and industry) and to meet environmental needs (Seckler et al. 1998). These factors placed a stronger urgency on improving the productivity of existing agricultural water supplies to meet future food demands. For e.g., improving water productivity by just 1% a year would assure full self-sufficiency in food-grains in India without the need to increase consumptive water use (CWU); increasing water productivity by 1.4% a year would mean that all water demand in 2050 could be met without increasing CWU (Amarasinghe et al. 2007).

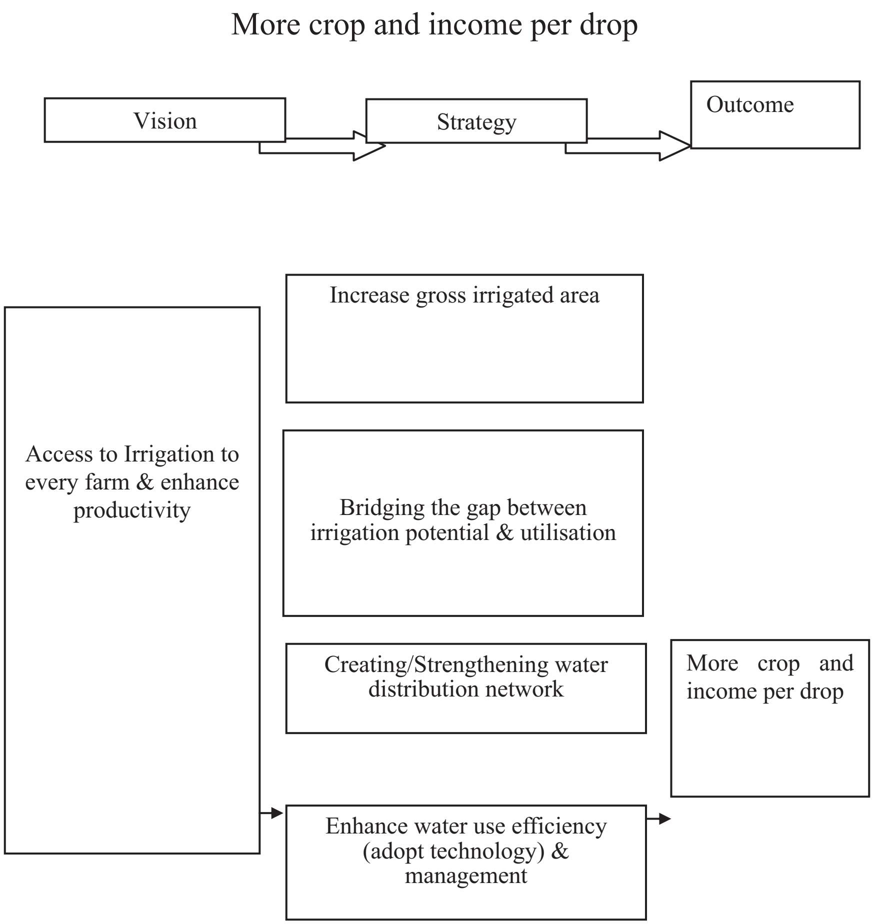

Fig. 10.5 Vision and strategies for achieving enhanced water productivity at national level

According to Ackermann (2012), there is vast scope for improving India's crop water productivity, while also freeing up water to meet urban and industrial demands.

This can be done by increasing the crop productivity both in high and low crop productivity regions by adopting the following three pronged strategies:

1. Focusing crops on those areas where higher crop productivity is experienced
2. Diversifying crops on those areas where lower crop productivity is experienced
3. Introducing improved land, crop and water management practices/technologies in all the regions to achieve more crop per unit of water. This includes better timing of water supplies to reduce stress at critical crop growth stages or by increasing the reliability of supplies to enable farmers to invest more in other agricultural inputs.

Since the above strategies 1 and 2 will be depending upon so many factors and economic feasibilities with socio-economic background of the locations and which can be possible in the long run, the medium term goal will be achieved by adopting strategy 3. Overall, this will focus on:

- adopting to capital intensive water saving technologies like micro irrigation;
- providing less capital intensive practices/ technologies such as agronomic practices, laser land leveling, mulching, changing crop planting dates to match periods of less evaporative demand, deficit irrigation etc.,

10.5.2 Raising Farm-Level Income

This can be done by increasing production in a given cropping pattern or by changing the cropping pattern with a move to higher-value crops (Molden et al. 2003). This will be possible by increased yield and reduced cost of technologies as well as connecting farmers to markets.

10.5.3 Reallocating Water from Agriculture to Other Sectors

Reallocation of the (saved) water to other sectors with higher-value water uses is often emphasized as a way of reducing problems of water stress and contributing to broader societal goals. It is seen as a pillar of water demand management, making better use of available resources as opposed to augmenting supplies. This will contribute to food security and poverty eradication by fostering the sustainable increases in the productivity of water through the management of irrigation and other water uses in the river basin (IWMI 2015).

10.5.4 Refocusing Water Management Research and Technology Up-Scaling

10.5.4.1 Water Management Research

Currently, the water management research centres give more focus (80–90%) in continuing more or less same type of research/experiments for the same set of crops and less attention is given for outreach activities. Hence, given the vast number of technologies available with the research institutions in each region, water management research centres should give more emphasis on technology transfer by working with farmers than technology development.

- Once the technology is proven in the research stations, farmer participatory action research can be conducted in a cluster of 5–6 villages continuously for 2–3 years. It should be made clear that no water management research can go beyond 4–5 years in one location without proper outreach activities.
- As still 78% of the practices in the farmers' fields are local wisdom based, future research should take the lead from these practices and validate them (bottom up approach). Technology audit should be made mandatory for all research centres to include demand driven research agenda.

10.5.4.2 Micro Irrigation

Since the current increase in adoption of micro-irrigation is rather slow, it is equally important to boost adoption. Regional water management research institutes can design micro-irrigation equipment that minimize the cost and improve fertigation schedules. The unit cost of micro-irrigation system is high, and this constrains the expansion of micro-irrigation. Hence, it is important to bring about design changes that minimize cost. Currently, drip companies, state agricultural extension departments, and drip suppliers recommend different fertigation schedules. Research is needed to develop a uniform schedule that suits the soil types in each region stressing the need for partnerships and convergence. The National Mission on Micro Irrigation (NMMI) has outlined the guidelines for better adoption of the MI systems in the country. The NMMI in fact is the timely initiative by the Government for improving the performance of the MI systems (GOI 2010; Global Agri-system 2014).

Drip subsidy is hindering the adoption and expansion of micro-irrigation in several states. Subsidy norms need to be simplified and made available to all farmers eligible for micro-irrigation. In many states, farmers reported losing interest in micro-irrigation after waiting up to 2 years for receiving micro-irrigation subsidy. Micro-irrigation equipment needs to be supplied quickly. The model of Gujarat Green Revolution Company (GGRC), which succeeded in Gujarat, can be examined and replicated. The state government of Gujarat set up the GGRC in 2005 mainly to raise the adoption of micro-irrigation. The area under micro-irrigation has grown three times in the last 10 years (Palanisami et al. 2011). To improve adoption in the long run, micro-irrigation service providers should be encouraged to provide farmers continual services. Micro-irrigation systems work for first 2 years, but tend to clog later. Farmers need help in unclogging the systems and in devising pressure and fertigation schedules, but service providers limit their assistance only to installation. Unemployed graduates in villages can be trained to provide such services at a nominal rate.

Promoting micro-irrigation in Canal Commands: Currently about 12 million ha (as on March 2020) is under micro irrigation. Use of micro irrigation in canal commands offer more scope for improving water use efficiency up to 65–70% resulting in higher productivity and income per unit of water. These interventions however, require better water control and water users' associations to manage and enforce discipline amongst its members at the local level emphasizing community participation. Use of solar energy as a package with micro-irrigation in canal commands will compliment this initiative. Better crop pattern based on agro-eco regions, communication network strengthening and produce marketing will become essential components of this intervention. A strong capacity building program in micro-irrigation to farmers and irrigation service providers will be highly warranted. Wherever needed public private partnership models can be explored.

10.5.4.3 Capacity Building and Up-Scaling

Most farmers have long ago moved to a new paradigm and will only support programs and projects which can benefit them in their current situation economically.

Capacity building programs on these technologies can be inbuilt in the extension programs of the research stations and state agriculture departments in each region. Details of the additional costs and benefits associated with new technology should be explained to the farmers. The transaction cost (hidden cost such as subsidy oriented items) if any, should be explained to the farmers so that uptake becomes easier.

Convergence of the government programs in technology transfer should be made so that scaling-up of the technologies will be much easier through involvement of different stakeholders such as government departments, NGOs, private sectors and farmers. As poor water control under canal systems is the major constraint in technology adoption, system improvement including improved water allocation norms should be given top priority by the concerned government departments.

Wherever possible, public- private partnership in technology promotion and uptake such as drip and sprinkler irrigation can be explored by initiating local skill development programs involving the drip manufacturers and suppliers.

Once the more crop per drop is achieved by following the above strategies, it is important to focus the agricultural water productivity and related metrics to include a wider perspective on water use—such as crop and non-crop and other livelihood and ecological benefits and costs from improving water productivity.

In order to achieve many of the goals and strategies outlined above, the water accounting framework should be strengthened so that it will help to demonstrate how much water is actually depleted in a given domain, where and for what purpose, compared to what is available. It provides a means to generalize about water productivity and use across scales—such as the crop, field, farm, irrigation system or the basin level—depending on the purpose and users of the analysis (for more details see, Molden et al. 2003). Tools such as hydrologic models coupled with crop models, and data generated with remote sensing technologies, have allowed researchers to estimate average current and potential water productivity; identify locations with high and low water productivity; explore possible entry points (technical, managerial or policy) to improve water productivity; and understand the potential consequences within and outside of the agriculture sector, including the effects on ecosystems (Karimi et al. 2012, 2013; Rebelo et al. 2014).

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Chapter 11
Scaling-Up of Conservation Agriculture for Climate Change Resilient Agriculture in South Asia

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Abstract Climate change impacts are getting more evident in agriculture in the form of changed rainfall patterns, abnormal temperature regimes, heat waves, wind storms *etc*. across the South Asia (SA). The SA has the unique challenge to feed about 2.43 billion population by 2050 from lesser but degraded resource base that too under changing climatic conditions. Tillage-based intensive agricultural practices are well known to degrade resource base including land, and harm the biological processes and the environment. Green revolution era technologies, mainly adopted in Indo Gangetic plains (IGPs) of the SA, no doubt were instrumental to achieve food security in the region but, concomitantly, caused numerous soil and environmental related issues. Conservation Agriculture (CA) is being propagated as panacea to above mentioned problems, and also to achieve the goal of sustainable crop production intensification in the SA. Copious attempts have been made to develop CA-based practices, mostly in cereal-based systems in IGPs, in the last two decades in SA region. However, in recent years CA principles have also been applied to other crops and cropping systems in the region and encouraging results have been obtained. As CA is a new set of production system, this technology needs to be promoted in mission mode under enabling policy environment. Develpoing context specific and locally adapted practices supported by supply of

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customized machinery and capacity building is the right way forward to scale up CA in the region.

Keywords Climate change · Conservation agriculture · IGPs · Land degradation · Residue management

11.1 Introduction

The South Asia (SA) region spreads over eight countries with Iran in the northwest and Sri Lank in southeast along with Afghanistan, Pakistan, India, Nepal, Bangladesh, and Bhutan. SA is known as world within the world due to great diversity in population, culture, language, climate, soil type, vegetation etc. The SA region has total land area of 641.7 million hectares (Mha), of which 228.0 Mha is arable, 22.2 Mha is grasslands, 13.9 Mha is permanent crops, 78.5 Mha is forest, and 93.3 Mha is permanent pasture (Lal 2011). Agriculture is the mainstay of life in SA region with millions depending on agriculture for their livelihood. However, agricultural production is afflicted with several problems like land degradation, water shortage, aberrant weather conditions, low level of mechanization, poor yields etc. in the region and, as such, sustainability of agricultural production is under threat in the region. To exacerbate the situation global warming and climate change is further threatening the agriculture systems in the SA region. Climate change is one of the most defining concerns of twenty-first century and has greatly affected ecosystems in different parts of the globe (Arora 2019). Although, climate change has been a constant process on earth, but in recent times, the pace of this change has increased manifolds, mainly attributed to anthropogenic activities.

The average temperature has increased by 0.9 °C since nineteenth century, primarily due to greenhouse gases (GHGs) emissions in the atmosphere. As per estimates, the way deforestation is occurring, GHG emission is increasing and soil, water bodies and air are being polluted, this rise is expected to be 1.5 °C by 2050 or may be even more. In SA, predictions show that the annual average maximum temperature may increase by 1.4–1.8 °C in 2030 and 2.1–2.6 °C in 2050, and thus, heat-stressed areas in this densely populated region could increase by 12% in 2030 and 21% in 2050 (Tesfaye et al. 2017). As per the projections, due to heat stress, almost half of the Indo-Gangetic Plains (IGPs), the major food basket of the SA region, may become inappropriate for wheat production by 2050 (Ortiz et al. 2008).

The major cause for global warming and climate change has been ascribed to the increased levels of GHGs like carbon dioxide, methane, nitrous oxide, chlorofluorocarbons *etc*. beyond their natural levels due to uncontrolled activities such as deforestation, burning of fossil fuels, increased uses of refrigeration, and enhanced agricultural related practices *etc*. (Venkateswarlu 2018). The fast pace of industrialization and indiscriminate destruction of natural environment have greatly contributed to the increased concentration of GHGs in the atmosphere. Impacts of global warming and climate change are being observed in different forms on the weather.

According to IPCC (2007) it is very likely that cold days, cold nights and frosts have become less frequent over most land masses, while hot days and hot nights have become more frequent. Similarly, frequency of heat waves, heavy precipitation events, and high sea level incidences have increased over most areas worldwide.

11.2 Climate Change and Food Security in South Asia

The impact of climate change on agriculture is bound to affect food security of the world including the SA. Climate change driven weather related aberrations like cyclones, floods, droughts, heat/cold waves *etc*. cause serious economic losses worldwide. As Arora (2019) pointed out natural disasters alone have caused economic loses in tune of US$ 225 billion across the world in 2018 and about 95% of these losses are attributed to weather related incidences (Arora 2019). Cyclones, floods and droughts are the major factors responsible for above losses and are directly related to climate change. Thus, climate change is expected to affect comprehensively but its far reaching effects are now clearly visible on agricultural sector which determines the food security of millions in the SA and world as a whole. It is worth noting that population in SA region is expected to reach 2.43 billion by 2050 and meeting the growing food demands especially under changing climate scenarios will be an uphill task (Lal 2011). As climate change and agriculture are closely related, any abrupt changes in climatic conditions at such a rapid pace have threatened the food security not only in SA region but at global scale (Arora 2019).

The current agriculture is still dependent on climate despite impressive advancement in the technology and hence, any adverse changes in climate affects food production dearly. Climate change and variability can affect agricultural production by affecting rainfall pattern, temperature regimes, pest and disease outbreak, heat/cold waves, frost, salinity ingression *etc*. Currently, unreliable variations in weather have emerged as a serious challenge for agricultural sustainability influencing vegetation, biodiversity, livestock, soil, water, and other natural resources. In the recent past, more frequent nature of extreme weather events affected farming community more seriously in their agricultural production. The matter is of great concern in South Asia region, which require more production to feed 1.94 billion strong populations from shrinking crop land, while poverty and malnutrition are already serious concerns in the region. The impact of climate change on agriculture may be more severe at regional level creating more food security related challenges rather than the global level as a whole. The potential impact may be felt in the form of shift of sowing time and length of growing seasons, which may necessitate effective adjustment in sowing and harvesting dates, change in genetic traits of cultivars and sometimes total adjustment of cropping system and production system itself. With warmer environment due to global warming, the rate of evapotranspiration will increase and would call for much greater efficiency in use of water to sustain crop productivity.

Apart from these, adaptation measures to tackle frequent and more intense extreme events like heat and cold waves, droughts and floods may become a common feature in the near future (IPCC 2001). Crop yield studies focusing on India have found that global warming has reduced wheat yield by 5.2% from 1981 to 2009, despite adoption of climate change adaptation measures (Gupta et al. 2017). According to Tesfaye et al. (2017) climate change would reduce rain-fed maize yield by an average of 3.3–6.4% in 2030 and 5.2–12.2% in 2050 and irrigated maize yield by 3–8% in 2030 and 5–14% in 2050 if current varieties were grown in the SA region. Similarly, Arshad et al. (2017) reported that despite better input use and crop management, there was a negative effect of both season-long and terminal heat stress on rice and wheat, though wheat is considerably more sensitive than rice. Besides its impact on crop production, climate change will also affect the natural resources, primarily land, water and biodiversity that are fundamental to agricultural production.

Groundwater availability is expected to decline due to climate change as the agricultural water consumption is predicted to increase by 19% in 2050 (UN-Water 2013). For instance, growing reliance of farmers in India on groundwater to cope with climate-induced drought has led to a rapid decline in the groundwater table, and it may worsen further due to increased climatic variability in future (Fishman 2018). According to Vinke et al. (2017) even a relatively modest warming of 1.5–2 °C in SA can severely impact the availability and stability of water resources due to increased monsoon variability and glacial meltwater, thereby threatening the future agricultural production systems. Thus with its impact on agricultural production and natural resources, climate change will bring greater fluctuation in crop production, food supplies, and market prices and will aggravate the situation of food insecurity and poverty in South Asian countries (Shankar et al. 2015; Wang et al. 2017; Aryal et al. 2019).

11.2.1 Land Degradation and Its Role in Food Security

The SA region is characterized by several problems including food insecurity, soil and environmental degradation, land desertification, pollution of water bodies, and loss of biodiversity *etc*. Soils of SA are prone to degradation and desertification (FAO 1994; Douglas 2006; Acharyo and Kafle 2009). Principal processes of soil degradation include erosion by water (81.7 Mha), erosion by wind (59 Mha), decline in soil organic matter (SOM), nutrient depletion and decline in soil fertility (42.4 Mha), salinization (33.3 Mha) and waterlogging (12.8 Mha) (Lal 2011). Agricultural activities and practices can cause land degradation in several ways depending on land use, crops grown and management practices adopted. Widespread use of extractive farming practices including: removal of crop residues for fodder and other uses, use of animal dung as household fuel rather than manure, and minimal use of fertilizers and soil amendments especially in rain-fed agriculture cause soil degradation and desertification (Lal 2007).

A comprehensive study, made on the impact of water erosion on crop productivity, revealed that soil erosion due to water resulted in an annual crop production loss of 13.4 million tons in cereals, oil seeds and pulses equivalent to ~US$162 billion in India (Sharda et al. 2010). Inappropriate agricultural practices leading to widespread land degradation has a direct and adverse impact on the food and livelihood security of millions of small holders in the SA region. There is a strong need for restoring degraded soils and ecosystems, and conserve fertile soils through improvements in soil organic carbon pool and creation of positive nutrient budgets. Adaptation to climate change necessitates improvements in soil quality to buffer against the adverse impacts of extreme events on crop production systems (Bhattacharyya et al. 2015).

11.2.2 Tillage and Land Degradation Nexus

Tillage has long been a vital agricultural practice to prepare seed bed, to incorporate fertilizer and crop residue into soil, to reduce soil compaction, and to control weeds (Sainju et al. 2012). Tillage plays an important role in the dynamic processes governing soil degradation, resilience and quality. Properly used, tillage can be an important restorative tool that can alleviate soil related constraints in achieving potential productivity (Lal 1993). Among the crop production factors, tillage contributes up to 20% (Khurshid et al. 2006) and affects the sustainable use of soil resources through its influence on soil properties (Lal and Steward 2013). However, any management practice imposed on soil for altering the heterogeneous body may result in generous or deleterious outcomes (Dwivedi et al. 2003). Unsuitable management practices not only degrade the soil health but also decrease crop productivity. Excessive tillage coupled with use of heavy machinery and lack of adequate soil conservation measures causes a multitude of soil and environmental problems (Bhattacharyya et al. 2015).

Decline in SOM due to excessive tillage adversely affects soil life and leads to poor soil structure. Poor physical condition of soil leads to poor crop establishment and root development, and waterlogging after irrigation. Conventional tillage (CT) removes the protective cover of crop residues from the soil surface which leads to exposing the soil to various degradation processes (Jat et al. 2012). CT practices cause change in soil structure by modifying soil bulk density and soil moisture content. In addition, repeated disturbance by CT gives birth to a finer and loose-setting soil structure while conservation and no-tillage methods leave the soil intact (Rashidi and Keshavarzpour 2007). The judicious use of tillage practices overcomes edaphic constraints, whereas inopportune tillage may leads to soil structure destruction, accelerated erosion, loss of organic matter and fertility, and disruption in cycles of water, organic carbon, and plant nutrient (Lal 1993). Conservation tillage causes more physical disruption coupled with less production of aggregate stabilizing materials (Laxmi et al. 2007).

11.3 Intensification of the Rice-Wheat System in IGPs and Its Impact on Land Degradation and Environment

The major cropping system in the IGPs is alternating rice-wheat, with rice grown in the wet, humid monsoon season and wheat in the dry, cool winter. Paddy-based crop rotations are the most energy-intensive production systems in the SA and particularly in the IGPs. Tillage has been and still is promoted as an essential component of management of these two crops in SA. For growing rice, the soils are plowed, flooded and then puddled. This is done with the objectives to reduce the percolation of water and promote ponding as the standing water helps control weeds. Puddling of soil for paddy cultivation also leads to degradation of soil quality due to several factors associated with it (McDonald et al. 2006; Hobbs et al. 2008; Dwivedi et al. 2011).

Intensive tillage followed by puddling in conventional systems leads to gradual decline in SOM through accelerated oxidation, with a consequent reduction in the capacity of the soil to regulate water and nutrient supplies to plants. Further, the land requires repeated plowings after the rice is harvested to bury the rice residues and to obtain a fine seedbed suitable for planting the next crop of wheat. This consumes large quantities of fossil fuels, emits large quantities of GHGs, increases cost of cultivation, and delays the planting of wheat, whose yield is affected by delayed crop establishment. Besides, the poor physical condition of the soil caused by puddling leads to poor crop stands and to waterlogging after irrigation, with aeration stress and yellowing of the young wheat plants. All these factors adversely affect yield potential, natural resource use efficiency, and environmental quality. Hence, these standard practices are now being replaced by new practices which focus on more ecologically-sound management of plants, soil, water and nutrients, supporting beneficial soil biological processes.

The groundwater for irrigation (freshwater) is a directly renewable natural resource. These natural resources are limited and depleting fast. Hence, the efficient use of these resources through strategic changes in the agro-technique(s) is warranted to remain sustainable in the long run (Kumar et al. 2018). Tube well is the primary source of irrigation in the IGP region and a remarkable fall in the groundwater table in paddy–wheat growing regions has been observed in the last two to three decades (Lal et al. 2019), warranting a serious attention.

Sustainability of these rotations is now-a-days questioned with declining natural resource base, soil degradation, environmental pollution, and declining factor productivity. As a consequence, the search for energy efficient production technologies is increasing for sustainable and cleaner production. Conservation Agriculture (CA) practices have been recommended for resource conservation, soil health restoration and sustaining crop productivity.

11.3.1 Residue Burning – A Burning Issue in South Asia

Large quantities of crop residues are generated every year, in the form of cereal straws, sugarcane trash, woody stalks of cotton, pigeonpea, castor *etc*. during harvest periods. A large portion of the crop residues is not used and remains unutilized and is left in the fields. These residues create problem in mechanical sowing of next crop in the rotation and also cause nutrition related problems in crops like yellowing in peanut. Hence, the disposal of such a large amount of crop residues, in a short period, remains a major challenge. To clear the fields timely and inexpensively, farmers resort to *in-situ* crop residue burning (Fig. 11.1). Farmers opt for burning because it is a quick, easy and inexpensive way to manage the large quantities of crop residues and prepare the field for the next crop well in time (Jain et al. 2014).

On-field crop residue burning causes loss of nitrogen, carbon and sulfur, destroys farmer-friendly insects as well as results in environment pollution. The emission from global paddy-wheat rotation is estimated at ~523 million tons CO_{2-e} year^{-1} and contributes ~10% of the total agricultural emission globally (Ravindra et al. 2019). Agricultural residue burning emits significant quantity of air pollutants like CO_2, N_2O, CH_4, emission of air pollutants such as CO, NH_3, NOx, SO_2, NMHC, volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) and particulate matter like elemental carbon (Zhang et al. 2011; Mittal et al. 2009). Burning of crop residues emitted 8.57 Mt of CO, 141.15 Mt of CO_2, 0.037 Mt of SOx, 0.23 Mt of NOx, 0.12 Mt of NH3 and 1.46 Mt NMVOC, 0.65 Mt of NMHC, 1.21 Mt of particulate matter for the year 2008–09 in India (Jain et al. 2014).

Crop residue burning, unnecessary tillage for land preparation and planting, indiscriminate irrigation, excessive fertilizer applications, use of heavy machinery *etc*. not only cause land degradation but also cause emission of GHGs (Hobbs et al.

Fig. 11.1 Open field burning of wheat residues in Junagadh district of Gujarat, India

2008). However, these crop residues can be utilized for increasing soil fertility. Specified machinery for crop residue management and direct seeding especially in heavy crop residues can play a significant role for adoption of conservation tillage practices. CA, originally advocated to arrest wind erosion in USA in 1930s, can be promoted in the SA region for soil conservation and quality enhancement, mitigating the problem of air pollution due to burning of residues, timely sowing of crops in the rotation, bring down cost of cultivation and other several associated benefits (Jat et al. 2012, 2014; Bhan and Behera 2014; Balwinder-Singh et al. 2019).

11.4 Conservation Agriculture: Concept and Definition

According to FAO (2014), CA is an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. CA is characterized by three linked principles, namely: (i) Continuous no- or minimal mechanical soil disturbance (i.e., no-tillage and sowing or broadcasting of crop seeds, and direct placing of planting material in the soil; minimum soil disturbance from cultivation, harvest operation or farm traffic, in special cases limited strip or band seeding disturbing less than 25% of the soil surface; (ii) maintenance of a permanent organic soil mulch cover, especially by crop residues, crops and cover crops; and (iii) diversification of crop species grown in sequence or associations through rotations or, in case of perennial crops, associations of plants, including a balanced mix of legume and non-legume crops. These three interlinked principles must be considered together for appropriate design, planning and implementation processes. CA principles are universally applicable to all agricultural landscapes and land uses with locally formulated and adapted practices.

Conservation Agriculture practices followed in many parts of the world are built on ecological principles making land use more sustainable (Lal 2013). Scaling out CA for improving soil health, climate change mitigation and adaptation, enhancing resource use efficiency, and sustained higher productivity is the need of the hour to achieve sustainability in agriculture production systems.

11.4.1 Minimum Soil Disturbance

Minimum soil disturbance maintains optimum proportions of respiration gases in the rhizosphere, moderates organic matter oxidation, improves porosity for water movement and limits the re-exposure of weed seeds and their germination (Kassam and Friedrich 2009). The soil biological activity produces very stable soil aggregates allowing air and water infiltration. This process can be called biological tillage and it is not compatible with mechanical tillage. Tillage operation leads to break down of biological soil structuring processes.

11.4.2 Permanent Soil Cover

A permanent soil cover is imperative to protect the soil from the detrimental impacts of rainfall and sun; to provide the feeding material to micro- and macro- organisms dwelling in the soil; and alter the microclimate for optimal growth and development of soil organisms as well as plant roots. It also improves soil moisture content, aggregation, soil biodiversity and C-sequestration (Ghosh et al. 2010).

11.4.3 Diversified Crop Rotations

The rotation of crops is not only essential to provide a diverse food to the soil micro-organisms, but also for exploring different soil layers for nutrients that have been leached to deeper layers. Crop rotations involving legume crops helps in mitigating the build-up of pathogenic pest species, through life cycle disruption, biological nitrogen fixation, control of off-site pollution and enhancing biodiversity (Jat et al. 2014).

11.4.4 History and Spread of CA Farming in South Asia

In India, though the zero tillage (ZT) research started in 1970 but non-availability of suitable equipment hampered any substantial adoption in the following two decades. A ZT drill was imported from New Zealand in India in 1988 at Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, following which local manufacturers started making drills at much reduced cost which were more affordable to farmers. The first prototype of the Indian ZT seed drill (Pantnagar drill) was built in 1991 (Laxmi et al. 2007). Further, improved ZT drill by private manufacturers was developed in 1997.

Several actors played a key and complementary role in spreading the ZT technology in India, including SAUs, ICAR and the State Agricultural Department aided by the various sponsored R&D projects from the rice wheat consortium (RWC), CIMMYT, and the Australian Centre for International Agricultural Research. The important events towards popularizing ZT in India were development of happy seeder (HS) in 2005 and turbo happy seeder (Fig. 11.2) in 2006 by Punjab Agricultural University, Dasmesh Mechanical Works, and CSIRO Land and Water, Australia (Sidhu et al. 2007, 2015). However, still the problem of loose rice straw was not completely solved and posed a major problem during seeding and ensuring satisfactory plant stand of wheat in the combine harvested rice fields. Recently, the development of super straw management system, a fitment attached to the combine harvester which picks up loose rice straw, shreds it and spreads evenly over the harvested strip, is a big leap towards residue management (Fig. 11.3). In Pakistan, ZT was initially introduced in 1983 for wheat cultivation; a drill being imported into Pakistan from Aitchison Industries (New Zealand) attracted the stakeholders towards ZT.

In Bangladesh, because of small (av. farm size 0.68 ha) and fragmented land-holdings two-wheel tractor popularly called power tiller is common in use (75% of total cultivated area in 2003) (Roy et al. 2009). Hence, the CA machinery, operated by four wheel tractors, developed in the neighboring countries was not of much use and therefore, fresh efforts were made to develop CA machinery suitable for power tillers (Gupta et al. 2002). A power tiller operated ZT seed drill was designed and fabricated locally in Bangladesh and performance evaluation was done in farmers' field from 1999 to 2002. Recently, efforts are being made for futher development and demonstration of CA machinery at farmers' field by CIMMYT, Bangladesh Agricultural Research Institute (BARI) and other developmental organizations in Bangladesh.

In Nepal, Nepal Agricultural Research Council and Department of Agriculture are the main drivers to develop, validate and disseminate the CA-based technologies mainly in rice-wheat system in terai area (Karki and Shreshtha 2014). Several CA machines are being tested and improved, however, still not perfectly executed. Cereal Systems Initiative for South Asia (CSISA) was instrumental in promoting CA-based technologies under rice-based system in eastern and mid Terai and International Fund for Agricultural Development (IFAD) through CIMMYT, Nepal was involved in testing and promoting CA-based technologies under maize based system in the western Terai and adjoining hills of Nepal. However, not much details are available about area expansion in Nepal, including Afghanistan, Sri Lanka, and Bhutan.

As against, quite rapid spread of CA in the world, from 2.8 Mha in 1973–1974 to 180 Mha during 2016, area under CA is rather small in SA (Gupta and Sayre 2007; Triplett and Dick 2008; Hossain et al. 2015; Kassam et al. 2018), primarily due to tillage mind set, lack of awareness about resource conservation, weed problem, lack of supporting policies *etc*. Moreover, the maximum efforts to promote CA in SA region were concentrated in rice-wheat system, as CA was seen as a potential solution to the problem of surplus residue and for timely sowing of wheat crop in the system. However, due to prevalent practice of puddling in lowland rice acreage under full CA in rice-wheat system is rather low. The whole concept and practice of CA has not been adopted by all the farmers, but the main elements of ZT and maintaining residue cover on the soil are gaining wide acceptance in wheat component (Gupta and Sayre 2007).

The main reasons of spread of ZT wheat area in Pakistan were the extra yield obtained by planting closer to the optimal sowing time and the cost savings in land preparation and planting (Khan and Hashmi 2004). Currently, there is large adoption of no-till wheat with some 5 Mha in the rice-wheat-cropping system in the IGPs across India, Pakistan, Nepal and Bangladesh (Kassam et al. 2018). Other than the IGPs, research and development efforts are in full swing to develop locally adaptable CA practices for different production systems in the region. Over the past few decades, international institutions such as Food and Agricultural Organization

(FAO) and the Consultative Group of International Agricultural Research (CGIAR) Centers like CIMMYT, BISA, and ICRISAT have focused more on the development and promotion of CA-based technologies. Initially, RWC promoted resource conservation technologies such as ZT wheat and initiated a base for spreading CA in the IGPs. This trend is continued with several other projects carried out by CGIAR Centers such as Cereal System Initiatives for South Asia (CSISA) and CGIAR Research Program on Climate Change Agriculture and Food Security (CCAFS).

11.4.5 Zero-Tillage Wheat After Rice in IGPs

As discussed previously, most efforts were focused around rice-wheat system of IGPs to popularize CA in the SA region. The time period between rice harvesting and sowing of succeeding wheat is very small and often sowing of wheat gets delayed. This stretches wheat maturity period up to April end thus, exposing the crop to terminal heat stress. Late planting can be caused by late harvest of the previous rice crop, or by the extensive tillage that farmers do to convert their physically degraded, puddled rice soil into a suitable seedbed for wheat (Hobbs and Gupta 2003). Data from the SA region show a 1–1.5% loss in yield potential for every day's delay after the optimum seeding date of November 15. Planting of wheat with No till drill offered an attractive solution to the problem of late planting. The main reason given for adoption of ZT since its introduction was the extra yield obtained by planting closer to the optimal sowing time and the cost savings in land preparation and planting. Farmers welcome higher yield at less cost. Over time, farmers have realized other environmental and resource-use efficiency benefits of ZT sowing wheat (Khan and Hashmi 2004).

11.4.6 Crop Residue Management Under CA in South Asia

The majority of farmers in the IGPs, and other parts of South Asian countries used to remove crop residues for animal feed or household fuel. Advances in mechanized harvesting of rice over the years have resulted in large amounts of loose residues in the field. However, with the introduction of combine harvesting system, mainly for rice and wheat, the issue of residue management has surfaced as the stubbles and loose straw humps left in the field by combine harvester are less preferred for fodder and involve extra cost in collection. Besides, it creates problems for direct drilling of wheat seed into combine-harvested rice fields using the normal ZT seed drill (Keil et al. 2020). Hence majority of farmers in IGPs and some other parts resort to open field burning (Sarkar et al. 2018). Other farmers also incorporate the residues into the soil (Ahmed et al. 2015), which has been made easier with the introduction of reversible mould board plough.

Fig. 11.2 The 9-row Turbo Happy Seeder sowing wheat into rice residues in a farmer's field. (Photo courtesy: BISA-CIMMYT, India, Sidhu et al. 2015)

Each residue management practice has different cost implications. Complete residue removal is, on average, 34% costlier to farmers than total burning of residues (Prasad et al. 1999; Ahmed et al. 2015). However, residue burning has serious implications in terms of environmental pollution and nutrient losses. Therefore, CA is being tested extensively and promoted in the rice-wheat as well as other production systems of SA as sustainable and eco-friendly way of residue management (Krishna and Veettil 2014). Happy Seeder (Fig. 11.2), a specialized no-till seeder, which has been developed, validated and refined by agricultural researchers over the last 15 years, is the most commonly used no till drill in the SA region (Sidhu et al. 2015). The Happy Seeder (HS) is a tractor mounted implement that combines a ZT seeder with a straw management unit. The latter comprises of serrated rotating flails attached to a roller that shreds and clean the residues in front of the tyne openers and then deposits the residue around the seeded row as mulch. This is done in one simple operation of direct-drilling in the presence of standing as well as loose surface residues. The residues left on the surface as mulch helps reduce evaporation losses, suppresses weed growth, buffers soil moisture and temperature, and facilitates a more efficient uptake of water and nutrients by plant roots (Bhan and Behera 2014).

The use of the HS also reduces labour requirements for crop establishment by as much as 80%, irrigation needs by 20–25%, and herbicide use by as much as 50% (Saunders et al. 2012). It further reduces fuel use and improves productivity, particularly under climatic stress conditions (Aryal et al. 2016). The HS works best in combination with a simple straw spreading mechanism, called the 'Super Straw Management System' (Super SMS) that can be attached to the combine harvester, which enables uniform spreading residue across the harvesting width (Fig. 11.3). The development of the Super SMS enhances the efficiency of the HS and improves crop establishment and yields (Lohan et al. 2018).

Still, some farmers in other parts use straw chopper to collect loose residues from combine harvested fields for use as animal feed. This helps in hindrance free sowing of crops through standing crop stubbles (Fig. 11.4).

