



CLIMATE-SMART AGRICULTURAL TECHNOLOGIES FOR RICE PRODUCTION SYSTEMS

A case of Odisha



ICAR-National Rice Research Institute
Cuttack - 753006, Odisha, India

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A K Nayak et al.



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Lead Coordinating author

Amaresh Kumar Nayak

Lead Authors

Dibyendu Chatterjee, Rahul Tripathi, Mohammad Shahid, Vijayakumar S, Bhabani Sankar Satapathy, Anjani Kumar, Sangita Mohanty

Contributing Authors

Pratap Bhattacharyya, Prasannajit Mishra, Upendra Kumar, Shyama Ranjan Das Mohapatra, Bipin Bihari Panda, Manoj Rajak, Debarati Bhaduri, Sushmita Munda, Koushik Chakraborty, Supriya Priyadarsani, Chinmaya Kumar Swain, Khitish Chandra Moharana, Prafulla Kumar Nayak, GAK Kumar, Padmini Swain, Mehertab Tesfai, Udaya Shekhar Nagaothu, Himanshu Pathak

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FOREWORD

Anthropogenic climate change pose a major threat to agriculture and allied sectors and is likely to exacerbate food and livelihood insecurity. Paradigm of future agricultural development in India needs to balance productivity with environmental sustainability. Agriculture requires to become climate-smart in order to perform climate actions and other developmental goals, if achieved, would contribute to Sustainable Development Goals (SDGs) and Intended Nationally Determined Contribution (INDC) targets committed to be fulfilled by 2030. Climate-smart agriculture (CSA) is considered as one of the approach that aims to address the climate change actions by reducing greenhouse gas (GHG) emissions, enhancing adaptation, sustaining productivity which ultimately ensures food security and developmental goals.

This book offers an assessment of the climate change, its impact and response in Odisha and provides recommendations in terms of various weather-smart, water-smart, nutrient-smart, carbon-smart, energy-smart and knowledge-smart technologies. Besides, this book has build-up a connection of SDGs and INDC with CSA technologies highlighting the synergy and trade-offs, that may guide not only Odisha but also other states to implement their State Action Plan on Climate Change (SAPCC). The synergy of these technologies with the existing schemes of Government of India and Government of Odisha need to be leveraged to make them reach to the doorstep of the farmers.

I appreciate the effort and teamwork of all the contributors for bringing such a valuable publication entitled **“Climate Smart Agricultural Technologies for Rice Production Systems: A case of Odisha”**. The book has addressed almost all of the relevant technologies across disciplines in a holistic manner. I am certain that this book will be helpful in providing guidance to all of its stakeholders by updating them with cutting-edge climate-smart technologies.

23rd November, 2020
New Delhi


(T. Mohapatra)



Dr. Pawan Kumar Agrawal

Vice Chancellor
OUAT, Bhubaneswar

**Odisha University of
Agriculture and Technology**

Bhubaneswar- 751003

Telephone- 2397970

E-mail: vc@ouat.nic.in



FOREWORD

The impact of climate change is more visible in Odisha due to its geographical location. The state is highly prone to floods, droughts, cyclones, and heat waves which occur almost every or alternate year. Such extreme events highly impacted the agriculture and allied sectors and the intensity of impact is increasing day-by-day. To maintain productivity of the system under such circumstances, climate-smart agriculture (CSA) has probably been evolved as a solution. It is high time to propagate the rationale of climate-smart agriculture and it is required to be understood and appreciated by decision-makers at the state levels.

The book “**Climate Smart Agricultural Technologies for Rice Production Systems: A case of Odisha**” thoroughly covers the baseline situation of Odisha, complete inventories of climate vagaries, prioritization framework of climate-smart technologies, steps in implementing the climate-smart technologies in Odisha, and synergy of climate-smart agricultural technologies with Sustainable Development Goals (SDGs) and Intended Nationally Determined Contribution (INDC).

The state of Odisha has already developed its state action plan on climate change (SAPCC) and it is likely to be revamped in every five years. I believe this book will help in planning and implementation of SAPCC and helps all the stakeholders involved in the climate action.

I wholeheartedly appreciate the praiseworthy effort of the authors for their painstaking effort in completing this book and I am hopeful that this book will disseminate climate action knowledge on agriculture to students, teachers, policymakers, researchers and farmers at large.

23rd November, 2020
Bhubaneswar



(PK Agrawal)

PREFACE

Increasing atmospheric concentration of greenhouse gases lead to the climate change that results into increase in temperature, erratic rainfall pattern, sea-level rise, increasing incidence of number and intensity of abiotic stresses viz. drought, submergence, stagnant flooding, cyclone, heat wave, cold wave, salinity and upsurge in the occurrence of biotic stresses. The productivity and sustainability of agricultural production system is facing humongous challenges due to climate change consequences. Climate-smart agriculture (CSA) is one of the approaches that aim to withstand the adverse effects of climate change by enhancing productivity, mitigating greenhouse gases (GHGs) emission and improving adaptation of the food production system. These technologies emphasize on the reorientation of agricultural practices towards attaining the food and nutritional security of a growing population.

This book covers brief account on assessment of climate change and its impact with focus on agriculture of Odisha. Climate-smart agricultural technologies including weather-, water-, nutrient-, carbon-, energy- and knowledge-smart, are lucidly illustrated that makes it easy for the readers to understand and implement as needed. The identification and prioritization of suitable climate-smart agricultural technologies and their synergy and trades-offs with sustainable development goals are also described. The book also extrapolates and structures the climate-smart agricultural technologies in such a way that its successful implementation will help Odisha and other states as well in achieving the targets set in SDGs and intended nationally determined contribution (INDC). Considering the fact that the paradigm of future agricultural development needs to balance between productivity and environmental sustainability, the CSA technologies described took into account GHG mitigation and C sequestration potential of agricultural production and at the same time also to ensure food security of small and marginal holders. The book also addresses the synergy between technologies and public policies for their real-time implementation in agriculture.

The authors sincerely acknowledge all the anonymous sources of the information and photographs. The authors also acknowledge the financial support received from the projects 'Enhancing resilience of rice-based production system to climate change', 'Building climate resilience of Indian smallholders through sustainable intensification and agro-ecological farming system to strengthen food and nutritional security' and 'National innovations on climate resilient agriculture'. The authors believe that the outcomes and recommendations of the book will be of immense help for strengthening and implementation of state action plan on climate change for Odisha and other states. This book will be of great interest to farmers, researchers, educationist, extension workers, policymakers, development practitioners, donors, academics and civil society.

Authors

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1. Climate Change, Impact, Response and Climate-Smart Agriculture

1.1 Introduction

Climate variability and extreme events have increased in frequency, amplitude and duration over the last three decades. Climatic hazards have caused extensive damage to national agricultural economics (both developed and developing countries). Many extreme weather and climate events continue to result from natural climate variability as well as anthropogenic climate change. The increasing concentration of greenhouse gases (GHGs) in the atmosphere due to anthropogenic activities causes natural calamities through global warming. Today's agriculture sector faces complex challenges like producing more food while using less water per unit of output; contributing productively to the local and national economy by understanding local indigenous customs; protecting the health of the ecosystem and ensuring environmental sustainability, reducing food shortages, famine, and hunger, while coping with changing climate and increasing the frequency of climatic hazards that threaten our natural resource base and agriculture.

Globally drought, catastrophic flooding, and tropical cyclone directly affect the lives, and properties of around 220, 196, and 90 million people annually, respectively and some people experienced more than one event every year. Besides, global warming also affects agriculture, livelihood, health, loss of biodiversity in many other ways. Climate impacts on humans are determined by exposure governed by both the assets and activities in areas affected by climate extremes. The livelihood of being affected by the climatic hazards is governed by the sensitivity of its exposure to harm and capacity for recovery. Climatic hazards are likely to affect the poor and developing economy the most because of their low adaptive capacity. Climatic hazards like droughts, cyclones are not new to India but its frequency and intensity of these events have increased abnormally in recent decades especially more so in the state of Odisha that has led to the development of response mechanisms in the form of the implementable action plan from time to time, both for agriculture and other sectors. Agriculture, being the lifeline of the country, impact assessment at national and state level, future climate projection, robust response mechanism, mainstreaming of appropriate location-specific climate-smart technology will ensure the resilience of the production system led by a cleaner path of development.

1.2 Climate change impacts on agriculture

A concurrent impact of climate change on agriculture both due to its direct and indirect effects is taking place over the decades. This has already affected productivity and reduced the water resources (Table 1.1). The direct impact of climate change includes frequent and intense droughts, floods, cyclones, heat and cold waves, and cloud burst in many agricultural regions. These events affect the crop, animal husbandry, and fishery and at times destroy the whole farming systems. Due to global warming, there is an increased number of heat waves and warm nights, a decreasing number of rainy days, and longer dry spells. Winter is warmer and shorter with fewer cold nights, the day and night temperatures increased in most of the months. On livestock, heat stress increased vulnerability to disease, reduced fertility, and milk production. Drought threatens fodder and feed supplies. Drought reduces the amount of quality forage available for grazing livestock. On fisheries, changes in temperature and seasons affected the timing of reproduction and migration.

An unexpected change in weather patterns during monsoon season causes the delayed onset of monsoon, long intervals for rain, or heavy rain causing shifting of planting time. The frequency of heavy precipitation (>64.5 mm per day), the number of very heavy rainy days (>125 mm per day), the dry spell is increased over the year. Heavy rainfall events leading to flash flooding can damage the crops over large areas, with increased coastal salinity, siltation of productive land, and reduced plant growth. Unseasonal rainfall during harvesting time leads to the sprouting of the grain in the field and loss of grain quality due to fungal infections *etc.* Severe tropical cyclones with a peak of wind speeds and heavier rainfall caused severe damage to crop and livestock. Increasing sea-level and salinization result in impermanent migration as coastal areas become uninhabitable. Impacts are more severe if multiple stresses occur in the same season.

The indirect climate impacts include a change in the farming system, cropping pattern, growing seasons, crop intensity, input use, tillage practice, increased competition from weeds, expansion of pathogens and insect pest ranges and seasons, delayed farming operations due to excess/deficit soil moisture, other management adjustments, and reduced grain yield. Overall, climate change could make it more difficult to do the crop and animal husbandry, fishery in the same ways as having been done in the past. The direct and indirect impacts of climate change on various sectors is presented in Fig 1.1

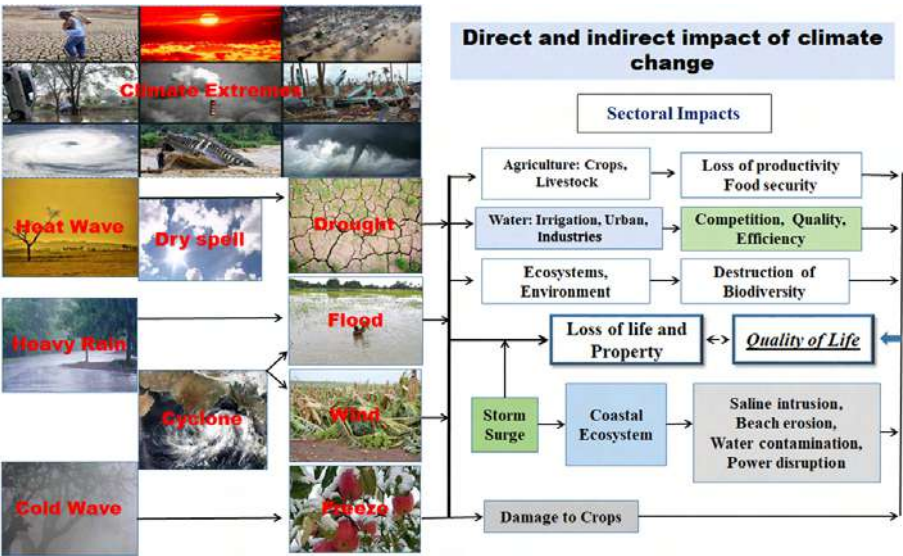


Fig. 1.1 Direct and indirect impact of climate change

Source: Authors' own compilation.

Table 1.1 Climate change impacts on agriculture and water resources.

Sl No.	Events and trends of trends of events	Probable future trend	Possible impact on agriculture	Possible impact on water resources
1	Less number of cold days and nights; more frequent hot days and nights	Virtually certain	Insect-pest outbreaks increase in yields in colder environments and decrease in warmer environments	Accelerated snow melt; increased evapo-transpiration rates
2	Increased frequency of warm spells/ heat waves	Very likely	Decrease in yields in warmer regions due to heat stress and shorter growing period	Increased irrigation demand; deterioration in water quality, e.g., algal blooms
3	Increased frequency of heavy precipitation events	Very likely	Waterlogging/flood, crop loss; soil erosion	Surface water quality problem; relief in water scarcity.

4	Increase in drought-affected area	Likely	Crop failure/ reduced yield, increased mortality of livestock, land degradation and desertification, and increased risk of wildfire	Scarcity of water both for drinking and sanitation
5	Increases in intense tropical cyclone activity	Likely	Crop loss: Lodging of field crop, horticulture, and agroforestry trees	Disruption of public water supply and drainage of water
6	Increased events of sea-level rise	Likely	The intrusion of seawater to aquifer and surface water bodies	Loss of cropland and a decrease in freshwater availability

Source: IPCC Assessment Report 2014

1.3 Odisha at a Glance

Odisha is one of the states of India situated on the eastern coast along Bay of Bengal. It lies between 17.49'N and 22.34'N latitudes and 81.27'E and 87.29'E longitudes. The total geographical area of the state is 15.5 m ha accounting for 4.87% of the total area of India, having a coastline of about 450 km. The topography of the state covers extensive hill ranges with forest, rolling upland, coastal plains, extensive river systems, and brackish water and mangroves.

Mahanadi is the largest river system of the state and its catchment area covers 42% of the state. The Subarnarekha, the Budhabalanga, the Brahmani, the Rushikulya, the Baitarani, and the Vansadhara are other major rivers of the state. Odisha is divided into

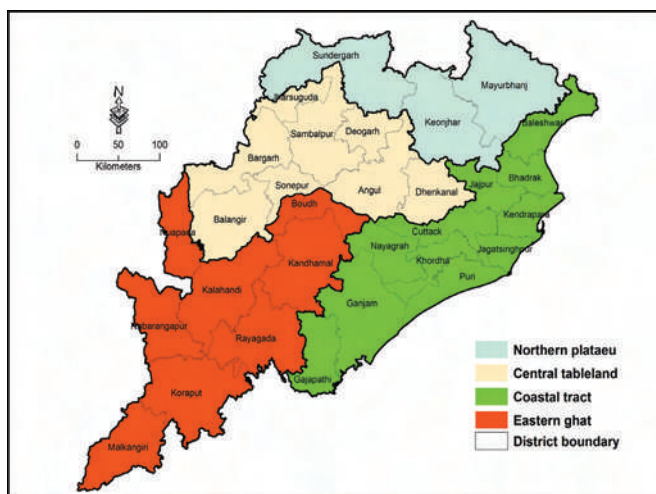


Fig. 1.2 Physiographic zones of Odisha

Source: Government of Odisha

four major physiographic zones: the Northern Plateau (18.3%), the Central Tableland (23.9%), the Eastern Ghat (32%), and Coastal Plains (25.8%) (Fig. 1.2). It is home for two Agro-biodiversity hot spots *i.e.* Mayurbhanj, Koraput, and three Biosphere Reserves *viz.*, Bhitarkanika, Similipal, and Chilka.

As per the 2011 census, its total population is 41,974,218 which is 6.86% of the total population of India. The state has a total cultivated area of 6.4 m ha, forest area 5.8 m ha, and permanent pasture area 0.49 m ha. It is having the problems of varying degrees of land degradation such as acidic soil 40 lakh hectares (13 lakh hectares with pH<5.5), prone to saline inundation- 4 lakh hectares, prone to flooding - 3.54 lakh hectares and prone to waterlogging 0.75 lakh hectares. The annual average rainfall of the state is 1451.2 mm out of which 75% to 80% of rainfall is received from June to September. Odisha state falls under Agro-Climatic Zone VII, one of fifteen major Agro Climatic Regions/Zones in the country. Further, the state is divided into ten Agro-Climatic Zones based on biophysical conditions such as topography, vegetation, rainfall, soil structure, humidity, elevation, and other factors (Fig. 1.3). The characteristics of different agro-climatic zones of Odisha are presented in Table 1.2.

Per capita availability of water during 2001 was 3359 m³ and projected to decrease to 2218 m³ by 2051. The irrigation potential created in the state by 2012-13 is 31.30 lakh ha in *kharif* and 15.73 lakh ha in *rabi*. More than 50 % of the cultivated area is rainfed in 60% of the districts which have faced the brunt of climate change the most. The small and marginal farmers constituting more than 92.97% (marginal 74.74% and small 18.23%) of the farming community.

The average size of landholding is 0.95 ha. The average size of holding is still less for marginal and small farmers which are largely fragmented (Agricultural Census, 2015-16). Paddy is the principal crop and is usually grown twice in a year.



Fig. 1.3 Agro-climatic zones of Odisha

Source: Center for environmental studies, Department of forest and environment, Govt. of Odisha.

Agriculture in the state is characterized by wide spatio-temporal variations in growth and productivity. The year to year fluctuations in rice production is largely due to frequent occurrence of natural calamities like drought, flood, and cyclone. Animal husbandry, poultry, goatary, fisheries, bees keeping helps the small and marginal farmers, and the landless labourer to supplement their income in the event of crop loss due to climate extremes.

Table 1.2 Characteristics of different agro-climatic zones of Odisha

Sl. No	Agro-climatic zone	Districts covered	Climate	Mean annual rainfall (mm)	Mean maximum summer temp (°C)	Mean maximum winter temp (°C)
1	North Western Plateau	Sundergarh, Deogarh	Hot & moist Sub-humid	1600	38.0	15.0
2	North Eastern Plateau	Mayurbhanj, Keonjhar	Hot & moist Sub-humid	1534	36.6	11.1
3	North Eastern Coastal Plain	Balasore, Bhadrak, Jajpur	Moist humid	1568	36.0	14.8
4	East and South-Eastern Coastal Plain	Cuttack, Kendrapara, Jagatsinghpur, Puri, Khurdha, Nayagarh	Hot & humid	1577	39.0	11.5
5	North Eastern Ghat	Ganjam, Phulbani, Rayagada, Gajapati	Hot & moist Sub-humid	1597	37.0	10.4
6	Eastern Ghat High Land	Koraput, Nabarangpur	Warm & humid	1522	34.1	7.5
7	South Eastern Ghat	Malkangiri, parts of Koraput	Warm & humid	1710	34.1	13.2

8	Western Undulating Zone	Kalahandi, Nuapada	Hot & moist	1352	37.8	11.9
9	Western Central Table Land	Bolangir, Boudh, Sonepur, Sambalpur, Bargarh, Jharsuguda	Hot & moist Sub-humid	1614	40.0	12.4
10	Mid Central Table Land	Angul, Dhenkanal	Hot & moist Sub-humid	1421	38.7	14.0

Source: Agricultural Statistics, Government of Odisha.

1.4 Climate change impact on agriculture of Odisha

In Odisha, extreme weather events such as flood, drought, cyclone, and heat waves occur separately as well as simultaneously causing damage to the life and properties of the state. The state is vulnerable to extreme climatic conditions due to its geographical location (OSDMA, 2016). The frequency of these climatic extreme events has been increasing in the state since the last few decades. During the period 1964-65 to 2015-16 (52 years), extreme events have occurred 35 times; droughts in 19 years, floods in 10 years, and cyclones in 6 years (Fig. 1.4) The probability of occurrence of drought, flood, and cyclone in a year has been worked out to be 0.37, 0.19 and 0.11, respectively. These extreme events have caused damage to the crops, livestock, infrastructures, livelihood resources, food security, and development of the state (Patel et al., 2019).

The climate change impact on agriculture is manifested in the form of delayed onset of monsoon (2 weeks), decrease in the number of rainy days/years, prolonged dry spell, more number of heavy rainy days, increased risk of crop submergence, decrease in *kharif* growing period by 2 weeks, fluctuating winter temperature, early start of summer (February onwards), reproductive stage of rice and pulses coinciding with higher temperature, increasing weather risk for timely operations, increased salinity in coastal areas, the emergence of newer pests (swarming caterpillar, sheath rot), more intense and prolonged heat wave, even in the coastal area. All these events have resulted in low input use efficiency, yield loss, and reduced quality of produce. The smallholders of the state are the major pillars of the rural economy and are majorly responsible

for national and global food and nutrition security. A large number of small and marginal farmers, have been struggling with low agricultural productivity and are unable to improve it as they have low incomes and less access to assets (such as land tenure, markets, credit, knowledge and technologies, and institutions). As one of the coping strategies, rural families are adopting migration (non-farm livelihoods) to increase the household's income (Bosc et al., 2013). The major impacts have been on the agriculture sectors of eastern and north-eastern states of India.

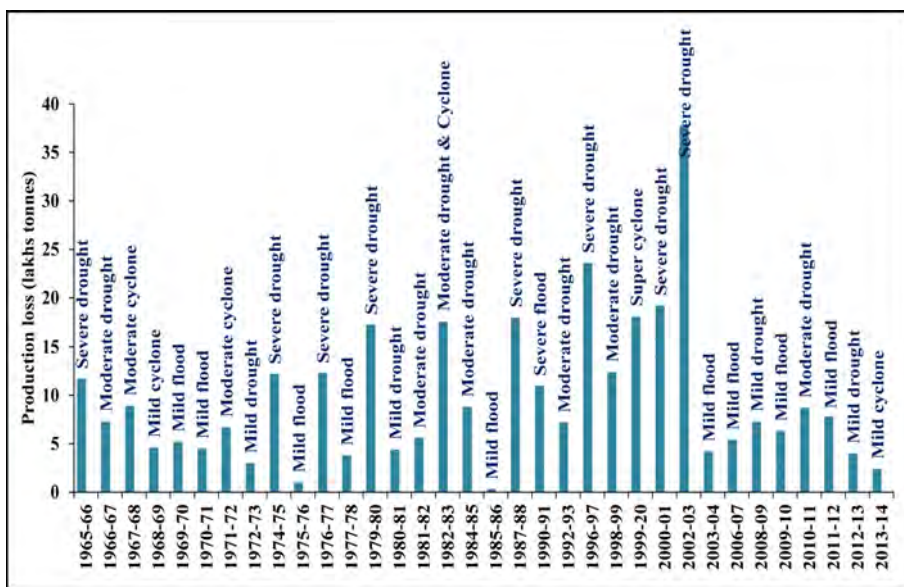


Fig. 1.4 Natural calamities of Odisha from 1965 to 2013.

Source: Authors' own compilation and analysis.

1.4.1 Impact of drought

The scarcity of rainfall and its poor distribution and prolonged long dry spell causes drought affecting crop productivity. In India, 12% of the population is found to be susceptible to drought. In the last 100 years, Odisha experienced drought in 30 years (Jena & Kalli, 2018). Sale of assets and migration are common in severe drought years (Samal and Patra, 2012), which causes a reduction in productive assets in subsequent years resulting in low yield in subsequent years. During 1960-2015, the total rice production fluctuated between 29.2 lakh tonnes to 82.98 lakh tonnes. The production was down too much during severe drought years (1965-66, 1974-75, 1976-77, 1979-80, 1987-88, 1996-97, and 2002-03) (Fig. 1.4). The yield losses from drought in eastern India to be 169 kg per ha per year. Using data for the period 1970-

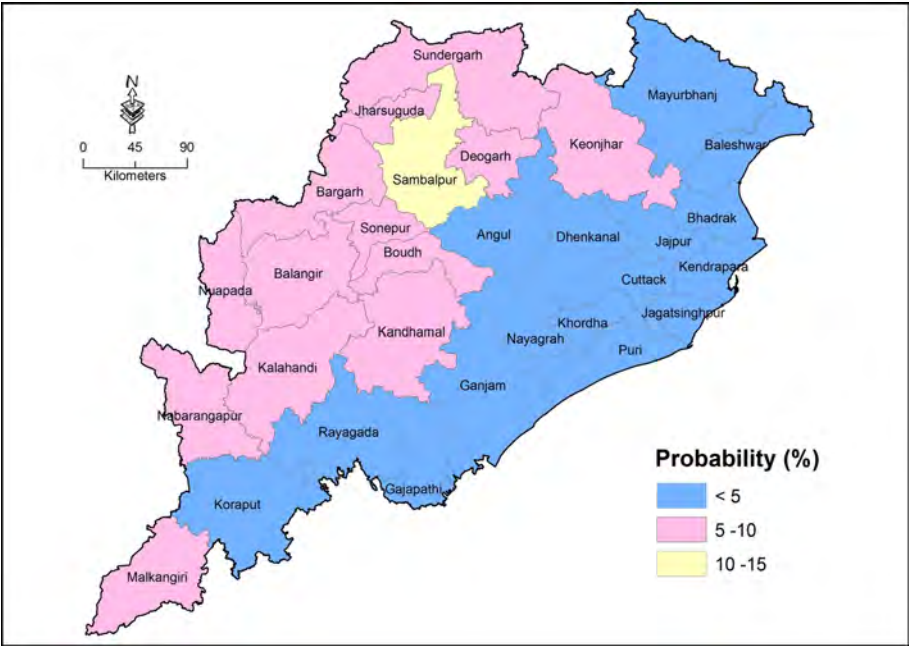


Fig. 1.5 District wise drought probability map of Odisha

Source: Adopted from Atlas of Vulnerability of India Agriculture to Climate Change, ICAR-CRIDA

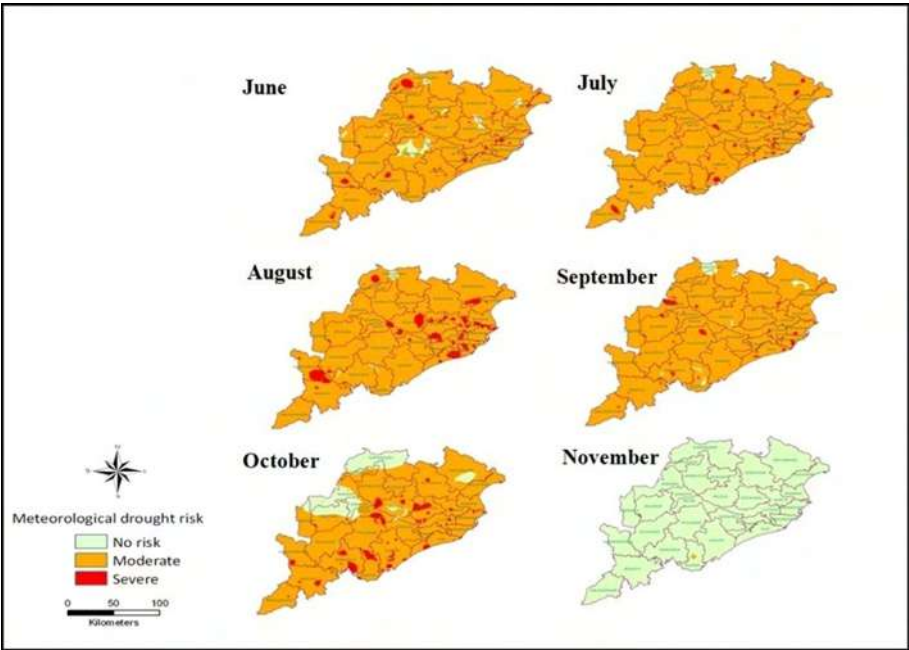


Fig. 1.6 Drought risk maps of Odisha based on 1-month SPI

Source: Adopted from Raja et al., 2014.

1996, Pandey et al., (2000) have estimated the rice yield losses of 1.5 Mt per year in Odisha under severe drought years. Ravichandran and Singh (2005) have estimated the highest production losses of 3.8 Mt rice for Odisha in the year 2002-03 in comparison to 2001-02, which was a normal year. The district-wise classification of drought-prone areas presented in Fig 1.5. Standardized precipitation index (SPI) is another tool used to detect drought over different periods at multiple time scales. The applicability of SPI is time scale-dependent, 1-month SPI reflects short-term soil moisture stress, 3-month SPI reflects seasonal while medium-term precipitation trend is indicated by 6 and 9-month SPI (Ji & Peters 2003). Temporal and spatial drought monitoring for rice in Odisha can be better done by using 1-month SPI tool. Based on 1-month SPI, August showed a higher risk for severe drought as compared to other months.

1.4.2 Impact of flood

In India, 49.8 million hectares (12.3% of the geographical area) is prone to flood (NRAA, 2013). Because of its long coastline (482 km), the state of Odisha is often exposed to flood, cyclones and storm surge. The district-wise flood severity map of Odisha is presented in Fig. 1.6. Flood is one of the frequently occurring climatic hazards in the state. The decreasing number of a rainy day (>2.5 mm) and the increasing number of a heavy rainy day (>62.5 mm), very heavy rainy days (>125 mm per day), and consecutive cumulative rainfall events increase the chance of flooding. Heavy rainfall during monsoon in the catchment area inside the state and the upper catchment of neighboring states also contributes to flooding downstream. The flat topography, drainage congestion, soil erosion, siltation in the rivers, breaching of the embankments, cause severe floods in the river basin and delta area of the state. This problem becomes even more acute in the coastal area when floods coincide with high tide. As a consequence houses, roads and bridges are washed away, crops and livestock are damaged, sometimes lives are lost too.

Nearly 1.40 lakh hectares of the total geographical area of the state is prone to flood (OSDMA, 2016). Out of a total of 22 lakh ha of rainfed lowland of Odisha, about 50% are submergence/flood-prone (Singh et al., 2006). For the people living in riverside, flooding is a regular phenomenon. Based on 47 years (1953 to 1999) data, on average 3.57 m ha of the cultivated area is damaged annually. In the last 100 years, Odisha experienced a flood in 49 years (Jena, 2018). The floods of 1980, 1982, 2001, and 2003 were notable ones that have caused damage to the properties amounting to crores of rupees. In recent days, floods in the years 2006, 2007, and 2008 have caused severe

damage to crops, livestock and other properties in the state (OSDMA, 2016). The damage of crops due to floods varied from 0.3 lakh tonnes (1985-86) to 7.3 lakh tonnes (2011-12) in a mild/flash flood year. It is estimated to be higher at 11 lakh tonnes in a severe flood year (1990-91).

1.4.3 Impact of cyclone

The cyclone is an annual phenomenon that severely affects the lives and livelihoods of the people of the coastal area. In India, 8% of the total geographical area is cyclone prone. West Bengal, Odisha, Andhra Pradesh, Tamil Nadu, Kerala, and Gujarat are the most severely cyclone-affected states. The east coast of India is more prone to cyclone as compared to the west coast. Out of the last 100 years, Odisha experienced major cyclones in 11 years (Jena, 2018). The districts such as Kendrapara, Jagatsinghpur, Balasore, Bhadrak, and Puri fall under the most severe cyclone-affected areas. The district-wise cyclone severity map of Odisha is presented in Fig. 1.7. Sometimes multiple cyclones hit the state in quick succession. Tens of thousands of people were killed in the Super Cyclone in 1999. During the Super Cyclone (1999) over 1 million hectares of land were affected. The cyclone wreaked havoc three weeks before the harvest destroying paddy fields, vegetable crops, and sugarcane (Sinha, 2002) causing the deaths of thousands of domestic animals.

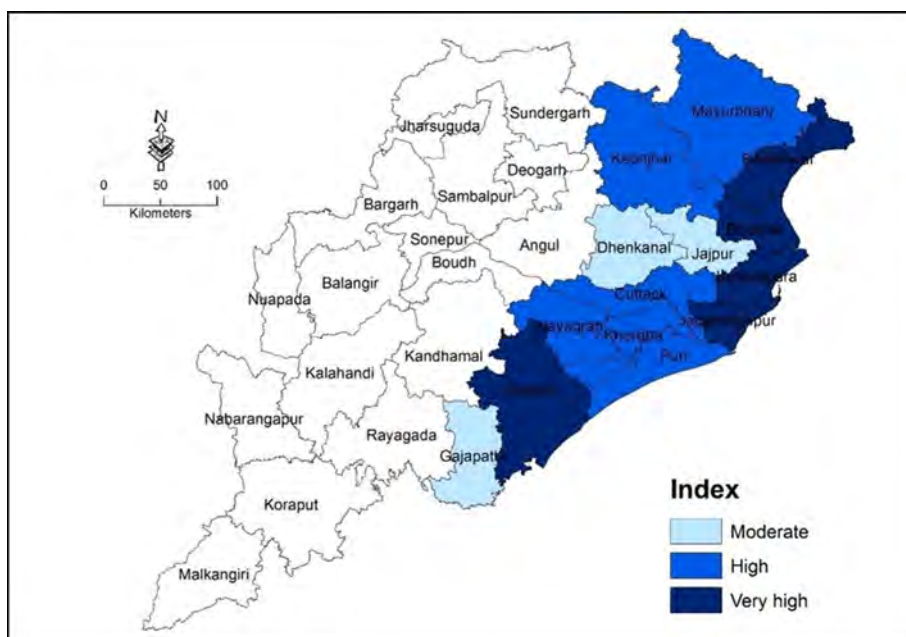


Fig. 1.7 District wise cyclone severity map of Odisha

Source: Odisha state disaster management authority, Govt. of Odisha

Cyclone Phailin in 2013 and Fani in 2019 have caused similar damage to the state. Because of cyclone preparedness, no major loss of lives reported this time in the state. The cyclone and its associated flood incidence cause severe damage to agriculture in several ways. Flood at early stage hampers crop establishment causing the field remained complete fallow. The flood at a later stage causes loss of productivity to varying degrees. The pulses, oilseeds, and vegetable crops are highly susceptible to flood. In the case of paddy, the duration of the flood will decide the extent of damage to the crop. The crop at flowering, grain filling, and maturity stage is affected to a great extent due to the lodging and shattering of pollens. In extreme cases, there is complete damage to the crop. The mature grains germinate due to lack of dormancy in some varieties. The losses due to cyclones have been quantified and varied from 4.6 lakh tonnes during a mild cyclone year in 1968-69 to as large as 18 lakh tonnes in a super cyclone year i.e. 1999-2000.

1.4.4 High-temperature and heat wave stress

Heat wave occurrence depends upon certain thresholds of maximum temperature over a region. According to India Meteorological Department (IMD), to declare a heat wave, at least 2 stations in a Meteorological sub-division for at least two consecutive days should either record temperature departure from normal by 4.5°C to 6.4°C or record the actual maximum temperature $\geq 45^{\circ}\text{C}$ in the plains. Similarly, a severe heat wave is declared when the temperature is departed from normal by $>6.4^{\circ}\text{C}$ or actual maximum temperature of $\geq 47^{\circ}\text{C}$.

The daily mean temperatures both the maximum and the minimum have been gradually increasing in Odisha (average 0.42 °C increased in the last 15 years). Heatwaves affect most of the districts in Odisha (Government of Odisha, 2015). The overwhelming majority of people employed in the unorganized sector working for long-duration are affected the most. Heatwaves force people to stay indoors and lose out on income-earning opportunities (OSDMA, 2016). A major heat wave in 1988 killed around 1500 people, mostly in the coastal Odisha region. The highest maximum temperature during 1988 was 42.6°C. Again in 2002, the peak temperature was 44.5°C in May but the human loss was less because of increasing adaptive capacity and enhancing protective measures. The extreme temperature events have a varying adverse impact on agriculture. The loss in net revenue at the farm level is estimated to a range between 9% and 25% for a temperature rise of 2°C to 3.5°C (Devagowda et al., 2019).

The impact of high temperature on the crop loss both quality and quantity depends on the stage of crop development. Short-term temperature extremes events can even be detrimental if it coincides with key phenological stages of development. Only a few days of extreme temperature at the flowering stage of many crops can drastically reduce yield and quality of produce. However, high temperatures for a few days during the vegetative stage do not have significant effects on growth and development. For example in groundnut, if the plants are exposed to temperatures exceeding 42°C after flowering even for short periods, drastically reduced the yield (Vara Prasad et al., 2003). Maize exhibits reduced pollen viability for temperatures above 36°C. High temperature affects negatively almost all the growth stages of rice. An increase of 2°C in temperature could decrease the rice yield by about 0.75 t ha⁻¹. Exposure of rice plant to 41°C for 4 hours at flowering causes irreversible damage and plants became completely sterile. In *rabi* rice cultivated in the state, the pollination gets affected if the temperature is above 37°C. The endosperm, the edible part of rice grains, is tightly packed with granules of starch under normal temperature. The starch granules do not grow enough and air spaces remaining between granules reflect light when the rice plant is exposed to high temperatures for a certain duration at the ripening stage. Such immature grains are chalky in appearance easy to crack during polishing & have low commercial value. High temperature during the night also decreases yield due to a decrease in photosynthetic function, increasing respiration rate, low pollen viability, and hastening crop maturity, and decreased antioxidant capacity sugar and starch content.

1.4.5 Low-temperature and cold wave stress

The low temperature causes cold stress in plants and affects several key components of photosynthesis. The cold stress in plants decreases membrane fluidity, alters the lipid composition of the membrane, retarded metabolism, and delayed energy dissipation leading to free radical formation and oxidative stress. Freezing causes ice to form in a plant cell wall and intercellular spaces. Chilling causes protoplast volume shrinkage upon extra-cellular ice formation. Late duration rice varieties are usually cultivated in the lowland ecology of Odisha. Sometimes the reproductive stage of these varieties coincides with the onset of winter and hence low-temperature events. The cold temperature at the reproductive stage affects the anther development and pollen germination leading to the development of chaffy grains (Table 1.3). In the case of the rice-rice system, the low-temperature event in December and January delays the planting time as it interferes with the germination and reduces the seedling vigor (Table 1.3).

Table 1.3 Symptoms of cold temperature damage in rice plants

Growth Stage	Symptoms	References
Germination	Delayed & lower percentage of germination	da Cruz and Milach, 2000
Vegetative stage	Slow growth, reduced vigor, yellowing of the leaves, lesser plant population, and reduced tillering	Ghadirnezhad and Fallah, 2014
Booting stage	Pollen abortion during microsporogenesis, when pollen grains are being formed	Mackill et al., 1996
Anthesis	Cessation of anther development, non-ripening of pollen, non-emergence of anthers from spikelet, partial or no anther dehiscence, pollen grains remaining in anther loculi, little or no pollen shedding, and failure of pollen to germinate after reaching stigmas	Ito et al., 1970
Reproductive stage	Incomplete panicle exertion and spikelet abortion	Satake and Hayase, 1970
Grain filling stage	Delayed and incomplete grain maturation	Ye et al., 2009

1.5 Future climate projection

Climate projections are important for future planning and for adapting to climate change. The climate system is very complex, and so we cannot just look at past trends and say they will continue. Instead, we use global climate models to project the future climate. Future projection of temperature and precipitation are important to agriculture, to improve the level of preparedness to face disasters like flood, drought, and cyclone and to protect life and property. Climate scenarios can inform the likely impacts of temperature, precipitation, and seasonality on food production. Using Coupled Model Inter-comparison Project (CMIP5) models ensemble it has been predicted that the minimum and maximum temperature of coastal Odisha is expected to increase by 0.6-0.7, 0.7-0.8, 1.2-1.4°C and 0.5-0.6, 0.6-0.7, 1.3-1.5°C, respectively under RCP4.5 scenario and 1.7-2.2, 1.6-2.0, 3.1-3.8°C and 1.7-1.9, 1.7-2.1, 3.0-3.4°C, respectively under RCP8.5 during near, mid and late century compared to the base year average (1980-2010). Season wise projection shows, the change in precipitation and temperature is expected to

be more in *rabi* (dry) season compared to *kharif* (wet) season under both the RCP scenarios. The summer is going to be longer and the intensity of rainfall will increase in the state. Projection of extreme climate events well in advance provides an opportunity to develop an adaptation option to cope up with the eventualities brought about by climate change. The expected climate change over Odisha coastal plains presents both advantages and disadvantages during the *rabi* season. For example, the co-occurrence of drought and heat stresses is likely to increase both in intensity and frequency in Odisha coastal plain due to the expected increase in temperature and decrease in precipitation during the *rabi* season. Conversely, increasing temperature provides an opportunity for early sowing of *rabi* rice crop. During December the temperature over Odisha coastal plains approaches near base temperature (lowest temperature below which rice growth stops). Farmers delay the sowing of *rabi* rice due to low temperature in December. The second crop of rice sown immediately after the harvest of *kharif* rice suffers poor crop establishment and very slow growth especially early vegetative stage due to cool weather conditions. While the delayed sowing of *rabi* rice leads to terminal heat stress during the flowering and maturity stage, and ultimately yield loss. Thus, expected temperature and CO₂ increase will benefit *rabi* rice by facilitating early sowing of rice and avoid terminal heat stress. It also facilitates efficient utilization of residual soil moisture by succeeding crop that is available immediately after the harvest of rice crop. The increase in temperature offers an opportunity to go for early sowing of dry season crops.

1.6 Response to climate change

India is already in the forefront in engaging in intense deliberations, planning, adaptation and mitigation action plan by establishing emission targets. Government of India is an early adopter of National Action Plan for Climate Change (NAPCC) in the year 2008 constituting eight missions such as National Solar Mission, National Mission for Enhanced Energy Efficiency (NMEEE), National Mission on Sustainable Habitat, National Water Mission (NWM) Mission National Mission for Sustaining the Himalayan Ecosystem (NMSHE), National Mission for A Green India (Green India Mission), National Mission for Sustainable Agriculture (NMSA). National Mission on Strategic Knowledge for Climate Change (NMSKCC). The objectives of these missions are to address the future policies and programs for the climate mitigation and adaptation. National Innovations on Climate Resilient Agriculture (NICRA) is a network project of the Indian Council of Agricultural Research (ICAR) launched in February, 2011. The project aims to enhance resilience of Indian

agriculture to climate change and climate vulnerability through strategic research and technology demonstration. Subsequently in the run up to the Paris Climate Change summit in the year 2015, India submitted its Intended Nationally Determined Contribution (INDC), including the targets to lower the emissions intensity of GDP by 33% to 35% by 2030 below 2005 levels. India also committed to create an additional carbon sink of 2.5 to 3.0 billion tons of CO₂ eq. by 2030.

Odisha is one of the first states in India to prepare a comprehensive State Action Plan on Climate Change (SAPCC) making a choice to adopt a climate friendly and a cleaner path for development. SAPCC targets to reduce emissions and follow a low-emissions growth strategy (to reduce emission intensity by 25–30%). India total emission is 2607 Mt CO₂ eq, out of which emission from agriculture is 16% (417 Mt CO₂ eq) (MoEFCC 2019). In Odisha the contribution of agriculture to the total emission from the state is 25% (SAPCC 2018), hence agriculture has to play a vital role in mitigation. Nevertheless, in this state climate change is perceived much through the experience of extreme weather events. Therefore, response to climate change will perhaps happen through adaptation to climate hazards. The adaptive capacity of a system is its capability to adjust to the climate change including climatic variations and extremes, in order to mitigate and to cope with its potential adverse effects. Better infrastructures such as irrigation, transportation, banking, education, and communication and health facilities ensure higher adaptive capacity in a region. It is now rightly recognized by international climate change negotiations that mitigation and adaptation are equally important in dealing with climate change. Therefore, the adaptation led mitigation measures required to cope with changing climate need more focus in terms of research, policy, and institutional interventions. Odisha, a predominantly agrarian economy is also expected to experience adverse impacts of the phenomenon mostly due to loss of productivity and livelihood. In such circumstances increasing agricultural production and productivity is necessary for ensuring food security, livelihood security, and nutritional security. Any agricultural policy intended to address climate change must focus on adaptation and mitigation, and product enhancement.

1.7 Climate-smart agriculture (CSA)

Climate change has brought out unpredictable natural challenges to agriculture. The stakeholders need to understand and adopt a new strategy to tackle the adverse impact of climate change. Climate-smart agricultural technologies

provide opportunities for adaptation and mitigation of the adverse effect of climate change. The mitigation of GHGs emissions from agriculture can be achieved by sequestering C in soil and reducing the emissions of methane and nitrous oxide from the soil through changes in land-use management and enhancing the input-use efficiency.

Climate-smart agriculture (CSA) is a priority for addressing the food and nutritional security and livelihood of a growing population in a situation of resource limitations, and climate change and variability. Climate-smart agriculture (CSA) is “an approach that helps to guide actions needed to transform and reorient agricultural systems to effectively support the development and ensure food security in a changing climate” (FAO, 2013). It involves a sustainable increase in agricultural productivity and incomes, adapting and building resilience to climate change, and, wherever possible, reducing and/or removing GHG emissions (FAO, 2013). Climate-smart crop production contributes to food security and this can be accomplished by addressing different aspects of current and projected climate change impacts through adaptation and mitigation actions. CSA is not a set of practices that can be universally applied, but rather an approach that involves different elements embedded in local contexts. CSA relates to actions both on-farm and beyond the farm and incorporates technologies, policies, institutions, and investment.

CSA is based on three pillars: (i) increase in productivity *vis-à-vis* income to have better food security; (ii) adaptation and increasing resilience to climate change; and (c) mitigation of greenhouse gas emissions from agriculture and allied activities (Fig. 1.8).

The CSA needs a considerable effort on the part of all stakeholders (farmers, researchers, extension professionals, policymakers). It prepares farmers to develop agriculture smart enough to survive the onslaught of climate change impacts on a regular basis as a permanent feature and not as an ad-hoc or temporary solution. With the experience of our farmers and expertise of our scientists, and appropriate government policies, it is possible to make agriculture smarter. Many experts have pointed out that there is a need for synergy between technology and public policy to overcome the adverse impact of climate change on crop and animal husbandry, fisheries, and forestry. In this book, we deal with detailed information about the most suited climate-smart technologies and its prioritization for different agro-climatic zones of Odisha.

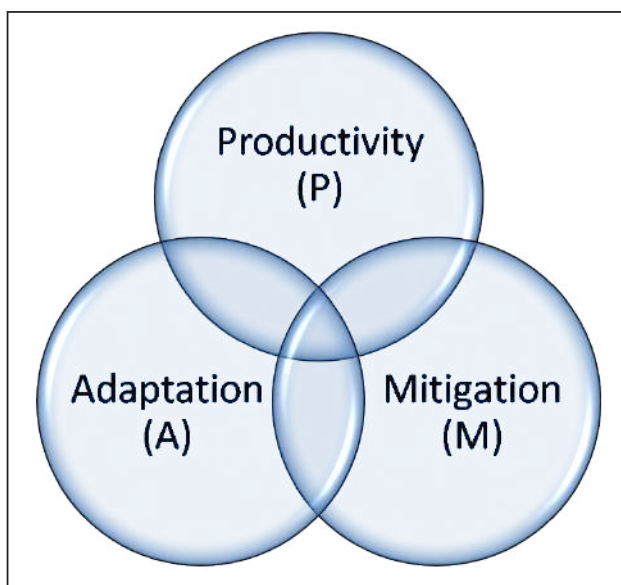


Fig. 1.8. Three pillars of CSA (the interaction points PA, PM, AP and AMP are climate smart agriculture)

Source: Author's own analysis.

1.8 Classification of CSA technologies

The CSA technologies are classified as water-smart, energy-smart, nutrient-smart, carbon-smart, weather-smart, and knowledge-smart based on their potential to withstand climate change.

1.8.1 Weather-smart technology

The increase in the number of extreme events (e.g. flood and drought) is the main hindrance in sustaining productivity and farm income. Weather-smart technology such as weather forecasts and early warnings, weather-based crop agro-advisory, crop insurance, change in planting time, stress-tolerant crops, and varieties, cropping system, off-farm income, etc. help in the reduction of risk through the dissemination of weather advisories and climate information, which enable farmers to take the right decision in proper time.

1.8.2 Water-smart technology

A major impact of climate will be visible in the form of water stress and agriculture being the major user of freshwater available is likely to be affected the most. Hence, to cope up with climate change, the ingenuity of water management sciences need to be used in developing location-specific water-

smart practices in agriculture in the field of on-farm and off-farm irrigation management, rainwater harvesting, groundwater recharge, watershed management, participatory irrigation management, *etc.* Some examples of water-smart technologies are aerobic rice, system of rice intensification (SRI), improved method of irrigations: check basin, border strip, drip irrigation, sprinkler irrigation, alternate wetting and drying, furrow irrigated raised bed planting, saturated soil moisture, tensiometer based irrigation, supplemental irrigation, rainwater harvesting: farm ponds, check dam, bandheras; dug out ponds, percolation tank and check dam, sub-surface dykes, recharge shafts, injection wells, soil moisture conservation: raising the bunds in the paddy field, conservation of wetlands, contour bunding, mulching; and excess water management using proper drainage, *etc.*

1.8.3 Nutrient-smart technology

Modern-day agriculture uses high yielding varieties which need a significant quantity of nutrient to be applied. However, because of poor knowledge about the right time, the right rate, the right source, and the right place of the fertilizers and manure application, indiscriminate use of fertilizers results in reduced nutrient efficiency, aggravates the problem of environmental pollution, and increase the release of greenhouse gases (GHGs) from agriculture. Hence technologies that save nutrients and/or cut off GHGs emissions are considered as nutrient-smart technology. Integrated nutrient management, real-time and site-specific N management, green manuring, brown manuring, organic manures, growing legumes in rotations and biofertilizers, *etc.* are considered as nutrient-smart practices.

1.8.4 Carbon-smart technology

Carbon is central to all biological systems and not harmful when it is in the soil-plant-microbe-human continuum. An increase in the gaseous form of C in the atmosphere (CO_2 and CH_4) mainly involves global warming. Therefore, agricultural technology that either increases its sink into the soil-plant-microbe-human continuum or minimizes the release of the gaseous form of C into the atmosphere is carbon smart. Technologies like minimum tillage (MT), zero tillage (ZT), crop residue management, agroforestry, *etc.* are a few examples.

1.8.5 Energy-smart technology

Saving of energy is directly and/or indirectly linked with greenhouse gas emissions. The increase in productivity with higher energy use efficiency is today's goal. Conservation agriculture (CA), zero tillage, minimum

tillage, various resource conservation practices such as the system of rice intensification (SRI) and the solar operated machineries (solar pump, solar operated sprayer) are a few examples of energy smart technology can be employed in agriculture at suitable locations.

1.8.6 Knowledge-smart technology

The new knowledge contributes to reduce climate-related risks and increase the capability of farmers to adopt climate-smart agriculture on large scale. Cropping system intensification, integrated farming system, ecology specific varieties, seed treatments/ priming, mechanical rice transplanting, integrated weed management, integrated pest management (IPM), use of information and communication technology (ICT) in extension, protected horticulture, hydroponics, seed and fodder banks, climate-smart villages, village knowledge centers (VKC), are the examples of knowledge smart technologies.

1.9 Prioritization of CSA technologies

The use of decision-support systems as risk management tools should be promoted as an effective means of providing the output of integrated climate-agronomic information in the form of scenario analyses relating to impending risks that can be valuable to users. Several factors influence the decision of CSA technologies to be adopted at the village level. Prioritization of CSA technologies is a participatory exercise by the stakeholders to support climate change adaptation planning by designing a portfolio for a specific vulnerable region. Multi-phase participatory exercises by the expert or farmers using the prioritization framework lead to the identification of a set of promising CSA technologies. Prioritization of CSA technologies discussed below is based on the synergy and trade-offs between different pillars of CSA for its implementation at the field level. However, for the national and state levels, the CSA portfolio is prepared by mapping and linkage analysis of CSA activities and the other developmental priorities of the state such as sustainable development goals (SDGs) and Intended National Determined Contribution (INDC) (discussed in Section 8).

1.9.1 Identification of promising CSA technologies

Preparation of CSA technology inventories based on suggestions from published literature, government report, discussing with farmers, extension agents, district agriculture officers, national and international

researchers, professors, and other stakeholders having good knowledge about the area under question.

1.9.2 Prioritization of the technologies based on expert opinion

The opinion of as many independent experts is collected on a structured questionnaire and the CSA technologies are ranked based on their opinion and the criteria discussed below. The experts are agricultural scientists and extension workers knowing the vulnerability of the target area to climate change. In the beginning, the weightage to each CSA pillar i.e. production (W1), adaptation (W2), and mitigation (W3) are decided upon expert opinions in a brainstorming session to get the total score of 100 (Table 1.4).

Table 1.4. Weightage of CSA pillar

Sl No	CSA Pillar	Weightage
1	Production	W1
2	Adaptation	W2
3	Mitigation	W3

$W1+W2+W3 = 100$.

Source: Authors' own compilation.

Each pillar of CSA is judged by a set of seven indicators assigning weightage by experts to get the total weightage of 100 (Table 1.5). The indicators comprise a set of questions, such as does it increase yield? (w1), increase income? (w2), improve nutrient use efficiency? (w3), improve water use efficiency? (w4), reduce vulnerability and risk? (w5), reduce GHG emissions? (w6), enhance energy efficiency? (w7).

Table 1.5. Weightage of indicators of the CSA pillar

Indicator	Weightage
Does it increase yield?	w1
Does it increase income?	w2
Does it improve nutrient use efficiency?	w3
Does it improve water use efficiency?	w4
Does it reduced vulnerability and risk?	w5
Does it reduce GHG emissions?	w6
Does it enhance energy efficiency?	w7

$w1+w2+w3+w4+w5+w6+w7$ should be 100

Source: Authors' own compilation.

Subsequently, the list of technology inventories is evaluated and scored in a -10 to 10 scale against each indicator. The experts individually score each indicator in such a way if it is increased or decreased by 10% the score may be raised or down by one. After the initial scoring is finished, an adjustment in the score is made if needed looking into the cumulative score (Table 1.6).

Table 1.6. Guidelines for scoring a technology

- 10	- 9	- 8	- 7	- 6	- 5	- 4	- 3	- 2	- 1	0	1	2	3	4	5	6	7	8	9	10
De-crease by 100%					De-crease by 50%					No change					In-crease by 50%					Increase by 100%

Source: Authors' own compilation.

After that, the cumulative score of each CSA technology is calculated by taking sum of the all scores (a, b, c, d, e, f, g). The range of cumulative scores varies between -70 to 70. After getting all weights and scores, the cumulative score is calculated by using the formula:

Cumulative score (CUS) =

$$\frac{(W1 \times w1 \times a) + (W1 \times w2 \times b) + (W2 \times w3 \times c) + (W2 \times w4 \times d) + (W2 \times w5 \times e) + (W3 \times w6 \times f) + (W3 \times w7 \times g)}{(W1 \times 2 + W2 \times 3 + W3 \times 2) \times (w1 + w2 + w3 + w4 + w5 + w6 + w7)} \dots (1)$$

Whereas, W1, W2, W3 are the weightage of CSA pillars, w1, w2, w3, w4, w5, w6, w7 are the weightage of CSA indicators, and a, b, c, d, e, f, g are the score of a specific technology against each CSA indicator. Based on the cumulative score, the technologies are ranked (Table 1.7).