Fig. 11.3 Rice loose straw management by super straw management system attached to combine harvester. (Photo courtesy: BISA-CIMMYT, India)

Fig. 11.4 Collection of loose wheat residues with straw chopper (**a**), minimum tillage between row of standing wheat stubble (**b**), peanut sowing betweeb stubble rows (**c**), and a healthy peanut crop in the CA field (**d**)

11.4.7 CA as Climate Resilient Production System-Experiences from SA

Increase in farm production/income due to CA is a proxy for house-hold food security due to increased availability and access to food. Similarly, improved soil health, increased water, nutrient and energy efficiencies, timely sowing, minimum heat stress indicate adaptation potential of CA to climate change and variability. Moreover, low GHG emission and higher carbon sequestration from the implementation of CA practices shows mitigation potential. Based on the results of several on-station and on-farm experiments, the benefits of CA in terms of food security, climate change adaptation and mitigation in SA are summarized below:

11.4.7.1 Role of CA in Soil Conservation and Quality Improvement

Conservation of precious natural resources including soil and water is vital not only for sustained agricultural production but for continuation of civilizations. Reducing disturbance of soil by CA influences several physically, chemically, and biologically interconnected properties of the natural body (Jat et al. 2014). The residue mulch cover in CA fields protects soil against water- and wind-led erosion and conserves rainwater in soil for its productive use (Jat et al. 2012). Jat et al. (2015a, b) reported that ZT+residues reduced total seasonal runoff by 28.6 and 80.22 compared to conv. tillage and residue removal during 2010–11 and 2011–12, respectively (Table 11.1). Only 17.5 and 1.3% of total rainwater was lost as runoff under ZT+residues compared to 24.4 and 6.4% under ZT without residues during 2010–11 and 2011–12, respectively.

Under CA higher rainwater infiltrates into the soil add to the green water. Similarly, peak rate of runoff, which indicates erosive capacity of runoff water, was reported to decrease by 25.1 and 72.7% under ZT+residues compared to conventional practice during 2010–11 and 2011–12, respectively. Retention of crop residues is expected to increase percentage of water stable aggregates in the organic matter starved soils of the SA (Kurothe et al. 2014). They reported that the practices like ZT and mulching (chopped pearl millet straw @ 2 t ha^{-1}) effectively reduced the average sediment concentration.

Improved soil quality is a must to make production systems climate change resilient. The CA-based practices specifically aims to address the problems of soil degradation due to water and wind erosion, depletion of organic matter and nutrients from the soils (Jat et al. 2012). Studies have demonstrated that CA technology plays

Table 11.1 Effects of tillage and crop residue management practices on runoff, peak rate of runoff and percent rainfall lost as runoff

	2010–2011			2011–2012		
Treatments	Runoff (mm)	Peak rate of runoff (cum/s/ha)	Percent rainfall lost as runoff	Runoff (mm)	Peak rate of runoff (cum/s/ha)	Percent rainfall lost as runoff
CT-RR	262.1	0.183	24.4	26.3	0.011	6.4
CT-RT	202.0	0.130	18.8	7.2	0.004	1.8
ZT-RR	253.4	0.126	20.0	11.8	0.005	2.9
ZT-RT	187.1	0.137	17.5	5.2	0.003	1.3

Source: Adapted from Jat et al. (2015b)
Note: *CT* conv. Tillage, *ZT* zero tillage, *RR* residues removed, *RT* residues retained

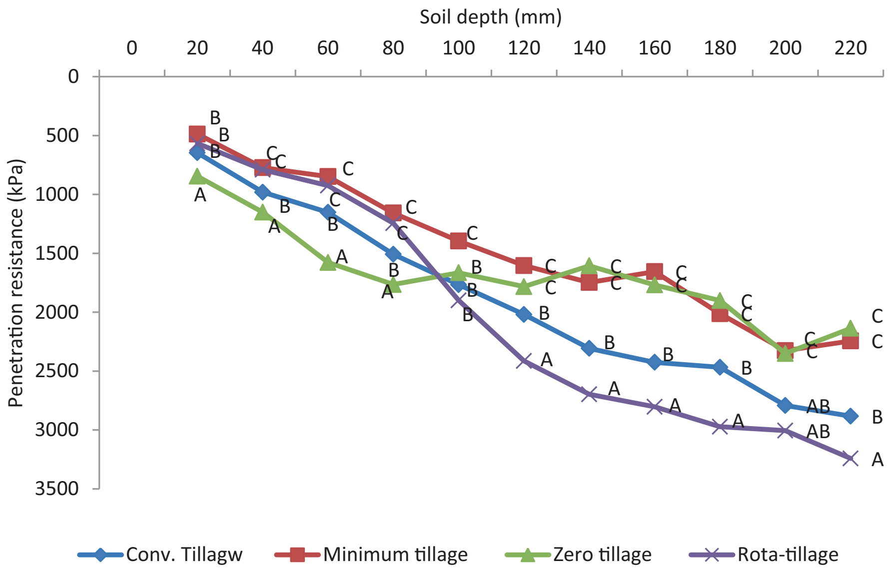

Fig. 11.5 Effect of tillage practices on soil penetration resistance in peanut-based cropping systems. (Source: Jat et al. 2020b)

an important role in rapidly improving the physical, chemical and biological properties of the topsoil (Gathala et al. 2014). ZT+residue retention brings higher aggregate stability, higher aggregate size and SOC than CT (Singh et al. 2014). Residues protect the surface soil from soil aggregate destruction, enhance water infiltration and reduce the soil loss (Das 2014). The 5 years data of ZT maize experiment revealed that soil wet aggregate stability, soil enzymes, SOC and microbial biomass (MBM) have increased over CT (Parihar et al. 2016, 2018). Jat et al. (2013) reported that ZT+residue retention resulted in a high mean weight diameter and a high level of stable aggregates in rain-fed systems.

Improved aggregation reduces soil compaction (Fig. 11.5), thus facilitates seed germination and plant root development. ZT along with residue retention results in a build-up of soil organic carbon (SOC) and nitrogen (N) in the surface layers (Lal 2005). Soil microbial population, enzyme activities and potentially mineralizable N status also improves under ZT (Parihar et al. 2016). Cover crops protect the soil not only against the splash effect of raindrops but also from the heating effect of the sun and gusty winds (Rao and Khan 2003). Residue retention plots have higher C, N, potassium (K), and lower sodium (Na) concentration as compared to residue removal in a rain-fed permanent raised bed planting system (Gangwar et al. 2006; Yadvinder-Singh et al. 2010). Singh et al. (2009) reported that retention of crop residues increased microbial biomass and micro-flora activity. Crop residues act as energy source for microorganisms for the continuous, uniform supply of C.

11.4.7.2 CA and Climate Change Mitigation Through Carbon Sequestration and Reduced GHGs Emission

CA practices such as ZT, crop residues retention, diversified crop rotation have great potential to climate change mitigation through enhancing carbon stock (carbon sequestration) in the soil and by reducing GHG emission (avoid burning of crop residue and less energy and nutrient use) (Gupta et al. 2016). The process of restoration of SOC pool, through conversion of atmospheric CO_2 into humus through photosynthesis is called soil C sequestration (Lal 2009). Lal (1994) reported that net CO_2 of 832 kg C/ha/year can be saved by shifting from CT to ZT. Researchers have reported that soil management practices like ZT, residue retention, mulching, and crop diversification can play important role in C-sequestration into the soil (Behera and Sharma 2009; Srinivasarao et al. 2013).

Zero till with residue retention produced net increase (15.8–27.1%) in the SOC content over the conventional tillage (CT) (Behera et al. 2009). They also reported that exposure of SOM in the soil due to continuous CT over years caused oxidation and mineralization for which there was a decline in SOC in CT plots. Maize-chickpea-greengram cropping system sequestered 19.3, 21.0 and 21.8% of higher carbon than maize-mustard-green-gram, maize-wheat-green-gram and maize-linseed-green-gram systems, respectively (Behera et al. 2009).

Chickpea being leguminous crop and also cover crop influenced positively in building the SOC. Behera (2014) also reported that effect of tillage and residue management was significant in influencing the SOC-sequestration in the surface soil. The highest C build up was observed with ZT+residue retention which was significantly greater than CT and residue removal. Bhattacharyya et al. (2015) observed that the distribution pattern of SOC under ZT soil was closer to the adjacent secondary forest soil than in CT soils. Saha and Ghose (2013) stated that ZT along with cover crops resulted in the greatest SOC content, which was similar to native undisturbed forest. Pathak et al. (2012) reported that a shift from CT to ZT can sequester 57 g C/m^2/year. Parihar et al. (2016) reported that maize based cropping system had a positive balance of almost 20 t CO_2/ha compared to fallow maize system. These results confirm the potential of CA for C-sequestration. CA leads to enhancement in the long-term C-sequestration and constitute a practical way to mitigate GHG emissions and impart greater resilience to agriculture production systems to climate change (Saharawat et al. 2012).

Results of field experiments conducted in Haryana revealed that CA reduced fuel consumption to a great extent due to ZT technology (Tirol-Padre et al. 2016). CA also reduces emission of GHGs because here residue is retained on the soil instead of burning. Further, ZT leads to less exposure of SOM to oxidation and hence, reduces CO_2 emission to the atmosphere compared to CT (Sharma et al. 2014; Gupta et al. 2016). ZT saves considerable amount of diesel and thus, reduces CO_2 emission, one of the gases responsible for global warming (Jat et al. 2015a, b). CA with direct seeded rice (DSR) could be a way to reduced CH_4 emissions since it would omit the puddling and ponding of water which will encourage more infiltration of water through the soil profile and help aerate the soil (Vijayakumar et al.

2018). Soils under ZT, depending on the management, might also emit less nitrous oxide (Sapkota et al. 2015a, b). Thus, the reduced use of fossil fuel and avoidance of burning and ponding under CA is likely to reduce the load of greenhouse gases in the atmosphere and thus adds to ecosystem services (Singh et al. 2016a, b). Adoption of CA in the region has been reported to reduce air pollution (due to less residue burning) also in the region (Grace et al. 2003).

11.4.7.3 CA and Sustained Productivity and Financial Return

Conservation agriculture aims for achieving higher productivity while protecting natural resources and environment (Sangar et al. 2005) resulting higher and stable yields, especially in medium and longer terms, due to improved soil quality, timely sowing, increased moisture availability, and higher nutrient and energy use efficiency (Jat et al. 2012, 2014). The residue retention, improved soil aggregation and SOC, extensive network of decaying roots, reduced crusting *etc*. leads to higher moisture content under CA systems (Mamta et al. 2011; Singh et al. 2014; Nandan et al. 2019). Jat et al. (2020b) have also found higher soil moisture regime under CA systems in light black soils of Saurashtra having poor water holding capacity (Fig. 11.6). According to Das et al. (2017) sowing of wheat crop can be advanced under ZT by 10–12 days and 5–10% higher yield can be obtained.

The improved moisture regime saves crops against short and medium duration water stresses and gives higher yields under rain-fed systems (Jat et al. 2015b). ZT also reduces weed infestation particularly of *Phalaris minor* due to avoidance of soil turning (Malik et al. 2005). Timely sowing of wheat under ZT also provides opportunity to escape wheat crop from terminal heat stress. Similarly, less insect pest and disease incidence in CA fields is reported to give higher yields (Bhan and Behera 2014). Because rotations enhance microbial diversity, the risk of pests and disease outbreaks is reduced, since the biological diversity helps keep pathogenic organisms below the threshold level (Chandra, 2011).

Yield and monetary advantages due to different CA systems in South Asian countries are presented (Table 11.2). Khan and Hashmi (2004) reported that ZT resulted in 13, 16 and 18% increase in wheat yield compared to farmer's practice in 1991–92, 1995–96 and 2000–01, respectively. Jat et al. (2019) also reported higher system yield and net returns with CA practices in peanut-wheat system. Farmer surveys in India and Pakistan have indicated that ZT wheat after rice reduces costs of production by US$ 60 per hectare mostly due to less fuel (60–80 l/ha) and labour (Hobbs and Gupta 2004). CA reduces input cost especially on tillage and irrigation, and nutrient cost in medium to longer term, thus bringing down over all cost of production (Fig. 11.7).

However, adoption of ZT without residue retention and without suitable rotations (excluding legumes) can be more harmful to agro-ecosystem productivity and resource quality than a continuation of conventional practices as it leads to soil compaction and reduced moisture conservation (Sharma et al. 2014).

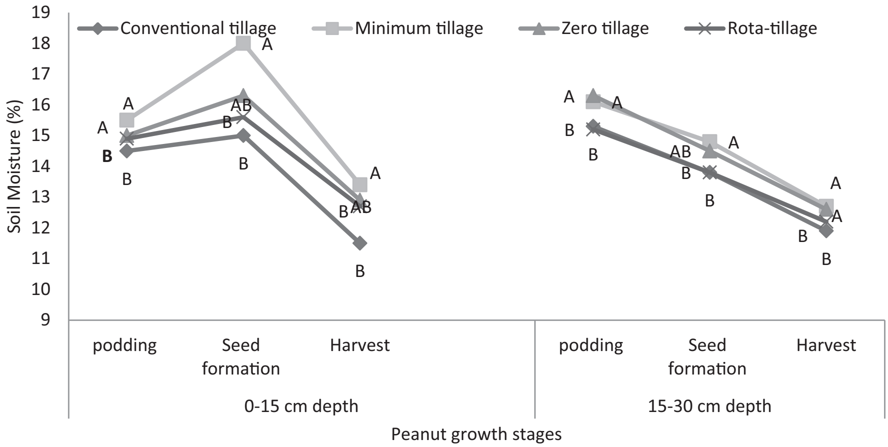

Fig. 11.6 Effect of tillage practices on soil moisture content in peanut (mean of two seasons). (Source: Jat et al. 2020b)

11.5 CA and Ecosystem Services

Biodiversity and uninterrupted flow of ecosystem services play important role in sustainability of production systems. CA practices not only improve above ground biodiversity but also provide more habitats and food for birds, small mammals, reptiles, earthworms, insects *etc*., which leads more species diversity and density (Jat et al. 2012; Pramanik et al. 2014). The density, diversity and activity of earthworm have been found to increase under CA system as compared to under conventional agriculture system (Jat et al. 2017). Use of wheat straw or hairy vetch as mulch crop under CA resulted in remarkable increase in beneficial fauna such as spiders and earthworms (Bhadu et al. 2018). ZT systems have more diversity and density of arthropods (Bhan and Behera 2014).

CA enhances the availability of pure and clean water since; pollution, erosion, and sedimentation of water bodies are reduced under CA (Jat et al. 2014). CA leads to reduction in soil erosion which eventually reduces rate of siltation of water bodies and increases recharge of aquifers (Lal 2007). CA practices have been reported to reduce water contamination which can be measured with water turbidity and the concentration of sediments in the suspension and thereby reduction in water treatment costs (Behera 2014). The flow in water streams has been reported to be more constant and improved recharge of the groundwater table with re-occurrence of water in inoperative wells. Kaur and Singh (2013) revealed that CA leads to non-disturbance of the channels created by decaying plant roots which ultimately helps in improving infiltration of water leading to recharge of groundwater.

Table 11.2 Effect of different CA practices on yield and economics of different systems in South Asia

S. No.	Crops/ Cropping system	Country	Duration of study	CA system	Increase in yield (%)	Increase in net/ gross return (%)	References
1	Rice-Maize	Bangladesh	2009–2013	Reduced tillage (RT) + residue retention	10 (maize)	19.9 net return	Gathala et al. (2015)
2	Maize-wheat	India	2012–2015	ZT + residue retention	14.4 (Maize) 13.5 (wheat)	13-27 net return	Jat et al. (2018)
3	Cotton-wheat	India	2010–2013	ZT + residue retention	46.5 (cotton) 11 (wheat)	29.9 net return	Das et al.
4	Maize-mustard	India	2008–2014	ZT	11.6 (Maize) 7.9 (mustard)	35.3 net return	Parihar et al. (2016)
5	Rice-wheat-mungbean	Bangladesh	2013–2015	ZT	5.1 (wheat) 13.7 (mungbean)	–	Islam et al. (2019)
6	Rice based cropping system	Bangladesh & Nepal	2014–2017	ZT+ stubble mulch	–	25 gross return	Gathala et al. (2021)
7	Rice based cropping system	Bangladesh & Nepal	2014–2017	ZT+ stubble mulch	10 (system yield)	12–32 gross return	Gathala et al. (2020)
8	Wheat	Pakistan	Field survey (150 farmers)	ZT	11.6 (wheat)	14.8 gross returns	Akhtar and Rasool (2017)
9	Maize-wheat	India	2009–2011	ZT+ *Sesbania* mulching	18.3 (maize) 8.0 (wheat)	10 net return	Jat et al. (2015a)
10	Maize based cropping system	India	2008–2015	ZT	20.2 (system yield)	35.3 net return	Parihar et al. (2016)
11	Maize-wheat	India	2010–2013	ZT + residue retention	39 (maize) 6.1 (wheat)	18 net return	Das et al. (2018)
12	Rice-Wheat	India	2002–2004	ZT	6.5 (wheat)	12.7 net return	Chhokar et al. (2007)

(continued)

Table 11.2 (continued)

S. No.	Crops/ Cropping system	Country	Duration of study	CA system	Increase in yield (%)	Increase in net/ gross return (%)	References
13	Rice-Maize	India	2006–2011	ZT + residue retention	14.2 (maize)	35.4 net return	Singh et al. (2016b)

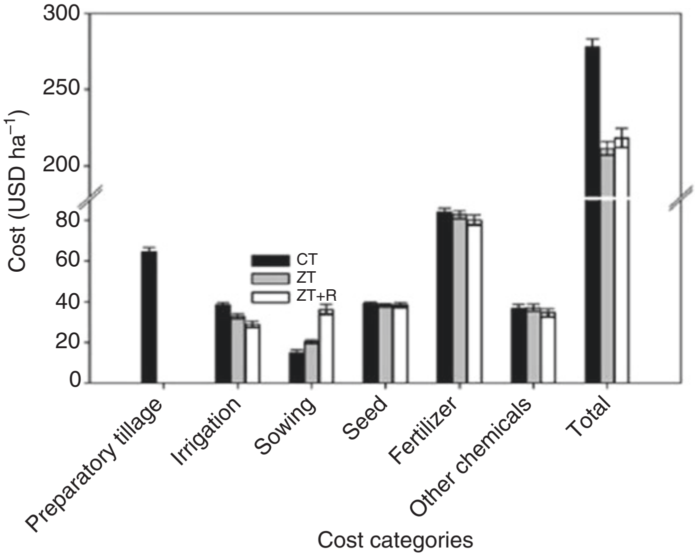

Fig. 11.7 Input cost for wheat production under various tillage and crop establishment methods. *CT* conventional tillage, *ZT* zero-tillage, *ZT+R* zero-tillage with residue retention. Vertical bars shows the standard error of the mean (n = 120). (Source: Aryal et al. 2015)

11.6 Crop Diversification in IGPs

Crop diversification is one of three interlinked and indispensable principles of CA. "Rice is now in the eye of perfect storm especially in northwest IGPs like Punjab, Haryana and Western Uttar Pradesh states of India". Rice is the root cause of problems like air pollution, depletion of groundwater, loss of biodiversity, soil degradation due waterlogging and salinization *etc*. in the region. Hence, sincere efforts are needed at top level to replace much of the non-*Basmati* rice with other suitable crops as growing rice in these states is no longer a national priority. Country has moved much ahead of food insecurity days of 1960s. Farmers should be incentivized to diversify with suitable oilseeds, pulses, cereals and horticultural crops keeping in view nutritional security and market needs.

The leguminous crop has a lower C-and water footprint as compared to cereals due to the lesser release of GHGs (Singh and Ahlawat 2015). Diversification of the rice-wheat system through climate-resilient millet-based production system reduces energy consumption and carbon footprint. The millet based production system also helps reduce the carbon input by 172% and improve the energy use efficiency by 61% compared to the cereal-based cropping system (Kumar et al. 2020). Further, the turnaround period is very long in rice-wheat system in western IGPs; hence, fields generally remain fallow for about 70–80 days after harvesting of wheat.

A short duration (60–65 days) variety of summer *mungbean* (greengram) may be introduced in rice-wheat system to diversify the system. Extra short duration pigeon pea is also an option for diversification of the system. Summer *mungbean* not only provides additional income but acts as a break crop and adds some nitrogen through biological nitrogen fixation (Das 2014). Summer *mungbean* residue incorporation in direct-seeded rice and rice residue retention in ZT wheat followed by summer *mungbean* gives higher system productivity, net returns and water productivity than the conventional transplanted RWCS (Das 2017).

Thus, promoting crop diversification by including non-paddy crops is a worthful challenge with the policymakers, government planners, researchers, and producers to achieve the sustainable development goals in IGPs.

11.7 Major Challenges to Promote CA in India

1. Tillage mindset: The deep tillage and pulverization of virgin and long time fallow soils leads to massive release of plant nutrients and better crop yields for coming few years. This was desirable practice during pre-industrialization era to realize better crop yields when chemical fertilizers were yet to be discovered. This has probably made lasting impression in the minds of farmers that intensive tillage is pre-requisite for higher yields. However, in the modern day agriculture fertilizers are used to replenish the plant nutrients in the soil. Another important role of tillage is weed control. With the availability of a range of crop specific pre- and post- emergence herbicides the requirement of tillage for weed control has greatly been reduced.
2. Weed incidence: Higher weed intensity, particularly perennial weeds, is a hurdle in promoting CA. As tillage operations are not performed under CA, herbicide use is important for weed control in CA fields. However, unlike developed countries, herbicide use is not so common in the SA region, and therefore, successful weed management is a major challenge to promote CA in different cropping systems in the SA region.
3. Lack of Customized machinery: The success of CA depends on successful crop establishment even in the absence of tillage. Availability of right type of seed-drills is crucial for proper seeding to get required seed and soil contact. However, availability of customised CA machinery at subsidised rates hinders fast spread of CA in the region.

4. Lack of awareness: There is lack of required awareness among the farmers about the benefits of CA. Also farmers lack required expertise to successfully implement the CA technoiligy in the field.
5. Low land rice in rice-wheat system: The availability of surplus residues and need of timely sowing of wheat are the two important push factors in favour of CA being up scaled in the rice-wheat system of IGPs. However, low land rice, which requires puddling of fields, stops short of full adoption of CA in the rice-wheat system in the region.
6. Competitive uses of residues: Animal production is an important aspect of agriculture in the SA region. As animals depend on crop residues for feed, availability of surplus residues especially in dryland systems is a major constraint to promote CA.
7. Lack of suitable policy support: Countries like USA, Canada, Brazil, Argentina, Australia which have significant acreage under CA have formulated national policies to promote CA. However, in the SA region no such policies have been unleashed like higher subsidies on CA machinery, promoting direct seeded rice, geo tagging CA fields etc.

11.8 Way Forward to Promote CA in South Asia

Currently, no-till wheat is sown on some 5 Mha in the SA, mostly in the rice-wheat system in the IGPs (Kassam et al. 2018). However, great scope lies to increase area under complete CA i.e. three interlinked principles of minimum mechanical soil disturbance, soil cover with crops/cover crops/residues, and diversified crop rotation as CA could provide multitude of benefits like climate change resilience, sustained and higher yields, air pollution control, soil conservation and quality improvement, ecosystem services *etc.* in medium to long terms. Apart from IGPs, availability of surplus residues in many areas, due to introduction of combine harvesting systems, offers good opportunities to promote CA. Hence there is good scope to promote CA in areas beyond IGPs. However, to up scale CA in the SA region following suugestions may be considered:

1. Efforts should be made for promoting direct seeded rice for adoption of complete CA in rice-wheat system in the IGPs of the SA.
2. Successful weed management is a big challenge towards up-scaling CA. Development of self-propelled weed puller using artificial intelligence (AI) in near future may prove greatly helpful to promote CA.
3. Achieving satisfactory plant stand is vital for success of CA. Emphasis should be given on development and subsidized supply of suitable ZT drills catering the needs of farmers of different categories.
4. A mechanism should be established to geo-tag CA fields so that farmers may be benefited through carbon credits and ecological services.

5. Outside IGPs, CA is only a buzzword with many State Agricultural Universities having no proper research and development agenda to promote CA in their domain areas. Hence national policies should be formulated to promote CA in mission modes.
6. Many researchers are working in isolation hence; frequent CA specific seminars/symposia/webinars should be organized at regional/national/trans boundary level to exchange ideas and research findings.
7. Extension mechanism should be strengthened so that technologies developed reach farmers' field. Participatory technology development involving farmers from the very beginning is essential for development and fast adoption of the CA technology.
8. During the initial years minimum tillage should be allowed especially in peanut, root crops, transplanted crops *etc*. in the fine textured soils. Once the soil quality improves with continuous residue retention, ZT may be followed.

11.9 Conclusion

South Asia has the unique challenge to feed 1.94 billion strong populations particularly when climate change effects on agriculture are getting more evident in the region and natural resource base is already degraded. Besides, air pollution due to burning of crop residues is affecting life of millions in the region. Conservation and judicious use of natural resources (soil and water), soil quality improvement, diversification of production systems, timely sowing, higher input use efficiency (water, nutrient, energy, labour) are critical to make production systems climate change resilient. Empirical evidences, especially in IGPs, indicate that CA has great potential to give sustained higher productivity and financial returns under changing climatic conditions.

However, despite about five decades of R&D efforts the acreage under CA in the region is not up to the desired levels. Low land paddy in rice-wheat system of IGPs, where maximum focus was put to promote CA, has hampered the efforts to enhance acreage under CA in the region. Availability of residues for mulching, suitable machinery, lack of focused R&D efforts, and absence of suitable policy environment are the major stumbling blocks to popularize CA outside IGPs. Weed control in the absence of tillage is also a major deterrent to win over the confidence of farmers. However, with proper policy environment in place and dedicated efforts through participatory R&D; significant area expansion is possible under CA in the SA region. Further, development of AI guided solar/fuel operated weed pullers in near future gives great hope to popularize CA in the region.

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Chapter 12
Monitoring, Evaluation and Learning Mechanism: Issues, Challenges and Policies for Scaling-Up for Impacts in Asia

D. Suresh Kumar and K. Palanisami

Abstract The Governments in developing countries implement various policies to achieve developmental objectives such as economic growth, poverty reduction and environmental sustainability. The key objective of such developmental interventions is transforming a set of resources into desired outcomes. Thus, understanding the nature, objectives and scope of the development interventions and the responsiveness of target groups is essential for development personnel/specialist, economists and policy makers. This calls for a systematic feedback of information from the project areas and beneficiaries for whom the project is intended. Realising the significance of impact assessment, the present chapter focuses on issues, challenges and needed policies for effective monitoring, evaluation and learning (MEL) mechanisms. Development interventions have become the main interventions for natural resource management (NRM). With the huge investment of financial resources in the development programmes, it is important that the development programmes become successful. Hence, monitoring and evaluation including impact assessment of development activities should be given due importance in the future planning and development programmes. Some of the key points that will make the program successful will be: better dissemination during the implementation phase, establishing proper institutional mechanism in a multidisciplinary approach will be a viable step in impact assessment, well designed capacity building programmes are essential to train the personnel involved in monitoring and evaluation of various development interventions, robust MEL system, integration of information technology (IT), dissemination mechanism through publication of evaluative evidence and feedback materials should be done with a clear format without any ambiguity, and with scalable solutions.

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12.1 Why Monitoring and Evaluation Is Must for Achieving Impacts?

The Governments in developing countries implement different policies to achieve developmental objectives such as economic growth, poverty alleviation and environmental sustainability. The key objective of any program or project is to transform a set of resources (inputs) into desired results or outputs towards achieving outcomes. Understanding the nature, objectives and scope of the development project and the responsiveness of target groups is an imperative for development personnel/specialist, economists and policy makers to recommend improvements that will guarantee more food, fodder, fuel, and livelihood security. This calls for a systematic feedback of information from the project areas and beneficiaries for whom the project is intended. To provide the project management with such information, it is essential to understand the results of the development activities wherein the data should be gathered continuously and analyzed without delay. A system combining such data gathering, analysis, interpretation and feedback mechanism is called a monitoring, evaluation and learning (MEL) system.

Monitoring is the process of observing progress and resource utilization and anticipating deviations from planned performance (United Nations 1993). Monitoring can be defined as a continuous/periodic review and surveillance by a project management at every level of the implementation of an activity to ensure that input deliveries, work schedules, targeted outputs and other required actions are proceeding according to plan. It is thus an early warning system of any deviations and shortcomings of a program's progress with a view to effecting appropriate corrective actions in time (Rajakutty 1992). In general monitoring is the management tool which facilitates continuous learning and provides quality information on which to base decisions.

The objective of monitoring is to ensure that resources are used as efficiently as possible to generate highest quality outputs. The purpose of monitoring is to ensure timely completion of projects for which resources have been allocated in the plans. The essence of good monitoring system is its speed of communication of dependable information on key result areas. Monitoring has several aspects. Broadly, it covers:

(i) Physical progress of implementation of the projects (e.g. irrigation canals),
(ii) Production, productivity and profitability performance, and
(iii) Maintenance of capital assets created to be monitored selectively so that expenditure is utilized purposively.

Primarily there are three areas viz., technical performance, time performance and cost performance in which monitoring has to play a role.

It is critical to assess the performance of the project and to know the reasons for failure / success of the project rather than what has been done and what has happened in the project. Evaluation serves the purpose. Evaluation can be defined as a process for determining systematically and objectively the relevance, efficiency, effectiveness and impact of project activities in the relation to their stated objectives. It is an organizational process for improving activities still in progress and for aiding project management in future planning/programming and decision making. The extent to which the objectives of a project are being realized provides the primary criterion for an evaluation.

Learning is a crucial stage in the MEL. Learning is taking messages and insight acquired in the monitoring and evaluation stages to effect corrective measures and take critical strategic decisions at management/organizational level or program design level. Learning can take place during monitoring, evaluation, and or both.

Periodic monitoring, evaluation and learning mechanism of any development program / project is essential in order to measure the progress and to know what had been achieved; help us see where we are going and if we need to change direction; help us to make better plan for the future; make our work more effective; collect more information; see if our work is costing too much and achieving too little; see all the effort has been effective; share the experiences and compare with the program/project with others and assess strengths and weaknesses and improve the monitoring and evaluation methods.

As both the developing and developed economies implement various development projects using the public funds, it is essential that these development projects are effective. In order to understand whether the development projects are successful, a well-established monitoring, evaluation and learning (MEL) mechanism is critical.

12.2 Key Challenges in Impact Assessment (IA) in Developing Countries

Impact assessment of development projects has many challenges. The problem of impact assessment of development project lies on the following:

(i) Developing a framework to identify what impacts to assess, where to look for impacts and selecting appropriate indicators to assess the impacts, and
(ii) Developing a framework to look after the indicators together and assessing overall impact of the project (Palanisami and Suresh Kumar 2006).

The nature of development interventions and its impact on different sectors pose challenges to Project Monitoring and Evaluating Agencies, economists, researchers and policy makers. More specifically, major challenges include:

(i) the choice of methodologies,
(ii) approaches of evaluation,
(iii) scale and time lags,
(iv) design of the study,
(v) samples for the study,
(vi) selection of indicators, and
(vii) choice of discount rate.

12.2.1 Choice of Methodologies

Choosing appropriate methodology for impact assessment is essential. Different methodologies have been used in the evaluation literature which broadly falls into two major categories such as qualitative and quantitative methods. The quantitative methods such as experimental or randomized control designs are being widely used. Some other quasi-experimental designs are widely used in the evaluation literature (Baker 2000). The non-experimental or quasi-experimental designs such as Matching methods or constructed controls, double difference, Instrumental variables or statistical control methods and Reflexive comparisons are being used by the evaluating agencies. Qualitative techniques are also used for carrying out impact evaluation with the intention to determine impact by the reliance on something other than the counterfactual to a causal inference (Mohr 2000). The qualitative approach uses relatively open-ended methods during design, collection of data and analysis. The benefits of qualitative assessments are that they are flexible, can be specifically tailored to the needs of the evaluation using open-ended approaches, can be carried out quickly using rapid techniques, and can greatly enhance the findings of an impact evaluation through providing a better understanding of stake holders' perceptions and priorities and the conditions and processes that may have affected program impact (Baker 2000). The qualitative methods are not exempted from limitations. Limitations like subjectivity involved in data collection, the lack of comparison group, and the lack of statistical robustness, given mainly small sample sizes, all of which make it difficult to generalize to a larger, representative population. Also, the validity and reliability of data from qualitative analysis are highly dependent on the methodological skill, sensitivity, and training of evaluator.

Economists have been employing Total Economic Valuation (TEV) methodology in assessing the impact of development projects which primarily focuses on natural resource interventions. In order to assess the impacts of such natural resource development interventions in a holistic perspective, bio-economic modeling is widely being employed by the researchers. Bio-economic modeling is considered as a hybrid methodology in impact assessment as it incorporates both bio-physical and socio-economic features. But one major lacuna in employing bio-economic modeling is that it requires experimental data on bio-physical parameters often which limit the economists to use this methodology.

12.2.2 Approaches of Impact Assessment

One dominant perspective in impact assessment literature is to view natural resources development projects as constituting a set of inputs that are transformed through activities into a set of outputs and the impact of these projects on people are through the changes in output and through activities that produce these outputs. These impacts are of main concern in economic approaches. The other approach, resulting from a change in the basic conception of development, sees projects more in terms of process pursuing multiple objectives: social, economic, environmental and institutional pursuing (e.g. equity, efficiency, sustainability, community organizations etc.,). Project goals and objectives, and assessment of achievements and impacts have become the central concerns. Many studies using this approach implicitly or explicitly use variants of a Logical Framework Approach (LFA) as a basis. These approaches build the evaluation function within the management systems of the project cycle. The third approach is Participatory Evaluation (PE) where evaluation systems are designed and implemented in partnership mode with the people involved in the projects (Ravindra 2000). Often, choosing a right approach would be a challenge for the evaluating agency.

12.2.3 Scale/Time Lags

Another important concern in monitoring and evaluation is the scale and time lag for which we look at impacts. Should we look at household level, project level, regional level or national level? As most of the interventions of the development projects also produce ‘externalities’ and ‘spill over effects’, it is thus essential to consider the scale. The time is an extremely important element in development projects where the benefits and costs of development activities rarely occur the same time. For instance, investments on construction of rainwater harvesting structures occur in the early years, but the benefits occur during later part resulting in a large time gap between investment and realization of revenues. Time also complicates comparing investments with different timings and magnitude of benefits and costs.

12.2.4 Design of the Study

The monitoring and evaluation of any program requires good quality and reliable data. Data will need to be collected on intermediate and final level indicators to carry out the impact evaluation (Subhrendu 2009). The data for the monitoring, process evaluation and impact evaluation will need to be collected using either experimental data or non-experimental data. The challenges remain in designing experiments for data collection whether it is a randomized design or non-experimental design. Randomized experiments are the best experiments for data collection in impact evaluation. These experiments basically capture the effects of a program or policy intervention by randomly distributing the different causes over experimental conditions. If Randomized experiments are implemented properly, this ensures potential confounders will be adjusted across program interventions in project area and control groups in non-project area. Hence, the difference between the project and non-project area is attributable to the particular program intervention. Though, the randomized designs are best designs, these are not exempted from challenges.

In the program evaluation literature, non-experimental designs such as Propensity Score Matching and Pipeline matching are the most widely used (Subhrendu 2009). Challenges remain in construction of right design for data collection for program evaluation.

12.2.5 Samples for the Study

Selecting sample units for the evaluation forms one of the important issues faced by the evaluators. Should the researcher study the samples from the 'project area' itself employing before / after approach or should he/she study samples both the 'project area' and 'non-project area' employing with / without approach. Each approach has its own pros and cons and no clear consensus seems to have emerged.

12.2.6 Selection of Indicators

Although several studies list a good number of indicators, challenge remains in identifying right indicators and a comprehensive framework for the identification, analysis and usage of appropriate indicators. They can be obtained either by synthesis (a range of information obtained from primary or secondary data is combined to form the indicator) or selection (from primary or analyzed data). It is important to identify data requirements, generate data and update the database at regular intervals. In using indicators there are many problems such as:

(i) establishing causal links between indicators and the actual changes they are supposed to reflect,
(ii) different indicators may give conflicting signals for the same results,
(iii) establishing the relative importance of changes in different indicators (as a common denominator like price/money value is lacking), and
(iv) lack of or problem of arriving at a rational method to assess the significance of quantum of change. Another such problem lies in inter-comparison of projects.