Table 1.7. Calculation of cumulative score of a CSA technology

	Tech-nology	CSA indicators							Cu-mu-lative score
		Does it in-crease yield?	Does it in-crease in-come?	Does it improve nutrient use effi-ciency?	Does it improve water use efficien-cy?	Does it reduced vulnera-bility and risk?	Does it reduce GHG emis-sions?	Does it enhance energy efficien-cy?	
1	Tech-nology A	a	b	c	d	e	f	g	CUS

Source: Authors' own compilation.

1.9.3 Farmers' opinion on the shortlisted technologies

For this, the research team interacts with the key farmers to assess their understanding of climate change and variability, climatic threats, and their impacts on agriculture, and what adaptation options are available to them. The team has to collect basic information like family, education, social, landholding, income, assets, *etc.* so that the ground factors behind the adoption of technologies can be identified. The list of CSA technologies which is already ranked by using expert opinion is again scored by the farmers in three/two categories: highly essential (score 3), essential (score 2), and not essential (score 1). Based on these scores the technologies are prioritized at the regional level.

1.9.4 Selection of technology for on-farm evaluation

After prioritization one or more technologies may be selected for on-farm trial to validate its performance based on adaptation, mitigation and productivity enhancement. On the basis of evaluation result, the technology is upscaled in the region as per the upscale plan.

2. Weather-Smart Technologies

2.1 Introduction

Weather anomalies and extreme events are dominant factors and always pose a challenge for coping with agrometeorological risks and uncertainties. The exposure of any region to the event (i.e., probability of occurrence at various severity levels) and the society's vulnerability decides the risk associated with weather and climate for any region. Risk scoping, risk characterization and evaluation, risk management, monitoring, and review are followed for characterizing and managing risks. Societal vulnerability to weather and climate risks can be reduced to a great extent by preparedness planning, risk assessments, and improved early warning systems. Weather-smart technologies aim to reduce the likelihood of weather-related risk event occurring, avoiding and redistributing the risk, and reducing the consequences. Providing climate services to various stakeholders is key to build climate resilience. World Meteorological Organization framed the Global Framework for Climate Services (GFCS) in 2009 for enabling better management of the risks of climate variability and change through provisioning of climate services at global, regional and national scale. At present farmers are getting many options and meteorological advisories for managing the risks by utilizing various strategies and tools. Weather forecast and early warning, well-differentiated and sufficiently scaled up operational agromet services supporting preparedness strategies, information and communication technologies (ICT), contingent crop planning, stress-tolerant varieties, crop, and varietal diversification, changing planting time, crop insurance, and household off-farm employment or investment are some of the weather-smart technology in agriculture.

2.2 Weather forecasting and early warning

The farming community requires different types of weather forecasting for managing the risks of climate change in agricultural operations. Four types of forecasts viz., nowcasting (6 to 12 hrs), short-range forecast (valid for 48 hours), medium-range (valid for 5 days to a week), and long-range or seasonal forecast (valid for a month to season) are made in India that provide inputs to take precautionary action directly to the farmer. All these four types of weather forecasts as well as the weather analysis for the past weeks/ fortnight (Fig 2.1 & 2.2) are provided by weather agencies involved in weather forecasting across the world, including India.

2.2.1 Now-casting

Very short-range forecasts *i.e.* nowcasting having validity for 6-12 hrs is prepared on monitoring local weather conditions through radar/satellite imageries *etc.* This type of forecast is almost accurate.

2.2.2 Short-range forecasting

Forecasts valid upto 2 days are generated by analysis of weather observations over a wider area (regional scale) by using satellite and radar observations. The short-range forecast can be generated anytime having a fairly high degree of accuracy (80%).

2.2.3 Medium-range weather forecasting

National Centre for Medium-Range Weather forecasting (NCMRWF) makes a medium-range forecast at 5 days interval having validity between 3-10 days (Fig. 2.2). Medium range forecast is most useful for farmers as it provides enough window for the farmers to take the suitable decision about many agricultural operations such as sowing seeds of weather-sensitive high yielding varieties, need-based application of fertilizer, pesticides, insecticides, planning irrigation and harvesting based on the anticipated weather changes. The current level of accuracy of 70% needs to be further improved for the effective planning of modern agricultural practices.

2.2.4 Long-range weather forecasting

Long-range forecast of monsoon (before the season) is made by India Meteorological Department (IMD). The performance of southwest monsoon is being predicted in India as a whole ten days in advance with a fair degree of accuracy of 50-60%. The accurate prediction helps in proper planning of land preparation, selection of crop and variety, planting dates, level of inputs, resource scheduling, and cultural practices *etc.*

2.2.5 Early warning

For agromet services, the IMD has been issuing rainfall, maximum and minimum temperature, relative humidity, surface wind, and cloud cover forecasts with a five-day lead time at the district level. By using rainfall, evapotranspiration, soil moisture data from agromet observatories, forecast are available for country-wide weekly drought outlook; weekly, bi-weekly and monthly aridity maps through the monsoon season. Similarly, using temperature, particularly maximums and minimums from different weather stations, IMD is providing country-wide heat wave warning bulletin (five-

day lead time). Cyclone early warning is being made through the country-wide daily weather-warning bulletin, with track and intensity forecast (six hours to five-day lead time) using wind, rainfall intensity, ocean-atmosphere interaction data collected from weather buoys, ships and airplanes, doppler radar, satellites. Similarly, all-India thunderstorms nowcast (few hours lead time) is made by IMD using precipitation, temperature, wind speed, dew point collected from radar, and upper air observatory.



Fig. 2.1 Rainfall departure from normal rainfall over different districts of Odisha.

Source: Adapted from Meteorological Centre Bhubaneswar, IMD

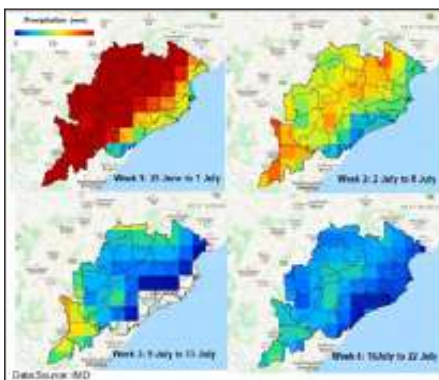


Fig. 2.2 Weather forecast provided by IMD

India Meteorological Department uses 4 coded warning system. Green means no advisory is needed. Yellow weather warning is issued to make people aware of the possibility of severe bad weather over the next few days and could affect people. It is issued to make people plan for their activities. Amber/Orange warning is issued to make people prepare for an increased likelihood of severely or extremely bad weather. People should change their plan, protect themselves and their communities from the bad weather. A red warning is issued when extremely bad weather. Not only for bad weather, but these warnings are also universal in nature and can be used for flood warning, depending upon the amount of water raised above the danger mark expected and action need to be taken to keep themselves safe and protect the life and property. IMD in collaboration with the Indian Council of Agricultural Research (ICAR), Indian Institute for Tropical Meteorology (IITM), Pune has developed 'Meghdoot' mobile app, which provides weather forecast-based agro advisories to farmers in 10 different languages. These advisories include wind speed, direction, humidity, and rainfall in every three hours. The app also provides crop and livestock advisories for selected locations every Tuesday and

Friday. Over the recent years, lightening is identified as the single most killer over India and the exact forecast of thunderstorms and lightening is a difficult job. IITM, Pune has developed a mobile app 'DAMINI' lightning, which uses the network with about 48 sensors over various parts of the country and gives exact location of current lightening strikes, probable locations of impending lightening around the area of 40 sq. km and movement and direction of thunderstorm. The precautionary steps to be taken during lightening are also provided by this app.

2.3 Operational agromet services

A comprehensive weather-based farm advisory informs how the crops, livestock, and farm operations are affected by the present and future weather parameters, and the location-specific actions are also suggested. To make it farmer's friendly, these advisories are generally provided in simple and local languages. Agromet advisory services are made robust by including agrometeorological database, real-time weather and crop conditions, crop-weather relationships, and skilled manpower in multi-disciplinary resources and user interface. Disaggregated scaled up agromet services in India includes:

2.3.1 Integrated Agromet Advisory Services (IAAS)

The increasing climate variability, associated extreme events, and climate change poses many challenges to agriculture which can be addressed by well-differentiated and sufficiently scaled up operational agromet services providing preparedness strategies. However, generalized forecasts have limited use in farming. The weather information for agricultural use has been made robust and designed to be used in an effective way for crop planning and management. The weather-based advisories not only provide the weather information but also the effect of these parameters on crops, livestock, and other agricultural management options for the present and future. To be more effective, these agromet advisory are given in simple and local languages using the latest media, IT and web technologies. Integrated Agromet Advisory Services (IAAS) launched by IMD is functioning in the country since 2007. The IAAS was launched in collaboration with State Agricultural Universities (SAU), few ICAR institutes, and other organizations. Presently IMD is issuing agromet advisory bulletins at the national and state level.

Currently, 2.5 million smallholder farmers across India are receiving the agromet advisories. Many studies have concluded that farmers receiving agromet advisories have resulted in 10-15% higher yield which is reducing 2-5% in cultivation costs compared to the farmers not receiving the advisories.

As per the report of CGIAR the Integrated Agrometeorological Advisory Service (IAAS) has resulted in an estimated economic impact of more than USD 10 billion.

2.3.2 Agromet Field Units (AMFUs)

About 130 Agromet Field Units (AMFUs) representing different agro-climatic regions supporting IAAS in preparing district level agromet advisory bulletin and providing advisory to the farmers in collaboration with All India Coordinated Research Project in Agro-Meteorology (AICRPAM) under the supervision of Central Research Institute for Dryland Agriculture (CRIDA). Ministry of Agriculture, Government of India has launched “Kisan SMS”, a portal for farmers under www.farmer.gov.in during July 2013. Agromet advisories are disseminated through SMS in both regional and English languages through Kisan SMS to the farming community.

2.3.3 District Agromet Units (DAMUs)

There is an urgent requirement for high resolution, more accurate weather forecast at the sub-district level for issuing crop and location-specific advisories. Under Gramin Krishi Mausam Seva (GKMS), IMD is planning to set up an additional 530 district Agrometunits, eventually for each district in the country. IMD is also introducing new products such as land surface water index, land surface temperature, and leaf area index which can be used for irrigation, sowing, and fertilizer applications.

Krishi Vigyan Kendras (KVKs) are currently being upgraded to serve as District Agromet Units (DAMUs). This involves equipping each KVK with an Automatic Weather Station and adding personnel with expertise in agrometeorology. District Agromet Advisory Units (DAMUs) is being guided by ICAR Institutions and SAUs. DAMUs are receiving and disseminating meteorological information and forecasts for the concerned districts. Many functions are performed by DAMUs such as on-farm testing of various agricultural technologies to assess the location specificity; organizing demonstrations of location-specific technologies on farmer's field to establish the production potential of technologies; capacity development training to farmers and extension personnel for enhancing their skill and knowledge about the modern agricultural technologies; For improving the agricultural economy of the district, working in close collaboration with public, private and voluntary sector initiatives to act as a knowledge and resource centers for providing farm advisories using social media, ICT and other media means on different aspects.

At present, around 400 District Agromet unit is functional throughout the country and it is planned that every district will have one such unit to ensure dissemination of improved district-scale agromet advisory services. These units receive forecasts from IMD. The experts from Universities, ICAR, and agro-meteorologist estimate the effect of weather parameters on crops and formulate the advisories. Advisories/ alerts are provided to farmers twice a week in regional languages through various media including Whatsapp and Facebook, television, and radio. The advisories are also sent through SMS. The nearest KVK may be contacted for adding the phone number of farmers in the database, after which they will start receiving the advisories in the chosen format. Recently, the IMD has started block level weather forecast and warning for farmers. Presently this service is provided to farmers in 2000 blocks in the country benefiting 43 million farmers. The farmers have made modification to atleast one of the following critical farm practices such as change variety/breed, arrange for storage of harvest, early/delayed harvesting, changed crop, early/delayed sowing, changed schedule of ploughing/land preparation, changed pesticide application schedule, changed fertiliser application schedule, and changed scheduled irrigation based on weather advisories. This helped them either avoiding loss or getting increased income. Immediate agro-advisory after unexpected weather changes have offered help to take timely corrective action to prevent crop loss.

2.3.4 ICT based dissemination of Agromet advisory

The farmers want on-demand advisory through various media. Follow up for an SMS received by them with a close loop in the information advisory and contact mechanism. Farmers further demand crop-specific SMS. Since cropping pattern is different in different places, managing crop-specific data is a challenge. Also, few farmers are unable to decode the advisories in regional language. All these can be achieved through a digital platform like

- SMS / IVRS to relatively much larger number of farmers.
- Modernize agromet website to make interactive
- Multi-platform backend: Web-based and front-end.
- Multi linkages among agri-experts, knowledge institutions, services providers, etc.
- ICT based agricultural information dissemination models.
- Media lab Asia : an interactive information dissemination system (IIDS)

- Agromet domain linked to websites of other ministries viz., rural, Panchayati raj *etc.*

2.3.5 Other weather services

Weather forecasts and weather graphics are also provided by Skymet, the first private sector entity to do so apart from IMD. Skymet provides weather service information to media and the major insurance companies in India, the power sector, and the agriculture sector. Different renewable energy companies receive the wind and solar forecasts from Skymet for their meso and micro-scale numerical weather prediction (NWP). Some NGOs are also working with Skymet for farmers in many states in India.

2.4 Changing the planting time of crops

Weather variability is now considered the major factor for causing inter-annual variability in crop growth and yield besides rainfall, temperature, and bright sunshine hours. Changing the sowing dates has a direct impact on thermo and photoperiod which ultimately influences the phase-wise development and partitioning of dry matter in crops. In those areas where rice varieties are being grown near to their temperature tolerance threshold, there will be a negative impact on the yield. There is an indirect impact of changing planting/sowing time in the form of water availability, soil moisture deficiency and dominance of insect-pest and diseases, whereas direct impacts are due to rising temperatures. The resource-poor small and marginal farmers are to be highly affected by the climate variability and change (Kelkar and Bhadwal 2007).

The proper sowing time of the rice crop ensures that vegetative growth completes during a favorable temperature period and sunshine hours. Crops respond differently to different temperatures at different growth stages. Too warm and too cold night temperatures are often more detrimental to crops than the day temperature. The warmer temperature at germination and early growth stage is helpful for better germination and faster growth. While temperature higher than the cardinal temperature at the reproductive and ripening stage of rice crop reduces the seed setting and grain quality. The adaptation to the climatic variability can be achieved to some extent by shifting planting dates to suit the temperature regimes, choosing varieties with different growth duration, or changing crop rotations. Results from many research showed that changing the planting time of rice at some locations from present practice could be an effective solution to improve rice yield and reduce the impacts of climate change. In the rainfed area, the sowing time of crops depends on the onset of monsoon and the availability of adequate soil moisture. It is reported

that the sowing time of rainfed rice in eastern India has been delayed by two weeks. By analyzing rice yields at Cuttack under three different climate change scenarios, it was found that rice yield can be improved when the sowing date of rice is advanced from 1 June to 15 July.

2.5 Piloting climate-resilient crop and crop varieties

The growth and yield of crops are affected by the combinations of abiotic and biotic stresses which are the result of global warming and potential climate abnormalities. Crop production is severely affected if the multiple abiotic stresses occur at the same time compared to their individual occurrence. Abiotic stresses such as drought, low and high temperature and salinity affect the crops by increasing the incidence of pathogens, insects, and weeds. In addition, these abiotic stresses provide a favorable environment for minor pests, which can pose danger in the future. Identification of suitable crop and cropping system and developing biotic and abiotic stress-tolerant varieties for different ecologies are important to overcome the negative impact of climate change on agricultural productivity. Replacement of traditional variety with climate-resilient varieties can reduce total GHG emissions by 25-30%. The suitable crop and varieties which are tolerant to various biotic and abiotic stresses for different ecologies are presented below.

2.5.1 Stress tolerant crops

Crops are exposed to abiotic stresses such as drought, salinity, cyclone, heat waves, cold waves, elevated temperature, submergence, and nutrient deficiencies more frequently in changing climatic scenarios. Managing these abiotic stresses is a great challenge for agriculture because these stresses often reduce the choice of different crops and sometimes the extreme events cause total crop failure. The livelihood of small and marginal farmers are adversely affected due to the abiotic stresses affecting the national economy and food security. The abiotic stresses affect different crops differently due to their sensitiveness and tolerance towards these stresses. The different strategies are adapted by tolerant plants to fight or avoid the negative effect of abiotic stresses. There is a wide variability of tolerance to abiotic stresses in each crop species and some useful traits to fight these abiotic stresses are found in wild relatives that are transferred to their progenies through traditional or biotechnological breeding. Identifying tolerant crop and cropping system for the various ecosystem of the different agro-climatic zone is very important. Growing tolerant crops reduce the risk of crop failure and minimize the adverse effect of extreme weather events on agricultural production. The list

of agriculture and horticultural crop, tolerant to various abiotic stresses is presented in Table 2.1.

Table 2.1 Suitable crops tolerant to various abiotic stresses

Ecosystem	Recommended crops
Field crops	
Waterlogged areas	Rice, jute, sugarcane
Drought	Pearl millet, sorghum, minor millets, chickpea pigeon pea, horse gram, sesame
Saline patches	Rice, wheat, sunflower, cotton, finger millet, sorghum, barley, safflower, sugar beets
Flood-affected areas	Rice, jute
High temperature	Pearl millet, sorghum, barley, chickpea, cluster bean
Horticultural crop	
Waterlogged areas	Taro, lotus, and makhana
Irrigated areas	Banana, betel vine, cowpea, french bean, guava, litchi
Drought	Mango, guava, cowpea, lime, lemon, french bean, <i>aonla</i> , guava, turmeric
Flood-affected areas	Japanese mint, marigold, vegetables
Saline patches	<i>Bael</i> , citronella, <i>karonda</i> , <i>mahua</i> , mint, <i>phalsa</i>
High temperature	Cabbage
High temperature & humidity	Carrot, cauliflower, turnip
High & Low temperature	Radish
Frost	Potato

Source: Authors own compilation

2.5.2 Stress tolerant crop varieties

Developing stress tolerant crop varieties one of the best mechanisms for a crop to endure the biotic and abiotic stresses. Stress tolerant varieties are an important component of climate-smart agriculture having the ability to maintain agricultural productivity under stress, sustenance of yield under suboptimal conditions, intensifying production into marginal lands, and explore mitigating options through the modified physiological structure.

2.5.2.1 Abiotic stress

Abiotic stress is the deleterious effect of non-living causes on crops in a particular environment. Abiotic stresses include drought, flood, submergence, cyclone, heat stress, cold stress, salinity, and other environmental extremes. Abiotic stress is a major threat to food security due to the continuous

fluctuations of climate and deterioration of the environment caused by anthropogenic activity.

(a) Cereals

Rice

Rice is a unique crop grown in various ecologies. It is cultivated in all types of ecologies. Rice productivity in stress-prone areas of eastern India is low and fragile. Growing tolerant varieties increase crop tolerance to abiotic stress and crop yield. Within rice crops, variety shows the difference in response to various stresses. Also, climate-resilient rice varieties with a higher allocation of photosynthates to seeds help in reducing photosynthate allocation belowground to methanogens, ultimately mitigating CH₄ emission.

i. Stagnant flood-tolerant rice varieties

Rice is affected either by flash or stagnant flooding. A complete inundation for a short duration (usually 1-3 weeks) occurs in flash flooding whereas 20-50 cm water stagnates for up to a few months in case of stagnant flooding. The *SUB1* gene is effective only under flash flood conditions. A large area in South Asia is affected by stagnant flooding or both flash and stagnant flooding. Stagnant flooding reduces yield through suppressing tillering; leaf area development; panicle size, fertility, and survival. Several varieties with stagnant flood tolerance were developed and released for their cultivation (Table 2.2). Similarly, several varieties have been developed with both flash flood (*SUB1*) and stagnant flood tolerance (Table 2.2).

ii. Flash flood-tolerant rice varieties

Rainfed shallow and semi-deep water lowland rice suffer from flash floods and waterlogging. Flash floods occur due to the overflow of rivers and canals because of heavy and intense rainfall events and sometimes due to tidal movements in coastal areas. Rice varieties with 140-155 day duration are usually cultivated in these flood-prone areas. Due to complete submergence aerobic respiration and gas exchange is restricted and chlorophyll senescence takes place consequently. Flood tolerant local rice landraces are cultivated in eastern India for the last seven decades. ICAR-National Rice Research Institute (then Central Rice Research Institute), Cuttack, India released pure line selections such as FR13A from Dhalaputia in the early 1950s. Three genes *SUB1A*, *SUB1B*, and *SUB1C* were identified within the *Sub1* (QTL) region of which *SUB1A* was subsequently identified as the major determinant of submergence tolerance. In 2003, IRRI in collaboration with the national

institutes initiated a programme to introduce the *SUB1A* gene into five mega varieties (Swarna, Sambha Mahsuri, BR 11, IR 64 and CR 1009) of South Asia. Marker-assisted backcross (MABC) breeding system was used to incorporate this gene into elite rice varieties. The new varieties with *SUB1A* retain the entire genome of the original varieties having a small segment of the donor genome containing *Sub1* (QTL) gene. These varieties possess all characteristics of original parental lines except for the added trait of submergence tolerance. The new *Sub1* introgressed lines exhibited tolerance to complete submergence for up to 2-3 weeks, depending on the floodwater conditions, whereas the original varieties cannot withstand submergence beyond 4-5 days (except for IR 64, which has moderate tolerance to submergence). These varieties were released for commercial cultivation after excellent performance under controlled flooding conditions, at research stations, and in farmers' fields during 2008 (flood-affected year) in India. Swarna-Sub1 was released for cultivation in 2009 in India and performed better under flood situation apart from being high yielding with good grain quality. *SUB1* gene is effective at all growth stages from seedling to about a week before flowering. *Sub1* varieties are not effective under stagnant flood or deep water conditions where more than 20 cm depth of water stays beyond 20 days. Farmers usually re-transplant their fields using aged seedlings of local varieties in case of early flood damage, but sometimes water accumulates in the field and it is not possible, moreover, the practice is very costly. From the field experiments conducted in 128 villages of Odisha, it was found that Swarna-Sub1, recorded 45% increase in yields over the popular farmer's variety when fields are submerged for 10 days. In another experiment in 2008 in Odisha, after severe floods during panicle initiation (PI) for 12-17 days, of Swarna-Sub1 yielded 2.9-3.2 t ha⁻¹ while surviving plants of Swarna did not flower. Similarly, in U.P. in 2011, Swarna-Sub1 under flooding for about one week during PI produced 4.75 t ha⁻¹ whereas Swarna yield was only 1.76 t ha⁻¹. This wide adaptability of *Sub1* varieties is important because flood incidences are becoming more erratic in recent years. The list of rice varieties tolerant to stagnant flood is given in Table 2.2.

iii. Drought-tolerant rice varieties

Drought is widespread climatic stress and can occur at any time and duration during the cropping season affecting crop physiological, biochemical, and molecular processes drastically reducing rice yield. The extent of loss due to drought varies depending on the timing, intensity, and duration of drought. To avoid drought, farmers quite often rely on early maturing varieties. These varieties are not tolerant of drought, but they escape late-season drought

due to earliness. If a drought occurs early in the season, these short-duration varieties can be sown late. Rice plant overcomes drought stress through two mechanisms *viz.*, drought escape and drought avoidance. Drought escape is an adaptive mechanism in which rapid plant development occurs to enable plants to complete the full life-cycle before the drought event. Whereas in drought avoidance, the plant maintains relatively higher tissue water content even when there is less water content in the soil. The higher relative tissue water content is maintained either through a prolific root system or increasing root growth, reducing transpiration, limiting vegetative growth or osmotic adjustment, *etc.* The development of drought-tolerant varieties will greatly enhance and stabilize rice productivity in drought-prone areas. Eight QTLs (DTY 1.1, DTY 2.12, DTY 2.23, DTY 3.1, DTY 3.2, DTY 4.1, DTY 6.1, and DTY 12.1) with large effects on grain yield under drought stress have been identified. These QTLs show effect against two or more genetic backgrounds and across both lowland and upland ecosystems. Efforts to transfer this drought tolerance QTLs into mega varieties such as IR 64, Swarna-Sub1, and IR 64-Sub1 using MABC breeding approach are ongoing. The first genuine drought-tolerant rice variety, Sahbhagidhan, developed through conventional breeding was released in India in 2010. Depending upon the severity of drought, this short duration (105-110 days) variety offers a yield advantage of 0.8-1.0 t ha⁻¹ both under upland and lowland conditions. Early harvesting of Sahbhagidhan facilitates early sowing of wheat and thereby increasing their annual production and income. There is evidence of increasing yield and cropping intensity along with a reduction in input and labor costs associated with the adoption of Sahbhagidhan. It was reported that from 2010-2017 in Eastern India (Uttar Pradesh, Bihar, and Odisha) Sahbhagidhan gave yield advantage of 0.8 to 1.6 t ha⁻¹ over currently grown long duration as well as traditional varieties during drought years. The list of drought-tolerant rice varieties is given in Table 2.2.

iv. Salt tolerant rice varieties

Crop species sensitive to soil salinity are known as glycophytes, whereas plants grown in the water of high salinity or which can generally tolerate high salt concentrations are known as halophytes. Salinity stress affects seed germination, seedling growth, leaf size, shoot growth, shoot and root length, shoot dry weight, shoot fresh weight, number of tillers per plant, flowering stage, spikelet number, percent of sterile florets, and productivity. Soil salinity is one of the major constraints affecting rice production worldwide, especially in coastal areas. Susceptibility or tolerance of rice plants to high salinity is a coordinated action of multiple stress-responsive genes, which also interacts

with other components of stress signal transduction pathways. Rice plants generally tolerate salt by mainly two mechanisms, ion exclusion, and osmotic tolerance. Ion exclusion mainly involves Na^+ and Cl^- transport processes in roots, which prevent the excess accumulation of Na^+ and Cl^- in leaves. Ion exclusion includes retrieval of Na^+ from the xylem and efflux of ions back to the soil. Osmotic tolerance is regulated by long-distance signals that reduce shoot growth and is triggered before shoot Na^+ accumulation. Osmotic tolerance involves the plant's ability to tolerate the drought aspect of salinity stress and to maintain leaf expansion and stomatal conductance. The ideal salinity tolerant variety should possess tolerance to a high amount of Na^+ , control the uptake of Na^+ and keep high uptake of K^+ , good initial vigor, agronomically superior with high yield potential. Few landraces/varieties of rice tolerant to soil salinity through various mechanisms like salt expulsion, cellular insulation, and DNA protection. Several rice varieties (CSR 10, CSR 27, CSR 30, and CSR 36) have been developed in India with tolerance to inland salinity/sodicity. However, all these varieties are of long duration. One medium duration salt-tolerant rice variety, CSR 43 (CSR-89IR- 8), was released in U.P. for the inland sodicity. Not much progress has been achieved in developing salt-tolerant varieties for the coastal salinity. Only in recent times, one IRRI line, IR 72046-B-R-3-3-3-1, was released in India as CR Dhan 405 (Luna Sankhi), which is suitable for both wet (*khari*) and dry (*boro*) seasons. CSR 36 has been showing remarkable performance in sodicity-affected soils. There was 35% higher yield in CSR43 along with its matching management practices over farmers' current varieties and management in sodic soils in the alluvial Indo-Gangetic plains. The list of salt-tolerant varieties are given in Table 2.2.

v. Heat tolerance rice varieties

Temperature regulates the process of photosynthesis; if temperature exceeds the critical level, which occurs when there is an elevation of 10-15°C in ambient temperature is known as heat shock. To avoid heat shock several heat-tolerant rice varieties are developed (Table 2.2). Heat tolerance studies in rice mainly deal with the reproductive stage as it is highly sensitive and influences grain yield. It affects the pollen viability, pollen production, dehiscence of the anther, pollen shedding. Heat tolerance rice varieties (N22, Annapurna) has certain physiological and morphological traits like early maturity, quick regeneration capability, fast recovery from heat, flexibility in accumulation, and translocation of carbohydrate.

vi. Low light stress tolerant rice varieties

Light is very important for the growth, development, and metabolism of the plant, and being an important environmental factor, plays a critical role in photosynthesis and photomorphogenesis. Due to increased cloud cover, the problem of low light, both quality and quantity, has become dominant stress in eastern India, causing yield loss particularly to the rice crop. is prevalent today and caused by blocking of light from snow and cloud. Low light hinders the physiological metabolic processes such as photosynthesis, antioxidant characteristics, carbon, and nitrogen fixation and greatly inhibits the agronomic traits of plants. It also decreases the leaf weight as well as flower bud numbers by causing slow growth. Low light causes change in color and extend the maturity time in some plants and also reduces sugar and starch contents in the grain. Higher chlorophyll-b content was found to be high in low light-tolerant rice. It was also reported in rice that low light increases the intercellular CO₂ concentration in leaves by affecting stomatal conductance negatively. The photosynthetic efficiency and stomatal conductance were found to be low in the plants grown under low light conditions as compared to those grown under natural light. Under the prevalence of low light stress from 5 to 15 days, the relative chlorophyll content, anthocyanin, net photosynthesis rate, transpiration rate, stomatal conductance, and antioxidant activity of plant decreases significantly while malonaldehyde content increased, which damages plant cells. Low light tolerant varieties of rice have been developed to reduce the impact of low light stress (Table 2.2).

vii. Cold tolerant rice varieties

The cold injury affects *rabi* rice when the germination and early growth stage coincides with the occurrence of low temperature. Low temperature stress commonly causes low germination, slow growth of seedlings, leaf yellowing, stunted growth characterized by reduced height. Under cold stress, seedling takes more number of days to attain four-leaf stage which delay transplanting. The delayed and slow growth of rice in the vegetative stage increases the duration of rice and makes it more susceptible to terminal heat stress at the time of flowering. Many cold-tolerant varieties of rice have been released for commercial cultivation especially in *rabi* season (Table 2.2).

viii. Multiple stress-tolerant rice varieties

Quite often crop may encounter more than one abiotic stresses during the same crop season at different points of time. Research emphasis, therefore, needs to be given on the development of multiple stress-tolerant rice varieties (STRVs).