As most of the development interventions are multifaceted and complex, it may not always be possible to measure the results that have been achieved because they may be intangible or it may be too costly to measure them effectively. In such cases indications that success is being achieved will make good proxies. Such indicators, however, must be chosen carefully so that they are reliable substitutes to direct measurement and are easy to measure in terms of time and effort. The choice of indicators is determined by who the end-user is.

12.2.7 Choosing the Discount Rate

Enough has been discussed and debated in natural resources economics on the determination of methodology to use in discounting and selection of a discount rate. If the economy is optimal and all of society's wishes are reflected in financial markets, the determination of a discount rate would be straight forward. It would be related to some financial rate such as interest on bank deposits. But, however, the economy is non-optimal or second best. Furthermore, determining society's preferences and how these are reflected through government spending is difficult. Problems centered on whether discounting should occur at the social rate of time preference (the social discount rate) or at a marginal rate for private investment (the private discount rate). It is generally argued that society is more concerned with the future, especially with negative natural resource and environmental consequences, than the individual or private firms. Consequently, the social discount rate will be lower, however, some support the notion that private and social rates do not differ. Most economists suggest using an opportunity cost approach for evaluating government projects as it is the most efficient and easiest to implement.

12.3 Approaches and Methods of Assessing Impacts of Scaling-Up Projects

12.3.1 Approaches

(a) ***Before and after Vs. With and with out***

The approach used for the analysis of impact can be accomplished in two ways. Firstly, 'with project' parameters compared to the 'pre-project' situation gives the incremental benefits due to the project. This is essentially '***before and after approach***'. But these increments in the parameters intrinsically include the changes due to the state of the art technology. Thus sometimes, the benefits maybe exaggerated. Secondly, the literature on project analysis unanimously suggests the use of comparison between the 'project parameters' and the 'non-project control region'. This method automatically incorporates the correction for the impact of the technology in the absence of the project. This essentially follows ***with and without approach***.

(b) ***Double difference***

Several tools or approaches are used for impact evaluation. The most commonly used tools are the financial measures like the benefit- cost (B-C) ratio and internal rate of return (IRR) (Namara et al. 2005; Narayanamoorthy 2005; Suresh Kumar 2012; Palanisami et al. 2012). The major problems with this approach is that the benefits and costs are calculated using either before and after or with and without concept which ignores some of the benefits that are considered as residual which may occur even without the intervention such as drip irrigation. Hence an approach that considers with and without as well as before and after situations is important (Table 12.1). This frame work is widely being adopted in the program evaluation literature (Maluccio and Flores 2005; Subhrendu 2009).

The resulting measures can be interpreted as the expected effect of implementing the program. The columns distinguish between groups with and without the program and the rows distinguish between before and after the program. Before the program implementation, one would expect the average economic parameters (indicators of evaluation) be similar for the two groups, so that the quantity (P0-WP0) would be close to zero. Once the program has been implemented, however, one would expect differences between the groups as a result of the implementation of the program. The impact of the program, however, would be better assessed considering any pre-existing observable or unobservable differences between the two randomly assigned groups is the double-difference estimate, obtained by subtracting the pre-existing differences between the groups, (P0 – WP0), from the difference after the program has been implemented, (P1 – WP1) (Maluccio and Flores 2005).

Double Difference (DD) approach is becoming a popular in program evaluation for studying the impact analysis using the panel data. It has the advantage to control for the time-invariant characteristics of beneficiaries when comparing beneficiaries and non-beneficiaries of a program implementation.

12.3.2 Methods

(a) ***Indicators***

The most important feature of evaluation is the selection of indicators and collecting information on these indicators. Indicators are ***markers*** and they show the

Table 12.1 Double difference method of program evaluation

Particulars	Project area	Without project area	Difference across groups
After Program implementation	P1	WP1	P1-WP1
Before Program implementation	P0	WP0	P0-WP0
Difference across time	P1-P0	WP1-WP0	Double difference (P1-WP1)-(P0-WP0)

progress and help measure changes. As our objective is to assess the implementation of the program, simple comparison of key indicators could be done.

(b) ***Selection of Indicators***

Development of monitoring and evaluation indicators forms crucial aspect, where the evaluation of different activities on different development domains is complex. Indicators should be SMART: Specific: - what is intended to be measured; Measurable - clear and unambiguous; Attributable - to the program; Realistic - reasonable cost and frequency of data collection; and Targeted - about the relevant or target population. Moreover, these should not be easily diverted or manipulated (Prenusshi et al. 2000).

Monitoring and evaluation of a program/project requires, a number of indicators and selection of those indicators should be based on the criteria such as a*vailability, relevance, coverage, quality, efforts, efficiency and impact*.

12.3.3 Economic Surplus Method

The Economic Surplus (ES) approach is widely followed for evaluating the impact of technology on the economic welfare of households (Moore et al. 2000; Wander et al. 2004; Maredia et al. 2000; Swinton 2002). The economic surplus method measures the aggregated social benefits of a technological intervention or adoption. With this method it is possible to estimate the return to investments by calculating a variation of consumer and producer surplus through a technological change originated by research. Afterwards, the economic surplus is utilized together with the research costs to calculate the net present value (NPV), the internal rate of return (IRR), or the benefit-cost ratio (BCR) (Maredia et al. 2000). The term surplus is used in economics for several related quantities. The consumer surplus is the amount that consumers benefit by being able to purchase a product for a price that is less than they would be willing to pay. The producer surplus is the amount that producers benefit by selling at a market price mechanism that is higher than they would be willing to sell for. In the case of natural resource development projects such as watershed development program, producers are mainly the farm households who produce the goods using the benefits of the watershed management technologies and consumers are mainly the other stakeholders in the state/region, viz. non-farm households representing the labourers, business people and people employed in non-agricultural activities.

Thus, the benefits from program interventions not limited only to the users/beneficiaries but are to the non-participating or non-project area also. For instance, the watershed development technologies are expected to have positive impacts on groundwater recharge, soil and water conservation, maintaining ecological balance, increased fodder availability, increased crop yield etc. Similarly, the increased agricultural production favours the non-farming community like labourers, rural artisans and other rural households. Thus, the watershed development brings benefits not only to the producers (farmers) but also to the consumers (farmers, labour households and other households in the watershed village). In this context, the economic surplus approach captures the total benefits accrued due to watershed development intervention in the rural areas. The advantage of the economic surplus approach lies in the fact that the distribution of benefits to different segments of the society could be estimated.

12.3.4 Econometric Methods

Economists use econometric methods like Instrumental Variable methods (IV) for program evaluation in a situation where randomization is not done or not possible. The instrumental variable method is usually implemented as two stage least squares (2SLS). However, implementing IVM is a challenging one. The major challenges for the evaluators remain at identifying valid instrumental variable.

12.4 Framework for Impact Assessment of Development Projects

Evaluation of programs, either before they are designed or after they are implemented, are increasingly viewed as a critical for learning and improving accountability of public policies (Subhrendu 2009).Any program or project involves investment of inputs through different activities. These activities result at the end of the project called 'output'. The outputs are generally the deliverables at the project level. These outputs leading to deliverables at society level called 'outcome'. This is generally an intermediate result of the project activities. Finally, these outcomes result in long-term achievements or effect on the targeted group, which is called the 'impact'.

The inputs generally include the financial, manpower and material resources invested for any development or technological interventions. These resources are used to achieve the targeted goals of the project through various activities. The outputs are generally direct and intermediate results; products or services result from the development or technological intervention. Outcomes are the likely or achieved short-term and medium-term effects of an intervention's outputs. Impacts are the effect on stakeholders. To what degree do the intended outcome changes could result in intended changes in the overall impacts? Impacts basically deal with changes in the system, changes in the conditions of the stakeholders and changes in the situation etc. (Wolf 2010; Simister 2015). The input and outputs are generally related to project level and outcome and impacts are related to the society level (Fig. 12.1).

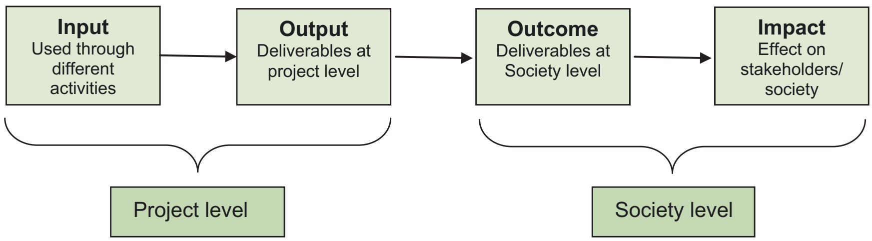

Fig. 12.1 Impact continuum

12.4.1 Case of Watershed Development Program in India

The well-defined framework for impact evaluation for an important natural resource intervention viz., watershed development program in India is discussed here. The watershed development programs influence different aspects like agricultural production system, environment and socio-economic conditions of the watershed villages. The watershed development programs involving the entire community and natural resources influence (i) productivity and production of crops, changes in land use and cropping pattern, adoption of modern technologies, increase in milk production etc., (ii) Attitude of the community towards project activities and their participation in different stages of the project, (iii) Socio-economic conditions of the people such as income, employment, assets, health, education and energy use, (iv) impact on environment, (v) use of land, water, human and livestock resources, (vi) development of institutions for implementation of watershed development activities and (vii) ensuring sustainability of improvements (Joshi et al. 2005; Palanisami and Suresh Kumar 2007; Wani et al. 2008).

It is thus clear that watershed development is a key to sustainable production of food, fodder, fuel wood and meaningfully addressing the social, economic and cultural conditions of the rural community. By virtue of its nature, watershed is an area based technology cutting across villages comprising both private and public lands. The benefits from watershed development activities not only limited to the users/beneficiaries but also the non-participating farmers.

To begin with, the conceptual framework for impact assessment of watershed development programs is given in Fig. 12.2. It depicts the pathways through which the watershed development affects the various domains such as bio-physical aspects, environmental aspects, socio-economic aspects etc. Different types of watershed treatment activities are carried out in a watershed. In the first phase of development (i.e. preparatory phase), building institutions and capacity building are done. Most watershed projects in India are implemented within a well-defined institutional framework. In Tamil Nadu, for instance, a state-level nodal agency called the Tamil Nadu Watershed Development Agency (TAWDEVA) coordinates the watershed development activities at the state level.

The District Watershed Development Agency (DWDA) undertakes similar tasks at the district level. It selects a Project Implementation Agency (PIA) and members

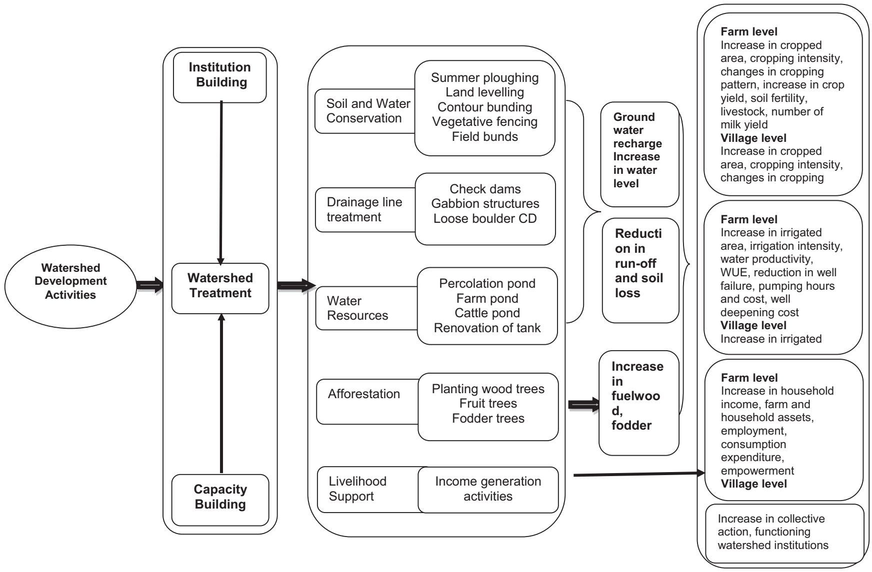

Fig. 12.2 Conceptual framework for impact assessment of watershed development. (Source: Suresh Kumar et al. 2015)

of a Watershed Development Team (WDT). The PIA is responsible for implementing watershed activities, which are actually undertaken by community-based-organizations. The PIA prepares development plans, undertakes community organization training, provides technical guidance, monitors and reviews implementation and sets up institutional arrangements for post-project operation.

The Watershed Development Team is made of multi-disciplinary members who provide technical support to the PIA and community groups. In addition to the above mentioned institutions, different types of community-based organizations are involved in watershed management. They are the Watershed Committee (WC), User Groups (UGs), and Self-Help Groups. The WC plays a crucial role in the implementation period. The Committee with the help of the UGs organizes meetings, mobilizes contributions, constructs structures, and engages in monitoring and maintenance activities. Most importantly, the WC operates the watershed project funds account. Devolution has meant that these organizations are responsible for monitoring resource use, identifying local contributions for new investments (e.g. constructing new percolation ponds, check dams and the like), enforcing rules and providing operation and maintenance services.

Training in watershed technologies and related skills is also given periodically to farmers in watersheds. In addition, members are also taken to other successful watershed models and research institutes for exposure. In the second phase of implementation, various watershed treatment activities are implemented. Activities such as soil and moisture conservation measures are undertaken in private agricultural lands (e.g. contour/field bunding, land levelling, and summer ploughing. Village common lands are improved through drainage line treatment measures (loose boulder check dams, minor and major check dams and retaining walls), water resource development/management (percolation pond, cattle ponds and renovation of tanks), and afforestation programs. The weaker sections of the rural households are also supported through Livelihood Support income generation activities (Palanisami et al. 2003).

These activities of soil and moisture conservation measures, drainage line treatment and water resources developments will result in substantial reduction in surface run-off. Reduction in surface run-off triggers the process of change leading to reduction in soil loss and increase in conservation of water and storage. These further trigger changes through different pathways. While both reduction in soil erosion and increased water retention lead to increased soil moisture, groundwater recharge and increase in water level through percolation, reduction in soil loss will improve soil quality through conservation of soil nutrients. As water becomes available even in dry months, there is expansion in irrigated area, cropped area, crop production and yield of crops. Similarly, the afforestation measures will lead to increased availability of fodder, fuel wood in the watershed. This results in increased milk yield of cattle etc. Increase in crop production and milk production will finally lead to increase in income of the households, asset position and welfare.

Thus, in order to effectively capture the impacts of watershed development activities, a number of indicators has been identified and estimated. These indicators are the markers of impacts of watershed development and broadly classified in to five major categories viz., bio-physical, environmental, socio-economic, overall impacts and institutional indicators. These indicators are given in the Table.12.2.

12.5 Successful MEL from the Scaling-Up Projects: Experiences from Case Studies

Successful case studies are the key to identify the specific project impacts. These case studies will reflect the immediate outputs and outcomes of the development interventions with respect to a project domain or region. The case studies generally help to synthesize success stories of the developmental interventions and identify the potential areas for further improvement.

For the purpose, case studies at national level meta-analysis results from comprehensive assessment of watershed programs in India are discussed. For micro-level MEL case study from Tamil Nadu state, India is presented here. Two watersheds such as Kuppanur and Kallipalayam watersheds, Tamil Nadu, India are demonstrated. The Kuppanur watershed was implemented under the Integrated Wasteland Management Program (IWMP) and the Kallipalayam watershed was implemented by the District Rural Development Agency of Coimbatore district, Tamil Nadu.

Table 12.2 List of monitoring and evaluation indicators of impact of Watershed Development Programs in India

Performance criteria	Indicators
Bio physical aspects	• Investment on SWC • Cropped area / Crop Diversification Index (CDI) • Cropping pattern • Productivity of crops/Crop Yield Index (CYI) • Cropping intensity
Environmental aspects	• Water level in the wells • Irrigated area • Water productivity and Water use efficiency • Duration of water availability • Water table of wells • Surface water storage capacity • Differences in number of wells, water quality • Number of wells recharged /defunct • Irrigation intensity • Vegetative cover (Watershed Eco Index)
Socio-economic aspects	• Household income, per capita income • Consumption expenditure • Employment, persons migrated • Education - enrollment, dropout etc. • Peoples participation and collective action • Household assets • Wage rate at village level • Awareness/attitude/practices • Change in terms of women drudgery in fetching water • Sanitation situation • Change in self esteem • Distribution of benefits of common resources • Nutrition • Linkages with other schemes • Women empowerment / Gender equality
Overall Impact	• NPV, BCR and IRR
Institutional	• No.of UG, SHG formed and functioning • Functioning of WA

12.5.1 Watershed Development Activities in the Selected Watersheds

The Drought Prone Area Program (DPAP) of Government of India funded jointly by Ministry of Rural Development, Government of India and Government of Tamil Nadu was taken up on watershed basis in Coimbatore. The major objectives of the program include (i) promotion of economic development of the village community which is directly or indirectly dependent upon the watershed through optimum utilization of watershed's natural resources (land, water and vegetation) that will mitigate adverse effects of drought, (ii) employment generation and development of the human and economic resources of watershed and (iii) encourage restoration of ecological balance in watershed through sustained community action. For the purpose, two watersheds such as Kuppanur and Kallipalayam watersheds were selected and studied for in depth case study to assess the impacts of watershed development activities. The Kuppanur watershed was implemented under the Integrated Wasteland Development Program (IWDP). This was implemented by District Rural Development Agency of Coimbatore district in Annur block of Coimbatore district during 2008–2012. The Kallipalayam watershed was implemented under Drought Prone Area Program (DPAP) by District Rural Development Agency of Coimbatore district in Sarkar Samakulam block in Coimbatore district during 2005–2006 to 2009-2010.

12.5.2 Operational Procedure and Implementation

Project account was opened for the study watersheds. The account has been operated jointly by the Watershed Committee chairman and a member of watershed development team. As per the guidelines, watershed development fund account was also opened in the watersheds wherein the contributions from the beneficiaries were deposited to take up the maintenance works after the completion of the project. All the accounts, records and registers were maintained at watershed office.

12.5.2.1 Release of Funds

The nodal agency, District Rural development Agency was releasing funds directly to the Project Accounts, being maintained by the Watershed Committees, on receipt of the proposal through Watershed Development Team/Project Implementing Agency. WDT used to put this proposal to DRDA based on the progress of the work and request from watershed Committee. It is said that the release from DRDA had been smooth and there was no delay or any problem in release of funds by DRDA. The funds for taking up formulation of community based organizations, training activities and to meet administrative overheads were released by DRAD to the PIA.

12.5.2.2 Execution of Works

The approved items of works/treatment activities were implemented by Watershed Committee with the help of Watershed Development Team. While implementation of various treatment activities, it was tried to ensure that more number of beneficiaries were covered in some activities or the other rather than giving all the benefits to one individual beneficiary. The decisions for selection of beneficiaries were taken up in the watershed Committee meetings and as per the list prepared by the Committee, the benefits of different works and activities were accordingly distributed.

12.5.2.3 Project Implementation

The watershed development activities were implemented from 2005 to 2010 under the DPAP. The impact assessment of watershed development was conducted during December 2013 to March 2014. The allotted share of the budget for different watershed development components includes the following: Community organization (5%), Training (5%), Entry point activities (5%), Watershed treatment activities (75%) and Project Administration (10%).

12.5.2.4 Participatory Rural Appraisal (PRA)

The WDT members of PIA conducted PRA exercise before the implementation of work. Transect walk was done along with the farmers in the village for deciding location of various structures in the gullies.

12.5.2.5 Watershed Treatment Activities

Different types of watershed development treatment activities were carried out in the study watersheds. They include Soil and moisture conservation measures in agricultural lands (contour/field bunding, land leveling and summer ploughing), drainage line treatment measures (loose boulder check dam, minor check dam, major check dam and retaining walls), water resource development/ management (percolation pond and farm pond).

The watershed treatment activities were broadly classified into soil and moisture conservation measures, drainage line treatment measures, water resources development, crop demonstration, and horticulture plantation and afforestation measures. The various treatment activities were basically carried out to improve agricultural productivity and biomass in the DPAP watersheds. Most of the entry point activities of common interest to the watershed community. The other major activities were training of Watershed Development Team members and Watershed Committee members and arranging exposure visits.

12.5.3 Impact Assessment of Watershed Treatment Activities

The major objective of watershed development projects includes (i) promotion of economic development of the village community which is directly or indirectly dependent upon the watershed through optimum utilization of watershed's natural resources (land, water and vegetation) that will mitigate adverse effects of drought, (ii) employment generation and development of the human and economic resources of watershed and (iii) encourage restoration of ecological balance in watershed through sustained community action. To achieve these developmental objectives many watershed development activities include soil and moisture conservation measures such as summer ploughing, contour bunding, land leveling, vetiver plantation etc., drainage line treatments like major and minor check dams, gully plugs, water resources development activities such as construction of percolation ponds, farm ponds etc. afforestation measures, crop demonstration etc. These activities bring changes in groundwater availability, potential recharge, cropping pattern, productivity, ecological development and socio-economic upliftment. Keeping these issues in view, the present study analyzed the impact of watershed treatment activities in three sub-sections viz., (i) groundwater resources and agricultural production, (ii) socio-economic and (iii) overall impact. The key results and findings are presented and discussed in the subsequent sections.

12.5.3.1 Impact on Water Resources Development and Agricultural Production

(a) ***Impact on water resources***

Construction of new percolation ponds, major and minor check dams and rejuvenation of existing ponds/tanks has enhanced the available storage capacity in the watersheds to store run-off water for surface water use and groundwater recharge. This additional storage capacity further helps in improving groundwater recharge and water availability for livestock and other non-domestic uses in the village as a result of watershed treatment activities. The rise in water level for the sample farm households was studied and presented in Table 12.3.

The average water column level in the few sample wells were collected both in watershed and control villages for comparison. It was evidenced that the average water column level in the watershed villages were higher than in wells in control villages. For instance, average water column level in the Kuppanur watershed village was 2.8 m and the control village was 1.48 m leading to a difference of 89.19%. Similarly, in the case of Kallipalayam, where the water level in the watershed village was 61.43% higher than the control village.

Information related to duration of pumping hours before well goes dry (or water level depressed to a certain level) and time it takes to recuperate to the same level

Table 12.3 Rise in water level due to watershed development activities

	Kuppanur		Kallipalayam	
Particulars	Watershed village	Control village	Watershed Village	Control village
Rise in water level (m)	0–3.6	..	0–3.3	..
Average water level rise (m)	0.8	..	1.69	..
Average water level in the wells (mtrs)	2.8	1.48	3.6	2.23
Percentage increase	89.19		61.43	

***, ** and * indicate values are significantly different at 1%, 5% and 10% levels from the corresponding values of control village

were collected for the sample farmers across villages. The recuperation rate for both watershed villages and control villages are presented in Table 12.4.

It could be seen from the table that due to watershed treatment activities such as construction of percolation ponds, check dams etc. the groundwater recuperation in the nearby wells were increased. For instance, in Kuppanur watershed, the recuperation rate has increased from 0.04 M^3/hour to 0.07 M^3/hour thus registering an increase of 0.04 M^3/hour. Similar trend is visualized in Kallipalayam watershed also, where the groundwater recuperation registered an increase of 0.02 M^3/hour. It is evidenced that the average groundwater recuperation rate was significantly higher in watershed villages. The average groundwater recuperation rate was worked out to 0.07 M^3/h and 0.03 M^3 / h for watershed and control villages in Kuppanur whereas it was 0.05 M^3/h and 0.03 M^3 / h in Kallipalayam watershed. The percentage difference due to watershed treatment activities was 133.33% and 66.66% respectively for Kuppanur and Kallipalayam watersheds.

Perenniality of wells i.e. duration of water availability across months in the wells was enquired during the survey. The perenniality of wells was found to be little higher in the case of watershed villages. For instance, out of 60 wells, 12 wells yielded water for 12 months and eight wells yielded water for 12 months respectively for watershed treated and control villages in Kuppanur watershed. Similar trend was visualized in Kallipalayam watershed (Table 12.5). It was not surprising that most of the wells in the study area yielded water for three months or less across

Table 12.4 Changes in groundwater recuperation rate in different watersheds

	Kuppanur				Kallipalayam			
	Watershed village		Control village		Watershed village		Control village	
Particular	Before	After	Before	After	Before	After	Before	After
Changes in Recuperation rate M^3/hour	0.04	0.07	0.03	0.03	0.03	0.05	0.03	0.03
Average recuperation rate M^3/hour	0.07		0.03		0.05		0.03	
Percentage difference	133.3				66.66			

***, ** and * indicate values are significantly different at 1%, 5% and 10% levels from the corresponding values of control village

Table 12.5 Duration of water availability in the wells influenced by percolation ponds and check dams (Number of wells)

	Kuppanur		Kallipalayam	
Particulars	Watershed village	Control village	Watershed village	Control village
12 months	12	8	10	6
9 months	8	6	4	4
6 months	10	10	12	8
3 months	30	36	34	42
Total no.of wells	60	60	60	60

seasons. This is mainly due to being hard rock tract; the water table has gone down due to over exploitation of groundwater.

Fluctuation of water table in a region gives the prevailing groundwater condition. Hence, measurement and monitoring of water level in wells is a basic task for proper assessment and management. By establishing a network of observation wells spread over the entire district, the fluctuation in groundwater level is being monitored periodically. The groundwater level lowers to the maximum during the pre-monsoon period, after which it starts rising soon after the monsoon. The rise and fall in water levels depend upon the amount, duration and intensity of precipitation, climatic conditions, depth of weathering, specific yield of the formation, general slope of the terrain towards drainage channel and various other factors. A general view of the water level hydrographs indicate that the water level tends to rise during the months of October to December/January to reach the peak and starts receding from February onwards to the end of August/September. During drought years, water table depletion continues even after monsoon periods. Water table behaviour is indicative of groundwater storage in response to rainfall and inputs to aquifer. Further, the hydrographs of individual wells have also been utilized to estimate the storage changes in the aquifer system, besides establishing the periods of natural recharge and discharge.

The fluctuation in water level in the open wells was observed to be higher in the control villages than the watershed villages. This is mainly due to the construction of water resources development structure like percolation ponds; farm ponds etc. help reduce variations in water level of the wells in watershed villages. Though there is larger rise in the wells of control villages the fluctuation is higher leading to more risk in agricultural crop production whereas, watershed treatment activities cushioned the fluctuation in water level and help minimize risk.

The impact of watershed treatment activities on groundwater area irrigated was analyzed and presented in Table 12.6. It could be seen from the Table 12.6 that the average net area irrigated in watershed villages registered a moderate increase after the watershed development activities in both the watersheds. When compared to watershed villages, the area irrigated in control villages has declined slightly over the period.

Table 12.6 Impact on area irrigated due to watershed treatment activities

	Kuppanur				Kallipalayam			
	Watershed village		Control village		Watershed village		Control village	
Particular	Before	After	Before	After	Before	After	Before	After
Net area irrigated (ha)	0.61	0.68*	0.43	0.43	0.46	0.53*	0.55	0.54
Gross area irrigated (ha)	0.72	0.89*	0.45	0.44	0.5	0.58**	0.56	0.55
Irrigation intensity (%)	118.03	130.88*	104.65	102.33	108.70	109.43*	101.82	101.85

***, ** and * indicate values are significantly different at 1%, 5% and 10% levels from the corresponding values of control village

It is evidenced that the irrigation intensity is higher in watershed treated villages than in untreated villages. This lucidly shows watershed development activities help increase the water resource potential of a region and thereby help in expansion of irrigated area and further leads to increased agricultural production and welfare of the farm households.

12.5.3.2 Impact on Cropping Pattern, Cropping Intensity and Crop Productivity

The impact of watershed intervention on cropping pattern, cropping intensity, and crop productivity were analyzed.

The cropping pattern i.e. proportion of area under different crops is a good indicator of resources development and agricultural production. It is expected that watershed treatment activities help in development of water resources potential and thereby help the farmers to go in for water intensive commercial crops. Analysis of cropping pattern captures this impact. Cropping pattern followed in the study area was analyzed and presented in Table 12.7. It is revealed that the proportion of area under water loving crops was higher in the watershed treated villages than in control villages.

It was evidenced that the water loving crops such as Banana, Turmeric, Tobacco, Flower crops and vegetables account for 65.60% in watershed village whereas it was 47.10% in control village in Kuppanur. The scenario was visualized in Kallipalayam watershed where the irrigated crops account 64.90 whereas in control village it was 50.90%. Thus, the watershed treatment activities helped the farmers to go for irrigated commercial crops which in turn help to enhance their farm income and welfare of the households.

The analysis of impact of watershed treatment activities on expansion in cropped area indicated that increase in net cropped area, gross cropped area and thereby cropping intensity was realized in both the watersheds. The cropping intensity

Table 12.7 Impact on crop (in Percentage)

	Kuppanur		Kallipalayam	
Crops	Watershed village	Control village	Watershed village	Control village
Fodder Sorghum	34.6	42.5	35.1	49.0
Banana	21.6	30.1	11.9	11.2
Turmeric	7.3	5.6	9.6	12.5
Tobacco	15.8	4.5	..	..
Tapioca	..	5.3	..	7.6
Greens	..	..	15.7	..
Flower crops	3.5	..	10.3	..
Sugarcane	..	4.6	..	10.6
Coconut	..	..	10.8	4.8
Vegetables	17.4	2.3	6.6	4.2

Table 12.8 Impact on cropped area, cropping intensity and crop diversification

	Kuppanur				Kallipalayam			
	Watershed village		Control village		Watershed village		Control village	
Particular	Before	After	Before	After	Before	After	Before	After
Net cropped area (ha.)	0.76	0.85**	0.71	0.71	0.62	0.65***	0.87	0.89
Gross cropped area (ha.)	0.89	1.14**	0.72	0.73	0.72	0.82***	0.87	0.91
Cropping intensity (%)	117.11	134.12*	101.41	102.82	116.13	126.15*	100.00	102.25
Crop diversification index (CDI)	1.0		0.93		1.0		0.94	

***, ** and * indicate values are significantly different at 1%, 5% and 10% levels from the corresponding values of control village

indicated that it was relatively higher in the case of watershed treated villages and this appears to be a common phenomenon in both watersheds (Table 12.8.). For example, the cropping intensity was worked out to 134.12% in the watershed village and it was little higher than the control where it was only 102.82% in Kuppanur watershed. Similar trend is seen in Kallipalayam watershed.

Crop diversification index (CDI) was worked out by employing Composite Entropy Index (CEI) based on the proportion of different crops in the farm. The Composite Entropy Index for crop diversification was worked out as:

$$C.E.I = -\left(\sum_{i=1}^{N} P_i . \log_N P_i\right) * \{1 - (1/N)\}$$

Where,

CEI = Composite Entropy Index
P_i = Acreage proportion of i^{th} crop in total cropped area
N = Total number of crops

The CEI is used to compare diversification across situation having different and large number of activities since it gives due weight to the number of activities. The CEI has two components viz., distribution and number of crops or diversity. The value of CEI increases with the decrease in concentration and rises with the number of crops/activities. The CDI values ranges between 0 and 1. The value nearer to 1 indicates that there is complete diversification.

It is evidenced that the CDI was worked out to 1 for watershed village implying that complete diversification. While CDI was less in the control villages than the watershed villages. It was 0.93 and 0.97 for control villages respectively in Kuppanur and Kallipalayam watersheds. In general, CDI was higher in the case of watershed treated villages than the control villages confirming watershed treatment activities helped diversification in crop and farm activities.

Increase in crop yields was reported by farmers though the extent of increase varied from crop to crop and watershed to watershed. Index of crop productivity was calculated by using the farmers' actual yield of various crops and normal yield of a crop as per the standard package of practices to evaluate changes in crop productivity. The index of crop productivity appears to be little higher in watershed treated villages than in control for almost all the crops across villages. The percentage difference varied from 3.0% in vegetables to 14.5% for banana in Kuppanur watershed. While the percentage difference varied from 2.3% for coconut to 15.5% for vegetables in Kallipalayam watershed (Table 12.9.).

The Crop Yield Index (CYI) represents a combined index of yield of all the crops on a farm. Average yield of the area for each crop is obtained and then the corresponding yield figures for the farm in question are used to work out the area needed to have the same production as actually obtained on the farm if area average yield prevailed. The total area required at area average yields to have the existing level of production area divided by the area as the farm to obtain the yield index. It can also be multiplied by 100 to express in percentage. A figure greater than 100 indicates that the farm in question is more efficient than the average farm in the area.

The Crop Yield Index was 0.97 and 0.92 in both the watershed treated villages and higher than the CYI in control villages. The % difference in Crop Yield Index was ranged between 8.9% in Kuppanur and 12.2% in Kallipalayam implying that the watershed treated farmers operated relatively efficient than the farmers in control villages.

12.5.3.3 Impact on Socio-Economic Conditions of the Households

The watershed treatment activities not only help groundwater recharge, expansion in irrigated area, alters cropping pattern, enhance crop productivity, but also produces other desirable impacts on the socio-economic conditions of the people who are depending on it. The effects such as increase in farm income due to increased agricultural production, increase in welfare reflected by nutritional status, increase in employment and reduction in migration.

Table 12.9 Index of crop productivity for major crops and Crop Yield Index

	Kuppanur		Kallipalayam	
Crops	Watershed village	Control village	Watershed village	Control village
Fodder Sorghum	0.89	0.82	0.86	0.83
Banana	0.87	0.76	0.85	0.82
Turmeric	0.86	0.80	0.90	0.82
Tobacco	0.85	0.72	..	..
Tapioca	..	0.76	..	0.74
Sugarcane	..	0.83	..	0.82
Coconut			0.88	0.86
Vegetables	0.68	0.66	0.67	0.58
Crop Yield Index (CYI)	0.97	0.89	0.92	0.82

(a) ***Impact on income of the households***

In both the watershed treated and control villages, households need cash income to supplement agricultural production to purchase commodities in the market, to pay for social obligations, school fees and health care. Most of this income was generated through off-farm and non-farm income activities. Table 12.10 presents worked out cash income and relative importance of different sources of income among farm households.

The income from crop and livestock sources was higher in the case of watershed treated villages than the control. Households participated in off-farm and non-farm income activities particularly during slack periods to get additional income for their subsistence needs. It is evidenced that the share of crop and livestock income sources was higher in watershed villages than the control villages confirming that the watershed treatment activities helped the farm households to derive more income from crop and livestock activities.

12.5.3.4 Overall Impact

Efforts have also been made in the present study to assess the overall impact of watershed activities on environment and overall agricultural production using indices and opinion survey.

Enough efforts have been taken in the present study to assess the overall impact of different watershed treatment activities in terms of Benefit Cost ratio (BCR) and

Table 12.10 Cash income and the relative importance of different sources of income among farm households (Rupees per household year)

	Kuppanur		Kallipalayam	
Particulars	Watershed village	Control village	Watershed village	Control village
Crop production	157237***	108930.1	163814.4***	112986
	(50.58)	(41.29)	(48.98)	(49.54)
Livestock	100320.9***	88141	118775**	66543
	(32.27)	(33.41)	(35.51)	(29.18)
Trees	999.2**	390.8	652.1*	542.3
	(0.32)	(0.15)	(0.19)	(0.24)
Off-farm and Non-farm income	52333.2***	66340	51200***	48000
	(16.83)	(25.15)	(15.32)	(21.04)
Total family income	310890.3***	293801.9	334441.5***	228071.3
	(100.00)	(100.00)	(100.00)	(100.00)
Per capita income	74554.0**	72672.7	85316.7***	58479.8
% difference in family income (%)	+ 17.84		+ 46.63	

(Figures in parentheses indicate percentage to total)
***, ** and * indicate values are significantly different at 1%, 5% and 10% levels from the corresponding values of control village

Internal Rate of Return (IRR). The BCR and IRR were worked out for the two watersheds by conventional methodology assuming 12.75% discount rate for a life period of 15 years.

The costs and benefits stream for the study were worked out. While working out the cost all the costs including the costs on watershed treatment activities, entry point activities, training, administration costs were included. In working out benefits only the benefits accrued from farm activities viz., crop activities and savings due to reduction in well deepening and new well drilling costs were accounted. The difference in farm income between before and after watershed treatment was taken into account for the purpose. The benefits from agricultural production due to watershed treatment activities are assumed to occur once in 2 years. This is done based on periodicity of rainfall, which has been worked out based on occurrence of rainfall over a period of 10 years. The benefits are valued at the prices of reference year. The maintenance cost was included in the cost stream as it is not available.

The results indicated that in general the BCR varied from 1.46 to 1.52 implying that the returns to public investment such as watershed development activities are feasible. Similarly, the IRR is worked out to 25% and 23% respectively for Kuppanur and Kallipalayam watersheds, which was higher than the long-term loan interest rate by commercial banks (12.75%) indicating the worthiness of the government investment on watershed development (Table 12.11). It is interesting to note that the BCR and IRR are more or less equal in both the watersheds and proved worthiness of the investment on watershed development activities.

Of the different beneficial impacts, the watershed treatment activities exert more impact on groundwater recharge, yield increase, improvement in soil fertility, and improvement in soil and moisture conservation. This impact appears to be common in both the study watersheds. For instance, in Kuppanur watershed, groundwater recharge appears to be the most important impact due to watershed treatment activities as evidenced by the highest mean score of 77.43 followed by yield increase 76.53, soil fertility improvement 63.90 and soil and moisture conservation 57.43. Thus, the watershed treatment activities bring significant impact on agricultural production through groundwater recharge.

12.5.4 Application of Economic Surplus Method

In order to get more insights into the methodological contribution in the impact evaluation, the economic surplus method was applied in two watersheds viz. Kattampatti and Kodangipalayam villages in Coimbatore district, Tamil Nadu state, India (Palanisami et al. 2009). The impact of watershed development activities on yield of crops and hence the cost was estimated and has been presented in

Table 12.11 Results of financial analysis on watershed development activities

Particulars	Kuppanur	Kallipalayam
Benefit Cost Ratio	1.52	1.46
Internal rate of return (%)	25	23

Table 12.12. The change in yield due to watershed intervention across crops varied from 31% in maize to 36% in cotton. It was the maximum change in yield due to watershed intervention. Reduction in marginal cost due to supply shift ranged from 32.8% in vegetables to 63.6% in sorghum. Net cost change varied from 32% in vegetables to 59.8% in sorghum. The change in total surplus due to watershed development activities was estimated and has been presented in Table 12.13. The change in total surplus was higher in sorghum and maize than crops like pulses and vegetables. Being the major rain-fed crops, these two crops benefited more from the watershed interventions.

Table 12.12 Impact of watershed development intervention on yield and cost

Crops/ Enterprises	Change in yield (%)	Reduction in marginal cost %	Reduction in unit cost %	Net cost change (∀)
Sorghum	33	63.6	3.76	59.8
Maize	31	39.9	2.29	37.6
Pulses	36	41.0	1.47	39.6
Vegetables	32	32.8	0.76	31.9
Milk	28	27.3	7.81	19.5

Note: The reduction in marginal cost was the ratio of relative change in yield to price elasticity of supply (ε_s). Reduction in unit cost was the ratio of change in cost of inputs per hectare to (1 + change in yield). Ci was the input cost change per hectare i.e., C_u = Ci/(1 + Change in yield;. The net cost change (∀) was the difference between reduction in marginal cost and reduction in unit cost, ie., ∀ = Cm-Cu

Table 12.13 Impact of watershed development activities on the village economy

Crops/ enterprises	Total benefits due to watershed intervention (B)		
	Change in total surplus (ΔTS)	Change in consumer surplus (ΔCS)	Change in producer surplus (ΔPS)
Sorghum	293177.3	113636.3	179541.0
	(100.00)	(38.8)	(61.2)
Maize	177774.2	85424.0	92350.2
	(100.00)	(48.1)	(51.9)
Pulses	25777.5	12580.3	13197.2
	(100.00)	(48.8)	(51.2)
Vegetables	29663.6	10627.5	19036.1
	(100.00)	(35.8)	(64.2)
Milk	176878.5	105974.1	70904.4
	(100.00)	(59.9)	(40.1)

Note: The change in total surplus in the village economy due to watershed intervention was decomposed in to change in consumer surplus and change in producer surplus. The decomposition of total surplus was as follows:

$$\Delta TS = \Delta CS + \Delta PS = \mathrm{P_0Q_0K}\left(1 + 0.5Z\eta\right)$$
$$\Delta CS = \mathrm{P_0Q_0Z}\left(1 + 0.5Z\eta\right)$$
$$\Delta PS = \mathrm{P_0Q_0}\left(\mathrm{K} - \mathrm{Z}\right)\left(1 + 0.5Z\eta\right)$$

The change in total surplus due to watershed intervention was decomposed into change in consumer surplus and change in producers' surplus. It was evident that the producers' surplus was higher than the consumer surplus in all the crops. For instance, in sorghum, the producers 'surplus worked out to be 61.2 per cent whereas the consumers' surplus was only 38.8%. Watershed development activities benefited the agricultural producers more. It was interesting to note that unlike in the crop sector, the milk production had different impacts on the society. The decomposition analysis revealed that watershed development activities generated more consumers' surplus in milk production.

The overall impact of different watershed treatment activities was assessed in terms of net present value (NPV), benefit-cost ratio (BCR) and internal rate of return (IRR). The NPV, BCR and IRR were worked out using the economic surplus methodology assuming 10% discount rate and 15 years life period (Table 12.14).

The BCR is worked out to be more than one, implying that the returns to public investment such as watershed development activities were feasible. Similarly, the IRR worked out to be 25%, which is higher than the long-term loan interest rate by commercial banks indicating the worthiness of the government investment on watershed development. The NPV worked out to be Rs 567912 for the entire watershed. The NPV per hectare worked out to be Rs 4542 (where the total area treated was 500 ha) implied that the benefits from watershed development were higher than the cost of investment of the watershed development programs of Rs 4000/ha.

12.5.5 Meta-Analysis of Watershed Programs

The meta-analysis is a powerful methodology that collates research findings from previous studies, and distils them for broad conclusions. It is, therefore, termed as the "analysis of analyses". Meta-analysis can be helpful for policymakers, who may be confronted by mountains of conflicting conclusions (Alston et al. 2000). Watershed programs in India are being implemented with objectives of improving production efficiency, equity and sustainability in the rain-fed areas. Sustainability of natural resources is, of course, a vital issue for the rain-fed areas. To document benefits of watershed programs on sustainability of natural resources, a few proxy indicators have been carefully chosen and analyzed. Five important indicators like (i) increased water storage capacity, increased irrigated area, (ii) increased cropping intensity, (iii) reduced run-off, which enhanced groundwater recharge, and (iv) reduced soil loss, have been identified to demonstrate the sustainability benefits.

Table 12.14 Results of economic analysis employing economic surplus method

Particulars	Economic surplus method	Conventional method
Benefit-cost ratio	1.93	1.23
Internal rate of return (%)	25	14
Net present value (Rs)	2271021	567912

Ordinary least square (OLS) approach was employed to estimate the regression equation with benefit-cost ratio (BCR) of watershed program as dependent variable and geographical location of watershed (L), size of watershed (S), focus of watershed (F), rainfall in the watershed area (R), implementing agency of the watershed (I), people's participation (P), and time gap between project implementation and evaluation (T), various activities performed in the watershed area (A) and the type of soil (L) in the watershed area as explanatory variables. Following model was estimated:

$$BCR = f\left(L,S,F,R,I,P,T,A,L\right)$$

A linear equation was estimated of following form:

$$BCR = b_0 + Xb + \varepsilon$$

Where, BCR is the benefit-cost ratio, b_0 is the intercept, X is the matrix of above mentioned explanatory variables included in the model, b is the vector of slope coefficients, and ε is the error term.

All the explanatory variables in the study are dichotomous dummy variable coded as equal to one if some characteristics are present and equal to zero if they are not. The dummy variable for one of the categories, the default category, is omitted from the regression in order to avoid the dummy variable trap, which occurs when too many dummy variables are included (Alston et al. 2000). Table 12.15 gives the specification of the variables included for the analysis.

Data: A number of studies have evaluated the performance of various watershed projects in India. About 20000 micro watersheds projects, distributed across the

Table 12.15 Summary of explanatory variables

Characteristics	Detail of the explanatory variable
Geographical location	Gujarat Plain & Hill region*
	Western Plateau & Hills Zone
	Trans-Gangetic Plains
	Southern Zone
	Western Himalyan Zone
	Eastern Himalayan Zone
	Central Plateau And Hills Zone
Rainfall	Less than 500 mm*
	501–700 mm
	701–900 mm
	901–1000 mm
	More than 1000 mm
Size of watershed	Micro watershed*
	Macro watershed
Focus of watershed	Rehabilitation of degraded lands*

Characteristics	Detail of the explanatory variable
	Soil & water conservation
	Both
Implementing agency	Central government
	State government
	Central & state governments
	Other agency in collaboration with central & state governments
	Other organizations*
People's participation	Low participation*
	Medium participation
	High participation
Income stratum of target region	Low income states*
	Medium income states
	High income states
Activities performed	Only agriculture
	Agriculture, Livestock and Forestry
	Agriculture and Livestock
	Agriculture and Forestry
Soil types in the watershed areas	Clay soils*
	Sandy loam soil
	Black cotton soils
	Red soils

* The variables were in default category
** People's participation was directly drawn from the studies

country, are being implemented under various watershed development projects. In addition, there are several macro watershed projects in the country. Obviously, these watershed studies cover the entire rain-fed regions of the country represent a wide range of environment according to their agro-ecological location, size, type, source of funding, rainfall, regional prosperity or backwardness, etc. The present study prepared an exhaustive bibliography on studies which evaluated watershed programs of which only 636 case studies could be scanned. These studies were published either as research articles or research reports (for more details see, Joshi et al. 2008, Wani et al. 2008).

Benefits of watershed programs: Watershed programs, which have been specifically launched in the rain-fed areas with the sole objective to improve the livelihood of poor rural households in a sustainable manner, have paid rich dividends. It emanates that watershed programs have been successful in raising income levels and generating employment opportunities and augmenting natural resources, specifically soil and water in the rain-fed areas. By the adoption of different soil and water conservation measures and trapping of surface run-off water, watersheds have emerged as the growth engines in the fragile and rain-fed areas.

Summary of multiple benefits derived from watersheds, as indicated in numerous studies, is shown in Table 12.16 It is obvious that watershed programs in India have yielded multiple exemplary benefits. On the part of efficiency, watershed programs performed well with a mean benefit-cost ratio of 2 that indicates that investment on watershed programs is economically viable and substantially beneficial. However, the performance of watershed in accordance with their BCR was quite varied. About 32% watersheds generated a mean BCR above 2, which is quite modest (Fig. 12.3). Merely 0.6% watersheds failed to commensurate with cost of the

Table 12.16 Summary of benefits from the sample watersheds

	Particulars	Unit	No. of studies	Mean	Mode	Median	Minimum	Maximum	t-value
Efficiency	B:C ratio	Ratio	311	2.0	1.7	1.7	0.8	7.3	35.09
	IRR	%	162	27.40	25.9	25.0	2.0	102.7	21.75
Equity	Employment	Person days/ha/year	99	154.50	286.7	56.5	5.00	900.0	8.13
Sustainability	Increase in irrigated area	%	93	51.5	34.0	32.4	1.23	204	10.94
	Increase in Cropping intensity	%	339	35.5	5.0	21.0	3.0	283.0	14.96
	Runoff reduced	%	83	45.7	43.3	42.5	0.34	96.0	9.36
	Soil loss saved	Tons/ha /year	72	1.1	0.9	1.0	0.1	2.0	47.21

Source: Joshi et al. (2008), Wani et al. (2008)

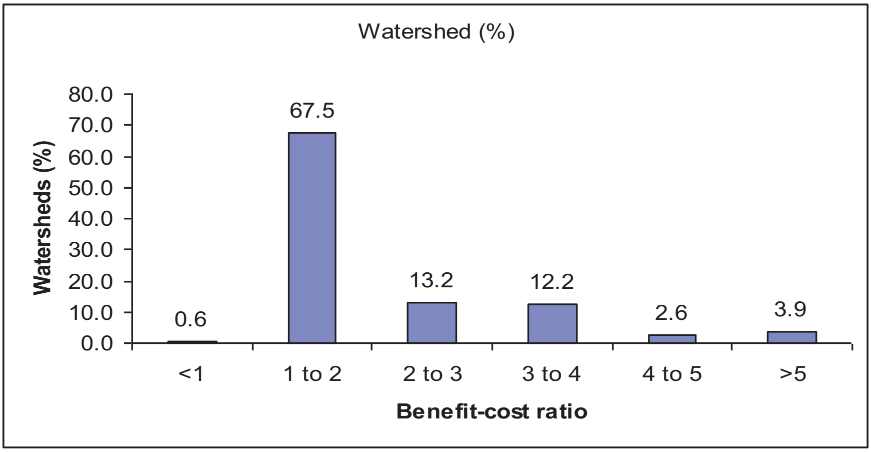

Fig. 12.3 Distribution (%) of watersheds according to benefit-cost ratio (BCR). (Source: Wani et al. 2008)

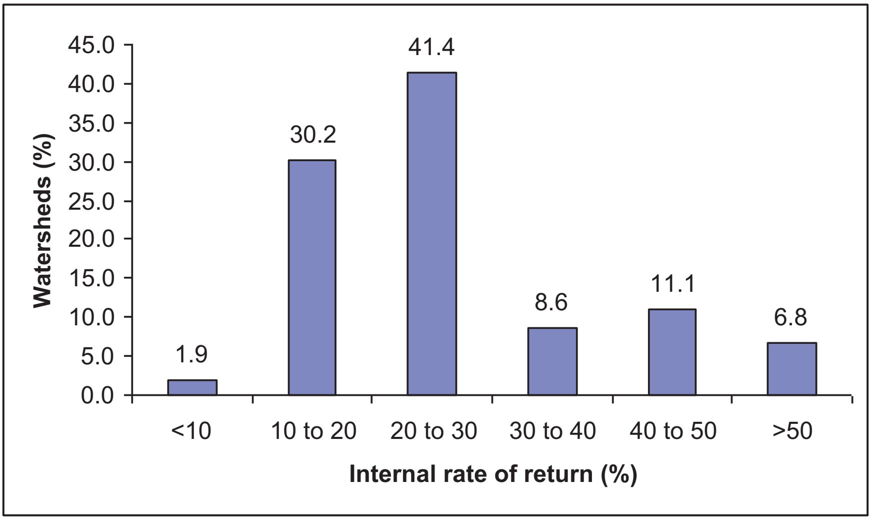

Fig. 12.4 Distribution (%) of watersheds according to internal rate of return. (Source: Wani et al. 2008)

project. The mean internal rate of return of 27.4% on watershed investment shows marginal efficiency of the projects, however, seems to be significantly high and ascertains that investment in watershed programs is comparable with any successful government programs. It is interesting to note that about 27% watersheds yielded an IRR above 30%. The watersheds with IRR <10% were only 1.9% (Fig. 12.4). These results reconfirm that watershed programs are able to meet their initial costs and generate substantial economic benefits and justify the investment in watershed programs as income levels were raised within the target domains.

12.6 What Is Needed?

Organizations in both developing and developed economies have their own MEL systems to achieve proper learning. For instance, the Government of India has established Development Monitoring and Evaluation Office (DEMO) during September 2015. For a specific program like watershed development programs, the GoI has developed clear guidelines for M&E. To inform the policy makers and donors better about the performance of the development intervention, it is essential to develop a robust monitoring, evaluation and learning (MEL) system taking into account the following:

(i) Process monitoring and evaluation,
(ii) Technical evaluation,
(iii) Impact evaluation, and
(iv) Comprehensive evaluation.

12.6.1 Theory of Change

In order to achieve effective monitoring and evaluation of various development interventions, the framework may rely on the "Theory of Change (ToC)" framework. The Theory of Change tool helps the evaluation team to clearly articulate and connect different activities being carried out in the project to your bigger goal to be achieved in the long-term; it allows the team to identify potential risks in the implementation plan by sharing the underlying assumptions in each step.

Generally, the ToC, starts from a situation analysis with a benchmark analysis of the context and issues. It then maps out the logical sequence of changes that are anticipated as being necessary amongst stakeholders and in the contextual conditions to support the desired long-term change (Vogel 2012a, b). A ToC approach has been used to guide project planning and evaluation for research, community-based management and international development programs for many years (Connell and Kubisch 1998; Vogel 2012a, b; Stein and Valters 2012).

The ToC fairly maps out the links between various developments interventions in the form of various activities carried out as part of the development process, the expected outputs, outcomes and the impacts. The Theory of Change for the impact of development intervention is presented in Table 12.17. The ToC forms the basis

Table 12.17 Theory of change for MEL of a climate resilient agriculture intervention

Activities	Output	Outcome	Impact	Indicators
a. Climate resilient agriculture systems	1. Number of demonstrations (Nos.) 2. Extent of tree cover (ha) 3. Extent of area treated for saline and sodic soils (ha)	1. Wider adoption of improved agricultural technologies by farmers 2. Improved Carbon sequestration 3. Enhanced soil health at farm level	1. Increased water productivity 2. Carbon sequestration and Greenhouse Gas emissions reduced 3. Improved yield These will lead to climate resilient and enhanced farm profits in the long run	1. Physical and economic water productivity 2. GHG emissions 3. Increased crop yield 4. Annual Farm Income
b. Promoting Efficient and sustainable use of water for agriculture	1. Number of water harvesting structures (checkdams, percolation ponds, gabion structures etc.) 2. Extent of area covered under micro irrigation system	1. Increased surface water storage capacity 2. Improved method of irrigation and improved water use efficiency at farm level	1. Increased water productivity These will lead to climate resilient and enhanced farm profits in the long run	1. Water productivity in kg.m^{-3}: (Agrl. production / water consumption) 2. Annual Farm Income
c. Climate and Weather Research and Advisory Centre (CWRAC)	Number of farmers receive services from the CWRAC	Advisory services such as business develop-ment, incubation etc. available	These will lead to climate resilient and enhanced farm profits in the long run	Annual farm income

for developing conceptual framework of the study and implementation of the impact evaluation study.

For example, consider a developmental intervention which primarily aimed to achieve the following two policy goals:

1. Promoting Climate-resilient Agricultural Systems in dry land regions
2. Developing institutions, Knowledge system and Policies for a Climate-resilient Agriculture in dryland region.

Given the theory of change mechanism, the effective MEL process may be accomplished through studying the three types of indicators viz., process indicators, outcome indicators and impact indicators. The process indicators are those indicators that are used to measure project processes or activities involved in different phases of implementation. The outcome Indicators generally measure the project outcomes which are usually at society level. These outcomes are intermediate impacts of the development intervention. The impact indicators which measure the long term impacts of the development interventions, what we mean as project impact.

12.7 Lessons Learnt and a Way Forward

Development interventions have become the main interventions for natural resource management. With the huge investment of financial resources in the development programs, it is important that the development programs become successful. Hence, the monitoring and evaluation including impact assessment of development activities should be given due importance in the future planning and development programs. Some of the key points that will make the program successful will be:

- **Better dissemination during the implementation phase**: Experiences of many development programs revealed that many stakeholders are unaware of how their responsibilities change in the different phases of implementation of the development projects. Increasing awareness and providing clear information about rights and responsibilities will likely make more empowered and involved stakeholders. This will also help get right information from the different stakeholders which facilitate implementing a good MEL.
- **Institutional mechanism**: Establishing proper institutional mechanism in a multidisciplinary approach will be a viable step in impact assessment. The organizations implement different development programs should ensure a more robust Centre for Monitoring, Evaluation and Learning for effective MEL. Panel data base should be created for the different intervention across regions for proper evaluations and updating the estimation procedure.
- **Capacity building**: Well-designed capacity building programs are essential to train the personnel involved in monitoring and evaluation of various development interventions.

- **Robust MEL system**: Experiences show that both government and NGOs implement development programs have their own MEL systems. However, it is often criticized that most of MEL systems, fail to provide scalable solutions. It is thus essential to develop MEL system which will fairly provide scalable solutions so as to achieve upscaling and mainstreaming of development interventions.
- **Integration of information technology**: Effective MEL system of any organization requires quality and reliable data in different phases of implementation so as to give proper feedback. In order to enhance the reliability and quality of data, integration of information and communication technology is essential. This will enable the evaluating agencies to achieve good quality and real time data collection with reduced cost.
- **Dissemination mechanism**: Publication of evaluative evidence and feedback materials should be done with a clear format without any ambiguity, and with scalable solutions.

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Chapter 13
Success Stories from Scaling-up Initiatives with State Governments and Corporate in India, China and Thailand

Suhas P. Wani and K. V. Raju

Abstract Science of development or research for development (R4D) is in the central stage as donors started looking for visible, and measurable impacts rather than funding the initiatives of research for research sake. International development investors like Asian Development Bank (ADB), The World Bank (WB), Bill and Melinda Gates Foundation (BMGF), International Fund for Agriculture Development (IFAD), and others were looking for the strategies and valuable inputs for scaling-up good technologies to achieve millennium development goals (MDGs) and sustainable development goals (SDGs). Innovative – Integrated – Inclusive – Impact oriented - Scalable – Sustainable – Simple – Socially acceptable – Efficient – Environment friendly – Equitable and ensuring Economic gain – Consortium – Convergence – Collective action – Capacity building (4ISECs) approach emerged through interdisciplinary watershed development research. This model was scaled-up in several states of India as well as other foundations-researchers also developed good success stories which can help in scaling-up and refinement of the approach. Using case studies as a CB tool for scaling-up by adopting the principle of "*Seeing is Believing*" is proposed by documenting several success stories from different states of India and one each from Thailand, Vietnam and China. In addition, two

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novel initiatives viz. consortium approach and integrated Watershed model success stories are also presented.

Keywords Success stories · Scaling-up · Impacts dissemination SDGs · Capacity building · Seeing is believing

13.1 Introduction

Farmers' distress, more poverty in rural areas, food insecurity, malnutrition are the issues which are directly related with farming and particularly so with small-farm holders in developing countries across the world. Main issues related with 500 million small farm-holders globally, amounting to upwards of two billion people are poverty, distress and food security. Mostly small-scale farmers cultivating less than five acres, they make up a significant portion of the world's poor who live on less than $2 a day (World Bank 2016; Graueb et al. 2016). In India, number of farm holdings has increased from 121 million in 2000–01 (Deo 2012) to 145 million in 2019 along with increased number of small and marginal farmers from 99 million in 2000–01 to 125 million currently. That is why improving the lives of this huge group is a priority in efforts to end global poverty (World Bank). Therefore the future of sustainable agriculture growth and food security in India and Asia depends on the performance of small and marginal farmers. However, existence of large yield gaps between the current farmers' yield and achievable potential yield across the developing nations in Asia, and Africa (Rockström et al. 2007, 2010; Singh et al. 2009; Bhatia et al. 2008; Wani et al. 2003a, b, c, 2011a, b, c), increased distress as evident from the number of farmers suicides (Indian Express 2020- NCRB) which is largely due to large-65% rural population and 44.2% population depending on agriculture for their livelihoods but agriculture sector's contribution to national gross domestic product (GDP) value was 16.5% in 2019–20 (NSO 2019).

How can research help to end hunger is the logical question on the minds of researchers, research managers, policy makers and development investors? One way to answer this question is to assess published research on hunger, and determine which interventions can make a difference to the lives of the 690 million people who go hungry every day. That's what an international research consortium called CERES 2030 has been doing (Laborde et al. 2020). The results of its 3-year effort to review more than 100,000 articles published by researchers, think tanks, non-governmental organizations, many UN agencies and the World Bank. The findings are published in October 2020 across the Nature Research journals (Bizikova et al. 2020; Nature Food 2020; Stathers et al. 2020; Pardey et al. 2016). The consortium's findings— coming just days after 2020's Nobel Peace Prize was awarded to the World Food Programme— are both revealing and concerning (Nature Food 2020) which indicated that:

- researchers except those working in CGIAR institutes across the globe work in isolation and not with small farm-holders,
- more than 50% research funding is from agribusiness,
- increasingly, university research-strategy teams want their academics to bid for larger grants,
- applied researchers working with small farmers does not boost their careers as editors consider working with small farm-holders not attractive and face difficulties in publishing their results,
- the subject matter for smallholder-farming research might not be considered sufficiently original, globally relevant or world-leading for journal publication (for more details refer Chap. 1 in this volume Wani 2021).

Under such situation, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has worked since 2000 on strengthening science of delivery along with science of discovery. The existence of "*Death Valley of Impacts*" was observed by the team in their multidisciplinary team survey in 1995–96 during rediscovering the learning cycle while assessing the adoption of Vertisol technology in different states where it was demonstrated to double farmers' income (Kshirsagar and Ghodake 1991; Wani and Raju 2020a).This was the starting point for development of new approach as described in Chaps. 1 and 4 in this volume Wani 2021; Bhattacharya et al. 2021; Wani et al. 2002). A new multi-disciplinary and multi institute/partners working together in a consortium mode to develop demand driven solutions for the farmers was developed (Wani et al. 2003a, b, c), pilot tested and scaled-up in different states of India as well as in China, Thailand and Vietnam (Wani et al. 2003a; Wani and Raju 2020a).

The consortium approach was proven as effective to cross the *Death Valley of impacts* and during scaling-up initiatives we observed that documenting success stories which are narrated by the farmers themselves was an effective communication means to convince researchers, development staff, development investors as well as policy makers.

13.2 Case Studies Process Adopted and Documented

For selecting subjects/topics for documenting case studies were deliberated amongst the team members based on the technologies/approaches adopted and their impact on ground. During field visits farmers' inputs indicated which technologies were performing good and keen interest by the surrounding farmers in particular technology clearly indicated the success of a particular intervention. The preliminary discussions in fields were validated through data collected for the same technology in different regions and based on the good impacts the technology was identified for case study by the team. Once the technology was identified the next step was to identify some good representative farmers who can narrate the details. Detailed questionnaire was prepared and used informally for discussion with the farmers after seeking their consent for recording data as well as in many cases video recording the interviews. Once the details were collected, the concerned responsible independent person put all the information, data, and photos together in a draft case study. The draft case study was circulated amongst the concerned team members and final case study was prepared. In this chapter the case studies are based on the documented success stories (ICRISAT 2017a, b, c, d, e, f, g), several research publications/presentations and personal interactions with researchers, policymakers and many farmers (Wani and Raju 2018, 2020a; Wani et al. 2003a, b, 2011a, b, c, 2015). In this chapter we present two innovative approaches as success stories and are applicable across the developing world along with one each success story from different parts of India, China, Thailand and Vietnam.

13.3 Selected Success Stories from Different Scaling-up Initiatives

In this section, six success stories are presented from different agro-eco regions by adopting the approach of "Golden circle" (Chaffey 2020) described as of why, how and what as the Sinek's Golden Circle theory. These case studies were documented through interactions and discussion with number of stakeholders/ farmers and based on the information/data collected as described above and the case studies were selected for their novelty in solution, impacts, approach adopted and spill over effect/trickledown effect on non-participating farmers, villages, policymakers, development investors. Focus is on their approach, technologies and achieved impacts, which serve as communication tools and lamp post for empowerment of different stakeholders. The success stories are proven as effective communication tool for impacts of the interventions for different stake-holders. This is useful for one pager with photos, graphs and tables with bulleted statements for policy makers, development and research managers.

13.3.1 List of Success Stories Documented

1. Consortium approach scaled-up for integrated and holistic solutions for farmers.
2. Scaling-up impacts of Watersheds using livelihood approach in Asia.
3. Improved livelihoods through Integrated Approach in Southern China.
4. Increased productivity through integrated watershed management in Vietnam
5. Reducing land degradation and improved livelihoods through sustainable management of natural resources in Thailand.
6. Improved livelihoods through integrated watershed management and convergence in India.

13.3.2 Consortium Approach Scaled-up for Integrated and Holistic Solutions for Farmers

13.3.2.1 Why Consortium Approach?

Our learnings from analysis of the reasons for low adoption of Vertisol technology for double cropping Vertisols (black cotton soils) through rediscovering the learning cycle in 1995–96 (Wani et al. 2003a) were confirmed with the existence of *Death Valley of* impacts (Wani and Raju 2016, 2020a) and recent meta-analysis based on more than 100,000 published papers (Nature Food 2020). Based on the learning in 1995–96 survey need for providing need-based /demand driven and developed in partnership with farmer's integrated solutions for the farmers was felt. In a review (Joshi et al. 2005; Kerr et al. 2000) on the watershed projects in India, it was observed that most watershed projects could not address the issues of equity for benefits, participation of community, scaling-up approaches, monitoring and evaluation measures which resulted in low impacts largely due to low community participation. Most projects were water harvesting structures driven and failed to address the issue of efficient use of conserved natural resources (soil and water) for translating them into increased systems productivity on large areas owned by small holders mainly due to lack of technical support to such projects implemented by NGOs (Wani and Raju 2020a).

In order to confirm the findings of low adoption of Vertisol technology, a meta-analysis of watershed programs in India was taken up by reviewing 311 papers published (Joshi et al. 2005) and later included more than 600 case studies (Joshi et al. 2008) which indicated that only 32% of watersheds were better than average B:C ratio and large scope existed to improve the performance of watershed programs in India by adopting holistic livelihood approach. Several researchers highlighted the need for going beyond compartmental solutions (Rockström et al. 2007, 2010; Laborde et al. 2020; Nature 2020) confirmed our observations from assessing the impacts of watershed projects in India that compartmental solutions such as rainwater harvesting and controlling soil erosion as the benefits of the program were skewed towards a small fraction of large farm-holders (Wani et al. 2002, 2003a, 2009a, b, 2011a, b, c; Joshi et al. 2008).There is a missing link between the researchers, institutes and farmers and generally new science tools are not benefitting the farmers. Traditional knowledge/technologies are not validated before discarding and technologies promoted were not environment-friendly and low-cost for sustainability (Wani et al. 2003c)

13.3.2.2 How Consortium Approach Was Developed?

Considering the need for increasing adoption of improved technologies/products developed by the researchers need for strengthening science of delivery and providing need-based holistic solutions to the farmers, new interdisciplinary (multidisciplinary) on-station experiment for harnessing the potential of Vertic Inceptisols through double cropping was initiated in 1995 which was also for getting best out of financial resource crunch (Wani and Raju 2020a). The selected mini-watershed was having varying soil depth from 75 to 5–10 cm along the slope mimicking the real-world situation in watersheds. The joint planning, execution, analysis and presentations of multidisciplinary experiment at mini-watershed scale provided new insights not only to the team but for the visitors and other researchers also and it became one of the best spots in the institute for the visitors for assessing the system's approach with all the data explaining various processes and interactions. During the visit of the Asian Development Bank (ADB), Manila officials in 1997–98 this approach attracted their attention and was identified for piloting in villages for improving the livelihoods of the rain-fed farmers for potential funding support. In 1999, the ADB approved the integrated watershed project for piloting in India (three sites) and one site each in Thailand and Vietnam. This success for system's approach emboldened the team and built its confidence.

Second success for the team was from local Collector of Ranga Reddy district (Telangana state previously Undivided Andhra Pradesh) who sought the help of the team for developing a mini-watershed for the common land to be distributed to 12–15 landless families. Following this, capacity building request for the District Watershed committee members was completed. During the field visit after inaugural session, Agriculture Minister was impressed with the system's approach and requested ICRISAT's help for developing a field watershed as a demonstration of various technologies. The Collector asked the team to develop a model watershed and agreed to exempt the project from general watershed norms. At the same time, the ADB also approved the project and Kothapally was selected as the potential pilot model watershed (Wani et al. 2002, 2003a, b, d; Wani and Raju 2020b). Being integrated system's model watershed based on the needs assessment the potential interventions viz.; improved livestock rearing, women empowerment as micro-entrepreneurs, crop diversification with high-value crops, and most importantly to ensure community participation, participatory monitoring, evaluation and learning system (MEL) in addition to crops, rainwater harvesting and soil erosion control were identified.

Once the potential need-based interventions were identified along with farmers we had to identify suitable institutions and agencies for providing the specific solutions. The standard operational practices (SOPs) had to be developed in consultation with the farmers and agreed up-on by all the partners (Wani and Raju 2020b) as follows (Wani et al. 2002, 2003a, b, d, e):

- Only knowledge and technical support will be provided by the project team and no other inputs will be provided by the project free of cost. The principle of users pay in cash or kind their share was agreed upon which **the first new parameter was included in the project. Responsibility for collection of farmers' contributions was rested with the Watershed Committee**;

- The villagers will need to select unanimously the Watershed Committee (WC) members as per the criterion provided by the Drought Prone Area Project (DPAP) department officials within 2 weeks;
- For watershed whole village should be united as one and for project activities political affiliation of members should not interfere in the project;
- The WC will have to be registered with the Department of Cooperatives, GoAP and bank account has to be opened by the WC in the nearest bank;
- All payments for the watershed activities undertaken will be through bank cheque payments and transparency will have to be maintained for all the expenses from the project as well as the contributions made by the members;
- Most importantly, for all the events and activities agreed time and schedules must be adhered to;
- No ICRISAT team member or partner will accept tea, snacks, lunch or any favours from the villagers, this was the second new parameter included in the process to avoid any misconception about favouritism shown by the project team for specific activities for the influential people in the village;
- Science-based interventions will be proposed by the project team and volunteer farmers will need to undertake participatory demonstrations and evaluation.

This process ensured that proactive engagement of community ensuring collegiate cooperation from the inception phase of the project to avoid the mistake of contractual participatory research undertaken during the earlier phase of on-farm watershed development. For each scaling-up initiative SOPs were developed, discussed and agreed upon amongst all the stakeholders. Brief timeline of development of consortium approach is indicated in Box 13.1.

13.3.2.3 What Need to Be Done for Effective Consortium Approach

The consortium approach is built on the principle of harnessing the strengths of the partners for the benefit of all the stakeholders including the farmers.

- First and foremost, important thing is to identify essential and suitable consortium partners based on the needs assessment.
- Critical point is we must have buy-in from the concerned local as well as district/state/national government agencies. The leader has to liaise with the appropriate authorities and get their buy-in.
- The potential partner individuals/ institutions to be identified (national, international, government agencies, non-government organisations (NGOs), state agricultural universities, private/corporate companies, extension agencies such as *Krishi vignan kendras* (KVKs), farmers' associations, and their support/help need to be requested and sought. Identification of right individual within the institute is critical as partners should have the aptitude and liking to help farmers. Process of partnership selection for each initiative has to be undertaken carefully. A generalized formula-based selection does not guarantee success. For example, not all NGOs adopted participatory approach and were successful.

- Technical change is intimately bound with broader institutional context of the initiative and the role of institutions and different players varies from location to location. Harness partnerships (need to learn to co-opt farmers and institutions). *Collaborative capacity > Investment capacity*
- Individual farmers should realize tangible economic profits from the watersheds; only then they would come forward to participate in community-based activities in the watershed. Small farm holders demand the best at affordable price through a lean organization ensuring tangible benefits with highest probability of success for the selected intervention
- All partnerships must be institutionalised through suitable mechanism such as memorandum of agreement (MoA) with clear roles, responsibilities and financial arrangements. For example, for Adarsha Watershed, Kothapally consortium partners (Fig. 13.1) were as follows:
- The concept for the formulation of the consortium consist of following major stages:
- Forming: During the forming stage of Consortium, agenda and scope of work should be discussed in details with the stakeholders.
- Storming: Issues have been dealt with through experience/knowledge sharing, workshops, meetings exposure visits etc.
- Norming: Broadly defined in the order of formulation of Consortium itself.
- Performing: More work is to be done on regular basis in all the sites through MEL framework.