The elite rice lines have been developed or in the process of development with multiple stress tolerance like flash flood + stagnant flood; flash flood + anaerobic germination (AG); stagnant flood + AG; flash flood + salinity; flash flood + salinity + Zn deficiency; flash flood + drought; flash flood + resistance to bacterial leaf blight *etc.* Many of these multiple stress-tolerant lines, under multilocal evaluation, are expected to be available to the farmers for cultivation in near future. Five multiple stress-tolerant rice varieties *viz.*, DRR 52, DRR 47, Sukhadhan 5, CR dhan 801, and CR dhan 802 have been released in India. ICAR-National Rice Research Institute (NRRI) has developed CR Dhan 801 and CR Dhan 802 possessing submergence as well as drought tolerance ability in the background of mega variety 'Swarna'. CR Dhan 801 is a short bold grain rice that has been released for the states of Odisha, West Bengal, Uttar Pradesh, Andhra Pradesh, and Telangana. It gives about 6.3 t ha⁻¹ yield under normal condition and 4 t ha⁻¹ under submergence while 2.9 t ha⁻¹ under drought conditions. Similarly, CR Dhan 802 (Subhas: IET 25673) is short bold grain rice that has been released for the states of Madhya Pradesh and Bihar. It produces an average yield of 6.5 t ha⁻¹ under normal condition and 4.3 t ha⁻¹ under submergence while 2.3 t ha⁻¹ under drought conditions. Some of the rice varieties tolerant to multiple stresses are given in Table 2.2.

ix. Lodging resistance rice varieties

The frequent occurrence of hail storm/thunderstorm and subsequent heavy rain in the advanced ripening phase, lodges the crop, increases chaffiness and significantly reduces the yield. To overcome such problem, Bina Dhan 11, a lodging-resistant variety was developed and demonstrated in farmer's fields in frequently lodging affected areas. It responded well by tolerating lodging up to maturity. This variety was also found to be moderately tolerant to BPH having no shattering habit upon delayed harvesting. The variety Bina Dhan 11 produces about 5.8 t ha⁻¹ yield. Some of the lodging resistant varieties are mentioned in Table 2.2.

Table 2.2 Rice varieties tolerant to different abiotic stresses

Abiotic stress	Varieties
Submergence	Bina Dhan 11, Sambha-Mahsuri Sub 1, CR Dhan 802, Swarna Sub 1, Ranjit Sub 1, CR Dhan 801, CR 1009 Sub 1, Bahadur Sub 1, CR Dhan 505, CR Dhan 401, Reeta, Sumit, Chakaakhi

Stagnant water	CR 1014, CR Dhan 70 (Hanseswari), Sarala, Gayatri, Durga, CR Dhan 511, CR Dhan 508, CR Dhan 507 (Prasanta), CR Dhan 502 (Jayanti Dhan), CR Dhan 503 (Jalamani), CR Dhan 500, CR Dhan 505, Varshadhan, Tulasi
Drought	Kalinga III, Rudra, Shankar, Vanaprava, Anjali, Vandana, Virender, Sahabthagidhan, CR Dhan 100 (Satyabhama), CR Dhan 101(Ankit), Ananda, CR Dhan 202, CR Dhan 206, BRRI Dhan 71, DRR 42, DRR 44, Swarna Sreya, Brahman Nakhi, Sal Kain, Khandagiri
Drought and Submergence (multiple)	CR Dhan 801, Sukhadhan 5, DRR 52, DRR 47, CR Dhan 802
Salinity	CR Dhan 405 (Luna Sankhi), CSR 10, CR Dhan 402 (Luna Sampad), Lunishree, CR Dhan 406 (Luna Barial), CR Dhan 403 (Luna Suvarna), DRR 39, CSR 30, SR-26-B, Getu
High temperature/heat	N22, Annapurna
Cold	Kalinga III, CR Dhan 601, CR Boro Dhan 2, Rajalaxmi (Hybrid), Chandrama, Sheethal (WGL-283), Erramallelu
Lowlight	Swarnaprabha, Rajalaxmi
Aerobic/mild water	Pyari, CR Dhan 201, CR Dhan 202, CR Dhan 203 (Sachala), CR Dhan 205, CR Dhan 206, CR Dhan 207, CR Dhan 209
Flash flood + Stagnant flood	Ranjit Sub 1, Bahadur Sub 1, Savitri Sub 1

Source: Authors' own compilation

Maize

Traditionally maize is a *kharif* crop in Odisha. It is the second most important crop next to paddy during *kharif* season in terms of both area and production. The *rabi* maize accounts for 7% of the total area and production of the state. The *rabi* maize is cultivated where sufficient irrigation is available. On the contrary, only 24% of the *kharif* maize area has irrigation facilities. Frequent failure of monsoon poses a serious drought threat to two-third of the total rainfed cultivated area. To overcome abiotic stress, tolerant varieties have been developed against waterlogging, cold, high temperature, and lodging as presented in Table 2.3.

Table 2.3 Maize varieties tolerant to different abiotic stresses

Abiotic stress	Variety
Waterlogging	DMRH 1419, PMH 3, CMH 08-282, BML 15
Drought	CMH 08-292, PMH 4, DMRH 1419, DMRH 1410, KDTML 3, KDTML 66, KDTML 19
Drought and waterlogging	KML 29, PEHM 1
Frost/cold	HM 5, HHM 1, HQPM 1
High temperature	Pusa Early Hybrid 3
Lodging	DHM 111, DHM 113, Nithya Shree, PEHM 1, Parkash, Pusa Composite 3, Pusa Composite 4

Source: Authors' own compilation

Wheat

Wheat is grown in *rabi* season in some part of Odisha. Though it is not cultivated in a large area still farmers are cultivating in some pockets. Wheat faces abiotic stresses like drought (low/no moisture), heat (high temperature), salinity (high salt concentration), alkalinity (high pH), and terminal heat stress. In terminal heat stress wheat crop is affected if air temperature goes beyond 32°C during the reproductive and grain filling stage. The tolerant varieties for various abiotic stress are available in wheat. Growing tolerant cultivars may increase the yield in stress-prone areas. The list of wheat variety tolerant to various abiotic stresses is presented in Table 2.4.

Table 2.4 Wheat varieties tolerant to different abiotic stresses

Abiotic stress	Variety
Drought	HPW 349, AKAW 4627, HD 2987, HI 1544, WH 1080, HI 1531, PBW 527, K 9423, PBW 396 2000 DT, HS 365, WH 1142
Heat	HD 2985, Raj 4120, K 0307, GW 322
Terminal heat	MPO 1215, MP 1203, Raj 4083, DBW 16, HD 2833, HI 1500, DBW 14, MP 4010, DWR 17, DBW 173, RAJ 3765, DBW 107, HW 2045, GW 322
Salinity, Alkalinity	KRL 210, KRL 213, RAJ 3077

Source: Authors' own compilation

(a) Millets and other minor millets

Among the various millet crops, small millet, finger millet, and little millet are mostly grown in Odisha. Finger millet (*ragi*) is the third most important food crop of the state next to rice. About 96% of finger millet and other small millet are mainly cultivated in rainfed conditions with marginal care. The area under small millets in the state is decreasing due to the change in the food habits of the people. The list of millets and other minor millet variety tolerant to various abiotic stress is presented in Table 2.5

Table 2.5 Millets and other minor millets varieties tolerant to different abiotic stresses

Abiotic stress	Crop/Variety
Sorghum	
Midseason drought	Indore 12, SPH 1148, JKSH 22, CSH 16, 27B, PVK 809, and local (Y75)
Drought and heat	CSH 13R, SPH 596, SPH 641, SPH 677, SPH 854, SPH 695, SPH 733, SPV 824, SPV 678, SPV 989, SPV 913, SPV 1046, SPV 1047, SPV 1089, SPV 1090, SPV 1161, SPV 932, SPV 1158, SPV 815
Drought	SPV 2074, SPV 2072, SPV 2073, CRS 1, CRS 4, Phule Anuradha, K 12, Dhansakthi
Finger millet	
Drought	CO 15, ML 365
Kodo millet	
Drought	CO (PV) 5
Little millet	
Drought	CO 4, ATL 1

Source: Authors' own compilation

(b) Pulses and oilseeds

Pulses and oilseed crops constitute an integral part of rainfed agriculture where water limitation is a major factor for decreasing productivity. There are many factors such as warmer climate, increasing temperature, solar radiation during critical crop growth stages which causes reduced water availability and ultimately resulting in less yield. Chickpea and lentil crops suffer from terminal drought stress resulting in reduced yield. The full yield potential of pulses is not realized due to their susceptibility towards various abiotic factors including drought, temperature extremes, salinity, *etc.* There are many factors responsible for the poor productivity of pulses in India such as non-spreading

of improved pulse varieties and technologies, non-availability of quality seeds of improved varieties, fertilizers and pesticides, rainfed area, low and high-temperature stress, pests and diseases, and cultivation on fragmented marginal lands. There are reports that heat stress occurs in chickpea, field pea (*Pisum sativum* L.), faba bean (*Vicia faba* L.) and lentil if the temperature rises beyond 25°C, whereas temperature rising above 35–40°C in rainy-season pulses causes 20–70% yield reductions through flower drop and pod abortion. The crop-wise list and major abiotic stresses limiting the productivity of major pulse crops in India are presented below in Table 2.6.

Table 2.6 Abiotic stresses limiting the productivity of major pulse crops

Crop	Season	Abiotic Stress
Chickpea	Timely sown	Low temperature, nutrient stress
	Early sown	Terminal drought, salt stress
	Late sown	Terminal drought, cold, nutrient stress
Pigeonpea	<i>Kharif</i> -early	Waterlogging, nutrient stress
	Medium late	Cold, terminal drought, waterlogging
	<i>Pre-rabi</i>	Cold, terminal drought
	<i>Zaid</i>	Pre-harvest sprouting, temperature, drought stress
	<i>Rabi</i>	Terminal drought
Urd bean	<i>Kharif</i>	Terminal drought
	<i>Zaid</i>	Pre-harvest sprouting, temperature, drought
	<i>Rabi</i> /rice fallow	Terminal drought
Lentil		Moisture, temperature
Cluster bean		Moisture and nutrient stress

Source: Authors' own compilation

i. Moisture stress

Soil moisture stress along with high-temperature results in poor growth and development of crop plants mainly in rainfed and dryland areas. Pulses are highly sensitive to waterlogging and there is a high incidence of soil-borne fungal diseases due to flooding. Flooding causes heavy yield losses due to poor drainage/waterlogging during the rainy season. Similarly, terminal drought causes 26 to 61% yield reduction in chickpea.

ii. Low-temperature cold stress

Low temperature or chilling stress is caused when the temperature is below the cardinal temperature. For the crops growing at 25–35°C, temperature less than 15°C causes chilling stress. Chilling stress occurs between 0 to 10°C temperatures. Tropical and sub-tropical crops such as pigeon pea and beans

are more prone to chilling stress. Flowering and early pod-formation stages are more sensitive to low-temperature in pulse crop. The cooler temperature along with moist conditions leads to increased incidence of ascochyta blight in chickpea, lentil, and pea; anthracnose in chickpea and lentil. Chilling causes more loss in areas where the growing season is short or the crop is of long duration. Pulse crops sensitive to frost are chickpea, lentil, peas, and long-duration pigeon pea.

iii. Salinity/ alkalinity stress

Salinity and alkalinity of soils are prevalent both in semi-arid tropics and in the Indo-Gangetic Plains (IGP) and some pockets in coastal Odisha. Pulses are more sensitive to salinity than cereals and oilseeds. This could be due to the accumulation of excess salts that quickens anthocyanin pigmentation in leaves and stems which reduces germination and seedling establishment of pulses. Hence the pulse growth and development would be hindered due to salinity-induced moisture stress. An adverse effect is observed in the reproductive growth phase due to reduced partitioning of metabolites leading to a greater loss in seed yield. Salt stress coupled with stem borer, pod-borer infestation, and yellow mosaic disease resulted in 80–100% yield loss in mungbean, particularly during the rainy season due to salinity-induced desiccation, flower shedding, and pod shattering. A list of pulse and oilseed varieties tolerant to various abiotic stresses is presented in Table 2.7 and Table 2.8, respectively.

Table 2.7 Promising pulse varieties tolerant to abiotic stresses

Abiotic stress	Crop/ varieties
Pigeonpea	
Drought	UPAS 120, Paras, BRG 1, BRG 2, ICPL 87, ICPL 151, JKM 189, ICPH 2671, Pusa 2002
Delayed monsoon	Asha, BRG 2, RVICPH 2671, RVA 28, JKM 7, TJT 501, JA 4, BDN 711, BDN 708
Suitable for rainfed conditions	Pusa Ageti, Sharda, ICPL 87, Pusa 991
Salinity	WRP 1, Pusa 991, Laxmi (ICPL 85063)
Waterlogging	Asha (ICPL 87119)
Mungbean	
Drought	RMG 268, Pratap (SG-1), K-1, RMG-344, MGG-348, RMG-492, MGG-347
Delayed monsoon	JM 721, TJM 3, SML 668
Heat tolerant	Narendra Mung 1, IPM 2–3, IPM 2 14, LGG 460, LGG 410
Cold tolerant	Pusa 0672

Black gram	
Drought	BDU 1, LBG-752
Delayed monsoon	BDU 1, Pant U 31, Pant U 19
Cowpea	
Drought	Gujarat Cowpea 2
Heat	Kashi Kanchan, Kashi Nidhi
Drought and delayed monsoon	RC 19, RC 101
Horsegram	
Drought	CRIDA 18R, CRHG 4, CRHG 19, AK 21, Pratap, Kulthi 1
Delayed monsoon	CRIDA 18R, CRHG 4, CRHG 19, GC3
Chickpea	
Drought	ICCV 10, JG 16, Pratap Chana 1, RVG 201, RVG 202, RVG 203, Pusa 1088, NBeG 3, PKV Harita, Ujjawal (IPCK 2004-29), Shubhra (IPCK 2002-29), Pusa 2024, Pusa 1088, Pusa 1105, CSJD 884 (ADASH), Anubhav (RSG888), PKV Kabuli-2, Pusa Chamatkar, Vijay (Phule G 81-1-1)
Delayed monsoon	Vijay, Shweta (ICCV-2), JG 11, KAK 2, Pratap Chana-1, JAKI 9218
Cold	PDG 4
Heat	JG 14, Indira Chana, JG 315, JG 11, RSG 888, GNG 663, Pant G 186, JGK 2, Pusa 547 (BGM 547), JG 130, JG 16 (SAKI 9516)
Drought	Pusa 1053, Pusa 256, Pusa 372, Pusa 362, Anubhav, Pant G 114, Ujjain 21, G 24, G 130
Salinity	Karnal Chana 1, Kranti (ICCV 37)
Field pea	
Heat	Azad Pea G 10
Lentil	
Drought	JL 3, RVL 31, Vamban
Clusterbean	
Drought and delayed monsoon	RGC 936, RGC 1002, RGC 1003
Heat	RGC 197, RGC 936
Mothbean	
Drought and delayed monsoon	CAZRI Moth 1, RMO 40, RMO 225, RMO 425, RMO 297, CZM 1
Heat	RMO 225, RMO 425
Suitable for rainfed condition	Maru Moth 1, Jadia, Jwala, RMO 40

Source: Authors' own compilation

Table 2.8 Oilseed varieties tolerant to abiotic stresses

Abiotic stress	Crop/Variety
Groundnut	
Wider adaptability	Pratap Raj Mungphalli, Bheema, Rohini, VRI (Gn) 6 (VG 9816), Abhaya (TPT 25)
Drought	JGN 23, ICCV 91114, AK 265, TMV 13, JGN 3, GG 5, Abhaya, Narayani, Kadiri 9, ICGS 44, TPG 41, TAG 24.
Heat	Greeshma, Amber (CSMG 84-1)
Salinity	TG-26, Somnath
Rapeseed & Mustard	
Heat	RH 0749, Divya 33, RH 0119, RGN 229, RGN 236, PR 20061 (Pant rai 19), Pusa mustard 26 (NPJ-113), Pusa mustard 27 (EJ-17), NRCDR 601 (DMR 601), Pusa mustard 25 (NPJ 112), Pusa Tarak (EJ-13), Pusa Mahak (JD-6), Gujarat Mustard 3, Kanti (RK9807), Urvashi, BPR 541-4, Pusa Agrani, RGN 13, Urvashi, NRCDR 02, Pusa mustard 25 (NPJ112), Pusa mustard 27 (EJ 17)
Lodging	RH 0406
Salinity	CS-52, Gujarat Mustard 3, CS 54, CS 56, NRCDR 601, RGN 236, RGN 229, Narendra Rai (NDR8501)
Drought	Pusa Swarnim (IGC-01), Pusa Aditya
Sesamum (Til)	
Delayed shattering	Shubra
Drought	Thilak
	Soyabean
Shattering resistance	DSb-1, RKS 24, JS 95-60, PS 1225
Drought	JS 97-52, JS 95-60
Lodging	PS 1225
Sunflower	
Drought	Olisun 3794 (PAC-3794)
Niger	
Drought	Birsa Niger-3 (BNS-11), Kadiri-5, TG37A, Narayani (TCGS 29)

Source: Authors' own compilation

(c) Horticultural crops

Horticultural crops play a unique role in increasing the income of rural people. A lot of employment opportunities are generated in rural areas due to the cultivation of horticultural crops. Moreover, fruits and vegetables provide

essential vitamins, minerals, proteins, carbohydrates, *etc.* to human beings. Thus, the adoption of horticultural crops will increase income through an increase in productivity. Similar to agricultural crops, the cultivation of fruits and vegetable crops facing the challenges of regional climate change regimes which are becoming more unpredictable from year to year. There is a need to improve the resistance/ tolerance level of these crops against various biotic and multiple abiotic stresses for enhancing their yield as well as stability. Combined efforts of plant breeders and physiologists have brought out many cultivars of these crops tolerant to the multiple stresses i.e. reduced moisture and drought-like conditions which are likely to get intensified due to climate change. The list of tolerant cultivars/ rootstock/varieties is presented in Table 2.9.

Table 2.9 Varieties/root stock tolerant to abiotic stresses

Horticultural crop		
Fruit crops		
Crop	Root stock / Variety	Abiotic stress
Mango	Kurakkan, Nileshwar Salinity tolerant dwarf, Bappakai	Salinity
Guava	P. molle × P. guajava, P. cujavallis	Drought, Alkalinity
Sapota	Khirmi	Drought tolerant
Anona	Arka Sahan	Drought tolerant
Ber	<i>Ziziphus nummularia</i> , <i>Z. mauritiana</i> var. Tikdi, <i>Z. mauritiana</i> var. Shukhawani, <i>Z. rotundifolia</i>	Drought
Lime	Rangpur lime, mandarin, and Cleopatra	Drought, Salinity
Pomegranate	Ruby	Drought
Vegetable crops		
Tomato	Pusa sheetal	Fruit set at 8°C (low night temperature)
	Pusa hybrid 1	Fruit set at 28°C (high night temperature)
	Pusa sadabahar	Fruit set at both low and high temperature
	Arka vikas	Drought
Vindi	Pusa sawan	Salinity
Brinjal	SM 1, SM 19, SM30	Drought
	Prajati, Pusa bindu	Salinity
Bottle gourd	Pusa	Heat and cold
Radish	Pusa chetki	Heat

Potato	Kufri surya	Heat
	Kufri deva	Frost / Cold
Cauliflower	Pusa meghna	Heat

Source: Authors' own compilation

(d) Fodder crops

Livestocks support the farmers during the adverse weather year. The scarcity of water and fodder reduces animal productivity and even death in some extreme cases. The milk productivity of livestock in India is 20-60% lower than the global average and one major reason for this may be the shortage of fodder availability. There is a deficit of approximately 20-25%, 10-12%, and 25-30% in the availability of dry fodder, green fodder, and concentrates respectively. The scarcity of fodder is even more during adverse weather year. Developing drought-tolerant variety will ensure sufficient fodder during the drought period. The supply of green fodder and quality feed will increase milk production. Some of the newly developed fodder varieties are drought tolerant e.g. fodder crops such as perennial sorghum (COFS-29 and COFS-31) and new variety Hybrid Napier Bajra (CO-5 and Sampoorina) and fodder trees (Agasti, Moringa and Hedge lucern). Farmers can grow these varieties to increase fodder production, especially in adverse weather year.

2.5.2.2 Biotic stress

Biotic stress refers to damage to crops by living organisms, such as bacteria, viruses, fungi, parasites, harmful insects, weeds, and cultivated or native plants. The changing climate and occurrence of extreme weather events caused a shift in biotic stress. Climate change is one of the major factors for spreading insect-pests and diseases. It affects not only the geographical distribution of pests, their population size and survival rate, but also the geographical distribution of diseases, their intensity, and development. The major environmental drivers for shifts and the spread of pests and diseases are temperature and rainfall. Developing pest and disease-resistant crop varieties are essential and also environmentally friendly as it reduces the use of pesticides and fungicides. The losses in yield due to lack of plant-protection measures vary from 46 to 96% depending on the crop and varieties. Appropriate plant protection measures are not taken up by the farmers to check the diseases like leaf blast, neck blast, and finger blast; and insect pests like stem borer, aphid, and the grasshopper in finger millet and shoot fly incidence in little millet. Delayed onset of monsoon leading to late sowing of pulses in dryland areas also increases the incidence of

pests, especially pod-borer in chickpea. Incidence of the sterility mosaic virus in pigeon pea plants when they are less than 45 days old, results in 95–100% yield losses, while older plants suffer only 26–97% loss. Growing tolerant cultivars will reduce the best option to overcome the problem of insect pests and diseases. The list of varieties tolerant to various insect pests and disease in cereals and millets (Table 2.10), pulses (Table 2.11), oilseed (Table 2.12), vegetables (Table 2.13) are presented below.

Table 2.10 Insect pest and disease tolerant varieties for different cereals

Biotic stress	Tolerant/ resistance varieties for disease and insect pests
Rice	
Blast	Phalguni, Naveen, Sahabhagidhan, Virender, Vandana, Ananda, CR Dhan 601, Parijat, Dharitri, Gayatri, CR Dhan 70 (Hanseswari), CR Dhan 403 (Luna Suvarna), CR Dhan 401(Reeta), Samalei, Pooja, Anjali, Ajaya, CR Sugandh Dhan 908, CR Dhan 311 (Mukul), CR Sugandh Dhan 908, CR Dhan 409 (Pradhan Dhan), CR Dhan 209 (Priya), CR Dhan 207 (Srimati), CRDhan 307 (Maudamani), CR Dhan 101 (Ankit), CR Dhan 205, CR Dhan 505, CR Dhan 303, CR Dhan 300 (140), CR Dhan 405 (Luna Sankhi, CR Dhan 406 (Luna Barial), CR Dhan 502 (Jayanti Dhan), CR Dhan 503 (Jalamani), CR Dhan 200 (Prari), CR Dhan 500, CR Dhan 402 (Luna Sampad), Chandan, NuaKalajeera
Neck blast	CR Sugandh Dhan 908, CR Dhan 507 (Prasanta), CR Dhan 409 (Pradhan Dhan), CR Dhan 209 (Priya), CR Dhan 207 (Srimati), CR Dhan 408 (Chaka Akhi), CR Dhan 307 (Maudamani), CR Dhan 101(Ankit), CR Dhan 505, CR Dhan 407, CR Dhan 303, CR Dhan 300, CR Sugandh Dhan 907, CR Dhan 502 (Jayanti Dhan), CR Dhan 503 (Jalamani), CR Basana Dhan 902 (Poorna Bhog), CR Dhan 200 (Prari), CR Dhan 500, CR Dhan 401 (Reeta), CR Sugandha Dhan 3 (Nua Dhusara), CR Dhan 10 (Satya Krishna) Varshadhan
Sheath rot	Phalguni, Sahabhagidhan, Anjali, CR Dhan 601, Reeta, Nua Dhusara, Nua Kalajeera, Luna Sampad, CR Dhan 508, CR Sugandh Dhan 908, CR Dhan 800, CR Dhan 507(Prasanta), CR Dhan 409 (Pradhan Dhan), CR Dhan 207(Srimati), CR Dhan 408(Chaka Akhi), CR Dhan 206 (Gopinath), CR Dhan 203 (Sachala), CR Dhan 101(Ankit), CR Dhan 205, CR Dhan 505, CR Dhan 202, CR Dhan 303, CR Dhan 300, CR Sugandh Dhan 907, CR Dhan 502 (Jayanti Dhan), CR Basana Dhan 902 (Poorna Bhog), CR Dhan 301(Hue), CR Dhan 10 (Satya Krishna), Varshadhan

Biotic stress	Tolerant/ resistance varieties for disease and insect pests
Sheath blight	Ajaya, Phalguni, Ketakijoha, CR 1014, Hanseswari, Rajalaxmi, CR Dhan 508, CR Dhan 311(Mukul), CR Sugandh Dhan 908, CR Dhan 507(Prasanta), CR Dhan 409 (Pradhan Dhan), CR Dhan 209 (Priya), CR Dhan 207 (Srimati), CR Dhan 408(Chaka Akhi), CR Dhan 307(Maudamani), CR Dhan 206 (Gopinath), CR Dhan 203 (Sachala), CR Dhan 101(Ankit), CR Dhan 505 CR Dhan 202, CR Dhan 300, CR Sugandh Dhan 907, CR Dhan 405 (Luna Sankhi), CR Dhan 406 (Luna Barial), CR Dhan 502 (Jayanti Dhan), CR Dhan 503 (Jalamani), CR BasanaDhan 902 (Poorna Bhog), CR Dhan 404(Sumit), CR Dhan 200(Prari), CR Dhan 100 (Satyabhama), CR Dhan 500, CR Dhan 601, CR Dhan 701, CR Dhan 402 (Luna Sampad), CR Dhan 403 (Luna Suvarna), CR Dhan 401(Reeta), Sahabhagi dhan, Chandan, CR Dhan 10 (Satya Krishna)
Brown spot	Phalguni, Vandana, Sahabhagidhan, Virender, Naveen, CR Dhan 401 (Reeta), CR Sugandh Dhan 908, CR Dhan 508, CR Dhan 311(Mukul), CR Dhan 507 (Prasanta), CR Dhan 209 (Priya), CR Dhan 307(Maudamani), CR Dhan 206 (Gopinath), CR Dhan 203 (Sachala), CR Dhan 101(Ankit), CR Dhan 205, CR Dhan 202, CR Dhan 503 (Jalamani), CR Dhan 200(Prari), CR Dhan 500, CR Dhan 601, CR Dhan 701, CR Dhan 402 (Luna Sampad)
Bakanae	Vandana
False smut	Gayatri, Savitri, CSR 30
Rice Tungro	Phalguni, CR Dhan 601, Hanseswari, Durga, Luna Sampad, CR Dhan 311(Mukul), CR Sugandh Dhan 908, CR Dhan 209 (Priya), CR Dhan 505, CR Dhan 303, CR Dhan 502 (Jayanti Dhan), CR Dhan 100 (Satyabhama), CR Dhan 701, CR Sugandha Dhan 3 (Nua Dhusara)
Bacterial leaf blight	Improved Lalat, Improved Tapaswini, Ajaya, Rajalaxmi, Ketakijoha, Dharitri, Savitri, Durga, Gayatri, CR Sugandh Dhan 908, CR Dhan 311(Mukul), CR Dhan 800, CR Dhan 408(Chaka Akhi), CR Dhan 206 (Gopinath), CR Dhan 203 (Sachala), CR Dhan 100 (Satyabhama), Chandan, Varshadhan, Ratna
Bacterial leaf streak	Gayatri, Durga, Varsadhan
Stem borer	Phalguni, Ananda, CR Sugandh Dhan 908, CR Dhan 205, CR Dhan 505, Improved Tapaswini, Improved Lalat, NuaKalajeera, Ketakijoha, Dharitri, NuaChinikamini
Brown plant hopper	Hansada, Hanseswari, CR Dhan 303, Improved Tapaswini, CR Dhan 403 (Luna Suvarna), Phalguni, Chandan, Ajaya
White back plant hopper	Phalguni, CR Sugandh Dhan 908, CR Sugandh Dhan 908, CR Dhan 209 (Priya), CR Dhan 408 (Chaka Akhi), CR Dhan 307 (Maudamani), Improved Tapaswini, CR Dhan 100 (Satyabhama), Ajaya

Biotic stress	Tolerant/ resistance varieties for disease and insect pests
Leaf folder	CR Sugandh Dhan 908, CR Sugandh Dhan 908, CR Dhan 507 (Prasanta), CR Dhan 409 (Pradhan Dhan), CR Dhan 209 (Priya), CR Dhan 207 (Srimati), CR Dhan 408 (Chaka Akhi), CR Dhan 307 (Maudamani), CR Dhan 206 (Gopinath), CR Dhan 203 (Sachala), CR Dhan 101 (Ankit), CR Dhan 205, CR Dhan 505, CR Dhan 202, CR Dhan 300, CR Dhan 406 (Luna Barial), CR Dhan 502 (Jayanti Dhan), CR Dhan 503 (Jalamani), CR Dhan 404 (Sumit), CR Dhan 200 (Prari), CR Dhan 100 (Satyabhama), CR Dhan 500, CR Dhan 601, CR Dhan 402 (Luna Sampad), CR Dhan 403 (Luna Suvarna), CR Dhan 401 (Reeta), Sahabhagidhan
Gall midge	Phalguni, Virender, Anjali, CR Dhan 10 (Satya Krishna), Ajaya, Geetanjali, Nua Dhusara, Hanseswari, Gayatri, Luna Sampada, Samalei, CR Dhan 311 (Mukul), CR Dhan 207 (Srimati), CR Dhan 307 (Maudamani), CR Dhan 304, CR Sugandh Dhan 907, CR Dhan 503 (Jalamani), CR Basana Dhan 902 (Poorna Bhog), Improved Lalat, CR Dhan 301(Hue), CR Dhan 200 (Prari), CR Dhan 100 (Satyabhama), CR Dhan 500, CR Sugandha Dhan 3 (Nua Dhusara), Ketakijoha, Kakatiya
Green leafhopper	CR Dhan 207 (Srimati), CR Dhan 101 (Ankit), CR Dhan 503 (Jalamani), CR Dhan 601, Phalguni
Hispa	CR Dhan 307 (Maudamani)
Thrips	CR Dhan 307 (Maudamani)
Whorl maggot	CR Dhan 505
Maize	
Maydis leaf blight (MLB)	HM 10, PAU 352, Malviya Hybrid Makka 2, PMH-1, PMH-2, Vivek Hybrid 17, Pusa Extra Early Hybrid 5, Vivek Hybrid 9, HHM 1, Vivek Hybrid 4, HIM 129, Parkash, DMH 1, DHM 109, DHM 107, Trishulata, Deccan 105, HQPM -7, HQPM 5, HQPM 1, Shaktiman 3
Turcicum Leaf Blight	Vivek 23, Vivek 21, Vivek 25, Buland, Vivek Hybrid 17, Pusa Extra Early Hybrid 5, Vivek Hybrid 9, Vivek Hybrid 4, HIM 129, DHM 109, DHM 107, Trishulata, Deccan 105, Ganga 11
Common rust	Buland
Wilt	Trishulata, Deccan 105
Brown Stripe Downy Mildew (BSDM)	PAU 352, PMH-2, Parkash, Pratap Makka 3, Gujarat Makai 6
Rust	HHM 1, HHM 2, HQPM 1, Histarch Hybrid Makka, Deccan, Ganga 5, DHM 1, Deccan Hybrid Makka 103

Biotic stress	Tolerant/ resistance varieties for disease and insect pests
Downy mildew	COH(M) 5, COH(M) 4, DMH 2, COH 3, DMH 1, DHM 109, DHM 107, Ganga 11, Shalimar KG 1, DMR 1, DMR 5, Ganga 11
Sheath blight	COH(M) 5, Pratap Hybrid 1, PEHM 1, HQPM 5, Histarch Hybrid Makka, Shalimar KG 1
Stalk rots	PMH-1, Pusa Composite 3, Hybrid Ganga safed-2, DHM 103
Stem borer	COH(M) 4, COH 3, Pratap Makka 4, Pusa Composite 4
Sorghum	
Striga weed	Gobiye, Abshir and Birhan
Shoot fly	IS-2205, IS- 3962, I-5469, IS-1054, S-386, SPV-102
Shoot fly, stem borer, downy mildew	CO 30, K12
Wheat	
Powdery mildew	HPW 42, WH 1105
Hill bunt	Kalyan sona (RR 21), Himgri, HS 375, HPW 42, VL 832,
Yellow rust	SKW 196, Chhotilerma (S331), HPW 251, Pusa Kiran (HS 542), Himgri, HPW 349, HS 507, HS 507, VL gehun, HPW 184, VL 804, HS 240, UP 1109, HS 86, HS 1138 -64, HS 420, HS 295, HD 2380, HD 3086, DBW 88, HD 2967, PBW 550
Loose smut	VL 421, HPW 251, Kalyansona (RR 21), UP 1109, VL 832
Black rust	Chhotilerma (S331), UP 1109, HS 1138 -64
Brown rust	HPW 251, Pusa Kiran (HS 542), Himgri, HPW 349, HS 507, VL Gehun, HPW 184, VL 804, UP 1109, HS 86, HS 1097-17, HS 1138 -64, HS 420, HS 295, HD 3086, DBW 88, HD 2967, PBW 550
Karnal bunt	HS 507, HB 501
Pearl millet	
Smut	WC-C 75, CM 46, MBH 110
Rust	IB 1203, ICML 11, MH 1192
Downy mildew	MH 1192, ICMH 451, Pusa 23, MBH 110, PHB 57, WC C 75, ICTP 8203, GHB 67, CO 10
Finger millet	
Blast	GPU 28, GPU 26, GPU 48, CO 15, KMR 301
Rust	SEC 915, 314, 712, ICMV-221
Little millet	
Grain smut	DPI 2394, PLM 202, OLM 203, DPI 2386, CO 2
Kodo millet	
Striga	JK 41, GPUK 1, GPUK 3, GPUK 5
Foxtail millet	
Rust, blast	CO (Te)7

Source: Authors' own compilation

Table 2.11 Suitable cultivar of pulses for various biotic stress resistances

Crop/ varieties	Biotic stress
Pigeon pea	
Azad, Narendra Arhar 1	Resistant to sterility mosaic (both) and tolerant to wilt, pod-borer
Pusa 991, Pusa 992, TJT 501	Resistant to wilt and sterility mosaic
Pusa 2001, Pusa 2002	Phytophthora blight resistant
Green gram (Mungbean)	
Pusa Vishal, PM 5, HUM 16, SML 668, RMG 492, Pusa 9531, Co 6, GG 2, OUM 11-5, COGG 912 and HUM 1, Pusa 9072, TARM 1	Resistant to yellow mosaic
VBN (Gg) 3	Powdery mildew
HUM 16, SML 668	Root-knot nematode resistant
Black gram (Urdbean)	
Pant U 30, NDU 99-3, Shekar 2, WBU 109, K 301, Prasad and Ujala, VBN 4, VBN 6 and VBN 7	Resistant to yellow mosaic
KU 96-3, VBN 5, Ujala VBN 5, Ujala (OBG 17)	Powdery mildew resistant
Cowpea	
PusaSampada, UPC 628	Resistance to major pest and diseases, root-knot nematode
IC 97787, IC 198333, IC 202824	Powdery mildew
Pusa Sukomal Arka Garima, Kashi Unnati and Kashi Kanchan	Resistant to golden yellow mosaic virus and leaf-spot disease
Horse gram	
VL Gahat 10	Yellow mosaic resistant
Birsa Kulthi 1	Macrophomina blight resistant
PHG 9	Powdery mildew and anthracnose resistant
Chickpea	
Pusa 256, Uday,	Resistant to wilt, tolerant to
Pusa 372, Pusa G 186	Ascochyta blight
BDG 72, Co 3	Resistant to wilt and collar rot
Pusa 1105	Moderately resistant to wilt and dry root-rot
WCG 10, Gram 3, kabuli varieties: Sweta, L 551, BG 1053	Resistant to wilt
Field pea	
IPF 99-25, Pant P 13, Pant P 14, Indra, Sapna, Alankar, TRCP 8	Resistant to powdery mildew

Lentil	
VL Massor 103, DPL 62, LLS 669, HUL 57	Resistant to rust
Pant L 5	Resistant to wilt, rust and blight
Mothbean	
FMM 96, JMM 259	Resistant to yellow mosaic

Source: Authors' own compilation

Table 2.12 Oilseed cultivar for various biotic stress resistance

Biotic	Variety
Groundnut	
Jassids	Girnar 1
Thrips	ALR 3, Robut 33-1, Kadiri 3 and ICGS 86031
Tikka	T-64, C-501, MH-4, TMV-6 and TMV-10
Aphids	Girnar 1
Stem rot	GJG 31, HNG 123, HNG 69
Rust	CO 6, GPBD-5
Leaf spot	Kadiri 6, Prakash (CSMG 884)
Rapeseed & Mustard	
NRCDR 515, Basanti, JM 1, JM 2	White rust
T 6342, Glossy B 85, RH 7846, RH 7847	Mustard aphid

Source: Authors' own compilation

Table 2.13 Vegetable cultivar for various biotic stress resistance

Crop	Variety	Biotic stress
Brinjal	Pusa Bhairav	Phomopsis blight
Cabbage	Pusa Mukta	Black rot
	Pusa Drum Head	Black leg
Cauliflower	Pusa Subhra	Black rot & curd blight
	Pusa Snow ball K-1	Black rot
	DCH-541	Downy mildew
Chilli	Pusa Sadabahar	CMV. Tobacco mosaic virus & Leaf curl
	Pusa Jwala	Thrips, mites and leaf curl
Cowpea	Pusa Komal	Bacterial blight
Lablab bean	Pusa Sem 2	Viral Diseases
	Pusa Sem 3	Viral diseases

Okra	Pusa A 4, Varsha Uphar, Arka Anamika	Yellow mosaic virus
Tomato	Pusa 120, Pusa Hybrid 2	Root knot nematode

Source: Authors' own compilation

2.6 Agro-ecological crop intensification/ cropping system

Agro-ecological intensification of the rice-based cropping system aims at achieving maximum system productivity with minimum environmental impact by managing and organizing crops in a way that they utilize the available resources efficiently with beneficial interactions among themselves. Cropping system adjustment in the rice-based cropping system has the potential to reduce total GHG emissions by 5-10%. Based on agro-ecological conditions, market and domestic needs and facilities available with farmers, major rice-based cropping systems recommended for Odisha are rice-cereals (rice-rice/maize), rice-pulses (rice-greengram/ blackgram/ horsegram/ lathyrus), rice-oilseeds (rice-groundnut/ toria/ sunflower/ sesame), rice-jute/mesta and rice-vegetables (rice-onion/garlic/brinjal/tomato/potatoes/beans). However, in some agroecology, the crops other than rice (pulses, oilseeds, jute, vegetables) are also grown as a major crop in the cropping system.

2.6.1 Rice-rice/rice fallow cropping system

Because of its wide adaptability, rice crop is grown in all the three types of ecosystem, viz., upland, medium land, and lowland and in all agro-ecological zones in Odisha. Rice is the most dominant crop in Odisha cultivated in 70 % of the cropped area. The upland ecosystem comprises about 15.7% of the rice area and 10.8% of total rice production in the state. The average yield of this ecosystem is about 1 t/ha. Major limitations associated with upland ecosystems are inherent poor soil fertility, severe weed competition, coarse-textured soil with poor water holding capacity, intermittent drought, and imbalanced fertilization. Short duration photo-insensitive cultivar mature in 80–100 days is most suitable. Rice is direct sown in June after the onset of the monsoon and harvested in September. The medium land ecosystem covers about 40% of the total rice area in the state. This ecosystem is highly suitable for intensive cultivation. Though this system is considered as less problematic still the occurrence of various insect pests and disease (brown plant hopper, white-backed plant hopper, stem borer, gall midge, sheath rot, and bacterial leaf blight) causes significant yield loss. High yielding short and medium duration (115 to 135 days) with photo-insensitive cultivars are suitable. The crop can be transplanted or direct seeded with *beushening*. The use of resistant

cultivars to combat the problem of insect pests is recommended. Lowland ecosystem constitutes 35% of the rice area of the state covers mainly in the coastal region. Long duration (145 to 165 days) photosensitive varieties with strong seed dormancy are grown under this ecosystem. Tall cultivars (height > 120 cm) are grown in lowlands. The productivity of these varieties barely reaches 1 t ha⁻¹. Considerable yield loss occurs due to bacterial leaf blight, sheath blight, sheath rot, stem borer, and brown plant hopper and leaf folder. The rice variety suitable for different agro-climatic zones and land types of Odisha is presented in Table 2.14(a). Rice-rice area is confined to 2.5 lakh ha and rice fallow covers 11.2 lakhs ha in Odisha.

Rice-rice cropping system is prevalent in the irrigated medium and shallow lowland ecosystem the suitable varieties for this system is presented in Table 2.14(b). District wise more than 90% of the area under rice-rice cropping system is followed in Balasore, Sonepur, Kalahandi, Puri, Baragarh, Sambalpur, Koraput, Bhadrak, Balangir, Cuttack, Rayagada, and Maurbhanj districts of Odisha. However, the intensification of rice fallows can be made by taking short-duration pulses and oilseed crops through proper utilization of residual moisture and supplemental irrigation either from harvested rainwater and the use of shallow tubewell in the coastal area. To harness the productive potential of rice in *kharif* as well as *rabi* season, identification of ecology/ agro-climatic region-specific varieties and suitable management practices need to be leveraged.

Table 2.14(a) Agro-climatic zone wise variety recommendation

Name of the zone	Land type	Suitable variety
Northwestern plateau (Sundar Garh, Deogarh)	Upland	Heera (68), Kalinga III (80), Khandagiri (95), Parijat (95), Sidhanta (95), Ananda (110), CR Dhan 100 (Satyabhama) (110), CR Dhan 101(Ankit) (110), CR Dhan 205 (110), CR Dhan 203 (Sachala) (110), CR Dhan 202(110)
	Medium land	Naveen(120), MTU 1001(120), Binadhan 11(120), Pratikshya (135), CR Dhan 311(Mukul)(125), CR Dhan 303 (125), Konark (125), DR Dhan 45, Ajaya (130), Rajalaxmi (135), CR Dhan 307 (Maudamani)
	Lowland	Mahanadi (150), Sarala (150), CR Dhan 401(Reeta) (150), Savitri (155), Gayatri (155), Indravati (155), Dharitri (155), CR 1014(155)

Name of the zone	Land type	Suitable variety
Northcentral plateau (Keonjhar, Mayurbhanj)	Upland	Kalinga III (80), Khandagiri (95), Sidhanta (95), Vandana (95)
	Medium land	Naveen (120), MTU 1001(120), Binadhan 11(120), CRDhan 310 (125), CR Dhan 311(Mukul)(125), CR Dhan 303 (125), Konark (125),DR Dhan 45, Ajaya (130), Rajalaxmi (135), CR Dhan 307 (Maudamani), Tapaswini (135), Improved Tapaswini (130) Aromatic: Geetanjali (130)
	Lowland	Mahanadi (150), Sarala (150), CR Dhan 401(Reeta) (150), Savitri (155), Gayatri (155), Aromatic: Ketakijoha (145), CR Sugandh Dhan 908 (145), CR Sugandh Dhan 910 (145)
Northeastern coastal plain (Balasore, Bhadrak, Jajpur,)	Upland	Khandagiri (95), Parijat (95), Ananda (110), CR Dhan 100 (Satyabhama) (110), CR Dhan 101(Ankit) (110), CR Dhan 205 (110), CR Dhan 203 (Sachala) (110)
	Medium land	Naveen(120), Binadhan 11(120), CR Dhan 310 (125), CR Dhan 311(Mukul)(125), CR Dhan 303 (125), Konark (125), DR Dhan 45, Ajaya (130), Rajalaxmi (135), CR Dhan 307 (Maudamani), Lalat (130), Improved Lalat (130), Swarna (145), Swarna sub 1 (145), Pratikshya (135)
	Lowland	CR Dhan 403 (Luna Suvarna) (150), Lunishree (145), Mahanadi (150), Sarala (150), Pooja (150), CR Dhan 401(Reeta) (150), Savitri (155), Gayatri (155), CR Dhan 502 (Jayanti Dhan (160), Varshadhan (160), CR Dhan 508(160), CR Dhan409 (Pradhan Dhan) (160), Uphar (160), Kalachampa (160), CR Dhan 505(162), CR Dhan 408(Chaka Akhi) (165), Tulasi (170)
East & south-eastern coastal plain (Kendrapada, Jagatsinghpur, Khurda, Puri, Nayagarh, Cuttack)	Upland	Heera (68), Kalinga III (80), Khandagiri (95), Parijat (95), Sidhanta (95), Vandana (95),Anjali (95), Sahabthagidhan (105), CR Dhan 100 (Satyabhama) (110), CR Dhan 101(Ankit) (110)

Name of the zone	Land type	Suitable variety
	Medium land	Naveen (120), Binadhan 11(120), MTU 1001(120), CR Dhan 310 (125), CR Dhan 311(Mukul) (125), CR Dhan 303 (125), Konark (125), Ajaya (130), Rajalaxmi (135), CR Dhan 307 (Maudamani), Lalat (130), Improved Lalat (130), Swarna (145), Swarna sub 1 (145), Pratikshya (135), CR Dhan 701(142) CR Dhan 10 (Satya Krishna) (135), CR Dhan 402 (Luna Sampad) (140) Aromatic: Geetanjali (130), CR Sugandh Dhan 908 (140), CR Dhan 300(140)
	Lowland	CR Dhan 801 (145), CR Dhan 802 (142), Swarna (145), Swarna sub 1 (145), Mahanadi (150), Sarala (150), Pooja (150), CR Dhan 401(Reeta) (150), Savitri (155), Gayatri (155), CR 1014(155), CR 1018 (155), CR Dhan 502 (Jayanti Dhan (160), Varshadhan (160), CR Dhan 508(160), CR Dhan 409 (Pradhan Dhan) (160), Uphar (160), Kalachampa (160), CR Dhan 505(162), CR Dhan 408(Chaka Akhi) (165), CR Dhan 406 (Luna Barial) (150), CR Dhan 402 (Luna Sampad) (140), CR Dhan 403 (Luna Suvarna) (150), Lunishree (145) Aromatic: Ketakijoha (145), CR Sugandh Dhan 908 (145), CR Sugandh Dhan 910 (145), CR Sugandh Dhan 907 (150), NuaKalajeera (150)
North east Ghat (Kandhamal, Rayagada, Gajapati, Ganjam)	Upland	Heera (68), Kalinga III (80), Khandagiri (95), Vandana (95), Sahabhagidhan (105)
	Medium land	CR Dhan 209 (Priya)(115), CR Dhan 207 (Srimati)(110-115), CR Dhan 206 (Gopinath) (115), CR Dhan 203 (Sachala) (110), CR Dhan 205 (110), CR Dhan 202(115), CR Dhan 200 (Prari)(115) Naveen(120), Binadhan 11(120), MTU 1001(120), CR Dhan 310 (125), CR Dhan 311(Mukul)(125), CR Dhan 303 (125), Improved Lalat (130), CR Dhan 307, Maudamani (135)
	Lowland	Swarna (145), CR Dhan 801 (145), CR Dhan 802 (142), Swarna sub 1 (145), Mahanadi (150)

Name of the zone	Land type	Suitable variety
Eastern Ghat highland (Nabarangpur, part of Koraput)	Upland	Heera (68), Kalinga III (80), Khandagiri (95), Vandana (95), Sahabhagidhan (105), Parijat (95), Sidhanta (95)
	Medium land	Naveen (120), Binadhan 11(120), MTU 1001(120), CR Dhan 310 (125), CR Dhan 311(Mukul)(125), CR Dhan 303 (125), Konark (125), Ajaya (130), Rajalaxmi (135), CR Dhan 307 (Maudamani), Lalat (130), Improved Lalat (130), Swarna (145), Swarna sub 1 (145), Pratikshya (135), Tapaswini (135), Improved Tapaswini (130) Aromatic: Geetanjali (130)
	Lowland	Indravati (155), Utakal Prava (155), Ramachandi Aromatic: Ketakijoha (150)
South eastern Ghat (Malkangiri, part of Koraput)	Upland	Kalinga III (80), Khandagiri (95), Vandana (95), Sahabhagidhan (105), Parijat (95), Ananda (110), CR Dhan 100 (Satyabhama) (110), CR Dhan 101(Ankit) (110), CR Dhan 205 (110)
	Medium land	Naveen(120), Binadhan 11(120), CR Dhan 310 (125), CR Dhan 311(Mukul)(125), CR Dhan 303 (125), Ajaya(130), Rajalaxmi (135), CR Dhan 307 (Maudamani), Lalat (130), Improved Lalat (130), Swarna (145), Swarna sub 1 (145), IR 64 Aromatic: Geetanjali
	Lowland	Swarna (145), Swarna sub 1 (145), Utakal Prava (155), CR Dhan 401(Reeta) (150), Savitri (155), Gayatri (155), Aromatic: Ketakijoha (150), CR Sugandh Dhan 908 (145), CR Sugandh Dhan 910 (145), CR Sugandh Dhan 907 (150), NuaKalajeera (150)
Western undulating zone (Kalahandi, Nuapada)	Upland	Heera (68), Khandagiri (95), Vandana (95), Sahabhagidhan (105), Parijat (95), Ananda (110), CR Dhan 100 (Satyabhama) (110), CR Dhan 101(Ankit) (110), CR Dhan 205 (110)
	Medium land	Naveen(120), Binadhan 11(120) MTU 1001(120), 0, CR Dhan 310 (125), CR Dhan 311(Mukul)(125), CR Dhan 303 (125), Konark (125), Lalat (130), Improved Lalat (130), Swarna (145) Pratikshya (135)

Name of the zone	Land type	Suitable variety
	Lowland	Indravati (155), CR Dhan 801 (145), CR Dhan 802 (142), Mahanadi (150)
Western central table land (Baragarh, Bolangir, Boudh, Sonapur, Jarsuguda, Sambalpur)	Upland	Heera (68), Kalinga III (80), Annapurna, Ghanteswari Khandagiri (95), Vandana (95), Parijat (95)
	Medium land	Naveen(120), Binadhan 11(120) MTU 1001(120), 0), CR Dhan 310 (125), CR Dhan 311(Mukul)(125), Konark (125), CR Dhan 303 (125), Lalat (130), Improved Lalat (130), Swarna (145) Pratikshya (135), IR-36, Ajaya (130), Rajalaxmi (135), CR Dhan 307 (Maudamani) Aromatic: Geetanjali
	Lowland	Mahanadi (150), Ramachandi, Utakal Prava (155), CR Dhan 401(Reeta) (150), Savitri (155), Gayatri (155), Indravati
Mid-central tableland (Angul, Dhenkanal)	Upland	Kalinga III (80), Khandagiri (95), Vandana (95)
	Medium land	Naveen(120), Binadhan 11(120) Lalat (130), Improved Lalat (130), Swarna (145) Tapaswini (135), Improved Tapaswini (130), BPT 5204, Konark (125) Aromatic: Geetanjali (130)
	Lowland	Mahanadi (150), CR Dhan 401(Reeta) (150), Savitri (155), Gayatri (155), Indravati, Upahar

The values within parenthesis indicate the duration of the respective variety

Source: Authors' own compilation

Table 2.14 b. Recommended rice varieties for *rabi*/summer season suitable for rice-rice cropping system under different Agro-climatic zone of Odisha

Sl No	Name of the zone	Rabi/Summer
1	Northwestern plateau (Sundar Garh [@] , Deogarh [@])	Bina dhan 11(120), CR Dhan 203 (115), Satabdi (115), CR Dhan 205 (115), CR Dhan 206 (120), Naveen(120)
2	Northcentral plateau (Keonjhar [§] , Mayurbhanj [*])	Bina dhan 11(120), CR Dhan 203 (115), Satabdi (115), CR Dhan 205 (115), CR Dhan 206 (120), Naveen(120), CR Dhan 310 (125), CR Dhan 311(Mukul)(125), CR Dhan 303 (125), Improved Lalat (130)