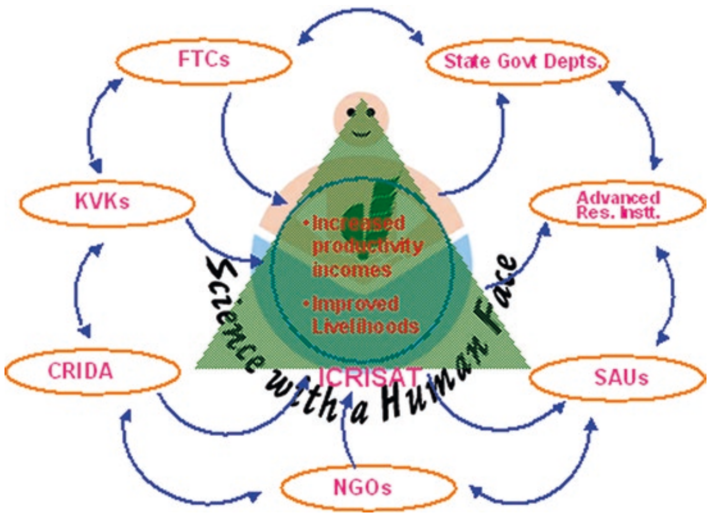

Fig. 13.1 Farmer participatory consortium approach for integrated watershed development. (Source: Wani et al. 2001)

- Access and influence without ownership are important while maintaining quality, mutual obligations, commitment to contractual relationships and a shared set of values
- For each initiative consortium need to be formed by adopting the principles described above in brief and 4 ISECs approach for more details regarding process for participatory consortium refer Chap. 1 in this volume (Wani 2021) and (Wani et al. 2001, 2002, 2003a, b).The consortium partners for *Rythu kosam* and *Bhoochetana* initiatives are described in this volume (Wani 2021; Bhattacharya et al. 2021).
- Once the consortium is formed most important activity to be taken on priority is team building through number of workshops in order to ingrain the goals, objectives, strategies, SOPs amongst all the partners. Different institutes bring their culture and practices in the consortium and it's important that uniform agreed practices are adopted in functioning of the consortium.
- Building trust amongst partners is critical and clear agreed mechanism to share the responsibilities, credit, and success need to be established. The leader must ensure timely delivery of agreed inputs to villagers/farmers and also keep a close watch on working as well as ways of interaction of each member in the team as well as with community members.
- The leader/Lead institution should link stakeholders and create a new ecosystem by becoming a facilitator and provide the framework for collaboration. Need to adopt a business Approach through affirmative action and by keeping passion high-surround yourself with big ideas. Don't pass on your fears to team members, get what you want while love what you have and take personal responsibility for success.
- Building good rapport amongst the team members is of paramount importance by keeping-up the commitments, clarifying expectations, showing personal integrity and most importantly admitting mistakes and regular communication.
- Farmers must be at the center for each intervention and empowerment of community and stakeholders was a core. Partnerships, timely delivery and quality outputs/impacts, transparency and no favoritism should be core values of the consortium team.
- More details can be referred in Chaps. 1 and 4 of this volume (Wani 2021; Bhattacharyya et al. 2021) and also (Wani et al. 2001, 2002).
- For ensuring community participation from the beginning starting with building rapport with the community knowledge-based entry point activities benefitting small farm-holders was adopted and also users pay principle was strictly adhered.
- Tangible economic benefits through different interventions must be ensured for the small farm-holders, this promotes community participation.
- New science tools must be harnessed to benefit small farm-holders through increased productivity, profitability and ease for accessing the knowledge.
- Holistic and integrated solutions must be provided instead of compartmental solutions (Figs. 13.2 and 13.3). Livelihood approach is a must for increasing family incomes as allied sector activities contribute around 65–70% of rural family income.

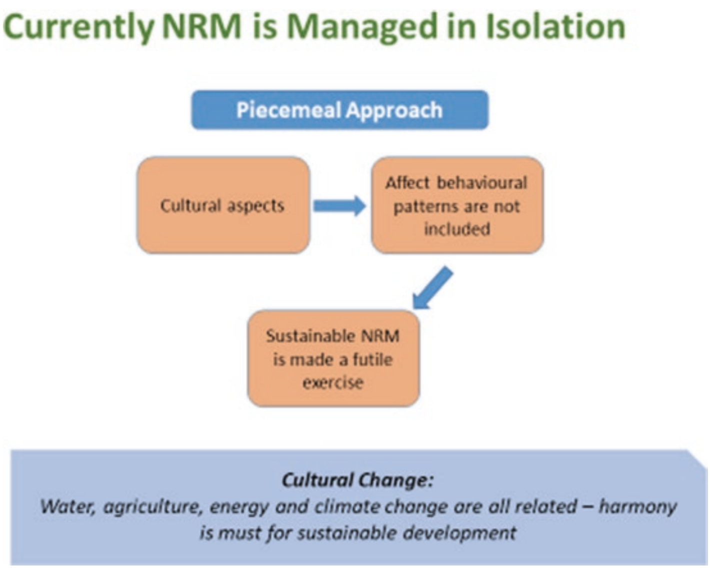

Fig. 13.2 Holistic approach for sustainable management and development of natural resources by addressing cultural and behavioural aspects in team building. (Source: Authors)

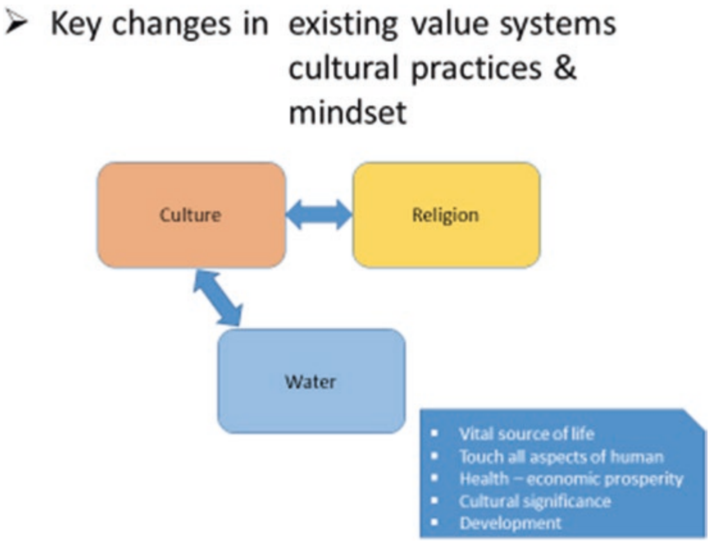

Fig. 13.3 Holistic stewardship approach to mitigate environmental challenges- as an example water is linked with religion and culture. (Source: Authors)

- Capacity building and empowering farmers to conduct participatory research as well as discuss with the farmers and other visitors for dissemination of results is a must.
- Dynamic, transparent and participatory MEL system need to be in place.

For achieving the targets and convergence of different government schemes is critical and heads of concerned institutes, policy makers should be involved in dissemination activities such as Farmers Days, training courses, travelling workshops, conferences, and planning and review meetings.

13.3.2.4 Impacts Achieved

Most important impact of any scaling-up initiative is noted when non-project small farm-holders demand the technical support/technologies/products on their own. Numbers of direct impacts of the consortium approach were noted as follows in addition to the ones mentioned in Box 13.1:

Box 13.1: Timeline of Consortium Formation

1995 – **Revisited Vertisol Technology watershed sites adopting learning cycle approach bya multidisciplinary team,** On-station multidisciplinary watershed experiment initiated for evaluation.

1996 – Recognized need to strengthen social mobilization

1997 – On-farm trials with NGO partner (BAIF)

1998 – District Collector sought help for WSD, training for WS Committee Chairs, Minister's request to demonstrate benefits in village

1999 – ADB funds for on-farm evaluation of the model, partnerships expanded, institutionalized, participatory planning, benchmark sites established, scientists located at project sites in Thailand and Vietnam.

2000 – Traveling WS, Annual Review & Planning Meeting rotated at sites, Tec. Disseminated to surrounding four villages.

2001 – DFID, TATA, reps visited Kothapally, Team gained confidence

2002 – **TATA in M.P. &Rajasthan and APRLP in Andhra projects for scaling-up,** team building, consortium expanded, Coordination committees, site and activity coordination, staff posted, projects launched by CMs, policy advocacy, nucleus watersheds established, scaling-out strategy worked out. CGIAR selected Consortium watershed management approach as one of the seven case studies across the 16 centers for publication by the Science Council.

2002 – **Planning Commission members visited Kothapally, MORD Sec visited**, contributed to common guidelines, Farmers Day at IISS, Bhopal, ADB supported II phase for scaling-up and expanded project to include China as additional country.

(continued)

Box 13.1 (continued)

2003 – Scaling-out to satellite WSs, Traveling Workshop, Review& Planning Meeting with expanded partners, GOI Ag. Sec visited, State level Farmers Day at Bundi and district level at other WSs, **leading project on Rainfed Agriculture for CA on water for food.**

2004 – Contributed in National WSC, Interactions with Rajasthan Chief Secretary and other officials, Farmers Day in A.P. with Agricultural Minister as Chief Guest, Karnataka Ag. Minister visited Kothapally, Mak Royal (private industry) joined consortium. **IPGRI, Rome documented learnings from watershed consortium project.**

2005 – **Karnataka WB project requested technical support, National Commission on Farmers identified Consortium Approach** and WS as entry point for rural poverty (GoI 2005) alleviation, Tamil Nadu government formed Mission on Rainfed Agriculture and requested for technical support, Moraraji Borax (private industry) joined consortium, Consortium expanded for biodiesel New initiative. **APRLP-DFID project for scaling-up watershed consortium model.**

2007 – ICAR-NAIP Project on improving livelihoods through consortium approach (2007–2012), IFAD Project for improved productivity in eight target districts (2007–2010). Assessment of Watershed Projects in India supported by DoAC, GoI.

2009 – GIZ requested to document learnings from APRLP Consortium. **DOLR, & DOAC, GoI approved projects to establish Model Watersheds in seven states.**

2011 – Mission project *Bhoochetana* in Andhra Pradesh launched (2011–2016). Coco Cola Foundation supported Model Watershed in Karnataka. *SuvarnaBhoomi* Horticulture project in Karnataka through Consortium approach.

2012 – India EU Consortium Project Integrating Bio-treated Wastewater with Enhanced Water Use Efficiency to Support the Green Economy in EU and India (Water4Crops). GIZ-India requested to lead CB Consortium for four states in India.

2009–16 – **Several initiatives supported by Newton Bhabha –GoI, DoAC, GoI, SAI platform, FAO, UNDP, Private corporates** such as JSW Foundation, Mahindra & Mahindra, SKOL-SAB Miller, Asian Paints, Power Grid Corporation of India, Rural Electrification Corporation of India, Tata Trusts, **University of Florida-USAID, Government of Philippines, GIZ, SDC. Prime Minister of India's office (PMO) asked the team to prepare strategy papers** for Soil health mapping, doubling farmers' income, DBT- Direct benefit transfer, Digital Agriculture, Weather-linked crop insurance, PMKSY- *Pradhan MantriKrishiSinchaiYojana,*

2018 – **Doubling Farmers Income (*KISAN MITRA*)** projects in Uttar Pradesh (7 dists.) and Maharashtra (13 dists.) approved and launched (2018–22). *Bhoochetana* Mission proram for enhancing productivity and profitability in 30 districts of Odisha launched (2018–2021).

- The first success of multidisciplinary approach was evident to the team when the Agriculture Minister of erstwhile undivided Andhra Pradesh requested the ICRISAT watershed team to replicate the benefits observed in on-station watershed in real world situation and agreed to provide the financial support. The Collector, Ranga Reddy district requested the team to develop a Model watershed and exempted the project from normal watershed guidelines.
- It was followed by the approval of Participatory Watershed Management for Reducing Rural Poverty and Land Degradation in SAT project for establishing pilot sites in India, Thailand and Vietnam in the first phase and later during second phase China was added as fourth country in the project by the ADB.
- In *Adarsha* Watershed during first season only five farmers agreed to conduct participatory evaluation of wilt-tolerant pigeonpea cultivar with improved management. However, looking at the financial benefits, during *rabi* season all farmers agreed to do what team asks. It was the great success for the strategy adopted for building trust amongst farmers and the team.
- During second year, surrounding villages started asking why not in our village to the government officials and it indicated the success as farmers were demanding the new knowledge, technologies and products. Four satellite villages were supported through govt. funding.
- Later Sir Dorabji Tata Trust requested the team for demonstrating the approach in selected districts of Madhya Pradesh and Rajasthan. Later during the second phase of 5 years the scaling-up was taken up in 11 districts of Madhya Pradesh and Rajasthan.
- DFID officials visited ICRISAT and *Adarsha* Watershed, Kothapally, and discussed with Andhra government officials that they would like to adopt Kothapally model in APRLP, the officials said yes, it's our model with ICRISAT which indicated the benefits of consortium for jointly owning the credit for the success which helped in scaling-up the model in APRLP-DFID livelihood improvement initiative with technical support from ICRISAT.
- Based on the several presentations made on Kothapally consortium success, and the meta analysis of 311 watershed projects in India, the Planning Commission of India asked the ICRISAT to undertake assessment of all watershed projects implemented by different Ministries in India. ICRISAT Team as a leader adopted consortium approach for undertaking assessment with all known players (Government depts., research institutions, NGOs together) and the reports were submitted unanimously. It resulted in New Watershed Guidelines approved by the GoI in 2008 and integrating all watershed activities under Department of Land Resources (DoLR).
- ICRISAT and other research institutes as well as leading NGO members were included in National Steering Committee for Integrated Watershed Management by the DOLR, GoI.
- The CGIAR program on Water led by IWMI asked ICRISAT to lead the Comprehensive Assessment (CA) of water for rain-fed agriculture globally by adopting consortium approach with ICARDA, ASARECA, SEI, and other national institutions. The flow of the consortium approach for watershed man-

Fig. 13.4 Flow of Consortium approach for watershed management from Andhra Pradesh to states of India and in Asia and Ethiopia. (Source: Authors)

agement in states of India and countries in Asia and Africa is depicted in Fig. 13.4 since 1999–2006.

- The World Bank team requested the presentation on Learning from Consortium approach of ICRISAT before initiating the National Agriculture Technology Project (NATP) in India with the Indian Council of Agriculture Research (ICAR) and incorporated the learning as all the NATP projects were multi-institutional adopting consortium approach.
- The CGIAR Fund Council selected ICRISAT's Consortium Project presentation in Delhi during their visit. The WB and EU representatives appreciated the model and sought more details.
- The GIZ, India requested ICRISAT to lead the CB Consortium with MANAGE for Watershed partners is Andhra Pradesh, Karnataka, Rajasthan, and Uttarakhand,
- EU Consortium leader contacted Watershed Team Leader and requested to join the Water 4 Crops (W4Crops) consortium and lead the Indian partners by bringing needed partners. The (Department of Biotechnology (DBT)-GoI funded the Indian consortium led by ICRISAT.
- Several state governments (Andhra Pradesh, Karnataka, Odisha, Uttar Pradesh, Maharashtra, Madhya Pradesh, Rajasthan) and national governments (India, Philippines, China), international funding agencies (World Bank, Asian Development Bank, UNDP, FAO, GTZ/GIZ, SDC, WWF, USAID, SDC,

University of Florida, European Union and several corporates (Tata Trust Foundations, JSW Foundation, SKOL-SABMiller, Mahindra &Mahindra, Power Grid Corporation of India-PGCI, Rural Electrification Corporation Limited-RECI, Asian Paints, Sustainable Agriculture Initiative-SAI Platform, Ultra Tech, D1 Oils, GRASIM, Associated Cement Companies-ACC, Microsoft, etc.) contacted the team and supported several initiatives for scaling-up.
- Detailed impacts are covered in several publications and books which can be referred for more details (Wani et al. 2001, 2002, 2003a, b, 2009a, b, 2011a, b, c, 2018, 2020; Wani 2021; Raju and Wani 2012; Joshi et al. 2008, 2009; Rockström et al. 2007; Bhattacharya et al. 2021).

13.3.3 Scaling-up Impacts of Watersheds Using Livelihood Approach in Asia

This success story on scaling-up impacts of watersheds using livelihood approach in Asia and the Consortium approach scaled-up for integrated and holistic solutions for farmers were developed together and need to be read together for completeness as each success story supports the other one. In fact, the consortium approach was developed for innovative, integrated, impact oriented encompassing inclusivity for equity, efficiency, environment protection and economic gain for the farmers through convergence, collective action, cooperation through consortium for sustainability, harnessing synergy, social acceptability and scalability (ISECs) (Wani et al. 2003a; Wani 2020a, b).

13.3.3.1 Watershed Development for Improving Livelihoods in Asia

Globally rain-fed agriculture covers 80% of arable land; however, the importance of rain-fed agriculture varies regionally, but produces most food for poor communities in developing countries. In sub-Saharan Africa more than 95% of the farmland is rain-fed, while the corresponding figure for Latin America is almost 90%, for South Asia about 60%, for east Asia 65% and for Near east and North Africa 75% (FAOStat 2005) and for India it is 52%. Most countries in the world depend primarily on rain-fed agriculture for food grains. Rain-fed areas are also the hot spots of poverty, food insecurity, malnutrition and distress for the large population (example in India livelihood of 58% population is dependent on agriculture where as in sub-Saharan Africa more than 90% population is dependent on rain-fed agriculture) (Wani 2021, Chap. 1 in this book).

Declining per capita land and water availability globally with increasing population of 7.3 billion which is expected to reach 9.3 billion by 2025, changing food habits with growing incomes in developing economies along with the vulnerability of rain-fed areas to impacts of climate change is threatening food, nutrition and economic security. However, existing low crop yields and large yield gaps observed in Asia, Africa and Latin America (difference between achievable potential and actual yield) varies from 0.5 to 5 t ha^{-1} (2–4 times) as per the agro-ecological zone and the available technologies used by the farmers (Rockstrorm and Falkanmark 2000; Wani et al. 2003b, d; Rockström et al. 2010; FAO and DWFI 2020). With the current situation of poverty, food insecurity and malnutrition, the 2030 Agenda for Sustainable Development, (17 Sustainable Development Goals-SDGs) will shape national development plans over the next 15 years. From ending poverty and hunger to responding to climate change and sustaining our natural resources, food and agriculture lies at the heart of the 2030 Agenda.

Drier climate and water scarcity in India led to numerous innovations in water management since ancient times (Singh et al. 2020). Integrated watershed approach is a proven approach for managing scarce water resources in rain-fed areas for sustainable development (Chopra et al. 1990; Farrington and Lobo 1997; Samra 1997; Hanumanth Rao 2000; Kerr et al. 2000; Wani et al. 2002, 2003a, 2008, 2008a) and has evolved over a long period to manage natural resources sustainably in rain-fed areas (Samra 1997; Joshi et al. 2005, 2008, 2009; Wani et al. 2003a, 2008, 2011a, b, c; Wani and Raju 2020a). Evidence from a long-term experiment at ICRISAT, Patancheru, India, since 1976, demonstrated the virtuous cycle of persistent yield increase through improved land, water and nutrient management in rain-fed agriculture. Improved systems of sorghum/pigeon pea intercrops produced higher mean grain yields (5.1 t/ha) compared with 1.1 t/ ha average yield of sole sorghum in the traditional (farmers') post-rainy system where crops are grown on stored soil moisture. In addition, in improved system good carbon sequestration over 24 years was also observed over traditional practice (Wani et al. 2003c; Raju and Wani 2016; Wani and Raju 2020b) indicating large untapped potential of rain-fed areas remains to be harnessed (Joshi et al. 2005, 2008, 2009; Wani et al. 2008, 2008a, 2009a, b, 2011a, b, c). From a government and donor perspective, watershed work clearly addresses important objectives related to poverty, productive capacity, environment, and output, and others relating to good governance, women in development, water productivity, and carbon sequestration. Watershed interventions "tick a lot of the right boxes" because they attend to pragmatism rather than rhetoric.

Though the concept and watershed programme in India started in 1880, with the Famine Commission, after independence government supported program started in 1950, the vigour and seriousness came only during the 1990s; particularly after the worst drought in 1987. The nature and scope of the watershed programmes evolved over different plan periods and recently tuned to encourage people's participation and became livelihood program in 2008 (Wani et al. 2008). In the past, several studies conducted to assess the impact of watershed programmes, and to examine the people's participation (e.g., Chopra et al. 1990; Farrington and Lobo 1997; Samra 1997; Deshpande and Thimmaiah 1999; Hanumanth Rao 2000; Kerr et al. 2000; Ratna Reddy 2000) reported mixed conclusions on the performance of watershed programmes in achieving the expected economic and environmental outcomes.

Based on a qualitative assessment of the impacts of the DPAP, Hanumanth Rao (2000) noted an overall positive and significant impact of the programme. Similarly, Palanisami et al. (2002) reported that watershed programmes did not perform well in terms of controlling reservoir siltation, mitigating the impact of drought and improving/stabilising the production of crops (like pulses and oilseeds) generally grown in rain-fed areas. The Mid-Term Appraisal of the Ninth Plan of the Planning Commission articulated satisfactory and unsatisfactory performance of watershed programme on different dimensions (Government of India 2001). On a satisfactory note, it stated that the impact was visible in increasing cropping intensity, changing cropping patterns, increasing crop productivity and augmenting underground recharge. On social aspects, the impact was noted in generating employment and increasing family incomes through diversified farming system such as livestock development, dryland horticulture and household production activities. On the other side, the Mid-Term Appraisal stated the increase in agricultural production did not last for more than 2 years. Structures were abandoned because of lack of maintenance and there was no mechanism for looking after common lands. Projects have failed to generate sustainability because of the failure of Government agencies to involve people (Government of India 2001)

Simultaneously, ICRISAT team was working in India on watersheds since 1974, developed Vertisol technology for double cropping in Vertisols (Walker et al. 1983), demonstrated in number of states in partnership with state governments (Kampen 1982). However, low adoption of component of technology and no adoption of integrated watershed technology was observed by a multidisciplinary team which adopted learning cycle approach (Kshirsagar and Ghodake 1991; Wani and Raju 2020a). In order to assess the reasons for very low adoption of natural resources management (NRM) technologies by the farmers, existence of large yield gaps, and *Death Valley of Impacts* and finding ways for crossing *Death Valley of Impacts*, systematic review of published literature, field visits, and meta-analysis of watershed reports was undertaken during 1995–1998 to develop holistic integrated demand driven approach (Wani et al. 2001, 2002, 2003a, 2005; Joshi et al. 2005; Wani and Raju 2020a).

13.3.3.2 How Watershed Programs in India Were Transformed from Compartmental to Holistic Livelihood Approach

Focus on watershed programmes was sharpened with the establishment of the Soil Conservation Research in mid-1950s, Demonstration and Training Centres at eight locations. In a landmark decision, the Central Soil and Water Conservation Research and Training Institute (CSWCRTI) was established by linking all the eight centres in 1956 which started watershed activities in 42 locations mainly at a small-scale to understand the technical processes of soil degradation and undertaking soil conservation (Samra 1997).The first large-scale government supported watershed programme was launched in 1962–63 to check siltation in the multi-purpose reservoirs as "Soil Conservation Works in the Catchments of River Valley Projects (RVP)".

Majority of watershed development projects in the country were sponsored and implemented by the Government of India with the help of various state departments, nongovernmental organizations (NGOs), self-help groups (SHGs), etc. River Valley Project (RVP) and Flood Prone Region (FPR), Drought-Prone Area Program (DPAP), Desert Development Program (DDP), National Watershed Development Project for Rain-fed Area (NWDPRA), Watershed Development in Shifting Cultivation Areas (WDSCA),Watershed Areas for Rainfed Agricultural Systems Approach(WARSA), which also allowed the participation of NGOs as implementing agencies. Integrated Watershed Development Project (IWDP), Integrated Watershed Management Program (IWMP) (Wani et al. 2008), *Pradhan Mantri Krishi Sinchai Yojana (*PMKSY), followed by creation of *Jal Shakti* Ministry handling all water related programs through convergence, Spring-shed Management are some of the important development programs that plan, fund and implement watershed development projects.

Several international organizations such as Department for International Development (DFID), Duetsche Gesellschaft for Technische Zusammenarbeit (GTZ), Swiss Agency for Development and Cooperation (SDC), The World Bank (WB), International Fund for Agricultural Development (IFAD), Asian Development Bank, (ADB), also sponsor and implement watershed development projects but a significant proportion (about 70%) of the investment in watershed development programs is being made by the Government of India. The projects benefited from newly emerging concepts of participation propounded by Chambers et al. (1989) from participatory technology. Meanwhile, the national institutes such as CSWCRTI, Central Arid Zone Research Institute (CAZRI), Central Research Institute for the Dryland Agriculture (CRIDA) as well as international institute like ICRISAT started on–station and on-farm demonstration its technologies in actual village conditions.

13.3.3.3 How Holistic Participatory Watershed Management Approach Was Developed?

As discussed above under Sect. 13.3.2.1 following detailed assessment of reasons for low adoption of Vertisol Technology in watersheds in Madhya Pradesh, Maharashtra, Karnataka and Andhra Pradesh during 1980s revealed that there is a need for strong co-operation between various stakeholders (researchers, administrators, extension workers and bankers) to enhance farmers' participation and to realise the potential benefits of watershed-based technologies in SAT regions (Kshirsagar and Ghodake 1991).

Multidisciplinary assessment in 1995–96 in different states of India identified the reasons for low adoption as- lack of tangible benefits to small farm-holders (equity issue), compartments approach adopted to provide supply driven solutions for crop production, contractual mode of cooperation for on-farm research, and providing free inputs(Joshi et al. 2005). A multidisciplinary integrated watershed experiment on station was initiated for double cropping in Vertic Inceptisols. At the same time on-farm work in Madhya Pradesh with Non- Governmental Organisation (NGO)-Bhartiya Agro Industries Foundation (BAIF) was initiated (Wani et al. 2002, 2003a; Wani and Raju 2020a). For sustainability of watershed interventions equitable property rights on water, fodder and fuel are critical irrespective of land ownership in Fakot and Sukhmajari watersheds (Dhyani et al. 1997; Arya and Samra 2001). In both the cases, the number of goats declined to avoid grazing, and number of cows and buffaloes increased.

Despite the long history of the watershed development programmes in India, there were no systematic and large-scale impact assessment studies on the performance of watershed programmes till the meta-analysis was undertaken for 311 case studies by Joshi et al. (2005). Individual scholars, NGOs, and international agencies undertook some studies largely on a project basis. The results from a meta-analysis comprising 311 watersheds revealed that the mean benefit-cost ratio of watershed programmes was quite modest at 2.14 (Table 13.1). The average internal rate of return was 22%. The study further revealed that the watershed programmes generated employment opportunities, augmented irrigated area and cropping intensity and conserved soil and water resources (Joshi et al. 2005). The study observed that the performance of watershed programmes was best in regions with a rainfall ranging between 650 and 1000 mm, jointly implemented by the state and central governments, targeted in low and medium income regions, and had effective people's participation.

The above evidence suggests that the watershed programmes successfully met the initial three principal objectives of raising income, generating employment and conserving soil and water resources. The long-term sustainability of majority of watersheds was still unsatisfactory. However, these benefits have been largely confined to a few successful watershed programs. In fact, almost two-thirds of the watershed programs performed below average, as indicated by a meta-analysis (Joshi et al. 2005). Therefore, at the Ministry level, there was apprehension about further investment to be made on watershed development programs in the country.

Table 13.1 Returns were higher in medium (2000–4000 Rs. Ag GDP) and low (<2000 Rs. Ag GDP) income states

			People's participation		
Indicator	Particulars	Unit	Low	Medium	High
Efficiency	B: C ratio	Ratio	2.63 (16.01)	1.60 (29.72)	1.42 (16.36)
	IRR	Percent	38.28 (10.21)	22.26 (4.74)	17.30 (8.21)
Equity	Employment	Person days/ha^{-1}/year	165.17 (5.29)	118.73 (4.31)	105.42 (9.97)
Sustainability	Increase in irrigated area	Percent	77.43 (8.23)	56.17 (8.07)	29.43 (10.32)
	Increase in cropping intensity	Percent	44.6 (9.37)	24.96 (10.21)	32.03 (14.21)
	Runoff reduced	Percent	43.2 (6.03)	40.41 (4.22)	69.00 (7.19)
	Soil loss reduced	t ha^{-1}/y	1.18 (43.21)	1.1 (18.21)	0.87 (22.33)

Figures in parentheses indicate t-values. Source: Joshi et al. (2005)

Thus, ICRISAT in partnership with ICAR institutions, state agriculture universities, a number of state government departments, and NGOs, undertook the comprehensive assessment (CA) during 2006–08 supported by Ministry of Agriculture, Cooperation and Ministry of Rural Development.

The CA concluded that community watershed programs could serve as growth engines for the development of rain-fed areas with prospects of doubling productivity and were silently revolutionising rain-fed agriculture in the country (Table 13.2, Figs. 13.5 and 13.6). The Comprehensive Assessment established the evidence that watershed programs were silently revolutionising the rain-fed areas in the country with average B:C ratio of 2 with IRR of 27.4%. However, large scope existed to enhance the benefits as 68% watersheds were performing below average for B:C ratio.

A number of factors determined the economic efficiencies of watershed programs. Geographical location, rainfall pattern, focus of watershed program, implementing agency, status of target population and people's participation are some of the critical factors that play a deterministic role in the performance and efficiency of watersheds (Table 13.2). The CA also highlighted the need for reform in institutional and policy front to ensure equity in benefit sharing among all sections of the community. It is in this context, the Planning Commission formulated Common Guidelines through National Rain-fed Area Authority (NRAA) for watershed development projects in order to have unified perspective by all ministries (Government of India 2008).

The special feature of the common guidelines 2008 is the convergence with other schemes such as National Rural Employment Guarantee Scheme (NREGS), Bharat Nirman, and Backward Region Grant Fund (BRGF). One of the major learning over

Table 13.2 Summary of benefits from the sample watersheds using meta-analysis the during during comprehensive assessment of watershed programs in India

Particulars	Unit	No. of studies	Mean	Mode	Median	Minimum	Maximum	t-value
Efficiency B:C ratio	Ratio	311		2.01	1.70	0.82	7.30	35.09
IRR	%	162	27.43	25.90	25.00	2.03	102.70	21.75
Equity employment	Person days/ha/year	99	154.53	286.67	56.50	0.05	900.00	8.13
Increase in sustainability irrigated area	%	93	51.55	34.00	63.43	1.28	204	10.94
Increase in cropping intensity	%	339	35.51	5.00	21.00	3.00	283.00	14.96
Runoff reduced	%	83	45.72	43.30	42.53	0.38	96.00	9.36
Soil loss saved	t ha^{-1} $year^{-1}$	72	1.12	0.91	0.99	0.11	2.05	47.21

Source: Wani et al. (2008)

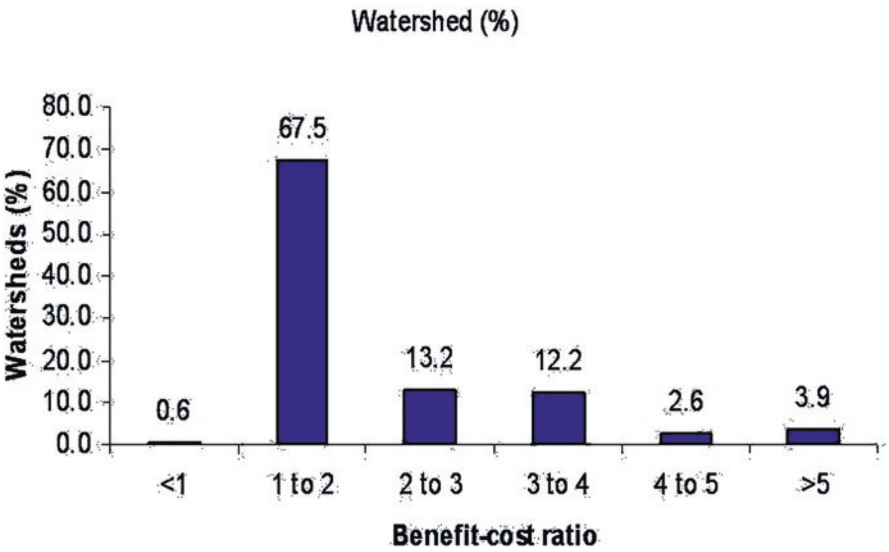

Fig. 13.5 Distribution of watersheds based on B:C ratios from meta-analysis. STEP: Sustainability. T-Technologies, E-Equity and P-Participation are holding back the impacts. (Source: Wani et al. 2008)

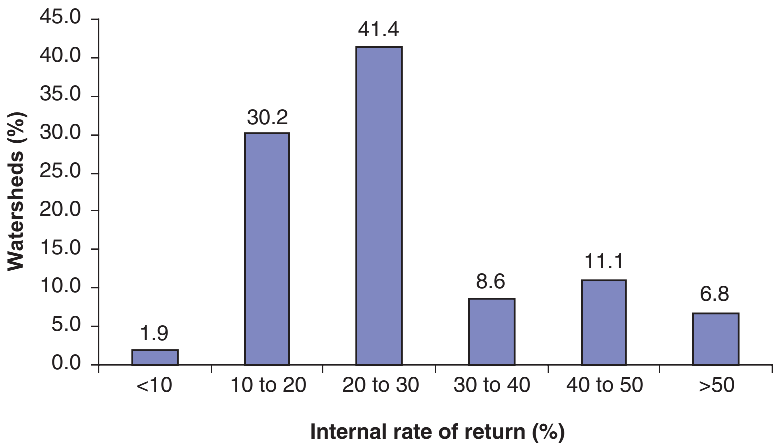

Fig. 13.6 Distribution of watersheds based on internal rate of return (IRR%)from meta-analysis of 611 watersheds. (Source: Wani et al. 2008)

a period of time has been that unless there is some tangible economic benefit to the community, peoples' participation does not come forth (Olson 1971; Wani et al. 2002). The inclusion of livelihood approach, enhancing per hectare investment to Rs. 12,000, establishment of Steering Committee at national level for approval of watersheds, and extending duration with preparatory phase of 1 year transformed the watershed initiative in the country (GoI 2008).

13.3.3.4 Impacts of Livelihood Watershed Management Approach in Asia

The holistic approach developed, tested and piloted in five countries in Asia (India, China, Philippines, Thailand and Vietnam) benefitting directly 450,000 people and also initiated this approach in southern and eastern Africa (SEA) through capacity building efforts with Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA). Lives of 450,000 people were improved as integrated watershed approach developed all the five capitals (natural, financial, social, institutional and human capitals) as depicted in Fig. 13.7. The specific impacts which are described above in Sect. 13.3.2.4 demonstrate the spread of the approach across Asia and particularly in states of India.

- In China, following successful approach where farmers shifted from maize, rice to vegetables, initiated on-line selling after grading, packaging at village level and most importantly collective crop planning as per market demand. The ADB moved forward for 100 million US $ for demonstrating the watershed approach in eight provinces.
- In Thailand, Department of Land Development (DLD), Department of Agriculture (DoA) and Khon Kaen University (KKU) started working together with ICRISAT for transforming lives of small farm-holders in north east Thailand.
- In Philippines, DoA and DA-Bureau of Soil and Water Management (BSWM) provincial governments started *Yamanglupa* initiative with technical support from ICRISAT for developing rain-fed areas in Philippines. DA-Bureau of Agricultural Research (DA-BAR) launched the Philippine Rain-fed Agriculture Research, Development and Extension Program (PHIRARDEP).
- ASARECA organised travelling workshop for policy makers from different eastern and central African countries to India for capacity building in the area of integrated watershed management. Several workshops in India and eastern Africa were held with resource persons form ICRISAT and ICAR-India.
- The watershed management approach has become a focal intervention for transforming rain-fed agriculture and also for enhancing water use efficiency in agriculture in India as indicated in Sect. 13.3.2.4
- Detailed impacts are described in Chaps. 1 and 4 in this volume (Wani 2021; Bhattacharya et al. 2021; Wani et al. 2003a, 2009a, b, 2011a, b, c; Raju and Wani 2016; Wani and Raju 2018, 2020b).
- In the Sect. 13.3.2.4 Fig. 13.4 has depicted the flow of integrated watershed management livelihood approach adopting consortium approach from ICRISAT (undivided Andhra Pradesh) to states in India and other countries in Asia.