Sl No	Name of the zone	Rabi/Summer
3	Northeastern coastal plain (Balasore*, Bhadrak*, Jajpur#)	Bina dhan 11(120), CR Dhan 203 (115), Satabdi (115), CR Dhan 205 (115), CR Dhan 206 (120), Naveen(120), CR Dhan 310 (125), CR Dhan 311(Mukul)(125), CR Dhan 303 (125), Improved Lalat (130), MTU 1001(125)
4	East & south-eastern coastal plain (Kendrapada\$, Jagatsinghpur@, Khurda#, Puri*, Nayagarh@, Cuttack*)	Bina dhan 11(120), CR Dhan 203 (115), Satabdi (115), CR Dhan 205 (115), CR Dhan 206 (120), Naveen(120), CR Dhan 310 (125), CR Dhan 311(Mukul)(125), CR Dhan 303 (125), Improved Lalat (130), MTU 1001(125), MTU 1010 (130), CR Dhan 405 (Luna Sankhi)(110)
5	North east Ghat (Kandhamal@, Rayagada*, Gajapati@, Ganjam#)	Bina dhan 11(120), CR Dhan 203 (115), Satabdi (115), CR Dhan 205 (115), CR Dhan 206 (120), Naveen(120)
6	Eastern Ghat highland (Nabarangpur@, part of Koraput*)	Bina dhan 11(120), CR Dhan 203 (115), Satabdi (115), CR Dhan 205 (115), CR Dhan 206 (120), Naveen(120), CR Dhan 310 (125), CR Dhan 311(Mukul)(125), CR Dhan 303 (125), Improved Lalat (130), MTU 1001(125)
7	South eastern Ghat (Malkangiri@, part of Koraput*)	Bina dhan 11(120), CR Dhan 203 (115), Satabdi (115), CR Dhan 205 (115), CR Dhan 206 (120), Naveen(120), CR Dhan 310 (125), CR Dhan 311(Mukul)(125), CR Dhan 303 (125), Improved Lalat (130), MTU 1001(125)
8	Western undulating zone (Kalahandi*, Nuapada#)	Bina dhan 11(120), CR Dhan 203 (115), Satabdi (115), CR Dhan 205 (115), CR Dhan 206 (120), Naveen(120), CR Dhan 310 (125), CR Dhan 311(Mukul)(125), CR Dhan 303 (125), Improved Lalat (130), MTU 1001(125)
9	Western central table land (Baragarh*, Bolangir*, Boudh@, Sonepur*, Jarsuguda@, Sambalpur*)	Bina dhan 11(120), CR Dhan 203 (115), Satabdi (115), CR Dhan 205 (115), CR Dhan 206 (120), Naveen(120), CR Dhan 310 (125), CR Dhan 311(Mukul)(125), CR Dhan 303 (125), Improved Lalat (130), MTU 1001(125), Ajaya (130), Rajalaxmi (135), CR Dhan 601 (130)
10	Mid-central table land (Angul@, Dhenkanal@)	Bina dhan 11(120), CR Dhan 203 (115), Satabdi (115), CR Dhan 205 (115), CR Dhan 206 (120), Naveen(120)

Note: Districts in * rice-rice area about 3000 ha or more, districts in \$ rice-rice area 1000-3000 ha and districts in @ rice-rice area in less than 1000 ha

Source: Authors' own compilation

2.6.2 Rice-maize cropping system

Rice (*Oryza sativa* L.) and maize (*Zea mays*) are cultivated in 3.5 million hectares (M ha) in Asia including 1.5 M ha in South Asia. To meet the rice demand for the increasing human population and feed for livestock and poultry, the rice-maize cropping sequence is followed either in double or triple cropping systems (Fig 2.3). Maize (*kharif*) is also grown as the main crop in the cropping system *kharif* season in Odisha. *Rabi* maize in the irrigated area followed by rice is an emerging cropping system that has the potential to replace the rice-rice system. It was found that there was a 95-99% reduction in methane emission by diversifying the rice-rice system to rice-maize in upland situations in Philippines. Although annual N_2O emissions increased two- to threefold in the diversified systems, the strong reduction in CH_4 led to a significant reduction in annual GWP ($CH_4 + N_2O$) as compared to the traditional double-rice cropping system. After rice, maize may be planted with a zero-till seed drill, turbo happy seeder, or combo happy seeder without any field operation with minimal disturbance of the soil and the surface residues. Application of Atrazine (1 kg a.i. ha^{-1}) or Pendimethalin (1 kg a.i. ha^{-1}) or tank mix application of Atrazine + Pendimethalin (500 g a.i. each ha^{-1}) or Alachlor + Atrazine (1.25 kg+ 375 g a.i. ha^{-1}) can effectively control annual weeds in *rabi* maize. Simultaneous planting of green gram/black gram as a cover crop on either side of maize row on beds is effective in controlling complex weed flora. Rice - maize cropping system can be further intensified with the introduction of cowpea as a third crop in the system to reduce the N requirement of the system by incorporation in the rice crop. Recommended maize varieties for different agro-climatic zones of Odisha are shown in Table 2.15.



Fig. 2.3 Rice-maize-cowpea cropping system in Odisha

Source: Authors' own collection

Table 2.15 Recommended maize varieties for different agro-climatic zones of Odisha

Agro-climatic zones	District	Varieties	Season
Northwestern plateau	Sundargarh Deogarh	Vijaya, Decan 103, Decan 105, HQPM 1, Bio 9544, Decan 107, PAC 745	<i>Kharif</i> (June-Oct)
Northcentral plateau	Keonjhar Mayurbhanj	Navjot, Kiran, VL 16, DHM 109, Vijaya, Decan 103, Decan 105, Bio 9544, Decan 107, PAC 745	<i>Kharif</i> (June-Sept)
Northeastern coastal plain	Jajpur Bhadrak Balasore	Kiran, VL 16, Pratap, Vijaya, Decan 103, Decan105, HQPM1, Bio 9544 , Decan107, PAC745, Ganga 5, KH 510, KH 101, Shakti 1, Novjyot.	<i>Kharif</i> (June-Oct)
East & south-eastern coastal plain	Nayagarh Cuttack Khorda	Navjot, Pragati, Shakti 1, Ganga 6, Ganga 11, Vijaya, Decan 103, Decan 105, Bio 9544 , Decan 107, PAC 745, Kiran, Pratap, VL 16	<i>Kharif</i> (June-Oct) <i>Rabi</i> (Sept-Dec)
North-easternGhat	Ganjam Rayagada Kandhamal Gajapati	Prabal, Pinnacle, Ganga 5, KH 510, KH 101, Maharaja, DHM 103, HQPM 1, HQPM 5, CP 999, DKC 91117, Vijaya, Decan 103, Decan 105, Bio 9544, Decan 107, PAC 745, 30R 77, Hysell, Kargil, Allrounder, DHM 103, Kujimaka (Local)	<i>Kharif</i> (June-Oct) <i>Rabi</i> (Sept-Dec)
Eastern Ghat highland	Koraput Nabarangapur	Navjot, Shakti, Vijaya, Decan 103, Decan 105, Bio 9544, Decan 107, PAC 745, Pioneer, Bio 9681	<i>Kharif</i> (June-Oct) <i>Rabi</i> (Sept-Dec)
South eastern Ghat	Malkangiri Part of Koraput	Kargil 633, Ganga 11, Novjot, Nabin, Vijaya, Decan 103, Decan 105, Bio 9544 , Decan 107, PAC 745	<i>Kharif</i> (June-Oct) <i>Rabi</i> (Sept-Dec)
Western undulating zone	Kalahandi Nuapara	Pragati, Shakti 1, Pratap, Arun, Vijaya, Decan 103, Decan 105, HQPM1, Bio 9544 , Decan 107, PAC 745	<i>Kharif</i> (June-Oct) <i>Rabi</i> (Sept-Dec)
Western central tableland	Bolangir Baragarh Boudh Jharsuguda Sambalpur	African Tall, Pragati, Navjot, Vijaya, Decan 103, Decan 105, HQPM 1, Bio 9544, Decan 107, PAC 745	<i>Kharif</i> (June-Oct) <i>Rabi</i> (Sept-Dec)

Mid-central tableland	Dhenkanal Angul	Vijaya, Decan 103, Decan 105, HQPM 1, Bio 9544, Decan 107, PAC 745	<i>Kharif</i> (June-Sept) <i>Rabi</i> (Sept-Dec)

Source: Authors' own compilation

2.6.3 Rice-pulse cropping system

To increase the cropping intensity in the state and bringing rice-fallow into cultivation, the rice-pulse cropping system is considered as the most suitable one for the state of Odisha. Rice-pulse cropping systems are mainly suitable for limited water conditions in irrigated areas or rainfed rice-growing areas. The suitable pulses after rice are green gram, black gram, horse gram, and lathyrus in rainfed areas (Fig. 2.4). In areas with limited irrigation or supplemental irrigation facility, soyabean, black gram or green gram can be grown. In rainfed areas, the crops should be selected based on the availability of residual soil moisture. In situations, where it is expected that land would be too dry for plowing at the time of rice harvesting, lathyrus should be sown as *paira* crop two weeks before the harvesting. If the moisture content of the soil is expected to be at saturation and above, black gram should be preferred as a *paira* crop, whereas if moisture content at or below field capacity and can be ploughed, green gram or black gram may be taken up. Under excess moisture situation, growing of green gram and black gram is not a good choice, rather crops like soyabean, field bean, and peas can be taken. The management practices for various rice-pulses cropping systems are presented below.

- Seed treatment with a fungicide like carbendazim (2 g kg⁻¹ of seed) or Thiram (3 g kg⁻¹ of seed) along with ammonium molybdate @ 3 g /10 kg of seeds, appropriate rhizobium culture @ 50 g kg⁻¹ of seed is beneficial.
- Application of post-emergence herbicides i.e. Quizalofop ethyl @ 50 g a.i. ha⁻¹ at 3 weeks crop growth stage or Imazethapyr @ 75 g a.i. ha⁻¹ at 15-20 days crop stage for weed control in pulses.
- For supplementing N, P and K to the crops, foliar spray of DAP (2%) or 1% DAP + 1% MOP should be done at 20 and 40 days after sowing.

Besides rice-pulse cropping system in which rice is grown in *kharif* and pulse crops in *rabi*, pulse crop can also be a part of another sequential cropping, viz., pigeon pea-wheat, green gram-mustard, green gram-vegetables, maize-horse gram. More intensive sequential cropping system rice-rice-green gram can also be followed in the area with a good irrigation facility. Intercropping

with pulses, viz., chickpea+mustard, chickpea+linseed, maize+lentil, wheat+chickpea are also successful in many places. Recommended varieties of pulses for different agro-climatic zones of Odisha are shown in Table 2.16.



Fig 2.4 Rice-pulse cropping system in Odisha

Source: Authors' own collection

Table 2.16 Recommended varieties of pulses for different agro-climatic zones of Odisha

Agro-climatic zones	District	Crop	Varieties	Season
North western plateau	Sundargarh	Greengram	Dhauli, PDM 54, PDM 11, IPM-02-03, IPM-02-14, OUM 11-5, COCC 912, HUM1, Pusa 9072, TARM 1	<i>Kharif, Rabi</i>
		Blackgram	Sarala, Prasad, Ujala, PU 31, PU 35	<i>Kharif</i>
		Redgram	UPAS 120, Maruti, ICPL87, Asha, BRG2, Durga, Kamika, ICPL 9905, C11, LRC41	<i>Kharif</i>
		Chickpea	JG 62, JG 74, Radhey, H 208, C 235	<i>Rabi</i>
		Field pea	Rachana, Dhusar, Swarnarekha, T 163	<i>Rabi</i>
		Lentil	B 77, k 76, Pusa 8, Pant L 406, DPL 15	<i>Rabi</i>
		Cowpea	Utkal manika, SEB 2, FS 68, Swarna	<i>Kharif, Rabi</i>
		Horsegram	Urmi	<i>Rabi</i>
	Deogarh	Greengram	Dhauli, Kamdev, Durga, OUM11-5, COCC 912, HUM 1, Pusa 9072, TARM 1	<i>Kharif, Rabi</i>
		Blackgram	Sarala, Prasad, Ujala, K301	<i>Kharif, Rabi</i>
		Redgram	UPAS 120, Maruti, ICPL 87, Asha, BRG 2, Durga, Kamika, ICPL 9905, C 11, LRC 41	<i>Kharif</i>
		Chick pea	JG 62, JG 74, Radhey, H 208, C 235	<i>Kharif</i>
		Field pea	Rachana, Dhusar, Swarnarekha, T 163	<i>Rabi</i>
		Cowpea	Utkal manika, SEB 2	<i>Kharif, Rabi</i>
		Horsegram	Urmi	<i>Rabi</i>

Agro-climatic zones	District	Crop	Varieties	Season
North central plateau	Keonjhar	Greengram	Dhauli, Kamdev, Durga OUM 11-5, COCC 912, HUM 1, Pusa 9072, TARM 1	<i>Kharif, Rabi</i>
		Blackgram	Sarala, Prasad, Ujala, K 301, PU 31, PU 35	<i>Kharif, Rabi</i>
		Redgram	UPAS 120, Maruti, ICPL87, Asha, BRG 2, Durga, Kamika, ICPL 9905, C11, LRC 41	<i>Kharif</i>
		Chick pea	JG 62, JG 74, Radhey, H 208, C 235	<i>Kharif</i>
		Field pea	Rachana, Dhusar, Swarnarekha, T-163	<i>Rabi</i>
		Lentil	B 77, k 76, Pusa 8, Pant L 406, DPL 15	<i>Rabi</i>
		Cowpea	Utkal manika, SEB 2	<i>Kharif, Rabi</i>
		Horsegram	Urmi	<i>Rabi</i>
	Mayurbhanj	Greengram	Dhauli, Kamdev, Durga OUM 11-5, COCC 912, HUM 1, Pusa 9072, TARM 1	<i>Kharif, Rabi</i>
		Redgram	UPAS 120, Maruti, ICPL 87, Asha, BRG 2, Durga, Kamika, ICPL 9905, C 11, LRC 41	<i>Kharif</i>
		Blackgram	Sarala, Prasad, Ujala, K 301	<i>Kharif, Rabi</i>
		Chick pea	JG 62, JG 74, Radhey, H-208, C 235	<i>Kharif</i>
		Field pea	Rachana, Dhusar, Swarnarekha, T 163	<i>Rabi</i>
		Lentil	B 77, k 76, Pusa 8, Pant L 406, DPL 15	<i>Rabi</i>
		Cowpea	Utkal manika, SEB 2	<i>Kharif, Rabi</i>
		Horsegram	Urmi	<i>Rabi</i>
North eastern coastal plain	Jajpur Balasore Bhadrak	Greengram	Dhauli,, Durga, Pusa 9072, TARM 1	<i>Rabi</i>

Agro-climatic zones	District	Crop	Varieties	Season
		Blackgram	Sarala, Prasad, Ujala, K 301	<i>Kharif, Rabi</i>
		Redgram	UPAS 120, Maruti, ICPL 87, Asha, BRG 2, Durga, Kamika, CPL 9905, C 11, LRC 41	<i>Kharif</i>
		Horsegram	Urmi	<i>Rabi</i>
		Greengram	Dhauli, Durga Pusa 9072, TARM 1	<i>Rabi</i>
		Blackgram	Prasad, Ujala	<i>Rabi</i>
		Field pea	Rachana, Dhusar, Swarnarekha, T-163	<i>Rabi</i>
		Cowpea	Utkal manika, SEB 2	<i>Rabi</i>
		Greengram	Dhauli, Durga Prasad, Ujala, K 301	<i>Rabi</i>
		Blackgram	Prasad, Ujala	<i>Rabi</i>
East & south-eastern coastal plain	Nayagarh	Green gram	Dhauli, Kamdev, Durga Pusa 9072, TARM 1	<i>Kharif, Rabi</i>
		Blackgram	Prasad, Ujala, K301	<i>Kharif, Rabi</i>
		Redgram	UPAS 120, Maruti, ICPL 87, Asha, BRG 2, Durga, Kamika, ICPL 9905, C 11, LR C41	<i>Kharif</i>
		Field pea	Rachana, Dhusar, Swarnarekha, T 163	<i>Rabi</i>
		Lentil	B 77, k 76, Pusa 8, Pant L 406, DPL 15	<i>Rabi</i>
		Cowpea	Utkal manika, SEB 2	<i>Kharif, Rabi</i>
		Horsegram	Urmi	<i>Rabi</i>
	Cuttack	Green gram	Dhauli, Kamdev, Durga	<i>Kharif, Rabi</i>
		Blackgram	Prasad, Ujala, K301	<i>Kharif, Rabi</i>
		Redgram	UPAS 120, Maruti, ICPL87, Asha, BRG 2, Durga, Kamika, ICPL 9905, C 11, LRC 41	<i>Kharif</i>
		Chick pea	JG 62, JG 74, Radhey, H 208, C 235	<i>Kharif</i>

Agro-climatic zones	District	Crop	Varieties	Season
		Field pea	Rachana, Dhusar, Swarnarekha, T 163	<i>Rabi</i>
		Cowpea	Utkal manika, SEB 2	<i>Rabi</i>
		Horsegram	Urmi	<i>Rabi</i>
	Puri	Green gram	Dhauli, Durga, Pusa 9072, TARM 1	<i>Rabi</i>
		Blackgram	Prasad, Ujala,	<i>Rabi</i>
		Horsegram	Urmi	<i>Rabi</i>
	Jagatsingpur	Green gram	Dhauli, Durga	<i>Rabi</i>
		Blackgram	Prasad, Ujala,	<i>Rabi</i>
		Cowpea	Utkal manika, SEB 2	<i>Rabi</i>
		Horsegram	Urmi	<i>Rabi</i>
	Khorda	Green gram	Dhauli, Durga, Pusa 9072, TARM 1	<i>Rabi</i>
		Blackgram	Prasad, Ujala, K 301	<i>Kharif, Rabi</i>
		Redgram	UPAS 120, Maruti, ICPL 87, Asha, BRG 2, Durga, Kamika, ICPL 9905, C 11, LRC 41	<i>Kharif</i>
		Chick pea	JG 62, JG 74, Radhey, H 208, C 235	<i>Kharif</i>
		Lentil	B 77, k 76, Pusa 8, Pant L 406, DPL 15	<i>Rabi</i>
		Cowpea	Utkal manika, SEB 2	<i>Kharif, Rabi</i>
		Horsegram	Urmi	<i>Rabi</i>
	Kendrapada	Cowpea	Utkalamani	<i>Rabi</i>
		Horsegram	Urmi (90-95)	<i>Rabi</i>
North-eastern Ghat	Ganjam	Green gram	Dhauli, Kamdev, Durga, IPM 02-14, IPM-02-03, PDM 54, PDM 11	<i>Kharif, Rabi</i>
		Blackgram	Sarala, Prasada,, Ujala, Mahuri	<i>Kharif, Rabi</i>
		Redgram	UPAS 120, Maruti, ICPL 87, Asha, BRG 2, Durga, Kamika, ICPL 9905, C 11, LRC 41	<i>Kharif</i>
		Chick pea	JG 62, JG 74, Radhey, H 208, C 235	<i>Kharif</i>

Agro-climatic zones	District	Crop	Varieties	Season
		Field pea	Rachana, Dhushar, Swarnarekha, T-163	Rabi
		Cowpea	Utkal manika, SEB 2	Rabi
		Horsegram	Urmi	Rabi
	Gajapati	Green gram	Dhauli, Kamdev, Durga	Kharif, Rabi
		Blackgram	Sarala, Prasada,,Ujala, Mahuri	Kharif, Rabi
		Redgram	UPAS 120, Maruti, ICPL87, Asha, BRG2, Durga, Kamika, ICPL 9905, C 11, LRC 41	Kharif
		Cowpea	Utkal manika, SEB 2	Kharif, Rabi
		Horsegram	Urmi	Rabi
	Kandhamal	Green gram	Dhauli, Kamdev, Durga	Kharif
		Blackgram	Sarala, Prasada,,Ujala, Mahuri	Kharif
		Redgram	UPAS 120, Maruti, ICPL 87, Asha, BRG 2, Durga, Kamika, ICPL 9905, C 11,LRC 41	Kharif
		Field pea	Rachana, Dhushar, Swarnarekha, T 163	Rabi
		Cowpea	Utkal manika, SEB 2	Kharif
		Horsegram	Urmi	Rabi
	Rayagada	Green gram	Dhauli, Kamdev, Durga	Kharif, Rabi
		Blackgram	Sarala, Prasada,,Ujala, Mahuri	Kharif, Rabi
		Redgram	UPAS 120, Maruti, ICPL 87, Asha, BRG 2, Durga, Kamika, ICPL 9905,C 11,LRC 41	Kharif
		Chick pea	JG 62, JG 74, Radhey, H 208, C 235	Kharif
		Field pea	Rachana, Dhushar, Swarnarekha, T 163	Rabi
		Cowpea	Utkal manika, SEB 2	Rabi
		Horsegram	Urmi	Rabi

Agro-climatic zones	District	Crop	Varieties	Season
Eastern Ghat highland	Koraput	Green gram	Dhauli, Kamdev, Durga, OUM 11-5, COCC 912, HUM1, Pusa 9072, TARM 1	<i>Kharif, Rabi</i>
		Blackgram	Sarala, Prasada,,Ujala, Mahuri, K301	<i>Kharif, Rabi</i>
		Redgram	UPAS 120, Maruti, ICPL 87, Asha, BRG2, Durga, Kamika, ICPL 9905, C 11, LR C 41	<i>Kharif</i>
		Chick pea	JG 62, JG 74, Radhey, H 208, C 235	<i>Kharif</i>
		Field pea	Rachana, Dhusar, Swarnarekha, T-163	<i>Rabi</i>
		Cowpea	Utkal manika, SEB 2	<i>Kharif, Rabi</i>
		Horsegram	Urmi	<i>Rabi</i>
	Nabarangapur	Green gram	Dhauli, Durga	<i>Rabi</i>
		Blackgram	Sarala, Prasada, Ujala, Mahuri	<i>Kharif</i>
		Redgram	UPAS 120, Maruti, ICPL 87, Asha, BRG 2, Durga, Kamika, ICPL 9905, C 11, LRC 41	<i>Kharif</i>
		Chick pea	JG 62, JG 74, Radhey, H 208, C 235	<i>Kharif</i>
		Field pea	Rachana, Dhusar, Swarnarekha, T-163	<i>Rabi</i>
		Cowpea	Utkal manika, SEB 2	<i>Rabi</i>
		Horsegram	Urmi	<i>Rabi</i>
South- eastern Ghat	Malkangiri	Green gram	Dhauli, Kamdev, Durga	<i>Kharif, Rabi</i>
		Blackgram	Sarala, Prasada,,Ujala, Mahuri	<i>Kharif, Rabi</i>
		Redgram	UPAS 120, Maruti, ICPL 87, Asha, BRG 2, Durga, Kamika, ICPL 9905, C 11,LRC 41	<i>Kharif</i>
		Cowpea	Utkal manika, SEB 2	<i>Rabi</i>
		Horsegram	Urmi	<i>Rabi</i>

Agro-climatic zones	District	Crop	Varieties	Season
Western undulating zone	Kalahandi	Green gram	Dhauli, Kamdev, Durga	<i>Kharif, Rabi</i>
		Blackgram	Sarala, Prasada,,Ujala, Mahuri	<i>Kharif, Rabi</i>
		Redgram	UPAS 120, Maruti, ICPL 87, Asha, BRG2, Durga, Kamika, ICPL 9905, C 11, LRC 41	<i>Kharif</i>
		Chick pea	JG 62, JG 74, Radhey, H 208, C 235	<i>Kharif</i>
		Field pea	Rachana, Dhusar, Swarnarekha, T-163	<i>Rabi</i>
		Lentil	B 77, k 76, Pusa 8, Pant L 406, DPL 15	<i>Rabi</i>
		Horsegram	Urmi	<i>Rabi</i>
	Nawapara	Greengram	Dhauli, Kamdev, Durga	<i>Kharif, Rabi</i>
		Blackgram	Sarala, Prasada,,Ujala, Mahuri	<i>Kharif, Rabi</i>
		Redgram	UPAS 120, Maruti, ICPL87, Asha, BRG 2, Durga, Kamika, ICPL 9905, C 11, LRC 41	<i>Kharif</i>
		Chick pea	JG 62, JG 74, Radhey, H 208, C 235	<i>Kharif</i>
		Field pea	Rachana, Dhusar, Swarnarekha, T-163	<i>Rabi</i>
		Horsegram	Urmi	<i>Rabi</i>
Western central tableland	Bolangir	Green gram	Dhauli, Kamdev, Durga	<i>Kharif, Rabi</i>
		Blackgram	Sarala, Prasada,,Ujala, Mahuri	<i>Kharif, Rabi</i>
		Redgram	UPAS 120, Maruti, ICPL87, Asha, BRG 2, Durga, Kamika, ICPL 9905, C 11, LRC 41	<i>Kharif</i>
		Chick pea	JG 62, JG 74, Radhey, H 208, C 235	<i>Rabi</i>
		Field pea	Rachana, Dhusar, Swarnarekha, T-163	<i>Rabi</i>
		Lentil	B 77, k 76,Pusa 8, Pant L 406, DPL 15	<i>Rabi</i>

Agro-climatic zones	District	Crop	Varieties	Season
		Cowpea	Utkal manika, SEB 2	<i>Kharif, Rabi</i>
		Horsegram	Urmi	<i>Rabi</i>
	Baragarh	Green gram	Dhauli, Kamdev, Durga	<i>Kharif, Rabi</i>
		Blackgram	Sarala, Prasada,,Ujala, Mahuri	<i>Kharif, Rabi</i>
		Redgram	UPAS 120, Maruti, ICPL87, Asha, BRG 2, Durga, Kamika, ICPL 9905, C 11, LRC 41	<i>Kharif</i>
		Chick pea	JG 62, JG 74, Radhey, H 208, C 235	<i>Rabi</i>
		Field pea	Rachana, Dhusar, Swarnarekha, T-163	<i>Rabi</i>
		Horsegram	Urmi	<i>Rabi</i>
	Boudh	Greengram	Dhauli, Kamdev, Durga	<i>Kharif, Rabi</i>
		Blackgram	Sarala, Prasada,,Ujala, Mahuri	<i>Kharif, Rabi</i>
		Redgram	UPAS 120, Maruti, ICPL87, Asha, BRG 2, Durga, Kamika, ICPL 9905, C 11,LRC 41	<i>Kharif</i>
		Chick pea	JG 62, JG74, Radhey, H-208, C-235	<i>Kharif</i>
		Field pea	Rachana, Dhusar, Swarnarekha, T-163	<i>Rabi</i>
	Sonepur	Green gram	Dhauli, Kamdev, Durga	<i>Kharif, Rabi</i>
		Blackgram	Sarala, Prasada,,Ujala, Mahuri	<i>Kharif, Rabi</i>
		Redgram	UPAS 120, Maruti, ICPL87, Asha, BRG 2, Durga, Kamika, ICPL 9905, C 11, LRC 41	<i>Kharif</i>
		Field pea	Rachana, Dhusar, Swarnarekha, T-163	<i>Rabi</i>
		Cowpea	Utkal manika, SEB 2	<i>Kharif , Rabi</i>
		Horsegram	Urmi	<i>Rabi</i>

Agro-climatic zones	District	Crop	Varieties	Season
	Jharsuguda	Green gram	OUM 11-5, COCC 912, HUM 1, Pusa 9072, TARM 1 IPM 02-14, IPM 02-03, PDM 54, PDM11,	<i>Kharif, Rabi</i>
		Blackgram	Sarala, Prasada,,Ujala, Mahuri, PU-31, PU-35	<i>Kharif, Rabi</i>
		Redgram	UPAS 120, Maruti, ICPL 87, Asha, BRG 2, Durga, Kamika, ICPL 9905, C 11, LRC 41	<i>Kharif</i>
		Chick pea	JG 62, JG 74, Radhey, H 208, C 235	<i>Rabi</i>
		Field pea	Rachana, Dhushar, Swarnarekha, T-163	<i>Rabi</i>
		Horsegram	Urmi	<i>Rabi</i>
	Sambalpur	Greengram	Dhauli, Kamdev, Durga	<i>Kharif, Rabi</i>
		Blackgram	Sarala, Prasada,,Ujala, Mahuri	<i>Kharif, Rabi</i>
		Redgram	UPAS 120, Maruti, ICPL87, Asha, BRG 2, Durga, Kamika, ICPL 9905, C 11,LRC 41	<i>Kharif</i>
		Chick pea	JG 62, JG 74, Radhey, H 208, C 235	<i>Kharif</i>
		Field pea	Rachana, Dhushar, Swarnarekha, T-163	<i>Rabi</i>
		Horsegram	Urmi	<i>Rabi</i>
Mid-central tableland	Dhenkanal	Green gram	OUM11-5, COCC 912,HUM 1, Pusa 9072,TARM1 IPM-02-14, IPM02-03, PDM 54, PDM11,	<i>Kharif, Rabi</i>
		Blackgram	Sarala, Prasada,,Ujala, Mahuri, K301 PU31, PU 35	<i>Kharif, Rabi</i>
		Redgram	UPAS 120, Maruti, ICPL87, Asha, BRG 2, Durga, Kamika, ICPL 9905, C 11, LRC41	<i>Kharif</i>

Agro-climatic zones	District	Crop	Varieties	Season
		Chick pea	JG 62, JG 74, Radhey, H 208, C 235	<i>Kharif</i>
		Field pea	Rachana, Dhusar, Swarnarekha, T-163	<i>Rabi</i>
		Horsegram	Urmi	<i>Rabi</i>
	Angul	Green gram	IPM 02-14, IPM 02-03, PDM 54, PDM 11, OUM 11-5, COCC 912, HUM 1, Pusa 9072, TARM 1	<i>Kharif, Rabi</i>
		Blackgram	Sarala, Prasada,,Ujala, Mahuri, K 301, PU 31, PU 35	<i>Kharif, Rabi</i>
		Redgram	UPAS 120, Maruti, ICPL87, Asha, BRG 2, Durga, Kamika, ICPL 9905, C 11,LRC 41	<i>Kharif</i>
		Chick pea	JG 62, JG 74, Radhey, H 208, C 235	<i>Kharif</i>
		Field pea	Rachana, Dhusar, Swarnarekha, T-163	<i>Rabi</i>
		Cowpea	Utkal manika, SEB 2	<i>Kharif</i>
		Horse gram	Urmi	<i>Rabi</i>

Source: Authors' own compilation

2.6.4 Rice-oilseeds cropping system

Oilseed crops such as groundnut, sunflower, sesame, *etc.* can be cultivated and economically profitable in tail-end areas of irrigation command, tank fed area, and well-irrigated areas with limited moisture conditions (Fig. 2.5). There is a great potential of *rabi*/summer groundnut in rice fallows on residual moisture in flood plains in Odisha. Rapeseed/mustard (*toria*) can be a better option in low-temperature areas of Northern Odisha. Most of the oilseed crops are mainly suitable for deficit moisture conditions. However, a variety of *toria*, TS-38 is highly preferable to the low lying flood-prone areas of Odisha and Assam. As a summer crop, sesame can be profitably grown after rice. In the upland areas of Odisha, groundnut (*kharif*) and sunflower are more remunerative as compared to upland rice. The management practices for various rice-oilseeds cropping systems are presented below.

- Seeds should be treated with Imidachloprid @ 2 mL kg⁻¹ seed followed by Tebuconazole 2ds @ 1g or Mancozeb @ 3 g kg⁻¹ seed. If the seed is dormant, it is soaked in 0.05% Ethrel solution for 12 followed by shade drying. Seed treatment with *Trichoderma viride*@ 4 g kg⁻¹ seed for rot prone areas. Rhizobium inoculation is necessary for groundnut in non-traditional areas and rice fallows. For quick germination and better stand in dryland conditions, soaking of seeds in freshwater for about 10 minutes is recommended.
- Oilseed crops should be kept weed-free up to 45 days after sowing by hand weeding at 20 and 40 days after sowing (DAS). The groundnut crop should not be disturbed by weeding or intercultural operation after 45 DAS. Pre-planting application of herbicides viz., Fluchloralin @ 1.0 kg a.i. ha⁻¹ or Pendimethalin @ 1.0 kg a.i. ha⁻¹ or Oxadiazon @ 1.0 kg a.i. ha⁻¹ or Thiobencarb @ 1.0 kg a.i. ha⁻¹ in moist soil at 1 day before sowing by mixing with 500 l ha⁻¹ of water effectively control the weeds.
- Groundnut should be fertilized with 20 kg N, 40 kg P₂O₅, 20 kg K₂O kg/ha and gypsum 250-500 kg/ha as basal.
- Application of N: P: K @ 50:25:25 kg ha⁻¹ under irrigated condition and @ 40:20:20 kg ha⁻¹ under rainfed condition along with sulphur @ 25 kg ha⁻¹, zinc sulphate @ 25 kg ha⁻¹ and borax 10 kg ha⁻¹ is sufficient for rapeseed /mustard.
- Seed set in sunflower is enhanced by honey bees hence 5 hives ha⁻¹ of honey bees facilitates optimum pollination, besides yielding valuable honey. A spray of insecticide at the blooming period is avoided as it affects the visit of pollinators (bees). If essential, spray or dust after 3.00 pm preferably with relatively safer insecticides.

Besides rice-oilseeds system dominating in most of the agro-climatic zones, other sequential cropping systems, viz., soyabean+sunflower, maize+mustard and intercropping, viz., groundnut+pigeonpea, groundnut+castor, groundnut+pearl millet, linseed+mustard, linseed+ safflower are also practiced. Recommended varieties of oil seeds for different agro-climatic zones of Odisha are shown in Table 2.17.

Table 2.17 Recommended varieties of oilseeds for different agro-climatic zones of Odisha

Agro-climatic zones	District	Crop	Varieties	Season
North western plateau	Sundargarh	Groundnut	Smruti, Kadiri 6, Devi, Ak 159, JL 24, Bikash	<i>Kharif, Rabi</i>
		Sesamum	Amrit (80), Smarak(75), Subhra (85), Uma (75), Nirmala(80)	<i>Kharif, Rabi</i>
		Rapeseed and toria	M27, Prabhati (75). Anuradha (75), Sushri(75), Pusa Agani	<i>Rabi</i>
		Sunflower	Sunrise, Morden, EC-68415, EC-68414, MSFH-8, MSFH-17, MSFH -1, KBSH-1	<i>Rabi</i>
		Niger	Deomali (110), Utkal-Niger 150(110)	<i>Rabi</i>
	Deogarh	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	<i>Kharif, Rabi</i>
		Sesamum	Amrit (80), Smarak (75), Subhra (85), Uma (75), Nirmala (80)	<i>Kharif, Rabi</i>
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75) Pusa Agani	<i>Rabi</i>
		Sunflower	MSFH-17, Sunrise, Morden, EC-68415, EC-68414, MSFH-8, MSFH -1, KBSH-1	<i>Rabi</i>
North central plateau	Keonjhar	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	<i>Kharif, Rabi</i>
		Sesamum	Amrit (80), Smarak (75), Subhra (85), Uma (75), Nirmala (80)	<i>Kharif, Rabi</i>
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75) Pusa Agani	<i>Rabi</i>
		Sunflower	Sunrise, Morden, EC-68415, EC-68414, MSFH-8, MSFH-17, MSFH -1, KBSH-1	<i>Rabi</i>

Agro-climatic zones	District	Crop	Varieties	Season
	Mayurbhanj	Niger	Deomali (110), Utkal-Niger 150(110)	Kharif, Rabi
		Groundnut	Smruti, Kadiri-6,Devi, Ak-159, JL-24, Bikash	Kharif, Rabi
		Sesamum	Amrit (80), Smarak(75), Subhra(85), Uma (75), Nirmala(80)	Kharif, Rabi
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75) Pusa Agani	Rabi
		Niger	Deomali (110), Utkal-Niger 150(110)	Kharif
North eastern coastal plain	Jajpur	Groundnut	Smruti, Kadiri-6, Devi,Ak-159, JL-24, Bikash	Kharif, Rabi
		Sesamum	Amrit (80), Smarak (75),Subhra (85), Uma (75), Nirmala(80)	Kharif,
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	Rabi
	Balasore	Groundnut	Smruti, Kadiri-6,Devi, Ak-159,JL-24, Bikash	Rabi
		Sesamum	Amrit (80), Smarak (75),Subhra (85)	Rabi
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	Rabi
	Bhadrak	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	Rabi
		Sesamum	Amrit (80), Smarak(75),Subhra(85), Uma (75), Nirmala(80)	Rabi
		Rapeseed and toria	Pravati (75),Anuradha (75), Sushree (75)	Rabi
		Sunflower	Sunrise, Morden, EC-68415, EC-68414, MSFH-8, MSFH-17, MSFH -1, KBSH-1	Rabi
	Nayagarh	Groundnut	Smruti, Kadiri-6,Devi,Ak-159,JL-24,Bikash	Rabi

Agro-climatic zones	District	Crop	Varieties	Season
		Sesamum	Amrit (80), Smarak (75), Subhra (85), Uma (75), Nirmala (80)	<i>Kharif, Rabi</i>
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	<i>Rabi</i>
	Cuttack	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	<i>Kharif, Rabi</i>
		Sesamum	Amrit (80), Smarak(75), Subhra(85), Uma (75), Nirmala (80)	<i>Kharif, Rabi</i>
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	<i>Rabi</i>
	Puri	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	<i>Rabi</i>
		Sesamum	Amrit (80), Smarak(75), Subhra(85)	<i>Rabi</i>
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	<i>Rabi</i>
		Sunflower	Sunrise, Morden, EC-68415, EC 68414, MSFH 8, MSFH 17, MSFH -1, KBSH-1	<i>Rabi</i>
	Jagatsingpur	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	<i>Rabi</i>
		Sesamum	Amrit (80), Smarak(75), Subhra(85)	<i>Rabi</i>
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	<i>Rabi</i>
		Sunflower	Sunrise, Morden, EC-68415, EC-68414, MSFH-8, MSFH-17, MSFH -1, KBSH-1	<i>Rabi</i>
	Khorda	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	<i>Rabi</i>
		Sesamum	Amrit (80), Smarak(75), Subhra(85), Uma (75), Nirmala(80), Vinayak (90)	<i>Rabi</i>
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	<i>Rabi</i>
	Kendrapada	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	<i>Rabi</i>

Agro-climatic zones	District	Crop	Varieties	Season
		Sesamum	Amrit (80), Smarak(75), Subhra(85), Uma (75), Nirmala(80), Vinayak (90), Kanak(85)	Rabi
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	Rabi
		Sunflower	Sunrise, Morden, EC-68415, EC-68414, MSFH-8, MSFH-17, MSFH -1, KBSH-1	Rabi
North east Ghat	Ganjam	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	Kharif , Rabi
		Sesamum	Amrit (80), Smarak(75), Subhra(85), Uma (75), Nirmala(80)	Kharif, Rabi
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	Rabi
		Sunflower	Sunrise, Morden, EC-68415, EC-68414, MSFH-8, MSFH-17, MSFH -1, KBSH-1	Rabi
	Gajapati	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	Kharif, Rabi
		Sesamum	Amrit (80), Smarak(75), Subhra(85), Uma (75), Nirmala(80)	Kharif, Rabi
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	Rabi
		Sunflower	Sunrise, Morden, EC-68415, EC-68414, MSFH-8, MSFH-17, MSFH -1, KBSH-1	Rabi
		Niger	Deomali (110), Utkal-Niger 150(110)	Kharif, Rabi
	Kandhamal	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	Kharif
		Sesamum	Amrit (80), Smarak(75), Subhra(85), Uma (75), Nirmala(80)	Kharif,
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	Rabi

Agro-climatic zones	District	Crop	Varieties	Season
		Niger	Deomali (110), Utkal-Niger 150(110)	Kharif
	Rayagada	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	Kharif, Rabi
		Sesamum	Amrit (80), Smarak(75), Subhra(85), Uma (75), Nirmala(80)	Kharif, Rabi
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	Rabi
		Sunflower	Sunrise, Morden, EC-68415, EC-68414, MSFH-8, MSFH-17, MSFH -1, KBSH-1	Rabi
		Niger	Deomali (110), Utkal-Niger 150(110)	Kharif, Rabi
Eastern Ghat highland	Koraput	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	Kharif, Rabi
		Sesamum	Amrit (80), Smarak(75), Subhra(85)	Kharif,
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	Rabi
		Niger	Deomali (110), Utkal-Niger 150(110)	Kharif
	Nabarangapur	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	Kharif
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	Rabi
		Niger	Deomali (110), Utkal-Niger 150(110)	Kharif
South eastern Ghat	Malkangiri	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	Kharif Rabi
		Sesamum	Amrit (80), Smarak(75), Subhra(85), Uma (75), Nirmala(80)	Kharif, Rabi
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	Rabi
		Niger	Deomali (110), Utkal-Niger 150(110)	Kharif
Western undulating zone	Kalahandi	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	Kharif, Rabi

Agro-climatic zones	District	Crop	Varieties	Season
		Sesamum	Amrit (80), Smarak(75), Subhra(85), Uma (75), Nirmala(80)	Kharif, Rabi
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	Rabi
		Sunflower	Sunrise, Morden, EC-68415, EC-68414, MSFH-8, MSFH-17, MSFH -1, KBSH-1	Rabi
		Niger	Deomali (110), Utkal-Niger 150(110)	Kharif
	Nawapara	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	Kharif, Rabi
		Sesamum	Amrit (80), Smarak(75), Subhra(85),	Kharif,
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	Rabi
Western central table land	Bolangir	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	Kharif, Rabi
		Sesamum	Amrit(80), Smarak(75), Subhra(85), Uma (75), Nirmala(80)	Kharif, Rabi
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	Rabi
		Sunflower	Sunrise, Morden, EC-68415, EC-68414, MSFH-8, MSFH-17, MSFH -1, KBSH-1	Rabi
	Baragarh	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	Kharif, Rabi
		Sesamum	Amrit(80), Smarak(75), Subhra(85), Uma (75), Nirmala(80)	Kharif, Rabi
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	Rabi
		Sunflower	Sunrise, Morden, EC-68415, EC-68414, MSFH-8, MSFH-17, MSFH -1, KBSH-1	Rabi
	Boudh	Sesamum	Amrit(80), Smarak(75), Subhra(85), Uma (75), Nirmala(80)	Kharif, Rabi

Agro-climatic zones	District	Crop	Varieties	Season
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	Rabi
		Sunflower	Sunrise, Morden, EC-68415, EC-68414, MSFH-8, MSFH-17, MSFH -1, KBSH-1	Rabi
	Sonepur	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	Kharif, Rabi
		Sesamum	Amrit(80), Smarak(75), Subhra(85), Uma (75), Nirmala(80)	Kharif, Rabi
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	Rabi
		Sunflower	Sunrise, Morden, EC-68415, EC-68414, MSFH-8, MSFH-17, MSFH -1, KBSH-1	Rabi
	Jharsuguda	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	Kharif, Rabi
		Sesamum	Amrit (80), Smarak(75), Subhra(85), Uma (75), Nirmala(80)	Kharif, Rabi
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	Rabi
		Sunflower	Sunrise, Morden, EC-68415, EC-68414, MSFH-8, MSFH-17, MSFH -1, KBSH-1	Rabi
	Sambalpur	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	Kharif, Rabi
		Sesamum	Amrit(80), Smarak(75), Subhra(85), Uma (75), Nirmala(80)	Kharif, Rabi
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	Rabi
Mid-central table land	Dhenkanal	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	Kharif, Rabi
		Sesamum	Amrit(80), Smarak(75), Subhra(85), Uma (75), Nirmala(80)	Kharif, Rabi
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	Rabi

Agro-climatic zones	District	Crop	Varieties	Season
	Angul	Groundnut	Smruti, Kadiri-6, Devi, Ak-159, JL-24, Bikash	Kharif, Rabi
		Sesame	Amrit(80), Smarak(75), Subhra(85), Uma (75), Nirmala(80)	Kharif, Rabi
		Rapeseed and toria	Pravati (75), Anuradha (75), Sushree (75)	Rabi
		Sunflower	Sunrise, Morden, EC-68415, EC-68414, MSFH-8, MSFH-17, MSFH -1, KBSH-1	Rabi
		Niger	Deomali (110), Utkal-Niger 150(110)	Rabi

Source: Authors' own compilation; figure in parenthesis represents the duration of the variety



Fig. 2.5 Rice-oilseed cropping system existing in India

Source: Authors' own collection

2.6.5 Millet based cropping system

Millets are small-seeded grasses which are hardy and cultivated in rainfed area with limited moisture availability and soil fertility. Millets are thought to be the first cereal grain domesticated for cultivation. The commonly grown millets are sorghum, pearl millet, finger millet, barnyard millet, foxtail millet, kodo millet, proso millet, and little millet. Jowar (*Sorghum bicolor*), bajara (*Pennisetum glaucum*), ragi (*Eleusine coracana*), and little millet (*Penicum sumatrense*) are cultivated in different agro-climatic regions of Odisha. They are highly nutritious, non-glutinous, and rich in fiber. It has a life cycle of 70-100 days that can survive and grow well in places with less than 350 mm of rainfall. Millets are suitable for growing in less privileged undulating terrain with less moisture availability. These characters make millet a popular crop in tribal dominating areas of Odisha. Barnyard millet, provides 10 times more fiber than wheat and considered to be the fastest-growing crop (six weeks). Similarly, foxtail millet is drought-resistant can be cultivated in any type of land while Kodo millet, another drought-resistant crop is ideal for fallow and infertile lands with pebbles. This crop is grown in a spacing of 25 x 10 cm and seed rate of 8-10 kg ha⁻¹ for line sowing, 12-15 kg ha⁻¹ for broadcasting. Nutrient recommendation is 20:20:0 kg NPK ha⁻¹. Inoculation of seeds with biofertilizers like *Agrobacterium* and *Aspergillus awamori* is recommended. Millets mostly finger millets (ragi) are also grown as a sole crop in upland and medium lands (rainfed area) of southern and western Odisha, however, it is also grown in some pockets of the central and northern parts of Odisha. There is also a great scope for bringing some upland area under sorghum, bajra, and little millet. These crops can bring the rainfed upland into agricultural intensification along with enhancing the nutritional security of the farmers because of their rich in proteins and minerals. Recommended varieties of millet crops in different agro-climatic zones of Odisha are shown in Table 2.18.

Table 2.18 Recommended varieties of millet crops in different agro-climatic zones of Odisha

Agro-climatic zones	District	Crop	Varieties	Season
North- west- ern plateau	Sundargarh	Ragi	Dibyasingha(85), VL149(90), Champavati (90), Kalua(110)	Kharif (June-Oct)
		Jowar	CSH-1(100), CSH-9 (105)	Kharif (June-Oct)

Agro-climatic zones	District	Crop	Varieties	Season
		Little-millets	Kolab (80), Sabra (75), TNAU (90), BL 6 (90)	<i>Kharif</i> (June-Sept)
North-central plateau	Keonjhar	Ragi	Dibyasingha (85), VL 149 (90), Champavati (90), Kalua (110)	<i>Kharif</i> (June-Oct)
		Jowar	CSH-1 (100), CSH-9 (105), ASH 1(110)	<i>Kharif</i> (June-Oct)
		Little millets	Kolab (80), Sabra (75), TNAU (90), BL6 (90)	<i>Kharif</i> (June-Sept)
	Mayurbhanj	Ragi	Dibyasingha (85), VL149 (90), Champavati (90), Kalua (110)	<i>Kharif</i> (June-Oct)
		Little millets	Kolab (80), Sabra (75), TNAU (90) BL 6(90)	<i>Kharif</i> (June-Sept)
North-eastern coastal plain	Jajpur	Ragi	Dibyasingha(85), VL149(90), Champavati(90), Neelachal (100), RAU8 (105), Kalua(110)	<i>Kharif</i> (June-Oct) <i>Rabi</i> (Sept-Dec)
		Jowar	CSH-1(100), CSH-9 (105), ASH 1(110)	<i>Kharif</i> (June-Oct)
East & south-eastern coastal plain	Nayagarh	Ragi	Dibyasingha (85), VL149 (90), Champavati (90), Neelachal (100), RAU 8 (105), Kalua (110)	<i>Kharif</i> (June-Oct)
		Little millets	Kolab (80), Sabra (75), TNAU (90), BL 6 (90)	<i>Kharif</i> (June-Sept)
North-eastern Ghat	Ganjam	Ragi	Dibyasingha (85), VL149 (90), Champavati (90), Neelachal (100), RAU8 (105), Kalua (110), Arjun (125), Godavari (115)	<i>Kharif</i> (June-Oct) <i>Rabi</i> (Sept-Dec)
		Jowar	CSH-1 (100), CSH-9 (105), ASH 1(110)	<i>Kharif</i> (June-Oct)
		Little millets	Kolab(80), Sabra(75), TNAU(90), BL 6(90)	<i>Kharif</i> (June-Sept)
	Gajapati	Ragi	Dibyasingha (85), VL 149 (90), Champavati (90), Neelachal (100), RAU8 (105), Kalua (110), Godavari (115)	<i>Kharif</i> (June-Oct) <i>Rabi</i> (Sept-Dec)
		Jowar	CSH-1 (100),CSH-9 (105), ASH 1(110),	<i>Kharif</i> (June-Oct)
		Bajra	HB-1, HB-2, HB-3	<i>Kharif</i> (June-Oct)
		Little millets	Kolab (80), Sabra (75), TNAU (90), BL 6 (90)	<i>Kharif</i> (June-Sept)

Agro-climatic zones	District	Crop	Varieties	Season
	Kandhamal	Ragi	Dibyasingha (85), VL149 (90), Champavati (90), Neelachal (100), Kalua (110)	<i>Kharif</i> (June-Oct) <i>Rabi</i> (Sept-Dec)
		Jowar	CSH-1(100), CSH-9(105)	<i>Kharif</i> (June-Oct)
		Bajra	HB-1, HB-2, HB-3	<i>Kharif</i> (June-Oct)
		Little millets	Kolab (80), Sabra (75), TNAU (90), BL 6 (90)	<i>Kharif</i> (June-Sept)
	Rayagada	Ragi	Dibyasingha (85), VL149 (90), Champavati (90), Neelachal (100), RAU 8 (105), Kalua(110)	<i>Kharif</i> (June-Oct) <i>Rabi</i> (Sept-Dec)
		Jowar	CSH-1 (100), CSH-9 (105)	<i>Kharif</i> (June-Oct)
		Bajra	HB-1, HB-2, HB-3	<i>Kharif</i> (June-Oct)
		Little millets	Kolab (80), Sabra (75), TNAU (90), BL 6 (90)	<i>Kharif</i> (June-Sept)
Eastern Ghat high-land	Koraput	Ragi	Dibyasingha (85), VL 149 (90), Champavati (90), Neelachal (100), RAU 8 (105), Kalua (110), Arjun (125), Godavari	<i>Kharif</i> (June-Oct) <i>Rabi</i> (Sept-Dec)
		Jowar	CSH-1 (100), CSH-9 (105), ASH 1(110), CSH-15	<i>Kharif</i> (June-Oct)
		Bajra	HB-1, HB-2, HB-3	<i>Kharif</i> (June-Oct)
		Little millets	Kolab (80), Sabra (75),TNAU (90), BL 6 (90)	<i>Kharif</i> (June-Sept)
	Nabaran-gapur	Ragi	Dibyasingha (85), VL 149 (90), Champavati (90), Neelachal (100), RAU 8 (105), Kalua (110)	<i>Kharif</i> (June-Oct) <i>Rabi</i> (Sept-Dec)
		Jowar	CSH-1 (100), CSH-9 (105), ASH 1(110)	<i>Kharif</i> (June-Oct)
		Little millets	Kolab (80), Sabra (75), TNAU (90), BL 6 (90)	<i>Kharif</i> (June-Sept)

Agro-climatic zones	District	Crop	Varieties	Season
South-east-ern Ghat	Malkangiri	Ragi	Dibyasingha (85), VL 149 (90), Champavati (90), Neelachal (100), Kalua (110), Godavari (115)	Kharif (June-Oct)
		Jowar	CSH-1 (100), CSH-9 (105), ASH 1 (110)	Kharif (June-Oct)
		Little millets	Kolab (80), Sabra (75), TNAU (90), Tarini (110), BL 6 (90)	Kharif (June-Sept)
Western undulating zone	Kalahandi	Ragi	Dibyasingha (85), VL 149 (90), Champavati (90), Neelachal (100), Kalua (110)	Kharif (June-Oct)
		Jowar	CSH-1 (100), CSH-9 (105), ASH 1(110)	Kharif (June-Oct)
		Little millets	Kolab (80), Sabra (75), TNAU (90), BL 6 (90)	Kharif (June-Sept)
	Nuapada	Ragi	Dibyasingha (85), VL 149 (90), Champavati (90), Neelachal (100), Kalua (110)	Kharif (June-Oct)
		Jowar	CSH-1 (100), CSH-9 (105), ASH 1(110), CSH-2 (105)	Kharif (June-Oct)
		Bajra	CSH-1 (100), CSH-9 (105), ASH 1 (110)	Kharif (June-Oct)
		Little millets	Kolab (80), Sabra (75), TNAU (90), BL 6 (90)	Kharif (June-Sept)
Western central table- land	Bolangir	Ragi	Dibyasingha (85), VL 149 (90), Champavati (90), Neelachal (100), RAU 8 (105), Kalua (110)	Kharif (June-Oct)
		Little millets	Kolab (80), Sabra (75), TNAU (90)	Kharif (June-Sept)
		Jowar	CSH-1 (100), CSH-9 (105), ASH 1(110)	Kharif (June-Oct)
	Baragarh	Ragi	Dibyasingha (85), VL 149 (90), Champavati (90), Neelachal (100), RAU 8 (105), Kalua (110)	Kharif (June-Oct)
	Boudh	Little millets	Kolab (80), Sabra (75), TNAU (90), BL 6 (90)	Kharif (June-Sept)
Mid-central table land	Dhenkanal	Little millets	Kolab (80), Sabra (75), TNAU (90), BL 6 (90)	Kharif (June-Sept)

Source: Authors' own compilation; figure in parenthesis represents the duration of the variety

2.6.6 Tuber crop based cropping system

Tropical tuber crops are considered as third important food crops of Odisha. Tuber crops have higher biological efficiency and produce more dry matter per day per unit area as compared to all other food crops. These crops have inherent capacity to withstand several adverse abiotic and biotic stresses. Crops like sweet potato and cassava can be grown profitably in marginal soil under rainfed ecosystem, whereas in waterlogged soil *colocasia* is a good choice. Tuber crops not only gained importance as food crop but also considered as a good source of vegetable and can be used as feed and as raw materials in several agro based industries. In Odisha, tubers of sweet potato, yams and colocasia are used as important ingredient in preparation of holy food. sweet potato (*Ipomoea batatas*), taro (*Colocassia esculenta*), greater yams (*Dioscoria alata*), yambean (*Pachyrrhizus erosus*), elephant foot yam (*Amorphophallus paeonifolius*), cassava (*Manihot esculenta*) and arrowroot (*Maranta arundinaceae*) are major tropical tuber crops grown in Odisha under different ecosystem (Fig. 2.6). Among these sweet potato and cassava are cultivated as subsistence food crop whereas *colocasia*, yams, elephant foot yam and yam bean are grown as a commercial crop in major agro-climatic regions of Odisha. Being a cheap source of starch cassava, sweet potato and arrowroot have the tremendous potential to develop agro-based industries on a commercial basis. Feed requirement for animal husbandry and fishery sector can be met by the utilization of tubers and leaves of cassava and sweet potato. The short duration crops like sweet potato and yam beans can be used in the prevailing rice-based cropping system. Elephant foot yam and yams are a good choice in nutritional garden, back yard garden, rice field bunds, orchards, and garden land for increasing the farm income. Proper selection of crop and crop varieties followed by the adoption of appropriate agronomic practices are advocated to enhance the farm profitability and income of the farmers. Cultivation of tropical tuber crops will ensure food, nutrition, and



Fig. 2.6 Tuber crops (taro, cassava and sweet potato) grown in Odisha (left to right)

Source: Authors' own collection

livelihood security for small and marginal farmers under the changing scenario of climate. The crop, varieties, and optimum growing seasons recommended for different agro-climatic zones of Odisha are listed in Table 2.19.