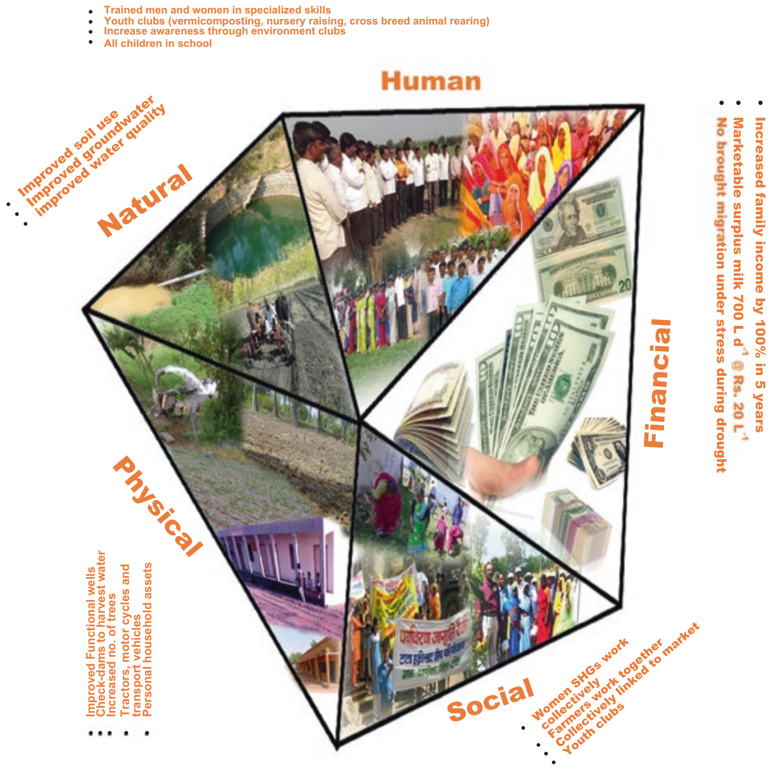

Fig. 13.7 Development of five capitals in rural rain-fed areas through integrated watershed management adopting consortium approach

13.3.4 Improved Livelihoods Through Integrated Approach in Southern China

Dryland agriculture is prone to severe land degradation and particularly so, in steep slope areas as found in China. Southwest China, administratively covering the provinces of Yunnan, Guizhou, Sichuan, and Chongqing Municipality, is characterized by mountainous topography, multi-ethnic residents, and poor eco-environmental conditions. Except some parts of Sichuan province, the rest of the region consists of hills and mountains, which occupy more than 90% of the land area. Therefore, the cultivated land is very scarce. These areas are hot-spots of poverty, malnutrition, water scarcity and are also more vulnerable to impacts of climate change. In South China severe erosion has caused exposure of karsts on hills as well as gully erosion has affected agriculture (Fig. 13.8).

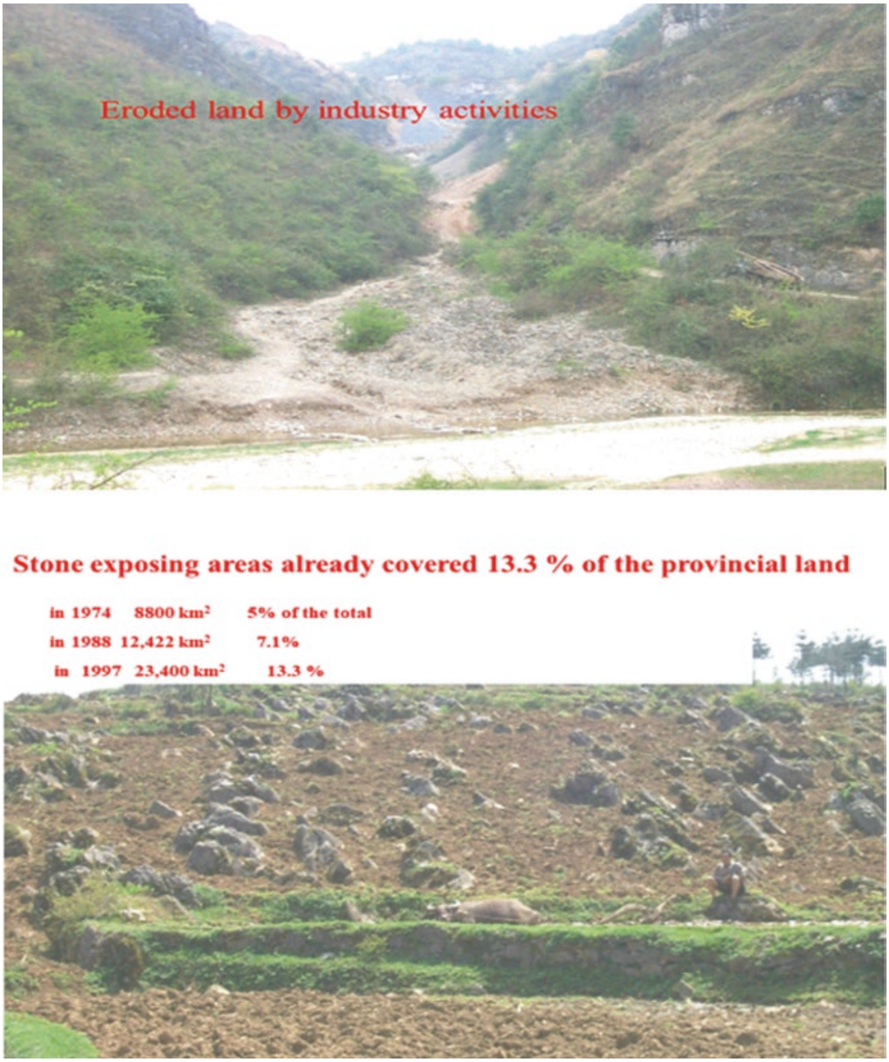

Fig. 13.8 Severe erosion observed in Guizhou province of China exposing rocks where farmers are cultivating crops. (Source: Authors)

13.3.4.1 Why Integrated Watershed Management (IWM) Approach in Southern China?

Considering the challenges of poverty- low per capita income of RMB 1450 annually, food insecurity, water scarcity- no irrigation, drought, land degradation- thin layer of soil, low crop yields, non-irrigation, 100% of upland area and vulnerability to impacts of climate change impacts, the area needed innovations for improving people's livelihoods. In order to address the issues of poverty, water scarcity, land degradation and low productivity of rain-fed agriculture in Southern China, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) adopting a farmer-centric, holistic and up-scalable consortium model, the ADB supported the scaling up of first phase watershed project by establishing 25 benchmark watershed sites in India, Thailand, Vietnam and China. The project was implemented with a focus on reducing poverty and land degradation by adopting holistic participatory watershed consortium approach. For improving livelihoods of people integrated watershed management approach was identified to harness large potential of rain-fed agriculture with improved knowledge-based technologies/products (Wani et al. 2002, 2003a, 2009a, b, 2011a, b, c; Rockström et al. 2007; Wani and Raju 2020a).

13.3.4.2 How IWM Was Implemented?

Under this ADB project, two benchmark watersheds namely Lucheba watershed in Guizhou and Xiaoxincun watershed in Yunnan province representing southern China (Table 13.3) were established by adopting the principle of consortium in partnership with Guizhou Academy of Agricultural Sciences (GAAS) and Yunnan Academy of Agricultural Sciences (YAAS), the provincial governments and farmers' associations under the umbrella of Chinese Academy of Agricultural Sciences (CAAS), Beijing. Lucheba watershed is located at latitude 25° 37′ 7.03″ N and longitude 103° 12′ 8.41″ E in the central region of Guizhou province, 75 km away from capital Guiyang. It belongs to Tianlong Township of Pingba County. The watershed is part of the Wujiang river basin. Its altitude is 1350 m above mean sea level with average rainfall of 1284 mm y^{-1}.

The watershed comes under the climate of sub-tropic humid monsoon zone with hilly topography with an average temperature of 13.8 °C and belongs to karst landform. The population is 1350 with 365 households dispersed in 11 such natural

Table 13.3 Rainfall and other water balance parameters of two benchmark watersheds, China

Parameters	Lucheba	Xiaoxincun
Latitude	25°37′ 7.03″ N	26°57′ 40.74″ N
Longitude	103°12′ 8.41″ E	105°39′ 24.22″ E
Altitude (MSL, m)	1350	1100
Mean annual rainfall (mm)	1284	641
PET[a] (mm)	891	1464
AET[b] (mm)	831	641
WS[c] (mm)	384	Nil
WD[d] (mm)	60	815

[a]*PET* Potential Evapotranspiration,
[b]*AET* Actual Evapotranspiration
[c]*WS* Water Surplus
[d]*WD* Water Deficit
Source: Authors

villages (hamlets) are there on the township with six farmers' village groups. The total area of the watershed is 721 ha, out of which 54% is wasteland (390 ha). Major crops grown before watershed were rice, corn, rape seed, soybean, sunflower, kidney bean, cabbage, watermelon and vegetables like tomato, pumpkin, chillies, eggplant, etc. Xiaoxincun watershed, a natural village of Jinlei village group, Julin town, is situated in the mid-north of Yunnan province, belonging to Yuanmou county, which is located at latitude 26° 57′ 40.74″ N and longitude 105° 39′ 8.41″ E, 180 km away from Kunming, the capital of Yunnan province. It is a typical hot-arid valley area with mild slope of hills with the altitude of 1100 m above sea level near the Longchuanjiang river.

It is representative of the Xerothermic valley region in China with hot wet summer and warm dry winter seasonal climate. The total land area is 186.7 ha of which 90% is rain-fed. Due to erosion many gullies have developed accounting for 71.5% of the total land area. The total population in the watershed is 316, consisting 194 males and 112 females. There are 86 households. Wasteland accounts for 133.4 ha, forest 11.3 ha and other 2.3 ha. Major crops/cropping systems are rice–vegetable (broad bean, chillies), corn, groundnut, sweet potato and watermelon. The major constraints for crop production are lack of water due to low and erratic rainfall and frequent droughts. Soil erosion is equally a major problem as meagre natural soil resource is already dwindling (Fig. 13.9). Farmers in the watershed were resource poor.

Through participatory rural appraisal (Fig. 13.10) needs of the farmers were identified by the team.

Farmers expressed the constraints as well as suggested solutions/interventions and ranked them. Major constraints identified by the farmers were lack of income sources, lack of information, lack of transportation, access roads, water scarcity and low productivity. Most farmers suggested diversification of cropping systems (vegetables, watermelon, sweet potato, cultivation) improvement of roads, market access, drinking water, diversification of livelihood sources (livestock, fish, pig and poultry rearing).All the activities were undertaken in participatory mode with the community. As an entry point activity two drinking water schemes were completed

Fig. 13.9 Severe soil erosion (gully erosion) in Xiaoxincun watershed, China. (Source: Authors)

Fig. 13.10 Participatory rural appraisal in Xiaoxincun and Lucheba watersheds for needs assessment with potential solutions. (Source: Authors)

by harvesting water from natural springs and brining it in villages through pipeline in Lucheba watershed (Figs. 13.11 and 13.12).

- Construction of small masonry water tanks (cistern) (151 nos.) of 5 m^3 capacity for runoff water storage and used for irrigating vegetable and other crops.
- Cultivation on contour and across the slope.
- Soil test-based balanced fertilization introduced and soils were found deficient in K.
- Cost-effective pest control through integrated pest management (insecticidal lanterns)
- Forage grass production was taken up in 16 ha.
- Afforestation in wastelands (100 ha).
- Establishment of 260 biogas plants in the village households reduced pressure on fuel wood to protect forest.

Fig. 13.11 Various interventions implemented in the Lucheba watershed. (Source: Authors)

- Infrastructure development through roads construction in the villages was undertaken to link the villages to connect to main road to facilitate easy vegetable transportation.
- Poultry farming, rabbit farms and livestock rearing.
- Internet connectivity at community level.
- Capacity building in improved farming and income-generating activities (IGAs).

13.3.4.3 Impact of Integrated Watershed Management Approach in China

The watershed interventions at Lucheba impacted the land use pattern as average households irrigated land area increased substantially (94%) resulting in significant increase in the area and yields under horticulture and high-value crops like vegetable cultivation and rain-fed area reduced (34%) (Table 13.4) due to improved water conservation measures along with other improved practices with improved water use efficiency (Table 13.5) as reported by Wani et al. (2011a, b, c, 2013).

Drastic shift to the vegetable and high-value crops by two to sixfolds from the traditionally grown rice–18%and maize-rape seed system-38% due to additional

Fig. 13.12 Various interventions done in Xiaoxincun watershed through community participation. (Source: Authors)

water availability in the project ensured higher income(Tables 13.5 and 13.6) to the farmers.

To increase and sustain the yields of the high-value crops such as vegetables and fruit crop like watermelon, 151 small masonry water tanks with storage capacity of 5 m^3 were constructed. These tanks served as runoff harvesting and storage to provide supplemental irrigation during critical growth stages to high-value crops, mainly to vegetables and watermelon. On an average a total of 37,750 m^3 (about 63 mm) of runoff water was harvested in these tanks. These tanks provided

Table 13.4 Average households land use pattern during pre- and post-project at Lucheba watershed

Land use pattern	Pre-project	Post-project	% change
Landholding per household	0.62	0.62	Nil
Rain-fed	0.44	0.29	−34
Irrigated	0.17	0.33	94
Vegetable crops	0.1	0.21	110
Horticulture	0.01	0.02	100
Forest	0.03	0.03	Nil
Wasteland	0.02	0.02	Nil

Source: Wani et al. (2013)

Table 13.5 Rainwater use efficiency of vegetable crops and watermelon during pre- and post-project in Lucheba watershed

Crops	Pre-project period		Post-project period		Increase (%)
	Crop yield (t ha^{-1})	RWUE[a] (kg mm^{-1} ha^{-1})	Crop yield (kg ha^{-1})	RWUE[a] (kg mm^{-1} ha^{-1})	
Rice	6.36	4.95	6.75	5.26	6
Maize	5.89	4.59	7.03	5.48	19
Vegetables	36.9	28.8	41.9	32.6	13
Watermelon	11.3	8.8	29.3	22.8	161

Source: Wani et al. (2013)
[a]Rainwater use efficiency (kg mm^{-1} ha^{-1}) = Crop yield (kg ha^{-1})/mean annual rainfall (mm)

Table 13.6 The average crops yields and the cultivated area of households during pre- and post-project period, Lucheba watershed

Crops	Pre-project				Post-project				Change (%)	
	Yield (t ha^{-1})	SE	Area (ha)	SE	Yield (t ha^{-1})	SE	Area (ha)	SE	Yield (%)	Area (%)
Rice	6.36	0.017	0.16	0.322	6.75	0.004	0.13	0.225	6	−18
Maize	5.89	0.047	0.354	0.342	7.03	0.036	0.22	0.293	19	−38
Tomato	4.50	0.004	0.006	3.147	34.77	0.010	0.04	7.358	673	582
Chilli	23.20	0.009	0.065	2.765	34.28	0.026	0.20	2.248	48	210
Cabbage	29.10	0.013	0.103	3.072	38.45	0.021	0.20	2.735	32	95

Source: Wani et al. (2013)

supplementary irrigation covering 60 ha benefiting 141 households (Box 13.2). Substantial increase in the area under high-value crops were observed (Table 13.4).

In 3 years (2003–2005), the net yield advantage and net monetary benefit per unit of water conserved for watermelon and vegetables were 287.3 and 78.7 kg mm^{-1} ha^{-1} respectively. Net monetary benefits for vegetables and watermelon were 147.1 and 83.4 RMB (US$ 18 and 10) mm^{-1} ha^{-1} respectively, which reflected a similar trend of net monetary advantage per unit area were 9253 and 5246 RMB (US$ 1141 and 647) ha^{-1} respectively over 3 years due to availability of water during most critically required stage by these crops as a result of water harvesting tanks that facilitated the

Box 13.2: Mrs. Song Pangying in Lucheba Becomes a Micro-Entrepreneur

Mrs. Song Pangying is the wife of Mr.Peng who has 1 ha land in the watershed. Before watershed development Mr. and Mrs.Peng's family had income of 3000 RMB (US$ 478) per year from the land. However, with increased water availability, family started growing three crops of vegetables in a year. With increased income to 10,000 RMB (US$ 1594) per year, family started investing in poultry farming. Now Mrs. Song Pangying is running a small shop in another nearby village. She comes home once in a week. She is earning 30,000 RMB (US$ 4780) per year. Although, all the money is held jointly in family she spends about 33% on her own. She works for 17 h where as Mr.Peng works for 8–12 h, clearly indicating increased workload on her.

Mrs. Song's daughter in law Mrs.CaiyangJu, elder son's wife is 22 years old and has completed middle level high school and can converse a little in English. She cooks for the family and takes care of house in the absence of her mother in law. She feeds the animals and also does house work. She does not hold any money with her but she can spend the jointly held money in the family. She plans to expand vegetable cultivation to earn more income for the family to have better life.

In the family they do discuss about ways to increase family income? She said "Prior to biogas plant we used coal for cooking but it used to be a costly affair and gas is very cheap for us". (However, she does not find any time saving due to biogas but it is clean and she has no clue about the adverse impacts of coal burning on environment).

Even with increased workload Mrs. Song and CaiyangJu are happy with increased family incomes.

supplementary application of water (Table 13.6). The increase in the net returns of vegetable per unit of water per unit area was about 3.5 times in 2005 compared to 2003. The benefit-cost ratios in vegetables and watermelon showed similar trend of B:C ratios for rice post-project period. During post-project B:C ratios were 1.89, 1.56, 1.84, 1.46 for rice, maize, vegetable and watermelon respectively (Table 13.6). Higher B:C ratios were observed with vegetables than watermelon during both pre- and post-project periods (Wani et al. 2013).

The net storage capacity of five water harvesting structure (WHS) at Xiaoxincun watershed created was 37,626 m^3, which played a crucial role in increasing and stabilizing agricultural productivity by increasing RWUE and livelihoods of farmers in the watershed. Rainwater use efficiency of some of the major crops rice, maize, groundnut, watermelon and sweet potato during pre-project was 9.5, 7.0, 2.2, 16.4 and 30.4 kg mm^{-1} ha^{-1} while post-project increased to 11.2, 8.1, 2.8, 19.5 and 35.5 kg mm^{-1} ha^{-1} respectively (Table 13.7). The RWUE increased in the range of 15–29%. Sweet potato had the highest RWUE both during pre- and post-project

Table 13.7 Rainwater use efficiency of vegetable crops and watermelon during pre- and post-project in Xiaoxincun watershed

Crops	Pre-project period		Post-project period		Increase (%)
	Crop yield (kg ha^{-1})	RWUE[a] (kg mm^{-1} ha^{-1})	Crop yield (kg ha^{-1})	RWUE[a] (kg mm^{-1} ha^{-1})	
Rice	5800	9.5	6300	11.2	18
Maize	4500	7.0	5200	8.1	16
Groundnut	1400	2.2	1800	2.8	29
Watermelon	10,500	16.4	12,500	19.5	19
Sweet potato	19,500	30.4	22,500	35.1	15

[a]RWUE (kg mm^{-1} ha^{-1}) = Crop yield (kg ha^{-1}) / mean annual rainfall (mm). Source: Wani et al. (2013)

Table 13.8 Effect of watershed interventions on crop yields per unit of water conserved at Lucheba watershed, China

Crops	Net yield advantage (kg ha^{-1})	Yield advantage per unit of water conserved[a] (kg mm^{-1} ha^{-1})	Net monetary advantage (RMB ha^{-1})	Net monetary advantage per unit of water conserved[b] (RMB mm^{-1} ha^{-1})
Rice	390	6.2	535 (66) $	8.5(1.1)
Maize	1140	18.2	1396 (172)	22.3 (2.8)
Vegetables	5000	78.7	9253 (1141)	147.1 (18.1)
Watermelon	18,100	287.3	5246 (647)	83.4 (10.3)

[a]Yield advantage per unit of water conserved (kg mm^{-1} ha^{-1}) = Net increase in yield (kg ha^{-1})/ water conserved (mm)
[b]Net monetary advantage per unit of water conserved (RMB mm^{-1} ha^{-1}) = Net benefit (RMB ha^{-1})/ water conserved (mm) $ values in the parentheses are US $ (1US $ = 8.11 RMB). Source: Wani et al. (2013)

period compared to other crops and followed by rice, maize and groundnut. While the highest percent increase of RWUE during pre- and post-project was recorded in groundnut (29%), followed by watermelon (19%), rice (18%), maize (16%) and sweet potato (15%) (Table 13.8) (Wani et al. 2011a, b, c, 2013).

Amongst the crops grown at Xiaoxincun watershed watermelon showed highest B:C ratio. The B:C ratios during pre-project were in the order of watermelon (3.4), sweet potato (2.5), groundnut (1.8), maize (1.9) and rice (1.9) and during post-project are 3.9, 3.0, 2.2, 2.2 and 2.0 respectively (Table 13.9). Higher B:C ratios were observed with watermelon and sweet potato during both pre- and post-project period (Table 13.10). Various soil and water conservation measures and water harvesting structures in the watershed significantly influenced groundwater in the watershed. The mean groundwater level from surface in wells, those used for irrigation, which were located in the lower part of watershed on topo sequence before watershed interventions were 13.9 m while after watershed interventions it was 10.1 m. The annual mean groundwater level rose by 3.8 m due to watershed intervention, whereas the wells located in the middle part of watershed on topo sequence,

Table 13.9 Effect of watershed interventions on benefit-cost ratio at Lucheba watershed, China

	Pre-project		Post-project		
Crops	Yield (t ha^{-1})	B:C	Yield (t ha^{-1})	B:C	% Increase in B:C
Rice	6.36	1.77	6.75	1.89	7
Maize	5.89	1.26	7.03	1.56	24
Vegetables	36.9	1.4	41.9	1.84	32
Watermelon	11.3	0.47	29.3	1.46	210

Source: Wani et al. (2013)

Table 13.10 Effect of watershed interventions on benefit-cost ratio at Xiaoxincun watershed

	Pre-project			Post-project		
Crops	Yield (kg ha^{-1})	Net income (RMB ha^{-1})	B:C	Yield (kg ha^{-1})	Net income (RMB ha^{-1})	B:C
Rice	5800	5700 (703)[a]	1.9	6300	6250 (771)	2.0
Maize	4500	4100 (506)	1.9	5200	4980 (614)	2.2
Groundnut	1400	4500 (555)	1.8	1800	6200 (765)	2.2
Sweet potato	16,500	10,425 (1287)	2.5	22,500	12,675 (1564)	3.0
Watermelon	10,500	12,150 (1500)	3.4	12,500	14,950 (1845)	3.9

[a]Values in parentheses are US $. Source: Wani et al. (2013)

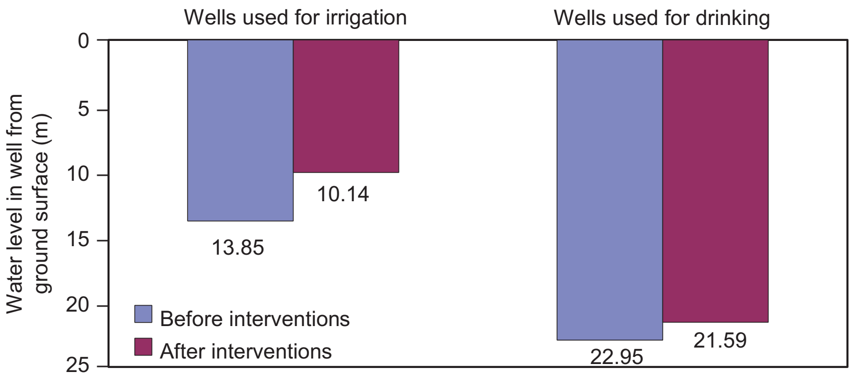

Fig. 13.13 Impact of water harvesting structures on groundwater level, Xiaoxincun watershed, China. (Source: Authors)

those used for drinking/domestic purposes, the increase in water level was 1.4 m (Fig. 13.13).

The location of wells on topo sequence had significant influence on water level in wells. The wells located at lower reach (valley) of watershed had water at shallow depth compared to the wells located at middle part of watershed. At Lucheba watershed, the area under forage production increased from 8.4 ha to 15.7 ha during project period, which resulted in the twin benefits of arresting soil erosion from sloping lands and increased forage supplies for animal-based livelihoods. The maximum area under forage crops was under rye (85%), followed by alfalfa (13%). The holistic watershed interventions increased substantially the livestock population and their productivity at Lucheba and other sites, and strengthened the alternative source of income and promoted biogas plants for daily energy needs of households in watershed areas. Construction of biogas plants in Lucheba watershed area has reached more than 230 in the village. By switching over to biogas plants for meeting domestic energy requirements, one household saved about 690 RMB (US $87) per annum because of the cost of purchasing coal and saved 3–4 h for women per day needed for collecting fuel wood from the forest and protected trees. Similarly, biogas initiatives benefited more than 80 families in Xiaoxincun. Seven solar water heaters were installed in the watershed villages as alternate eco-friendly energy sources for domestic use that reduces the pressure on the use of fire wood or electricity (Fig. 13.14).

Farmers' groups in watershed management (Fig. 13.15) shared great amount of information involuntarily amongst farmers. However, formation of farmers' associations in Lucheba watershed was found to be a very useful strategy to upscale the research outcomes to the larger community (Fig. 13.15). In case of Lucheba watershed, social organization received better attention, as seen from the interventions which was reflected in formation and functioning of farmers' groups in each of the six hamlets of the watershed. The project activities taken up in the watershed such as drinking water initiative, village approach road construction and farmers'

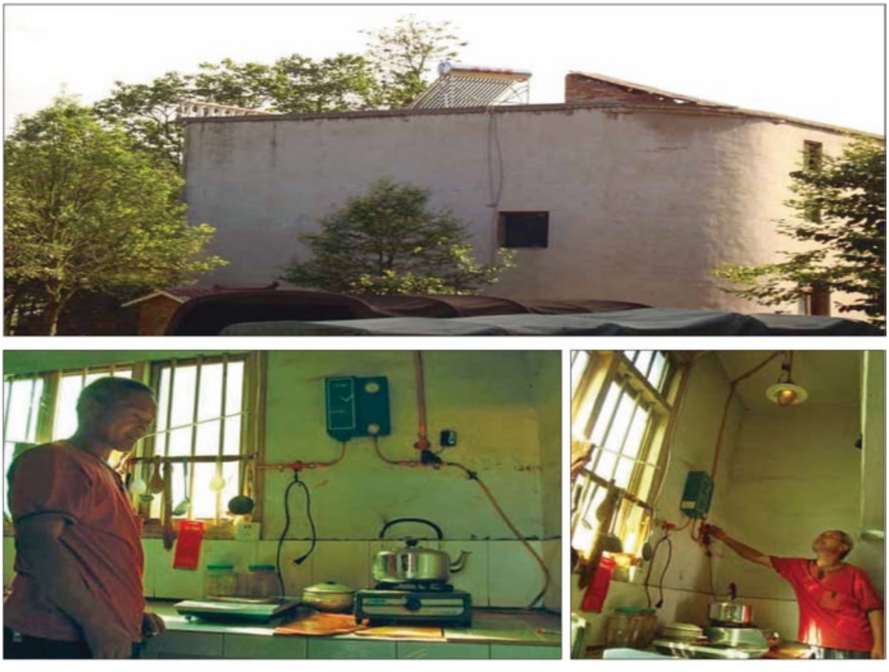

Fig. 13.14 Solar heater and biogas in Lucheba watershed houses. (Source: Authors)

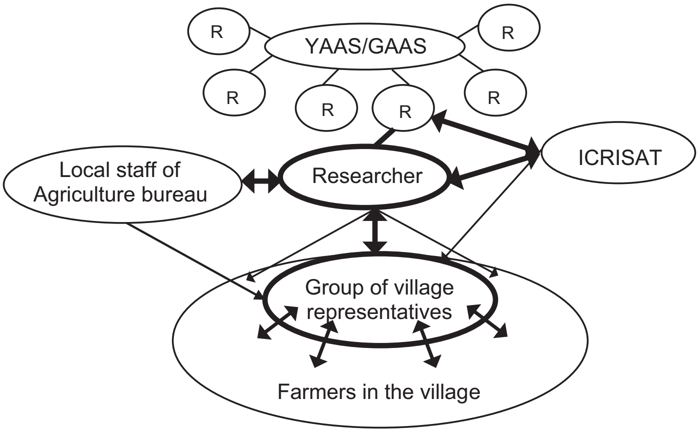

Fig. 13.15 Organisational linkages observed in the two benchmark watersheds in China. (Thicker lines indicate higher role in the programme. Arrows show information flows). (Source: Wani et al. 2013)

associations were based on strong social organization. From the functioning of these groups it can be inferred that these groups exhibit features of sustainability. Two farmers' cooperative associations with a focus on livestock development in their respective hamlets and one farmer's cooperative association with focus on vegetable cultivation are formed during the project period which significantly impacted on the livelihoods of the watershed community (Wani et al. 2013). Impacts as described by the community members are indicated in the Boxes 13.2, 13.3 and 13.4. The approach was scaled-up in eight provinces through ADB assisted integrated watershed management approach with US $ 100 million.

13.3.5 Increased Productivity Through Integrated Watershed Management in Vietnam

In Vietnam, uplands are fragile and sloping lands covering three-fourth of the territory and shelter one-third of the population of the entire nation threatened by issues of climate change vulnerability, erosion, declining forest cover, water scarcity, low crop yields and family incomes. Substantial areas of cultivated land are affected by severe soil erosion and land degradation with >11 million ha (33%) is barren land as a result of deforestation and inappropriate land use. As increasing population expand to steeper, more fragile areas in the uplands, more catchments are affected by severe soil erosion, declining soil productivity, and environmental degradation posing a threat to the economy and livelihoods of Vietnamese depending on these resources.

Box 13.3: Xiaoxincun Watershed Impact as Felt and Observed by the Community

Fifty five farmers dominated by 44 women community members attended the focused group discussion and from their words following impacts associated with watershed project interventions harnessed by the community members were recorded.

- Community hall constructed with the partial support from the project is found very useful by the women group for conducting group meetings, to undertake cultural activities, collective activities and festival celebrations, to discuss issues of how to enhance incomes for their families?
- Fodder and forage initiative has helped 26 families in the village and biogas initiative has benefited 83 families. Prior to project no one used to grow fodder plots in the village as well as no one had biogas plant.
- Prior to project 20 mules were there and now 50+ mules are there in the village.
- New knowledge (rainwater harvesting, kitchen garden, forage cultivation, improved cultivation methods) is perceived by the community as important gain from the project.
- Family incomes are increased and in most cases doubled during the project. Increased incomes are spent on food items, children education as well as purchasing of luxury items for family.
- Increased family incomes did not end up in alcohol consumption as there is not much difference for alcohol consumption in the village before and after the project.
- Women control money in the family. They are also decision makers in the family; in most cases they discuss things together and then take decision and money is also held together.
- Men use their portion to spend for smoking and drinking.
- Children get educated up to primary level and boys and girls are treated uniformly. However boys are preferred in the family although boys have to give gifts to girls’ family at marriage.
- Families are prepared to spend increased incomes for the elderly members in the families.
- Prior to biogas plant villagers were using fire wood and electricity for cooking and they had to spend at least 2 h for collection every day. Since 2005 due to biogas plants they do not cut trees or use electricity for cooking. There is also saving time (2 h) which they spend now on productive farm work (80%) and 20% on child care. For biogas plant, pig and human excreta are used as feed stock and slurry and slurry is used as manure in fields. The benefits from the biogas plant are ascribed as sparing of trees from cutting for fire wood, reduction in drudgery for women, clean environment, saved time and also resulted in good health.

(continued)

Box 13.3 (continued)

- In village tuberculosis cases are there and other health issues are joint pains, gall bladder stone, coughing. Villagers are not aware about relationship between smoking and TB.
- In village non-farm activities are limited to cycle repair and shoe repairing services. Farmers still have water shortage and they are trying to mobilize government help to lift water from river which is estimated to cost 300,000 RMB and government can contribute 90,000 RMB.
- Kitchen garden is also very preferred activity in the village. Almost each house has a small kitchen garden where they grow fruit trees such as papaya, jack fruits, lemon, longoan. Ninety percent of the produce from the kitchen garden is sent to market and 10% is consumed in the family.
- Community's aspirations are to have drinking water supply in the village, diversification of crops and water saving technologies. There is no school in the village and kids have to go 1 km away and market place is 4 km from the village.

Box 13.4: Mrs. Wang Xianhui, Women Group Leader in Lucheba Says Our Village Environment Is Cleaner than in the Cities

During the FGD in Lucheba Watershed women came forth happily to discuss with the team and indicated the impacts in their own words:

- On an average all families' incomes increased by 1200 RMB per year.
- Mrs. Wang Xianhui, group leader stated, "I wanted to go to city for better income but now I don't want to go to city as we all are having better income in the village itself. Moreover, in a village environment is better and cleaner than the city."
- When men stated project team. With the initial introductory discussions when the team asked them about the watershed activities and the impacts they can feel themselves, the members were very enthusiastic that workload on women has increased *substantially*, women said "We are happy as our family incomes have also increased substantially and we need to learn new methods more to earn additional income". With increased incomes whole family is happy.
- They wish to provide better opportunities for their children to learn and have better life. At present 33% women had no formal education where as 66% had middle level and elementary levels education (33% each).
- Women stated that they wish to invest their additional income in better water use system and roads.
- Collective action in the village has increased immensely for men as well as women members. Women in the village meet together to organize festivals. Discuss how to maintain village traditions? How to enhance use of new technologies? They do undertake excursions, group singing etc. which serves as good social bonding.
- They feel, diversification with fruit trees in this region will benefit them more.

13.3.5.1 Why Integrated Watershed Management in Vietnam?

The northern Vietnam hilly upland areas face multiple challenges of poverty, food insecurity, vulnerability to impacts of climate change, water scarcity, low crop yields and severe soil erosion causing on-site and off-site impacts of severe erosion. Severe erosion has broader economic and environmental implications including sedimentation, flooding, and reduced water quality resulting in poor living conditions of the people. In addition to above mentioned reasons for IWM approach described under Consortium approach and IWM, two on-farm watersheds viz.; Than ha watershed in Kim Boi district, Hoa Binh province and Huong Dao watershed in Tam Duong district, Vin Phuc province were established during two phases of the ADB assisted project. The central thrust of pilot research was to enhance productivity of land and water resources using IWM approach on the basis of a scientifically defined watershed that connotes a geographical unit rather than economic administrative units (like household or village).

13.3.5.2 How IWM Approach Was Implemented in Northern Vietnam?

The IWM Program, a new paradigm for research, was promoted under the Asian Development Bank (ADB)/International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) initiative for 6 years to address the above constraints. The holistic consortium on-farm participatory research approach in partnership with Vietnam Agricultural Sciences Institute (VASI) now Vietnam Academy of Agricultural Science (VAAS), Hanoi, Legume Research and Development Centre (LRDC), National Institute of Plant Protection (NIPP), Hanoi, National Institute for Soils and Fertilizers (NISF), Hanoi, The Ministry of Agriculture and Rural Development (MARD) and the farmers' groups was adopted. Science-led on-farm research interventions, capacity building of all the stakeholders along with watershed interventions, viz., introduction of new crops and cropping systems, soil and water conservation, integrated nutrient management (INM), integrated pest management (IPM), etc. were thoroughly discussed and decided by the farmers (Long et al. 2003; ICRISAT 2006). The interventions focussed on:

- Simultaneous development of land, water, and biomass resources in the light of the symbiotic relationship among them.
- Integrated farming systems approach.
- Meeting food, fodder, and fuel requirements of the human and livestock population that depend on these resources.
- Ensuring environmental sustainability along with economic viability by promoting low-cost technologies such as integrated nutrient management (INM).
- Improving land productivity by promoting improved agronomic practices, and input use.
- Releasing population pressure on land by creating non-farm employment.

- Development of local institutions for future management through participatory approach.
- Micro-watershed was used as a demonstration block for appreciating the benefits in terms of reduced runoff and soil loss through scientific measurements.
- Farmers in rest of the watershed evaluated improved soil, water, and nutrient management options and cropping systems along with IPM and IDM for efficient use of natural resources and sustainable productivity gains.

The partnership research at the benchmark watersheds (Tan ha and Huong Dao) was conducted under three sub-projects viz.; socioeconomic surveys- to collect baseline data, needs assessment, prioritisation of interventions, assess adoption patterns etc.; Eco-regional data bases- to assess agro-ecological potential, yield gaps, assess water balance and potential to diversify agri-systems and livelihood systems; On-farm research- to demonstrate innovative science-led rainwater conservation, harvesting(Figs. 13.16 and 13.17) and it's efficient use, soil, water, crop management options, market-led diversification to high-value crops, etc. for enhancing productivity and profitability for the farmers.

13.3.5.3 Impact of IWM in Tan Ha and Huong Dao Watershed in Vietnam

- In Than ha watershed only 28% area was cultivated although 53% of 1522 ha area was suitable for agriculture. Major crops in terms of cropped area are maize, sugarcane, legumes and watermelon. Groundnut was grown in the past but is not cultivated now due to severe problem of pod rot. Farmers used high quantity of inorganic fertilizers (Table 13.11). Usage of organic manure (39–46 t ha^{-1}) was limited to watermelon and sugarcane crops. The Huong Dao benchmark watershed located in Tam Duong district of Vinh Phuc province has 916 ha cultivated areawith 1727 households with 8128 people. Fifty-six percent of the population is dependent on agriculture for their livelihood. The major crops grown were

Fig. 13.16 Soil and water conservation practices in Vietnam: (left) contour bunding with pineapple and (right) stone barriers. (Source: Authors)

Fig. 13.17 Contour trenches (left) and groundwater recharging structures (right) in Vietnam. (Source: Authors)

Table 13.11 Input usage for various crops in Vietnam

Particulars	Maize	Watermelon	Sugarcane	Mung bean	Cowpea	Rice
Seed[1] (kg ha^{-1})	23	1	–	22	23	100
Urea (kg ha^{-1})	444	561	670	12	Nil	220
Super phosphate (kg ha^{-1})	525	579	554	500	500	500
Murate of potash (kg ha^{-1})	136	127	1467	Nil	Nil	85
Manure (t ha^{-1})	Nil	46	39	Nil	Nil	10
Labor (person-days)	198	552	414	190	215	200

Source: Long et al. (2003)
The average yields were low to moderate (maize 0.9–7 t ha^{-1}; watermelon 10–36 t ha^{-1}; and mung bean 0.3–1.2 t ha^{-1}) with low benefit-cost ratio (maize 1.4, watermelon 1.7, and mung bean 1.9)

rice, cassava and maize as main sources of income. Soybean, groundnut, sugarcane and vegetables occupied a small area.

- Large varying yield gaps existed among districts and provinces. Overall, the yield gap was 1010 kg ha^{-1} for summer season and 680 kg ha^{-1} for spring season for soybean; 2650 kg ha^{-1} for spring season and 2010 kg ha^{-1} for autumn season for peanut; and for maize it was 1990 kg ha^{-1} for summer season and 1650 kg ha^{-1} for spring season, indicating the potential for future yield improvements. Because of high rainfall in northern Vietnam, significant amount of surface runoff and deep drainage occurred leading to land degradation (Chuc et al. 2006) (Table 13.12).
- Maize was normally sown in spring and summer in the rain-fed area of northern Vietnam. Sowing window for spring season was 1–15 April and for the summer season it was 1–15 June. For six benchmark sites in northern Vietnam yield gap between simulated and province yields ranged from 1030 kg ha^{-1} (19.7%) in Ha Tay in the spring season to 2650 kg ha^{-1} (49.9%) in Hoa Binh in summer season (Table 13.13).

Table 13.12 Simulated potential and province average yield and yield gap of rainfed maize in the spring and summer seasons at benchmark locations in northern Vietnam

Location	Simulated yield (kg ha^{-1})	Province yield	Yield gap	Yield gap (%)
Spring season				
Vinh Phuc	4890	3290	1600	33
Ha Nam	5430	3520	1910	35
Ninh Binh	4800	3360	1440	30
Phu Tho	4980	3240	1740	35
Ha Tay	5210	4180	1030	20
Hoa Binh	4850	2660	2190	45
Mean	5030	3380	1650	33
Summer season				
Vinh Phuc	5330	3290	2040	38
Ha Nam	5570	3520	2050	37
Ninh Binh	5310	3360	1950	37
Phu Tho	5250	3240	2010	38
Ha Tay	5420	4180	1240	23
Hoa Binh	5310	2660	2650	50
Mean	5370	3380	1990	37

Source: Chuc et al. (2006)

- Mean simulated yields were compared to rainfed experimental and province yields for each location to calculate yield gaps. Because of high potential yield due to more favourable climate for peanut growth, the yield gap was larger in spring season (Table 13.13). Total yield gaps observed at Hoa Binh (3050 kg ha^{-1}), Ha Tay (3000 ha^{-1}) and Vinh Phuc (2700 ha^{-1}) were larger compared to other sites during the spring season. (Chuc et al. 2006).
- Using a simple water balance model (WATBAL), soil water availability and water surplus during the year for each location were also estimated (Pathak et al. 2002). All locations have at least 540 mm of water available for groundwater recharge or runoff water harvesting. This analysis showed the potential of the locations for reducing soil erosion and as well as water harvesting for supplemental irrigation during the dry periods (Table 13.14).
- Groundwater level monitoring in 10 wells on a topo sequence in Than ha watershed showed about 2.5–3 m increase in the water level in the benchmark watershed wells compared to those outside the watershed.
- Wide variation in biological soil quality attributes along the topo sequence and soil depths were observed (Table 13.15). High organic C content (8517–9633 mg C kg^{-1} soil) and soil respiration was recorded. Samples from top of the topo sequence showed more soil C, microbial biomass C and nitrogen (N), and respiration than the samples from middle and lower positions on a topo sequence indicated low erosion on top as fruit trees were grown there.
- High-yielding disease tolerant soybean cultivars (AK 06, DT 84, M 10, DT 22.4 and VX 93) evaluated in both watersheds, in Huong Dao benchmark watershed

Table 13.13 Simulated potential, experimental and province average pod yield and yield gap of rainfed peanut at benchmark locations in northern Vietnam

Location	Simulated yield	Exptl. yield	Province yield	Yield gap I	Yield gap II	Total
	(kg ha^{-1})					
Spring season						
Vinh Phuc	3900	2380	1200	1500	1180	2700
Ha Nam	4700	3330	2200	1360	1130	2500
Ninh Binh	3740	2550	1710	1190	840	2030
Phu Tho	3870	3400	1270	470	2130	2600
Ha Tay	4560	3200	1560	1360	1640	3000
Hoa Binh	4230	3200	1180	1030	2020	3050
Mean	4170	3010	1520	1150	1490	2650
Autumn-winter season						
Vinh Phuc	3270	2300	1200	970	1100	2070
Ha Nam	3920	2780	2200	1140	580	1720
Ninh Binh	3430	2700	1710	730	990	1720
Phu Tho	2910	–	1270			1640
Ha Tay	3880	2500	1560	1379	940	2320
Hoa Binh	3760	2800	1180	960	1620	2580
Mean	3530	2620	1520	1040	1050	2010

Source: Chuc et al. (2006)

cv. DT 84 and cv. VX 93 yielded higher grain yield (0.73 t ha^{-1}) compared to AK 06 (0.6 t ha^{-1}) At Tanh Ha Soybean cv. DT 22–4 gave 10% more yield than the check cultivar DT 84. Five soybean cultivars (AK 06, DT 84, VX 93, DT 22 and M 103) were evaluated during Autumn-Winter in the two benchmark watersheds. AK 06 & VX 93 soybean varieties yielded 2.4 t ha^{-1} grain yields as compared to DT 84 (2.1 t ha^{-1}). At Thanh ha highest groundnut pod yield of 1.18 t ha^{-1} was produced by cv. 9905–3 followed by L 16 (1.01 t ha − 1) while groundnut cv. L 17 gave maximum yield of 1.10 t ha^{-1} followed by cv. 9905–3 (0.86 t ha^{-1}) in Huong Dao watershed.

- Polyethylene mulch increased soil temperature by 2–3 °C in autumn-winter and 1–2 °C in spring at 10 cm depth promoted early (about 2–3 days) and better germination with good seedling vigor while in winter, good pod development and early maturity was noticed with associated conservation of soil moisture in the entire soil profile. Application of polyethylene mulch doubled the groundnut yield (1.5 t ha^{-1}) than the control (0.7 t ha^{-1}) treatment in autumn-winter season. Environment-friendly straw mulch was economical and increased groundnut yields by 71% over the non-mulch control treatment (1.2 t ha^{-1}). Significantly higher yields (3.23 t ha^{-1}) were recorded in polyethylene mulch treatment than in control (2.74 t ha^{-1}). The beneficial effects of straw mulch appeared to be masked by the increased incidence of fungal disease. (Ramakrishna et al. 2006). Similarly, soybean crop produced 113% increase in grain yield (1.7 t ha^{-1}) in polyethylene mulched treatment, 88% increase in straw mulched treatment (1.5 t ha^{-1}) and

Table 13.14 Analysis of water availability and duration of rainy periods for 10 locations in North Vietnam

Sl. No.	Location	Latitude	Longitude	Annual rainfall (mm)	CV (%)	DP[a] (mm)	Water surplus (mm)	Duration of rainy period (weeks)	Database (years)
1	Hai Duong	20° 56′ N	106° 19′ E	1553	19	1349	540	29	1960–93
2	Nho Quan	20° 18′ N	105° 44′ E	1930	24	1600	886	32	1960–94
3	Tuyen Quang	21° 49′ N	105° 12′ E	1712	16	1480	680	29	1960–94
4	Van Chan	18° 41′ N	105° 40′ E	1548	17	1340	544	29	1961–94
5	Dien Bien	21° 22′ N	103° 00′ E	1570	18	1357	565	27	1959–94
6	Moc Chan	20° 51′ N	104° 36′ E	1662	14	1438	640	29	1961–93
7	Thei Binh	20° 27′ N	106° 20′ E	1769	24	1471	749	31	1961–94
8	Ninh Binh	20° 15′ N	105° 58′ E	1854	23	1545	826	30	1960–97
9	Phu Tho	21° 40′ N	105° 21′ E	1756	25	1457	705	31	1970–98
10	Vinh Phuc	20° 19′ N	105° 36′ E	1585	23	1322	586	29	1970–98

Source: ICRISAT (2006)
[a]*DP* Dependable precipitation, i.e. amount of rainfall at 75% probability

Table 13.15 Variation in soil biological properties along the toposequence at 0–105 cm soil depth

Soil property	Lower	Middle	Top
Microbial biomass C (mg kg [1] soil)	108	112	125
(mg kg – 1 soil) Microbial biomass N	11	10	16
(mg kg - 1 soil) mineral N	19	18	12
(mg kg – 1 soil) Net N mineralization	9	8	10
Organic C (mg kg – 1)	8517	8233	9633

Source: Long et al. (2003)

75% increase in improved practice (1.4 t ha^{-1}) when compared to farmers' practice (0.8 t ha^{-1}). Groundnut crop produced 57% increase in pod yield (3.3 t ha^{-1}) in polyethylene mulched treatment, 38% increase in straw mulched treatment (2.9 t ha^{-1}) and 24% increase in improved practice (2.6 t ha^{-1}) when compared to

Table 13.16 Effect of improved production technologies on soybean, groundnut and maize yields, Autumn-Winter, in Vietnam

	Yield (t ha^{-1})		
Treatment	Soybean	Groundnut	Maize
Farmers' practice (control)	0.8	2.1	5.5
Improved practice (IP)	1.4	2.6	6.2
IP+ straw mulch	1.5	2.9	6.9
IP + PE mulch	1.7	3.3	7.4
CV (%)	5.3	5.1	4.6
LSD (5%)	0.14	0.28	0.59

Source: ICRISAT (2006)

farmers' practice (2.1 t ha^{-1}). Maize crop produced 35% increase in grain yield (7.4 t ha^{-1}) in polyethylene-mulched treatment, 25% increase in straw mulched treatment (6.9 t ha^{-1}) and 13% in improved practice (6.2 t ha^{-1}) when compared to farmers' practice (5.5 t ha^{-1}) (Table 13.16).

- Watershed soils were deficient in nutrients like boron, zinc, sulphur and molybdenum, trials with Comex and Grow more providing micronutrients showed increased groundnut (10–24%) and soybean (14–22%) yields (with and without *Rhizobium* inoculation) indicating good scope for reduction of N fertilizer from 30 to 15 kg ha^{-1}.
- Farmers diversified crops with pine apple and litchie in Huong Dao, and litchie, longan, papaya, sweet lime, custard apple and sapota in Hoa Binh. Maize, groundnut, soybean alley cropping with litchie or longan (750 ha) gave substantial yield advantages and attracted farmers.
- Scaling-up of IWM approach based on the Thanh Ha watershed, neighbouring districts of Thanh Ha, viz.; Luong Son and Lac Thuy preferred soybean cvs (DT 1 & DT 22)which gave 15% more yield over the local variety (1.2 t ha^{-1}) and groundnut varieties (L18 & L14) in Lac Thuy district. The farmers preferred L14 in spite of its lower pod yield as compared to L18 (2.7 tons and 3.2 t ha^{-1}, respectively) because of its high shelling percentage and thin pod wall (ICRISAT 2006).
- The two micro-watersheds equipped with digital recorders monitoring runoff and sediment samplers to measured soil loss and nutrient loss which showed that during annual rainfall of 1349 mm runoff of 29.5% rainfall was recorded. Total soil loss from the developed watershed was 6.8 t ha^{-1}.

13.3.6 Reducing Land Degradation and Improved Livelihoods Through Sustainable Natural Resources Management (NRM) in Thailand

13.3.6.1 Why IWM in North-East Thailand?

Northeast Thailand is situated between 19° and 14° N latitude, and 101° and 106° E longitudes encompassing 17.02 million hectares, (roughly 1/3rd of the entire country) and is the poorest region of Thailand in terms of resources, economy and per capita income. Most of the region's inhabitants are small farm-holders (80% rain-fed farming) having low income and face diverse agricultural and resource problems related to extreme environmental variability, an adverse climate, poor soils, and water scarcity. Northeast Thailand has annual mean rainfall between 1300 and 1400 mm, but with considerable variation. More than 90% of the annual rainfall occurs between May and October (i.e. rainy season).

Soils in the northeast region are generally sandy or sandy loam, both having low fertility and a poor moisture retention capacity. Through deforestation, the cultivable area has expanded rapidly which has changed the hydrologic environment and caused widespread salinity problems. Soil erosion, soil fertility deteriorations and water scarcity are some of the serious problems for increasing and sustaining productivity resulting in poverty and food insecurity for people in the region. Due to climate change many regions of Thailand had longer than usual drought periods, higher temperatures and unusual rainfall anomalies devastating rural economies in rain-fed areas. In Thailand, 46 out of its 76 provinces generally suffer from water shortage initiating a vicious cycle of soil degradation, low yields, poverty and low investment in rain-fed agriculture (Senanarong et al. 2003; Tongpoonpol et al. 2012). To address the above mentioned problems for sustainable development several watershed management programs were implemented in Thailand during 70s & 80s by various government departments and institutions but adopted compartmental approach without consulting other projects.

Most of the initial watershed programs by Thai Royal Irrigation Department, Ministry of Agriculture and Cooperatives, and Kingdom Watershed Management Program were primarily focused on increasing the availability of water for agriculture. Several other watershed programs by Agriculture Development and Research Center (ADRC) and Land Development Department (LDD) were focussed on reducing land degradation and improving soil quality. It was realized that more of the integration of multi-disciplinary partnerships is required for holistic management (Wangkahart et al. 2005).

13.3.6.2 How IWM Was Initiated in Thailand?

Under the ADB assisted project two representative benchmark watersheds viz.; Tad Fa, Wang Pu Sawarb, Phuphaman, and Wang Chai, Din Dum,Pu Wieng in Khon Kaen province were collectively selected by the consortium members. We adopted integrated science-based holistic participatory consortium approach for improving livelihoods of people in north east Thailand. Tad Fa watershed is situated about 150 km northwest of Khon Kaen and is at a junction of three big watersheds namely Mae Khong in the northeast, Chi in the east, and Pasak in the southwest and represents the "ecoregion" covered by these three watersheds. Main crops grown were upland rice (2.5–3 t ha^{-1}) for consumption, maize was the main cash crop which was fertilised and grown in two seasons (3–3.5 t ha^{-1}), ginger and soybean. Wang Chai watershed, Phuwiang district in Khon Kaen province is part of Nam-Phong basin and is about 75 km northwest of Khon Kaen city receives mean annual rainfall 1000 mm. Soils in Wang Chai watershed are sandy or sandy loam and low in organic matter content. Major crops grown in the watershed are rice, sugarcane, cowpea and groundnut. Small areas are also under fruit trees and vegetables. The average productivity of most of the crops is quite low. Integrated Watershed Management Project was implemented by consortium of theRoyal Department of Agriculture (DOA), the Royal Department of Land Development (DLD), Khon Kaen University (KKU), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and farmers' organisations. The majority of the northeast farmers are dependent on the cultivation of crops with >60% of the total family's income and livestock and agricultural employment account for about 32% income of families indicating employment outside the farms is necessary for the majority of NE farm families.

In Tad Fa watershed 17 farm ponds each of 1260 m^3 capacity (Fig. 13.18) and 13 at Wang Chai watershed were constructed by the LDD. In large areas the field bunds with vetiver grass as well as semi-circular rings around banana plants were put and contour cultivation on slopy lands was introduced (Figs. 13.19 and 13.20a) and total 9 km village roads were constructed. Drains were constructed for safe disposal of excess run-off water. Integrated nutrient management, integrated pest management, water management, crops and cropping systems were taken up. Several self-help groups were formed. Farm and community based activities were initiated to enhance the agricultural productivity and income. New crops and varieties were introduced in the watersheds. Village-based pure rice seed production farms were established. Training was given to farmers for value addition to field crops products. Hydrological gauging stations were also established in the pilot watersheds (Fig. 13.20b).

13.3.6.3 Impact of IWM in Thailand

- Rainwater harvesting, contour cultivation, contour bunds with vetiver, crop diversification with fruits, vegetables with INM and diversification of livelihoods resulted in development of all five capitals (Fig. 13.7) – increased productivity, profitability for the farmers along with conservation of natural resources.

Fig. 13.18 Farm-pond constructed in Tad Fa watershed with fruit trees planted on bund. Pond water is also used for fish cultivation. (Source: Authors)

Fig. 13.19 Vetiver planted on contour bunds (above picture) and (**a**). Conventional practice (before project), and (**b**) contour cultivation (after project). (Souorce: Authors)

- Water balance studies showed that at Tad Fa watershed with 1220 mm average annual rainfall potential evapotranspiration (PET) was 1511 mm and actual transpiration was (AT) was 1081 mm with 147 mm surplus water for harvesting. At Wang Chai with 1171 mm average annual rainfall the PET was 1315 mm and AT

Fig. 13.20a Semi circular vetiver rings around banana plants for effective soil and water conservation. (Source: Authors)

Fig. 13.20b Hydrological monitoring system at TadFa watershed. (Source: Authors)

1031 mm with 138 mm potential water for harvesting (Pathak et al. 2002). Farm ponds were used for growing fruit trees, vegetables as well as for irrigating rice and fish cultivation resulting in higher family income (Table 13.17). Non-DLD ponds were used for animals too and indicated threefolds higher income from fish (Table 13.17).

- Cultivation of groundnut preceding upland rice and application of groundnut straw either incorporated or mulched, increased growth and yield of rice by 24–53% over the non-straw treatments. Treatments in which groundnut stover was returned could supply sufficient N for rice as N application at panicle initiation did not significantly increase rice biomass growth and grain yield. Similarly, total biomass and grain yield of maize grown after groundnut cultivar Tainan 9 was higher than after mung bean. The amount of N fixed using ^{15}N isotope dilution technique revealed that the NHI (%) of mung bean was higher than % Ndfa (N derived from atmosphere). Thus mung bean is a soil fertility exhaustive crop and the succeeding maize crop yield was not significantly different from that following the non-nodulating groundnut. In case of sugarcane, preceding groundnut crop only gave increased income US$ 61.6 ha^{-1} and negative benefit was recorded ranging from US$ –437.5 to US$ –452.9 ha^{-1} with preceding maize due to low price, soybean- with low yield, pigeon pea, hairy indigo, and sunnhemp mainly due to no economic yield from these crops. In ratoon sugarcane, the highest net

Table 13.17 Households information having farm ponds with and without DLD farm ponds in Wang Chai watershed

Utilization and benefits	DLD farm ponds	Other farm ponds
Paddy area per household (ha)	2.7	2.4
Average no. of ponds per household	1.2	1.3
Rice as target crop (%)	100	90
Pumping use (%) Direct returns from farm ponds	100	100
Fish (Baht year^{-1})	600	1878
Vegetables (Baht year^{-1})	706	700
Fruit trees (Baht year^{-1})	435	591
Animal drinking (frequency)	0	187
Domestic use (frequency) effective utilization	37	67
Indiscriminate use	100%	62%
Deepening of pond	38%	24%
Enlargement of pond	8%	10%

Source: Wangkhart et al. (2012)

profit was observed in pigeon pea treatment (US$ 517.1 ha^{-1}) and lowest in the case of sunnhemp (US$ 209.0 ha^{-1}) (Banyong et al. 2012).

- Plantation of fruit trees provided a long-lasting suitable technology for erosion control, while sowing groundnut, rice bean and black testa cowpea through suitable cultivation was effective in reducing erosion on any degree of slope. Groundnut cultivars KK 5 and KK 6 performed better in terms of pod yield (26% and 30% respectively) and shelling % over local variety. Farmers gained about 48.8% and 31.5% by selling fresh pods (11.11 bahts kg^{-1}) of KK 5 and KK 6 respectively, ie, about 20,554 and 13,254 bahts ha^{-1} higher compared to the local cultivar (Idiphong et al. 2012).
- Higher runoff (320 mm) and soil loss (34.2 t ha^{-1}) was recorded with 1725 mm rainfall as compared to runoff of 131 mm and soil loss of 6.1 t ha^{-1} in case of fruit trees. Similarly, rainwater harvesting in ponds positively affected groundwater levels differently at different topo sequence positions (Wangkahart et al. 2012).
- Most important impact was change of mind-set of various departments officials working in watersheds that for achieving desired impacts partnerships are must amongst different stakeholders for providing holistic solutions to farmers as earlier watershed interventions provided compartmental solutions working in isolation. The consortium partners started adopting the consortium approach.

13.3.7 Improved Livelihoods Through Integrated Watershed Management and Convergence in India

Innovative integrated consortium approach for integrated watershed management (IWM) developed at *Adarsha* watershed, Kothapally as indicated above attracted several state governments as well as national government of India as well as corporate and international donors for scaling-up in India. Here we discuss the success stories from representative integrated watershed projects to benefit farmers through scaling-up the innovative consortium approach based on the work undertaken through CSR funds (ICRISAT 2017a, b, c, d, e, f, g; Wani and Raju 2018).

13.3.7.1 Why CSR Funds for Scaling-up IWM?

For addressing challenges of climate change, water scarcity, land degradation for achieving zero hunger, wellness with good nutrition and marching towards no poverty SDGs GoI notified the section 135 of the Companies Act along with Companies CSR policy Rules 2014 (GoI 2013). Companies must spend 2% of their annual profits on CSR activities. ICRISAT's motto "*from Science of Discovery to Science of delivery*" enabled the researchers to scale-up technologies and new knowledge which could harness the opportunity of CSR funds for scaling-up initiatives of IWM for improving livelihoods through climate resilient agriculture (Wani and Raju 2018) who compiled the results from CSR projects in a book titled "Corporate Social Responsibility: Win-Win Proposition for Communities, Corporate and Agriculture". Most of the CSR-IWM projects were in states of Andhra Pradesh, Maharashtra, Jharkhand, Rajasthan, Madhya Pradesh, Odisha, Karnataka, Telangana states (Wani 2021, Chap. 1 and Wani et al. 2021, Chap. 4 in this volume) where rain-fed areas are predominant, farmers are distressed and their family incomes are lower almost half of their urban counterparts (Wani 2020a, b; Singh and Wani 2020).

13.3.7.2 Approach Adopted in the CSR-IWM Projects

In all the CSR-IWM projects innovative-integrated consortium participatory approach with science-based interventions was adopted as described in detail above under 13.3.2 (Fig. 13.21).

For each project partners (knowledge generating& knowledge transforming/ delivering) along with concerned state government departments, NGOs, farmers' organizations and *Krishi vignan Kendras (KVKs)* were selected, consortium was formalised through detailed MoUs with clear responsibilities, timelines for delivering agreed outputs and financial arrangements.

Fig. 13.21 Holistic integrated consortium approach adopted in all CSR-IWM projects. (Source: ICRISAT 2017d)

13.3.7.3 Details of Watershed Sites and Interventions Made Under IWM

As mentioned earlier CSR-IWM projects supported by Jindal South West (JSW) Foundation six villages in Jawahar Taluka of Palghar district, Maharashtra benefitting 6000 families, and six villages in sandur Taluk of Ballari district, Karnataka benefitting 2225 families and Power Grid Corporation of India (PGCI) in Bethamcharala manadal, Kurnool district, Andhra Pradesh benefitting 5000 farmers and Ukkali in Basavana Bagewadi taluk of Vijayapura district, Karnataka benefitting 3000 farmers. Similarly, Rural Electrification Corporation of India (RECL) in four villages of Penukonda mandal, Ananthapuram district, Andhra Pradesh benefitting 1500 families and four villages in Wanparthy district (earlier Mahboobnagar), Telangana benefitting 2300 families, Coca Cola Foundation covering eight villages in Kolar district, Karnataka benefitting 1400+ families and Parasi Sindhh watershed

Fig. 13.22 Representative interventions made in the model watersheds in different districts. (Source ICRISAT 2017a, b, c, d, e, f, g)

covering three villages in Jhansi district, Bundelkhand region in Uttar Pradesh benefitting 1200 families. All the IWM initiatives were in water scarce regions with rain-fed areas affecting farmers with low crop yields, low family incomes, prone to severe land degradation and vulnerable to impacts of climate change (Fig. 13.22).

Key interventions in all the watersheds as reported (ICRISAT 2017a, b, c, d, e, f, g; Wani and Raju 2018) were:

- Community mobilization
- Rainwater harvesting and efficient management

- Soil health analysis- use of micro- & secondary nutrients (INM) and soil conservation
- Crop productivity enhancement measures including high-yielding cultivars
- Crop diversification through horticulture and vegetable cultivation
- Agro forestry
- Diversification of livelihoods- Income generating activities (IGAs) including livestock development
- Wastewater treatment
- Monitoring and evaluation
- Market linkages
- Capacity building

13.3.7.4 Representative Impacts Achieved in Different CSR Watershed Initiatives

- In Anantapur, rainwater harvesting and groundwater recharging structures constructed have created storage capacity of 35,600 m^3 resulting in total conservation of about 70,000 m^3 of surface run off water in 2–3 fillings. In the Wanaparthy watershed, a net storage capacity of 39,900 m^3 resulted in total conservation of about 99,500 m^3 of surface runoff water in two three fillings. Harvested rainwater helped in providing supplemental irrigation during dry spells, recharged groundwater and reduced run-off by 50% and significantly reduced soil loss (ICRISAT 2017a).
- The soil and water conservation structures at Kurnool watershed have created a net storage capacity of 81,200 m^3 resulting in total conservation of 203,000 m^3 in 2–3 fillings. Also, one percolation tank with 58,700 m^3 capacity with 144 m long bund length and 5.8 ha water spread area with average depth of 1 m was constructed (ICRISAT 2017b).
- In Parasi Sindh watershed in Uttar Pradesh rainwater harvesting capacity of 1,15,000 m^3 was created and there were 2–3 times of filling of structure during rainy season. Water table in Parasai Sindh watershed increased by 2.5 m on an average, as compared to pre-watershed interventions. Increase in water table was found as high as 4.0 m near stream locations and 2 m at upstream areas. Surface water in *nallah* is available throughout the year against 4 months only in untreated area.
- In Parasi Sindh watershed cropping intensity in treated watershed increased from 150% (pre watershed interventions) to 200%. About 40–200 ha permanent *rabi* fallow in the upper reach was cultivated due to improved yield of open wells after rejuvenation of *Haweli* system and other water harvesting structures. In Parasi Sindh watershed wheat yields doubled and 18–59% increased yields over farmers' practice with improved management of barley, pigeon pea, chickpea, mustard, and green gram were recorded(ICRISAT 2017g).General productivity of major crops increased up to 33% as compared to baseline productivity during rainy season and by 50–100% during *rabi* (post-rainy)season. Improved crop

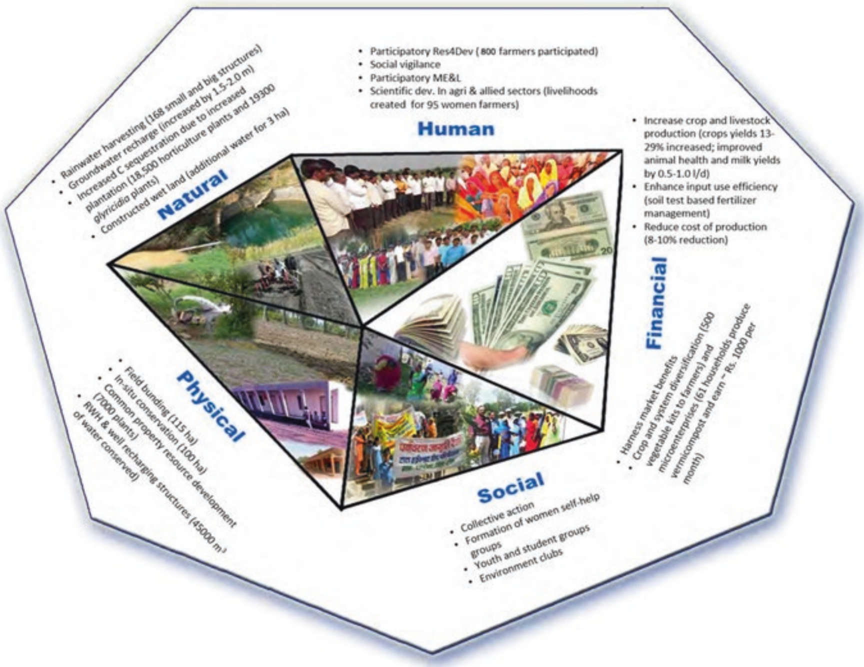

Fig. 13.23 Overall impacts in development of five capitals in Sandur taluk, Ballari, Karnataka watershed. (Source: ICRISAT 2017e)

management practices recorded 14–26% increased yields of *ragi* (finger millet), groundnut in Kolar watershed (ICRISAT 2017f).

- In Jawahar watershed in Maharashtra 50,000 cubic meter additional water was harvested during three feelings. Overall impact achieved in all five capitals is depicted in Fig. 13.23.
- At Parasi Sindhh watershed in Bundelkhand region of Uttar Pradesh, cost of irrigation to wheat crop (90% of cropped land) reduced bỳ 6000–12,000 Rs ha^{-1}. No. of livestock increased by 950–1300 and its productivity was substantially increased. Area under improved pasture and cultivated fodder has increased from 5 ha to 60 ha. About 2100 *desi-ber* plants were budded with improved cultivars. Two SHGs of landless were formed and their livelihood strengthened through leaf cup making machine. During implementation phase, about 10,000 human days employment was created through construction activities and adoption of agro forestry interventions. Now, 17,000 additional human days are created annually due to increased cropping intensity, crop demonstrations, agro forestry interventions, etc. Migration in search of livelihood has been reduced from the watershed area Even during continuous drought of 2 years (2014 & 2015), none of the farmers migrated from the watershed in search of livelihood opportunities (ICRISAT 2017g).

Table 13.18 Additional gain in yield and farmers' income with improved management practices, Kurnool watershed

Crop	Average % increase in improved practice over farmers practice	Additional yield gain (kg ha^{-1})	Additional economic gain ₹/ha
Maize (65 ha)	22	750	7500
Groundnut (35 ha)	10	150	6800
Pigeonpea (350 ha)	25	220	8800
Paddy (50 ha)	9	250	4500
Foxtail millet (200 ha)	35	400	8800

Source: ICRISAT (2017b)

Fig. 13.24 Income generating Dhal mill at Ananapur watershed and village seed bank at Jawahar watershed in Maharashtra run by women SHGs. (Source: ICRISAT 2017a)

- In Kolar watershed, Karnataka bund plantation with horticultural plants such as mango 4173 plants covering 18 ha benefitted 132 farmers and forestry species 4565 plants of silver oak, Gliricidia and neem covering 12 ha benefitted 40 farmers. Vermi composting beds of 3 m × 1 m × 1 m benefitted 40 farmers, which can prepare 10–12 tons of manure in 8–10 weeks. During four animal health camps more than 1200 cattle were vaccinated. Four silage making units were constructed to help improve quality of feed (ICRISAT 2017f).
- Stratified soil analysis revealed that in Anantapur watershed, 69% fields were deficient in phosphorus, 15% for potassium, 77% for sulphur, 94% for zinc, 77% for Boron and for organic carbon 87%. In Wanaparthy watershed, the deficiencies were 13% for phosphorus, 6% for potassium, 64% for sulphur, 69% for zinc, 63% for boron along with low carbon levels in 83% of the fields.The participatory soil test-based fertilizer trials showed 25–27% yield benefit in crops like groundnut and paddy in Anantapur watershed and 14–22% increased yields of groundnut crop in Wanaparthy watershed (ICRISAT 2017a).

- In Kurnool watershed soil analysis results revealed severe deficiency for organic carbon (17–85% deficiency), sulphur (36–100%), zinc (58–100%) and boron (0–75%). Yield gains with improved crop productivity interventions were 22% in maize, 25% in pigeon pea, 10% in groundnut, 35% in foxtail millet and 9% in paddy with additional income ranging from ₹ 4500 to ₹ 8800 per hectare (Table 13.18). In Vijayapura watershed improved crop management practices including soil test-based fertilizer recommendations, improved cultivars and *in-situ* moisture conservation practices showed productivity improvement by 27% in groundnut, 25% in pigeon pea and 25% in paddy (ICRISAT 2017b, c).
- In Jawahar watershed in Maharashtra sowing groundnut crop on BBF across the slope yielded 46% higher yield. Similarly, transplanted finger millet with balanced nutrient applied yielded 43% higher finger millet as compared to broadcasting seeds. During *kharif,* crop wise yield increase in paddy by 35%, groundnut–48%, finger millet – 45% and pigeon pea was 75% with improved management practice over the farmers 'practice (ICRISAT 2017d).
- At Anantpur watershed 215 Self Help Group (SHG) women member benefitted from various watershed activities. One hundred and twenty SHG members increased monthly income from ram lambs rearing of ₹2400 – ₹2800, petty shops run by 173 members increased income of ₹2000–₹3000 per month per family, tailoring by two members raised net income of ₹4000–₹5000 per month (Fig. 13.24)

Gangama's Success Story from Ballari-JSW Watershed

Gangamma K T from Kodalu village has been immensely helped by the JSW watershed project. She has 5 ha of land and was earning only ₹ 50,000 per year by harvesting dry land crops. After the initiation of the watershed project in her village, she single handed developed Sneha SHG group and became the leader of the group. She took a loan of ₹ 30,000 from the revolving fund given to the group and purchased one local breed cow. Through the artificial ***i***nsemination program, she managed to increase the breed and now has 4 HF, 1 Jersey, 2 local breed and four calves in her dairy business (Fig. 13.25).

She cleared the loan and the money is now with the group. She also procured a loan of ₹2,50,000 through the local bank and convergence activities and built a shelter for the livestock. The 4 milking cows provide a milk yield of 30 l per day and she sells the milk to the nearby factories at ` 40 per litre. As a part of the project, seeds were supplied for fodder crops and she grows the fodder in 0.40 ha of land. Green fodder used for the cows has ensured milk yields of 30 l per day from 4 milking animals. She now earns a net income of ₹24,000 per month and is thankful that the project helped her to reap the benefits and sustain her family (ICRISAT 2017e).

Fig. 13.25 Gangama's Success Story from Ballari-JSW Watershed. (Source: Authors)

13.4 Lessons Learnt and a Way Forward

Large yield gaps between the current farmers' yield and achievable potential, growing per capita water and land scarcity, vulnerability to climate change impacts are the greatest challenges of the twenty-first century to meet the SDGs of no poverty, zero hunger and wellbeing with good nutrition. In spite of available technologies and products available with researchers existence of *Death valley of impacts* is the main reason for rural poverty, food insecurity, malnutrition and vulnerability to impacts of climate change resulting in farmers distress. The science of delivery is very weak and not developed as scientists, development workers, policy makers and corporate worked in isolation in compartments and tried to provide supply driven solutions to the farmers. Above all, as evident in India, 51% of the farmers do not get any extension support (NSS 2013) and poor small farm-holders are deprived of new knowledge and products developed by the researchers. As the recent meta-analysis undertaken by the CERES 2030 based on more than 100,000 research papers indicated that except CGIAR scientists other scientists do not work with the small farm-holders and that's the reason for not reducing poverty globally (Nature 2020). The learning got from this unique scaling-up approach by scientists working at ICRISAT and other CGIAR centres are of immense value and would definitely help the stakeholders to achieve the SDG targets of zero hunger, no poverty and wellbeing with good nutrition. Important and critical learning are:

- Most important learning from the scaling-up work undertaken is that there is an urgent need to ensure that researchers adopt the learning cycle approach for the knowledge and technologies developed but not adopted by the farmers. Evaluation of the reasons for low adoption must be undertaken by revisiting the small farm-holders by the multidisciplinary team of scientists and assess the lacunae with open mind by the team members which must be deliberated by the team and documented as learning.
- Second important learning also validated by the CERES 2030 team meta-analysis (Nature 2020) is that researchers must work with small farm-holders and secondly they should provide demand driven holistic solutions by building partnerships instead of providing compartmental and supply driven solutions to the farmers which they are not keen to adopt. Working on demand driven solutions is very critical for reducing poverty, achieving food and nutritional security.
- Change of mind-set of researchers, research managers, policy makers and even editors of the scientific publications is must to accept that working on farmers' fields and that too with small farm-holders is not a low-rung scientific activity but it's a challenging science of delivery which must be strengthened. Important criteria for evaluating scientists work should be with more emphasis and weightage on how many farmers benefitted/adopted the new technology/knowledge/product rather than how many papers published in scientific journals. Science of delivery is a complex, challenging and emerging branch of science and it needs to be nurtured, developed and used for achieving larger desired impacts.
- For enhancing impact community participation is critical and to get higher quality of community participation (collegiate in place of cooperative-consultative – contractual participation). For better cooperation and participation of the community project should ensure tangible economic benefits to maximum community members considering equity. Free inputs except scientific knowledge/advice should be kept out of projects and free riders should be kept out. For rapport building with the community before starting the project knowledge-based entry point is far superior over the cash based activities such as opening a bore well, constructing a meeting room etc. which do not benefit larger section of the society.
- For addressing the issue of providing holistic and demand driven solutions for higher desired impact partnerships need to be built as needed by adopting consortium approach with clear responsibilities, expected contributions, financial arrangements and equal credit to all the partners. The Consortium approach based on the partnerships should be Innovative-Impact oriented- Integrated and Inclusive to be *Sustainable-Synergistic-Scalable* and *Socially acceptable* to address the issues of *Equity-Economic gain -Efficiency-Environment* protection to achieve *Convergence-Collective action- Capacity building* through *Consortium* (4ISECs) approach.

- Consortium approach harnesses synergy amongst the partners, avoids duplication of efforts and power of cooperation or collective action is far more than the financial investment capacity. However, transaction costs are high and team building of consortium partners is a must and not one-time activity. Through team building workshops standard operational practices (SOPs) for the consortium must be developed and internalised amongst all the partners. For successful operation of consortium leadership is critical and leader should be unbiased, able to absorb the failures and overcome the fears and not pass on to the members and liberal to appreciate contribution of each partner openly and generous in giving credit for the successes to partners. Leader should have foresight and also must be able to take calculated risks for new interventions which are proven, tested and assured success of 90–95% success.
- For achieving higher desired impacts of new knowledge/technologies of participatory research for development, dissemination of knowledge and information about technologies is critical. For better dissemination all means of communication viz.; traditional (wall writings, awareness meetings, pamphlets, group discussions, field/farmers days, publicity material in local language etc.) as well as new IT-based technologies (SMSs, use of social media, digital advisories, GIS, etc.) must be used in the scaling-up initiatives.
- On-farm participatory research cum demonstrations of new technologies with technical support from the experts is a proven tool which must be used for detailed monitoring of impacts (increased productivity, reduced cost of cultivation, increased incomes, improved quality of produce, valuation of eco-system services etc.) with full involvement and ownership of the farmers. During visits to demonstrations farmers must be empowered with full details of interventions, impacts and should be helped to build confidence to talk in front of visitors/ stakeholders (farmers, researchers, policy makers, officials etc.).
- Success stories must be identified collectively and independent person should record the success stories (to avoid bias for or against interventions) with farmers' full involvement with authentic data. Use of videos and suitable pictures are must for success stories documentation. Local farmers/farm facilitators/ volunteers/ SHG leaders should be capacitated to handle the equipment (recording and projecting) and good quality videos (farmer to farmer as promoted by Digital Green and used in several scaling-up initiatives) must be used for dissemination and collecting feedback from the farmers.
- Success stories are good learning tools for all the stakeholders and in a particular format (length, language, audio, video, etc.) can be converted for policy makers, researchers, farmers, development workers as well as development investors as needed
- The principles of scaling-up holistic participatory solutions are common across the countries and need to be adjusted as per local situations prevailing in that country. The consortium approach was successfully employed/used in Asia by several CGIAR institutions as well as international development investors such as CGIAR, World Bank, Asian Development Bank, SDC, UNDP, FAO and others.

- Drivers of success are common for scaling-up of technologies across the countries and regions. Important drivers are economic benefits, demand driven, holistic/integrated solutions, equally adaptable to different groups of farmers, scientifically proven with 90–95% success rate, scalable and knowledge should be at farmers' doorstep.
- Finally, scaling-up using success stories played important role and there is need to develop good formats for documenting/recording success stories to be used for effective dissemination of new knowledge/technologies and products to benefit millions of small farm-holders.

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Chapter 14
Farmers and Their Benefit: A Way Forward

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Abstract Achieving the sustainable development goals (SDGs) of food (SDG 2 – Zero hunger) and nutrition security (SDG 3 – good health and wellbeing) along with improved income security (SDG 1 – poverty reduction) with growing water scarcity, land degradation and impacts of climate change are the greatest challenge for the mankind during the twenty-first century. Yield gaps between the farmers' and the potential yields are largely due to weak science of delivery resulting in *Death Valley of impacts*. In this chapter, innovative consortium approach (4ISECs) to provide holistic and demand driven solutions are described for the farmers. These are scalable, economically remunerative. Several scaling-up projects implemented by CGIAR institutions in Asia and Indian Council of Agricultural Research (ICAR) in India are described to support this chapter. Technologies for reduced water requirement through direct seeded rice, higher potato yields through establishing effective seed supply chains, and use of climate resilient, drought-tolerant, high yielding crops and cultivars as well as conservation tillage are used in scaling-up initiatives. Finally, efficient monitoring, evaluation and learning system with examples are described for successful scaling-up through building partnerships, technologies and convergence to benefit millions of farmers. Lessons learnt from large scaling-up projects benefitting more than 10 million people are documented. Based on these lessons a way forward is suggested for successful scaling-up solutions for farmers through partnerships, convergence and technologies.

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14.1 Strengthening Science of Delivery Is Must for Impacts

In spite of new knowledge, technologies and products developed by the researchers and farmers', present crop yields in developing countries are lower by three to four folds of achievable potential yields (Wani et al. 2003a, b; Lobell et al. 2009; Rockström et al. 2010; Anderson et al. 2016; FAO and DWFI 2015). Such large yield gaps along with inefficient and long value chains and lack of suitable market access for the farm produce have resulted in rural poverty and farmers' distress and might have caused their untimely demise. Farmers and particularly small farm-holders who constitute large number (84%) in India and 500 million globally are deprived of new knowledge/information due to inadequate extension services at their doorsteps. In India, the national sample survey (NSSO 2013) indicated that 51% of farmers do not receive any extension support and the current government extension support reaches only to 11% farmers and remaining 38% farmers receive extension support from peer farmers, media and private agents (NSSO 2013). This challenge is further exacerbated with the vulnerability of small farm-holders in developing countries to climate change impacts, decreasing per capita water and land availability due to growing population with special reference to Asia and Africa. New technologies such as information and communication technology (ICT), internet of things (IoT), including machine learning (ML), artificial intelligence (AI), geographical information system (GIS), simulation modelling, remote sensing (RS) and penetration of internet and mobiles in rural areas provide an excellent opportunity to strengthen the science of delivery for achieving desired impacts to benefit millions of small farm-holders. Learnings from large scaling-up projects implemented by the CGIAR scientists benefitting millions of farmers in Asia as well as ICAR in India will definitely benefit other countries worldwide.

14.2 Lessons Learnt from Innovative Large Scaling-up Initiatives

The insights and learning recorded by teams of scientists who have implemented scaling-up initiatives through building partnerships with different stakeholders are of immense importance for strengthening the science of delivery to benefit millions of farmers globally. Here, we have synthesised the learning from each chapter starting with causes for existence of *Death Valley of Impacts* to achieve desired impacts in Asia benefitting more than 10 million farmers. Based on these experiences a road map has been suggested to achieve the SDGs targets of zero hunger, well being with good nutrition and no poverty.

14.2.1 Crossing Death Valley of Impacts Through Effective Science of Delivery

Globally 500 million small farm-holders are distributed in Asia, Africa and Latin America as described in Chap. 1. In India alone, smallholder and marginal farmers with less than two hectares of land account for 86.2% (125 million) of total farmers (145 million) possessing only 47.3% of the arable land (GoI 2018). However, 51% farmers do not get any extension support and are deprived of new developments in farming and allied sectors resulting in low adoption of technologies (Wani 2002, 2003).This has been referred as *Death Valley of Impacts* (Wani and Raju 2016). These findings find support from the CERES 2030 team's exhaustive meta-analysis using more than 100,000 published papers/reports (Nature Food 2020) There is a need for providing holistic demand- driven solutions through building partnerships, and participatory research with small farm-holders through collectivization mechanisms such as farmers' producer organizations (FPOs), self-help groups (SHGs), and farmers' cooperatives, instead of working in isolation and providing compartmental solutions which are not accepted by the small farm-holders.

The way forward suggested is to adopt innovative consortium approach adopting principles of 4 ISECs through strengthening science of delivery amongst researchers through changing their mind-set. To achieve this, a critical role to be played by research managers, development investors, policy makers, as well as editors/publishers of research journals who consider working with small farm- holders is less desirable. Except CGIAR researchers most researchers do not work with small farm-holders (Nature Food 2020) and urgent steps must be taken to change this scenario and strengthen the science of delivery.

Allied sectors play key role in family incomes of small farm-holders and diversification through market-led diversification with high-value fruits and vegetables and changing the concept from *Farm to fork* to *plate to farm* is suggested. By using new science tools, need to work with policy makers, putting in place on-line monitoring evaluation and learning (MEL) system in place and capacity building of all stakeholders to benefit millions of farmers. This approach is based on the empirical evidence showed in large size scaling-up projects in China, India, Philippines, Thailand and Vietnam and capacity building initiatives in southern and eastern Africa (SEA) through south-south collaboration initiative of government of India (Wani et al. 2021, Chap. 1 in this book).

14.2.2 Scaling-Up Using Agro-ecological Regional Approach

Scaling-up of targeted new technologies to appropriate regions is critical as observed in case of Vertisol (mostly spatially associated red and black soils; Bhattacharyya et al. 1993, 1999, 2006; Bhattacharyya 2021a, b) technology developed by the researchers at ICRISAT which was developed to alleviate water logging in Vertisols. However, targeting the technology to all Vertisol areas faced low adoption rates as all Vertisols selected were not prone to waterlogging as they had good drainage (Kshirsagar and Ghodake 1991; Wani and Raju 2020a, b) due to the presence of positive soil modifiers like calcium rich soil zeolites (Bhattacharyya 2021a, b). The FAO has defined Agro Eco zone (AEZ) as a near homogeneous area similar with respect to (a) broad soil groups, (b) overhead climate and (c) length of moisture availability period in relation to crop production.

In India, with varying climate and soils, the ICAR-National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) has divided whole country in to 20 AERs using length of growing period (LGP) as an integrated index for crop production as it considers soil water balance as a direct function of moisture availability for crop growth instead of only rainfall. For better targeting of technologies and crops 20 AERs were further subdivided in to 84 sub-regions using different feasible cropping systems in an agro-environment with modified FAO concept of LGP (Bhattacharyya et al. 2014, 2021a this book; Mandal et al. 2014). The AESRs give better understanding of climate change, rainfall, soil moisture availability, temperature and livelihoods options adopted by the farmers. Using AERs and AESRs along with the innovative consortium approach through building partnerships provides better tool for scaling-up suitable technologies and livelihood options in a given region and move towards achieving land degradation neutrality for sustainable development (Bhattacharyya 2020; Bhattacharyya et al. 2021a, Chap. 2 in this book).

14.2.3 Harnessing New Technologies for Empowering Stakeholders for Scaling-Up

There is an urgent need to strengthen empowerment of millions of small farm-holders across the developing world as even in country like India with largest research and extension network. Nearly 51% (74 million) farmers are not reached by the existing agricultural extension systems indicating the last mile delivery issues. New technologies have demonstrated their huge potential to strengthen knowledge delivery system to benefit millions of small farm-holders. Use of IT-based advisories delivered on farmers' phones, on-line monitoring system/dash board for research managers, farmer to farmer videos, websites, social media groups as well as short messaging systems (SMSs) along with traditional but transformed extension agents such as farm facilitators/volunteers are used successfully in large scaling-up initiatives such as *Bhoochetana, Bhoo Samruddhi,* *Suvarna Bhoomi yojane, Rythu Kosam,* more crop per drop and integrated watershed management benefitting more than 10 million farmers.

Partnerships with IT companies such as Microsoft and ICRISAT developed sowing advisories based on the historical weather data, weather prediction and estimating moisture adequacy index (MAI) and advised farmers to sow rain-fed crops like groundnut. In a pilot study, farmers who adopted sowing advisories sent on the mobiles recorded 30% higher groundnut yields than non-adopters in Andhra Pradesh. Similarly, using water balance modelling approach when and how much to irrigate advisories enabled farmers to save 30% water for crops without any yield reduction which helped farmers to reduce cost of cultivation and increased their profitability. New technologies have opened up new vistas for empowerment of stakeholders which must be harnessed for strengthening knowledge delivery systems to reach millions of farmers who are unreached currently resulting in large yield gaps as well as main cause of poverty for small farm-holders (Bhattacharyya et al. 2021b, Chap. 3 in this book).

14.2.4 "Seeing Is Believing" Approach as a Powerful Tool for Scaling-Up

"Seeing is believing" approach is a well-tested and proven tool for enhancing desired impacts through greater adoption by the farmers. Not only farmers but also for other stakeholders such as development investors, researchers and research managers, policy makers etc. as it provides opportunities for visualising the performance of technologies under real world situation as well as an opportunity to interact with the farmers who have undertaken participatory demonstrations. Important principle in this approach is, it should be conducted by adopting participatory principles of highest order. Including collegiate and cooperative participation rather than consultative and contractual participation, size of demonstration should be nearer to farmers' holding, and all operations needed in the intervention to be demonstrated must be conducted by the farmers.

Researchers should provide knowledge and farmers should contribute in cash/kind for needed inputs for the demonstrations to ensure demand driven solutions. Farmers must be empowered to take right decisions for the demonstrations and in all operations, transparency and full involvement is a must for crossing the *Death Valley of impacts*. Monitoring and evaluation should be concurrent and participatory and all partners involved including government representatives should be present when crop cutting experiments are done. The results should be publicised amongst policy makers, researchers, extension staff as well as farmers and consortium partners with clear SOPs to benefit the farmers. For farmers' meetings, Field Days, workshops, training events suitable policy makers should be involved for greater impact. Most important part is the solutions to be demonstrated must be holistic and well tested with 90–95% probability of success. As farmers' livelihoods are complex. Interventions proposed must be addressing their needs for crossing the *Death*

Valley of Impacts and supply driven solutions must be kept out (Wani et al. 2021, Chap. 4 in this book).

14.2.5 Harness the Potential of Neglected Crops for Achieving Zero Hunger and Nutrition

To address the issues of food security and nutrition for the growing population along with impacts of climate change there is an urgent need to expand the food basket as only three crops—wheat, rice and maize—cover 40% of all arable land globally, delivering more than 60% of the world’s consumption of calories and protein (FAO 1995). About 95% of the world's food needs are provided by just 103 species of plants when there are 300,000 edible species available in the nature out of which 7000 crop species are cultivated/domesticated (Garn and Leonard 1989). To achieve the Zero Hunger goal, the agriculture and food system has to be transformed into economically efficient, socially inclusive, and environmentally sustainable to improve dietary and production patterns, allowing everyone to access sufficient amounts of nutritious food (UN 2017).

For addressing the SDG 2 (Zero hunger) and all forms of malnutrition, the FAO has launched a regional initiative “*Future Smart Foods*” for the Asia-and Pacific Region which has been working closely with national governments and stakeholders in the region to formulate food security and nutrition strategy and policy mechanisms, promote nutrition-sensitive agriculture and provide data analysis and monitoring of SDGs for decision-making for increasing productivity and maximizing their nutritional outputs through the introduction of alternative crops such as the neglected underutilised species (NUSs).

Member countries have identified and prioritised local NUSs in the region and are being popularised amongst farmers. Indian example has demonstrated the potential of short-duration legumes such as chick pea, mung bean, and lentil. for cultivating rice-fallows and making the country self-sufficient within 3 years. The FAO is popularising the concept of FSFs and also promoting cultivation of diversified food crops and cultivars which are nutri-dense as well as climate resilient and less water requiring. This chapter describes the concept of FSFs as well as how it is implemented in partnership with member countries along with examples (Li et al. 2021, Chap. 5 in this book).

14.2.6 Self-Sufficiency for Pulses in India Through Scaling-Up Rice-Fallows Cultivation

Pulses are the main source of protein for the large vegetarian population in India (55% of 1.33 billion) which are cultivated largely as rain-fed (78%) crops on >27 m ha and is the largest producer, consumer of pulses in the world. However, till 2017 India had to import 6 million tons pulses to meet the local demand (UN 2017) annually. Globally, India ranks first in area (38%) and production (28%) of pulses. Using new science tools like remote sensing (RS), geographical information system (GIS) 11.6 m ha rice-fallow areas were identified as an opportunity to increase pulses production. The pulses are low water requiring crops therefore have a very low water footprint. The multi-pronged innovative strategies adopted by the government such as adopting mission approach through convergence, partnerships and providing integrated solutions through increased availability of quality seeds of newly released varieties, promotion of micronutrients, micro-irrigation, integrated diseases and pest management along with positive policy support from the Government of India in terms of announcement of remunerative minimum support price (MSP) well before sowing and assured procurement at MSP etc. enabled scaling-up initiative. The *Pulses Mission* scaling-up initiative enhanced contribution (8–9%) of the pulses to total food grains basket in 2018–19 in comparison to the previous years (6–7%), which was the ever highest after 2000–01. The productivity of pulses increased by 41% to reach 853 kg/ha during 2017–18 from 607 kg/ha during 2000–01, and the production by 90% whereas area increased by 35% only during same period. The innovative integrated partnership approach for scaling-up pulses production in India provides the best example for scaling-up any program in developing countries in Asia and Africa. It could turn India from largest pulses importing country to self-sufficient country for pulses through innovative scaling-up initiative as well as enhanced water and land use efficiency which are critical for achieving SDGs of food, nutrition and income security for small farm-holders (Rajender et al. 2021, Chap. 6 in this book).

14.2.7 Diversification with Winter Legumes for Cultivating Rice Fallows in Indo-Gangetic Plains

In continuation of FSFs and pulses revolution in India, ICARDA played and playing an important role along with other CG centres for diversifying rice fallows in Indo-Gangetic Plains (IGP) covering India, Bangladesh, and Nepal. Out of 15 million ha rice fallows in IGP, five million ha were identified as suitable area for growing pulse crops like lentil, grass pea, chickpea, pea, mung bean and black gram using new science tools viz. remote sensing, GIS and ground truth. Holistic and integrated approach including availability of seeds of climate resilient pulse crops must be ensured through strengthening local seed systems and participatory demonstrations using the principle of *Seeing is believing* and cluster approach enabled scaling-up in Bangladesh, India and Nepal.

More than 550,000 farmers are benefitted through scaling-up initiative of lentil and grass pea cultivation. Empowerment of stakeholders and concurrent monitoring evaluation and learning (MEL) by the team of all partners including policy makers ensures timely changes in the scaling-up strategy and higher adoption. Economically remunerative crops, and cultivars with value addition through empowerment of women groups ensured higher adoption of holistic solutions by the farmers which highlighted the role of enabling policies and institutions in scaling-up process. Continued flow of new technologies and products developed by researchers should be ensured in farmers' fields where partnerships through consortium plays important role (Sarker et al. 2021, Chap. 7 in this book).

14.2.8 Environment-friendly Rice Cultivation Is a Must for Sustainable Development

Rice is the food for 3.5 billion people worldwide and is also one of the three crops (rice, wheat and maize) which are cultivated on 40% of arable land globally and provides 60% calories and protein intake of global population. However, puddled rice is also known for its very high water use (around 5000 l per kg rice production) and greenhouse gases (GHGs) foot print (55% of agricultural GHG emissions). Skewed government policies in Asia since green revolution resulted in expanding rice cultivation to new areas which were not waterlogged and artificially created puddling. For sustainable development, globally cry for resource conserving rice cultivation has grown louder and louder.

Resource conserving rice growing practices such as direct seeded rice (DSR), system of rice intensification (SRI), alternate drying and wetting are being evaluated. Direct seeded rice (DSR) which is labour and water saving cultivation technique reduced water consumption by 30–50% as well as reduced the GHG foot print and increased profitability for farmers without reducing yields. Looking at the scaling-up of DSR in Sri Lanka, USA, and Malaysia development and dissemination of suitable rice cultivars for DSR is critical and empowerment using new dissemination methods such as Rice Doctor, web & GIS- based rice monitoring system can be used successfully.

Empowerment and providing holistic solutions played important role in scaling-up DSR *albeit* not without enabling policies and institutions. Sustainable development as well as achieving food, nutrition and income security for small farm-holders can be achieved through scaling-up of resource (water, labour and energy) conserving technologies such as DSR by adopting holistic approach to overcome the issues of water scarcity, GHG emissions, growing labour scarcity without reducing productivity and profitability for the farmers. Importance of strengthening knowledge delivery system cannot be under estimated which played important role for scaling-up through partnerships using participatory demonstrations (*Seeing is believing* approach) (Sandhu et al. 2021, Chap. 8 in this book).

14.2.9 Sustainable Intensification of Potato in Asia

Potato is food for 1.3 billion people and its consumption in Asia has increased from 11 to 33 kg per capita annually, particularly in south and east Asia over the time and increase is expected to continue with growing population and increasing incomes.

Sustainable intensification of potato in Asia can be achieved through low-cost apical root cutting (ARC) technique for producing quality seed material at low cost through farmer producer organization (FPOs) in place of aeroponic culture which needs heavy investment and is also time consuming. The farmers are connected with suppliers of needed inputs and have increased potato productivity up to 100%. The CIP has piloted scaling-up of ARC seed production in Karnataka, Haryana, and Odisha, India in partnership mode through participatory on-farm research cum demonstrations enabling farmers to produce lakhs of ARCs and each ARC is able to produce 10 seed tubers.

A business model for seed production through ARC has been piloted and validated for profitability successfully. Sustainable intensification of potato cultivation in India can be achieved by strengthening the knowledge delivery system for farmers to adopt improved knowledge/technologies such as zero tillage potato cultivation, ARC of improved stress-tolerant cultivars at their doorstep. Holistic integrated solutions including backward and forward market linkages as well as collectivization for promoting micro-enterprises and achieving scale for operations are must for sustainable intensification of potato (Baruah and Mohanty 2021, Chap. 9 in this book).

14.2.10 Scaling-Up Enhancing Water Use Efficiency Initiative in India

Unique and innovative scaling-up initiative of Water Resources Ministry, Government of India by undertaking 50,000 farmer participatory action research program (FPARP) by the researchers in 21 states demonstrated water saving technologies. The initiative established increased productivity, incomes and reduced water consumption through different technologies. However, for enhancing adoption by the farmers it is recommended that science of delivery to benefit farmers as well as refinement of technologies as per local situation is essential. For enhancing desired impacts public-private partnership particularly for local skill development in drip and sprinkler irrigation as well as convergence of different technology dissemination programs of the government along with improved water control in canal system is recommended.

More importantly water technology centres should do more research for development and strengthen science of delivery particularly so for efficient methods of irrigation to develop sustainable water management practices and scale-up the same to benefit the farmers. As GoI has taken the approach of FPARP, other governments may initiate such activities. The GoI need to strengthen FPARP initiative for popularising all such improved technologies in integrated manner (Palanisami et al. 2021, Chap. 10 in this book).

14.2.11 Conservation Agriculture Is Must for Sustainable Development

Green revolution in south Asia ensured food security but also caused severe degradation of natural resources mainly land and water. Impacts of climate change, water scarcity and increasing land degradation calls for transforming agricultural practices by shifting to conservation agricultural practices. Most of the CA work in IGP is confined to rice-wheat systems and that too where after rice wheat is grown with zero tillage. The conservation agriculture as defined has three interlinked principles of minimum mechanical soil disturbance, soil cover with crops/cover crops/residues, and diversified crop rotation.

However, all these principles are not followed in south Asia, but lot of natural resource conservation interventions such as watershed management, minimum tillage and in-situ rainwater conservation measures as well as rotations with legumes are adopted extensively in south Asia. The CA where in rice-wheat rotation rice straw can be used as soil mulch can reduce the environmental pollution in IGP caused due to burning of straw before wheat sowing as well as return valuable carbon to soil to build soil fertility. Promotion for increased adoption of DSR in rice-wheat rotation in the IGP can increase area under CA in IGP substantially. It calls for convergence and partnerships for mechanization of CA and suitable machineries need to be developed and promoted on hire basis through Uberization to benefit small farm-holders (Jat et al. 2021, Chap. 11 in this book).

14.2.12 Robust and Dynamic Monitoring, Evaluation and Learning System Is Must for Scaling-Up

With increasing emphasis of development investors on climate resilient and sustainable management of natural resources to achieve the SDGs target, impact of each intervention must be at desired level. To reach the desired level in scaling-up programs is a challenging task however, with the help of independent expertise concurrent monitoring, evaluation and learning system must be put in place. Before the program initiation outputs and outcomes must be carefully selected and appropriate indicators also need to be identified which are specific, measurable, achievable and time bound (SMART). Appropriate method also has to be identified and use of IT technologies along with GIS, RS, simulation modelling, econometric modelling along with conventional data capturing methods, robust and dynamic MEL system can be put in place for achieving the desired level of impacts in scaling-up projects.

Capacity building and awareness raising amongst the stakeholders plays an important role. Success stories/case studies can be effectively used for assessing the impacts of scaling-up programs. However, putting institutional mechanism in place for regular MEL is critical and should be used as a learning tool for modifying strategy for implementing scaling-up programs. Theory of change mechanism can be successfully employed for the MEL process which can be accomplished through studying the three types of indicators viz., process indicators, outcome indicators and impact indicators. The results from the MEL mechanism must be disseminated suitably to all the stakeholders and midcourse correction in the strategy is to be done for achieving the desired impact from scaling-up programs (Kumar and Palanisami 2021, Chap. 12 in this book).

14.2.13 Success Stories Can Enhance and Disseminate the Impacts by Using as Effective Tool for Empowerment

Success stories documented by independent experts can be used as effective and efficient tool for empowerment of stakeholders as well as can be converted in suitable formats for donors, policy makers, and research managers. Success stories can be in the form of videos (farmer to farmer) or documented with suitable and good quality geo-tagged pictures and opinions of the farmers in their own words. Success stories from different countries in Asia clearly indicated that these are country neutral/without boundaries and can be successfully used in any country for dissemination and empowerment of stakeholders.

Selection of technologies/interventions as well as subjects for identifying success stories must be done in consultation with team members as well as informal discussions with the farmers which must be validated with hard data from the field. The farmers identified for recording success story must be a representative, preferably a small farm-holder, apolitical who can be trusted by the peer farmers. Good quality and appropriate pictures or recordings collection is a continuous process and cannot be onetime activity.

Farmer to farmer videos approach developed by Digital Green are successfully used for documenting feedback from the farmers along with the success story where in farmer speaks. Peer to peer farmers trust is higher than with the project staff and the selected farmers need to be empowered suitably to discuss the matter in the video independently. It's a powerful tool if done well and suitable format need to be adopted depending on the target group. For example, Coffee Table books with more pictures and less written material can be a powerful tool for convincing donors, policy makers and research administrators. Farmer to farmer videos are proven their effectiveness in scaling-up programs in India and once uploaded on U-Tube can be accessed by the farmers from other regions/countries equally well (Wani and Raju 2021, Chap. 13 in this book). Shortened versions with one or two pictures can be used in research publications as boxes to attract the readers' attention. Success stories are well proven as effective prototype for dissemination and scaling-up initiatives.

14.3 A Way Forward

It's a well-established fact that large yield gaps between the farmers' present and the potential yields are a cause of concern. Food, nutrition and income security for small farm-holders are largely due to "*Death Valley of Impacts*" because of low adoption of available improved knowledge, technologies and products by the farmers (Anderson et al. 2016; Nature Food 2020; Wani et al. 2002, 2003b, 2009; Wani and Raju 2016, 2018, 2020). Recent meta-analysis by the CERES 2030 team based on >100,000 published papers and reports indicated that poverty cannot be reduced mainly due to compartmental supply driven solutions provided by the researchers without working with small-farm holders.

The researchers working at CGIAR centres such as ICRISAT have suggested open-minded learning cycle approach undertaken by a multidisciplinary team of researchers to assess the reasons for low adoption of technologies by the farmers (Chap. 1 in this book, Wani 2021). With vulnerability of small farm-holders to adverse impacts of climate change resulting in increased frequency of drought spells, increased variability in rainfall events, increased water scarcity and land degradation there is an urgent need to transform agriculture in developing countries across the globe. Scaling-up of impact- oriented solutions for the farmers is the need of the hour for achieving the SDG targets of no poverty, zero hunger and wellbeing of human beings with nutrition. Based on the lessons learnt from several large scaling-up projects successfully implemented by the CGIAR and ICAR provide good opportunities for enhancing desired impacts through scaling-up initiatives implemented properly.

- **Science of delivery must be strengthened:** The CERES 2030 team's meta-analysis as well as the ICRISAT researchers' work since 1995 clearly established that the weak link for achieving the desired impact is mainly due to weak science of delivery. In a country like India, government extension support reaches to only 11% farmers and 51% farmers do not receive any extension support (NSSO 2013). Strengthening science of delivery to cross the *Death Valley of impacts* calls for hard decisions by the research managers, policy makers, researchers as well as editors/publishers of the scientific journals. Linking on-station research to on-farm sites is must and to achieve these researchers must work with small farm-holders.
- **Changing the mind-set of stakeholders is must:** Researchers from CGIAR institutes work more with small farm-holders in comparison with researchers from other research institutes, who are constrained with several factors. This may be improved by changing the criteria for assessment of researchers' performance. More emphasis need to be given on how many farmers adopted the new knowledge/technologies/products rather than the number of papers published by the researchers in reputed journals. The editors/publishers of scientific journals also need to change their mind-set who considered working with small farm-holders is not strategic and not important for publications.

- **Provide holistic and demand driven solutions:** Low adoption rates are largely due to compartmental and supply driven solutions developed without involving farmers and provided to them. It is well proven and tested that holistic demand driven solutions which provide economic gain to the farmers are adopted by the farmers. For providing holistic solutions partnerships are must and adoption of 4 ISECs approach (Innovative-integrated-impact oriented and inclusive approach which is Sustainable-scalable-synergistic and socially acceptable which provides Economic gain-environment friendly-equitable and efficient by adopting Consortium-convergence-collective action and cooperation with stakeholders).
- **New science tools including IT should be harnessed to benefit farmers:** New science tools such as satellite imageries, GIS, simulation modelling, AI, ML, IoT, mobile telephony, social media as well as conventional proven extension methods and approaches need to be integrated to cover the last mile delivery which has eluded large impacts. India's example of self-sufficiency for pulses through partnerships, using satellites to identify suitable rice-fallow areas for targeting and providing integrated holistic solutions is praise worthy implemented by the government agencies.
- **Value addition and market linkages are critical to benefit the farmers:** Along with increasing productivity for ensuring profitability it is essential to adopt value chain approach for small farm-holders through collectivization mechanism such as self-help groups (SHGs), farmer producer organisations (FPOs), farmers' cooperatives as demonstrated in China, India, and Thailand. Similarly, allied sector income-generating activities also must be undertaken during scaling-up for diversifying the sources of livelihoods. New technologies and government policies such as refrigerated Kisan Rail initiated by the GoI to connect farmers to large cities would benefit the farmers by connecting them to distant markets. Here too, role of FPOs or cooperatives is critical for logistic arrangements.
- **Stress on Women empowerment and capacity building:** Empowerment of women for income-generating activities (value addition, diversification, allied sector activities) plays important role in sustainability of scaling-up solutions. Holistic solutions for enhancing family incomes and better nutrition undertaken by women and youths ensure sustainability as well as adoption of new technologies such as IT tools at local level. In addition, other capacity building interventions as per the stakeholder group must be taken-up by the qualified consortium members. For each scaling-up initiative, master trainers should be identified and empowered to undertake capacity building and proper documentation of each activity in a timely manner is essential. Exposure visits for the farmers to identified sites for seeing the performance of specific interventions as well as interaction with the farmers is a proven tool for adoption.
- **Strengthen participatory on-farm research strategy**: Approach of on-farm participatory research cum demonstrations "*Seeing is believing"* is well tested and proven strategy for scaling-up which should be adopted and transparency in all aspects need to be maintained. It must be ensured that no free riders are allowed to be part of the program, and the principle of "*Users pay"* in cash or kind as agreed must be followed in totality. Any contribution of farmers in the

participatory research ensures that demand-driven knowledge/ technologies/ products are demonstrated as to get any contribution from farmers, farmers will ask or raise good number of questions/doubts and unless satisfied they don't come forward. Honorary farmers or farmer facilitators/farm leaders should be empowered to bridge the gap of extension personnel who can serve as bridge between researchers/extension staff and farmers through building public private partnerships. However, these honorary farmers should never be allowed to become part of the government extension machinery. The private company partners could pay honorarium to such para extension staff/personnel.

- **Strengthen simplified risk coping weather-linked crop insurance:** Small farm-holders are most vulnerable to vagaries of monsoon as well as impacts of climate change. There is need to simplify and popularise schemes of the Government of India as the *Pradhan Mantri Fasal Bima Yojana* (Prime minister's crop insurance scheme) to benefit large number of small farm-holders to cope with the losses caused due to weather as well as pest. At the same time diversification of livelihood sources also must be undertaken to minimize dependence on crop incomes.
- **Enabling policies and institutions are must for scaling-up:** Enabling policies and institutions are critical for scaling-up science-based interventions in terms of incentivising inputs, recommended, markets, price control as well as import and export management, conflict resolution mechanisms between private companies and farmers as well as convergence of related initiatives by different departments, etc. Policies should be in place to ensure sustainable management of natural resources such as proper land use, water saving technologies, agro-eco region and market demand-based crop planning etc. through proper implementation in letter and spirit by putting in place incentives as well as punitive mechanisms.
- **Robust and dynamic MEL system must be institutionalised:** No scaling-up initiative can be successful without proper MEL system as it is said "*What gets measured gets delivered*". Clear roles and responsibilities for each consortium partner with targets and time lines must be in place for successful partnerships and to avoid the blame game which is order of the day observed in various departments as well as amongst the stakeholders. For reviewing progress as well as to assess the challenges and harness the opportunities high-level decision makers must be involved in the MEL institutional mechanism and review meetings must be planned at regular intervals. The video conferencing/ review meetings chaired by the additional chief secretary /Development Commissioner or Chief Minister in large scaling-up initiatives such as *Bhoochetana, Bhoosamruddhi* and *Rythu Kosam* ensured timely delivery of agreed targets by resolving issues timely. New IT tools such as AI, ML. IoT, GIS, RS need to be integrated in developing the robust MEL system for each scaling-up initiative for providing holistic solutions to farmers through partnerships, technologies and convergence.
- **Dissemination of impacts to right stakeholders is must for scaling-up** Documentation of strategy adopted, the process followed, the interventions made along with the detailed results is essential for scaling-up any initiative. The novelty of approach as well as the impacts achieved from on-farm participatory

demonstrations must be documented and suitably published in the scientific journals as research papers, news items, and suitably but in a measured way in public media. It must be kept in mind that reserved strategy should be adopted while discussing the results and impacts and never it should be exaggerated or pushed up. It's always preferred to let the farmers speak and interact with the media to gain credibility and authenticity. Appropriate success stories must be identified by the team partners as well as through interaction with the farmers. Once topics and proper representative farmers are identified, he/she must be empowered to talk and describe the approach, interventions and the benefits. The case study must be documented by the independent person to gain insights and avoid biases also. Farmer to farmer videos is powerful and tested tool for peer to peer dissemination. From case studies, as needed for a particular stakeholder the material can be put in as policy brief, broucher, coffee table book, scientific report, news item etc. Field days/Farmers' Days should be organised for dissemination of technologies/knowledge for other farmers, but care must be taken that researchers should give more responsibility to talk to the farmers for successful dissemination. Dissemination using appropriate format and authenticity is critical for scaling-up solutions for the farmers with the help of development investors, policy makers, research managers and researchers.

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