Table 2.19 Recommended varieties of tuber crops under different agro-climatic zones of Odisha

Agro-climatic zones	Crop	Varieties	Growing season
Northwestern plateau (Sundar Garh, Deogarh)	Sweet potato	Kanjangad (110), Kishan (110), Bidhanjyoti (105), Kalinga (105), Sourin (105), Bhusona (105), Goutam (105)	<i>kharif</i> (July-October) <i>rabi</i> (October-February)
	Greater yam	Odisha elite (240-270), Hatikhoja (210-270), Sree Keerthi (240-300), Sree Nidhi (210-240)	Annual crop May- March
	Yam bean	Rajendra misirikanda 1 (90)	October-December
	Elephant foot yam	Gajendra (180-210)	<i>kharif</i> (May-December)
Northcentral plateau (Keonjhar, Mayurbhanj)	Sweet potato	Kanjangadl (110), Kishan (110), Bidhanjyoti (105), Kalinga (105), Sourin (105), Bhusona (105), Goutam (105) Gouri (105)	<i>kharif</i> (July-October) <i>rabi</i> (October-February)
	Greater yam	Odisha elite (240-270), Hatikhoja (210-270), Sree Keerthi (240-300), Sree Nidhi (210-240)	May-February
	Yam bean	Rajendra misirikanda 1(90)	October-December
	Elephant foot yam	Gajendra (180-210) Bidhan Kusum (200-210)	May-December
	Arrowroot	Local	May- March
	Colocassia	Muktakeshi (180), Telia (150), Manasaru (210), Topi (180)	May-December
Northeastern coastal plain (Balasore, Bhadrak, Jajpur,)	Sweet potato	Kanjangad (110), Kishan (110), Bidhanjyoti (105), Kalinga (105), Sourin (105), Bhusona (105), Goutam (105)	<i>kharif</i> (July-October) <i>rabi</i> (October-February)

Agro-climatic zones	Crop	Varieties	Growing season
	Greater yam	Odisha elite (240-270), Hatikoja (210-270), Sree Keerthi (240-300), Sree Nidhi (210-240)	May-February
	Yam bean	Rajendra misirikanda (90)	October – December
	Elephant foot yam	Gajendra (180-210) Bidhan Kusum (200-210)	May-December
	Arrowroot	Local	May- March
	Colocasasia	Muktakeshi (180), Telia (150), Topi (180), Panisaru 1 (180), Panisaru II (180), Jhankdi (180)	May-December, February-August
East & south-eastern coastal plain (Kendrapada, Jagatsinghpur, Khurda, Puri, Nayagarh, Cuttack)	Sweet potato	Kanjangad (110), Kishan (110), Bidhan Jyoti (105), Kalinga (105), Sourin (105), Bhusona (105), Goutam (105)	<i>kharif</i> (July-October) <i>Rabi</i> (October-February)
	Greater yam	Odisha elite (240-270), Hatikhoja (210-270), SreeKeerthi (240-300), Sree Nidhi (210-240)	<i>kharif</i> (May-March)
	Yam bean	Rajendra misirikanda 1 (90)	October-December
	Elephant foot yam	Gajendra (180-210) Bidhan Kusum (200-210)	<i>kharif</i> (May-January)
	Arrowroot	Local	<i>kharif</i> (May-March)
	Colocassia	Muktakeshi (180), Telia (150),Topi (180), Panisaru 1 (180), Panisaru II (180), Sankasaru(180), Sankhasaru (180)	May-December, March-August
Northeast Ghat (Kandhamal, Rayagada, Gajapati, Ganjam)	Sweet potato	Kanjangadl (110), Kishan (110), Bidhanjyoti (105), Kalinga (105), Sourin (105), Bhusona (105), Goutam(105)	<i>kharif</i> (July-October) <i>rabi</i> (October-February)
	Cassava	Sreejaya (210), Sreevijaya (210), Sreepakash (210)	<i>kharif</i> (June-January)
	Greater yam	Odisha elite (240-270), Hatikoja (210-270), SreeKeerthi (240-300), Sree Nidhi (210-240)	<i>kharif</i> (May-March)

Agro-climatic zones	Crop	Varieties	Growing season
	Yam bean	Rajendra misirikanda 1 (90)	October-December
	Elephant foot yam	Gajendra (180-210)	<i>kharif</i> (May-January)
	Colocassia	Muktakeshi (180), Telia (150), Topi(180), Sankasaru (180-210),	May-December, Feb-August
	Arrowroot	Local	<i>kharif</i> (May-March)
Eastern Ghat highland (Nabarangpur, part of Koraput)	Cassava	Sree Jaya (210), Sree Vijaya (210), Sree Prakash (210), H-165 (240)	June- January
	Greater yam	Odisha elite (240-270), Hatikhoja (210-270), SreeKeerthi (240-300), Sree Nidhi (210-240)	May- March
	Yam bean	Rajendra misirikanda 1(90)	
	Elephant foot yam	Gajendra (180-210) Bidhan Kusum (200-210)	May- January
	Arrowroot	Local	<i>kharif</i> (May-March)
	Sweet potato	Kanjangad (110), Kishan (110), Bidhanjyoti (105), Kalinga (105), Sourin (105), Bhusona (105), Goutam (105)	<i>kharif</i> (July-October) <i>rabi</i> (October-February)
South eastern Ghat (Malkangiri, part of Koraput)	Sweet potato	Kanjangadl (110), Kishan (110), Bidhanjyoti (105), Kalinga (105), Sourin (105), Bhusona (105), Goutam(105)	<i>kharif</i> (July-October) <i>rabi</i> (October-February)
	Cassava	Sreejaya (210), Sreevijaya (210), Sreeprakash (210), H-165(240)	June- January
	Greater yam	Odisha elite (240-270), Hatikoja (210-270), SreeKeerthi (240-300), Sree Nidhi (210-240)	May- March
	Colocassia	Muktakeshi (180), Telia (150), Topi(180), Sankasaru (180-210)	May-December, March-August
	Yam bean	Rajendra misirikanda 1(90)	October-December

Agro-climatic zones	Crop	Varieties	Growing season
	Elephant foot yam	Gajendra (180-210)	May- January
Western undulating zone (Kalahandi, Nuapada)	Elephant foot yam	Gajendra (180-210) Bidhan Kusum (200-210)	May- January
	Cassava	Sree Jaya (210), Sree Vijaya (210), Sree Prakash (210)	June- January
	Sweet potato	Kanjangad (110), Kishan (110), Bidhanjyoti (105), Kalinga (105), Sourin (105), Bhusona (105), Goutam(105)	<i>kharif</i> (July-October) <i>rabi</i> (October-February)
	Yam bean	Rajendra misirikanda 1(90)	October-December
Western central tableland (Baragarh, Bolangir, Boudh, Sonapur, Jarsuguda, Sambalpur)	Arrowroot	Local	May- March
	Elephant foot yam	Gajendra (180-210) Bidhan Kusum (200-210)	May- January
	Yam bean	Rajendra misirikanda 1 (90)	October-December
	Colocassia	Muktakeshi, Telia, Jhankdi, Sankasaru	June-December
Mid-central tableland (Angul, Dhenkanal)	Sweet potato	Kanjangad (110), Kishan (110), Bidhanjyoti (105), Kalinga (105), Sourin (105), Bhusona (105), Goutam (105)	<i>kharif</i> (July-October) <i>rabi</i> (October-February)
	Greater yam	Odisha elite (240-270), Hatikhoja (210-270), SreeKeerthi (240-300), Sree Nidhi (210-240)	May- March
	Yam bean	Rajendra misirikanda 1(90)	October-December
	Elephant foot yam	Gajendra (180-210) Bidhan Kusum (200-210)	May- January

Source: Authors' own compilation; figure in parenthesis represents the duration of the variety

2.6.7 Rice-vegetable cropping system

Vegetables are more sensitive to temperature and moisture stress. The selection of suitable vegetable crops and varieties are the important components of any management system targeted to reduce the impact of climate change. Vegetables like radish, spinach, and leeks are least susceptible to frost injury. The advantages of this system include year-round employment opportunities, higher farm family income, and nutrition. Vegetable crops are suitable for

production on small pieces of land and their inclusion in traditional cropping systems can improve the nutritional potential of the system as vegetables are rich in vitamins, minerals, and other health factors. Vegetables are an excellent choice of cash crops as they can be grown easily, produce good yields, and generate higher prices in the market as compared to cereals. Most of the vegetables, if properly grown, can give a higher yield than many cereal crops. The selection of varieties for a suitable crop can also reduce the impact of extreme climatic events, such as high temperature and precipitation and other extreme climatic events. For example, flower drop in tomato occurs when day temperature exceeds 30°C, and night temperature exceeds 20°C. Most of the vegetables are also susceptible to waterlogging, hence, can not be grown in the lowland situations during *kharif* season. In such ecology, suitable land modifications can be done by making a ridge and furrow system that can bring lowland into the rice-vegetable cropping system (Fig. 2.7). Some suitable varieties of selected vegetable crops suitable for different agro-climatic situations of Odisha are given in Table 2.20.

Table 2.20 Vegetable varieties recommended for different agro-climatic zones of Odisha

Crop	Varieties
Tomato	BSS-488, Tai 01458, Pant T-10, BCTH-4, ARTH-2104, Kashi Abhiman, Kashi Aman, DARL-68, Punjab Ratta, Improved Bhagya, Kaveri 304, TODHYB-05, Kashi Chyan, Swarna Lalima, Swarna Naveen, Swarna Samridhi, Swarna Sampada, Swarna Vijaya, Pusa -120, Pusa Ruby, Pusa hybrid -4, Arka Ananya, Arka Abhijit, Arka Vikas, Arka Abha, Arka Saurabh, Kashi Vishesh, Kashi Hemant, HS-101, HS-102, Hisar Lalit, Hisar Arun, Utkal Kumari, Utkal Pallavi, Utkal Deepti, Utkal Urbashi, Utkal Raja, Utkal Pragyan
Cherry Tomato	VT-95
Brinjal	PB 67, Rasika, Shamli, VNR-51C, PB-70, DBL-02, DBHL-20, PHBL-51, PBHSR, HABR-21, PBHL-52, Nishant, IC-0598429, IVBL-23, DBPR-23, Bidhan Super, Swarna Shree, Swarna Mani, Swarna Shyamali, Swarna Pratibha, Swarna Shobha, Swarna Abhilamb, Swarna Shakti, Swarna Mohit, Swarna Ajay, Swarna Neelima, Pusa Purple Cluster, Kashi Sandesh, Kashi Komal, PH-4, BR-112, Hisar Shyamal, Anand Brinjal Small Round-2, Pant Rituraj, Utkal Tarini, Utkal Keshari, Utkal Madhuri, Utkal Jyoti, Utkal Anushree
Chilli	PC-7, PC-56, NCH-587, VNR-332, LCA-620, CHIHYB, CH27, Bidhan Chilli-4, Indira Mirchi 1, LCA-436, Swarna Praphulya, Pusa Jwala, Pusa Sadabahar, Arka Lohit, Arka Meghana, Kashi Surkh, Pant C-1, Utkal Abha, Arka Neelachal, Utkal Rashmi

Crop	Varieties
Vegetable pea	VRPMR 11, Mattar Ageti, VRPE-25 (Kashi Ageti), Swarna Amar, Swarna Mukti, Bonneville, Arkel, Pusa Pragati
Cow Pea	VRCP-6 (Kashi Nidhi), Ankur Gomati, Bidhan Sadabahar, Indira Barbali Lal, Swarna Harita, Swarna Sweta, Swarna Suphala, Swarna Mukut, Kashi Kanchan, Utkal Manika
French bean	Arka Anoop, Swarna Lala, Swarna Priya Contender, Pusa Parvati
Dolichos bean	HADB-3, IIVR Sem 8 (Kashi Haritima), Chattisgarh Sem 1, SwarnaAkrist, Swarna Rituvar
Bottle Gourd	Santosh-20, PBOG-89, Anurag, Narendra Pooja, Swarna Sneha, Pusa Summer Prolific Long, Pusa Hybrid-3
Bitter gourd	NBHI-2009, Swarna Yamini, Pusa Hybrid-2
Sponge gourd	Kashi Divya, Kashi Shreya, Kashi Rakshita, Swarna Prabha, Pusa Chikni
Ridge gourd	Pallavi, Kashi Shivani, Swarna Manjari, Swarna Uphar, Swarna Sawani, Pusa Nasdar, Utakal Trupti
Ash gourd	Kashi Sarabhi, Pusa Shreyali
Cucumber	DC-83, Swarna Ageti, Swarna Sheetal, Swarna Poorna
Long Melon	VRSLM-16
Okra	JOH-05-9, VRO-22 (Kashi Kranti), JOL-2k-19, AROH-631, Kashi Vardan, Pusa Sawani, Pusa A-4, Perkins Long Green, Arka Anamika, Kashi Pragati, Varsha Uphar, Hisar Unnat, Hisar Naveen, HBH-142, Utkal Gaurav
Cauliflower	DC-31, Pusa Snowball K-1, Pusa Snowball Kt-25, Pusa Himjyoti, Hisar-1
Radish	Kashi Arada, Japanese White, Pusa Reshmi, Pusa Desi, Pusa Himani, Arka Nishant
Ivy gourd	Arka Neelanchal kunkhi, Arka Neelanchal Sabuja
Pointed gourd	Arka Neelanchal kirti, Swarna Rekha, Swarna Alaukik, Swarna Suruchi
Spine gourd	Arka Neelanchal Shanti
Teasel gourd	Arka Neelanchal Gaurav
Capsicum	Swarna Atulya, California Wonder, Pusa Deepti, Arka Mohini, Arka Gaurav, Arka Basant
Pumpkin	Swarna Amrit, Pusa Vishwas
Cabbage	Pusa Ageti, Pusa Drum Head, Golden Acre
Knol Khol	Purple Vienna, White Vienna
Sprouting Broccoli	Pusa Broccoli Kt-1
Carrot	Nantes, Pusa Kesar, Pusa Yamdagni
Turnip	Purple Top White Globe, Pusa Swarnima, Pusa Chandrima, Pusa Sweti, Pusa Kanchan
Beet Root	Detroit dark Red, Crimson Globe

Crop	Varieties
Long melon	Karnal selection
Water Melon	Sugar Baby
Summer Squash	Australian Green, Pusa Alankar
Palak	Pusa Bharati, Pusa Jyoti, Pusa Harit
Amaranthus	Pusa Lal Chaulai, Pusa Kirti, Pusa Kiran, Utkal Mayuri
Fenugreek	Pusa Early Bunching, Pusa Kasuri, Hisar Sonali, Hisar Mukta, HM-219
Lettuce	Great Lakes, Chinese Yellow
Parsley	Moss Curled
Onion	Pusa White Flat, Pusa White Round, Pusa Ratnar, Sel-126, Arka Kalyan, Agrifound Dark Red, Agrifound Light Red, Agrifound White, N-53, Hisar-2, Bhima Shakti, Bhima Shweta
Garlic	Yamuna Safed (G-1)
Potato	Kufri Girdhari, Kufri Lauvkar, Kufri Badshah, Kufri Pukhraj, Kufri Surya, Kufri Jyoti, Kufri Himsona, Kufri Chandramukhi

Source: Authors' own compilation



Fig 2.7 Ridge and furrow based rice-vegetable system in lowland ecology during *kharif* season

Source: Authors' own collection

2.7 Contingency plan for abiotic stress

Contingency crop planning indicates a set of a plan for dealing with sudden changes in normal crop growth/period caused by abiotic stress. It is mainly tuning the options for choosing an alternate crop or cultivar based situation. In India, the southwest monsoon accounts for about 75% of rainfall and this rain is a major source of water for *kharif* food grains. However, the occurrence of monsoon rainfall is highly speculative. Delayed onset, uneven distribution, and sudden stop in rainfall after onset cause deficit and excess water stress during *kharif* season. Moreover, the eastern part of India faces many cyclonic events with varying degrees of severity. These abiotic stresses result in poor crop performance or even complete failure of food grains crop on which the whole population of India relies. Hence, there is a need to develop befitting strategies to tackle such eventualities. Such strategies are broadly classified as (i) preventive measures: control or measures are to be taken based on prediction before it happened and (ii) contingent/ameliorative measures: to be implemented based on the degree of severity of the stress after its occurrence.

2.7.1 Contingency plan for drought

Reduce supply of surface water due to inadequate rainfall or when demand is projected to exceed supply trigger the farmers to adopt a contingency plan for drought (Fig 2.8). Contingency measures differ with the stages of crop growth and associated farm practices. Generally, the contingency measures varied with early (June 1 to July 31), mid (August 1 to September 15) and late (September 16 to October 31) seasons drought.

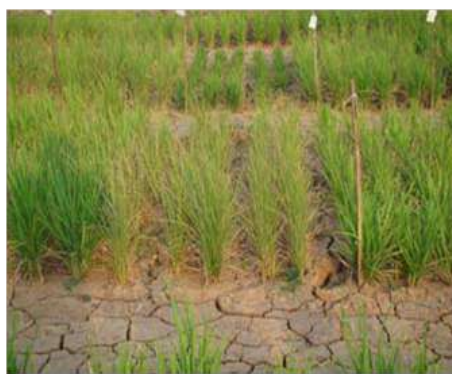


Fig. 2.8 Rice cultivars under drought stress
Source: Authors' own collection

2.7.1.1 Early season drought (June 1 to July 31)

Early season drought occurs due to normal onset followed by a long dry spells or delayed onset of monsoon. In most cases, rice crop is in the nursery are about to transplant or already transplanted. The main problem is poor germination in the nursery or poor plant population in the main field. Hence the contingency measures mostly rely on resowing of the same variety or alternate short duration crop varieties, alternate crops depending on the situation.

Besides, it also affects tillage operations, sowing, application of fertilizers and intercultural operations. Drought at this stage can cause a moderate reduction in yield due to seedling mortality or poor germination/ establishment, which can be tackled by taking timely steps.

i. Preventive measures

Crop and weather scenarios during drought or dry spells are very difficult to anticipate. Hence, taking rigid preventive measures is useful for short and long term basis in the places of frequent drought occurrence. Selection of efficient crops and cropping systems matching the length of the growing period. e.g. maize, cowpea, pigeonpea, black gram, ragi, groundnut, rice bean, castor, pumpkin, and sweet potato is probably the primary steps in preventive measures. Besides, the following preventive measures are also recommended:

- Selection of short duration varieties
- Storage of rainwater for life-saving irrigation
- Ploughing and sowing of crops across the slope
- Ploughing during the off-season to conserve moisture and to facilitate early sowing
- Mechanization to ensure for timeliness in operation
- Intercropping/ mixed-cropping system may be recommended in recurrent drought-prone areas
- Adopt an integrated farming system
- Tree-based farming systems should be encouraged
- Construction of water harvesting structures
- Promotion of groundwater recharge

ii. Contingent/ameliorative measures

It is sometimes very difficult to predict drought or dry spells in advance. In such a situation, the late adoption of preventive measures cannot resolve the problem, for which there is a requirement for a separate set of measures which can help the crop to withstand the stress. Low and medium lands are mostly suitable for the crop with high water requirements like rice. Uplands are mostly suitable for most of the pulses, oilseeds, and vegetables, for such situation management of weeds in time, mulching, and supplemental irrigations are suggested. Contingent measures for rice with early-season drought based on two scenarios are suggested hereunder:

Scenario 1: Timely onset and sudden stoppage of monsoon

- The growing of drought-tolerant cultivars will prevent or minimize crop loss
- Drought impact can be minimized by spraying of potassium silicate (10%) or cycocel (10 ppm)
- When mortality exceeds 50%, the rice crop can be resown which is a viable option till the end of mid-August. In the subsequent days, if sufficient rainwater is received, extra early paddy or non-paddy crops like ragi can be grown
- If mortality is less than 50%, gap-filling by using the leftover nursery of the same varieties or using the clonal tillers of the same field
- Follow effective weed control measures using herbicides to ensure early season weed control to minimize the competition and ensuring better growth of rice
- The full recommended dose of P, K and about 20% of N should be applied as basal along with well-decomposed organic manure for early seedling vigour

Scenario 2: Late-onset of monsoon (main field not covered till mid-July)

- Community rice nursery near a reliable water source should be encouraged to avoid delay of transplanting
- The topdressing of N in the nursery should be avoided to reduce the rapid growth of the nursery
- Mechanization should be promoted to cover more area with less time for speedy land preparation/puddling upon receive of rainfall
- Aged rice seedlings (upto 45 days for medium duration varieties and 60-70 days for long-duration varieties) should be transplanted closer (15 x 10 cm) with 3-4 seedlings/hill. About 70% of the recommended N fertilizer should be applied as basal
- Wet direct seeding using drum seeder can be done wherever possible in place of transplanting to avoid transplanting shock for late planting rice. In puddled soil, sprouted seeds of relatively short duration rice varieties may be broadcasted or line sown
- If the drought prevails up to mid-July, medium duration varieties (125 days) can be selected for coastal districts. Short duration (3-months) rice varieties can be selected for the medium land if the drought continues up to the end of July

- Rice seeds are recommended for sowing at 3-5 cm depth by *punji* method (10-15 seeds at one point) and covered with a mixture of FYM: SSP (10:1) to avoid seedling mortality due to moisture stress

2.7.1.2 Mid-season drought (August 1 to September 15)

Midseason drought causes reduced growth at the vegetative stage, if the drought occurs at the early reproductive stage, the yield is affected adversely. Panicle initiation to flowering is the most susceptible stage, a drastic reduction in yield even crop failure may happen if drought occurs at this stage. Some contingency measures for midseason drought are suggested.

i. Preventive measures

Preventive measures for drought is similar to the early-season drought (section 2.7.1.1).

ii. Contingent/ameliorative measures

Contingency measures at this stage mainly relied upon in-situ soil moisture conservation by preventing the water loss from the field by plugging the crab-holes and mud plastering of bund, removing the weeds, taking timely plant protection measures, avoiding top dressing of fertilizer, conservation furrows, and supplemental irrigation. However, for upland area where non-paddy crops are taken contingent/ameliorative measures are: (i) thinning of the crop by removing every alternate row or every third row and use the removed plants as cattle feed, (ii) adopting intercropping/mixed-cropping systems in regular drought-prone areas, (iii) spraying of 2% urea at 7-10 days interval in groundnut, castor, and red gram during prolonged dry spells, (iv) ratooning can be practiced in sorghum and bajra, (v) mulching by covering material like straw or stover on the soil surface (vi) weed control, especially during the early stages of crop growth to reduce the impact of the dry spell by soil moisture conservation, (vii) drought at the pre-flowering and flowering stage of green gram and black gram can be mitigated by foliar application of 2% DAP, (viii) N fertilizer application can be withheld up to receipt of rainfall, (ix) lifesaving irrigation may be provided through drip/sprinkler irrigation system at critical crop growth stages like flowering and grain filling, and (x) 2% KCl + 0.2 ppm boron should be sprayed in black gram to overcome drought.

Midseason drought scenarios and the corresponding contingency plans for rice are discussed hereunder:

Scenario 1: Delayed bushening in direct-seeded rice

- If the rice crop is older than 45 days, *bushening* should be avoided
- Weeding and thinning of plants if required should be completed on time
- Seepage loss can be avoided by strengthening the field bunds and clogging the holes
- N fertilizer application can be delayed upto receipt of rainfall

Scenario 2: Delayed rice transplanting

- Nursery seedlings to be maintained in good health by providing lifesaving irrigation
- Mechanization should be promoted to cover more area with less time for speedy land preparation/puddling
- The rice field should be ploughed and soils are pulverized in the dry condition to save the time of puddling immediately after receive of adequate rain
- Half of the recommended N should be applied at the time of transplanting
- For medium and late duration rice varieties, aged seedlings of 45 and 60-70 days respectively can be transplanted upto the end of August
- Close transplanting with 5-7 seedlings/hill should be done
- Weeding should be done and suitable plant protection measures against blast in the nursery should be followed

Scenario 3: Bushened/transplanted rice affected at early vegetative stage

- Lifesaving irrigation may be provided if possible through drip/ sprinkler irrigation system. Harvested rainwater can also be used for this purpose
- Weeding and plant protection measures should be taken in time
- Application of N and K fertilizer should be done upon receipt of rainfall
- Seepage loss can be avoided by strengthening the field bunds and clogging the holes

2.7.1.3 Late-season drought (September 16 to October 31)

Late season drought also known as terminal drought, coincides with reproductive growth stages and it adversely affects yield if occurs during panicle initiation to flowering stages. Terminal drought increases spikelet sterility in cereals, reduces oil content in oilseeds, and reduces yield in almost all crops.

i. Preventive measures

Preventive measures for late-season drought is similar to the early-season drought (section 2.7.1.1).

ii. Contingent/ameliorative measures

The contingency measures at this stage include plant protection, soil moisture conservation, supplemental irrigation, harvesting for fodder, preparation for next *rabi* sowings in double-cropped areas, and contingency crops like horsegram. Terminal drought is reported to causes yield loss varying from 25-60% in many non-rice crops due to poor dry matter production and partitioning. To manage terminal drought for non-paddy crops the following measures are recommended: (i) provide protective irrigation at critical growth stages such as flowering and grain filling through the sprinkler, (ii) irrigate the field to alternate furrows to save irrigation water, (iii) harvest sorghum/maize at physiological maturity, (iv) harvest the late sown crops of cowpea, maize, green gram, and black gram for fodder purposes, (v) in the event of complete failure of *kharif* crop, the field should be ploughed for sowing of next crops like horsegram, niger, sesame, (vi) Foliar spray of 2% KCl+ 0.2 ppm boron may be done in blackgram under drought situations.

Contingency plans for rice under late season drought are discussed hereunder:

- Lifesaving irrigation may be provided through drip/sprinkler irrigation system at critical crop growth stages like flowering and grain filling. Harvested rainwater may be used for this purpose.
- In the event of complete failure of *kharif* crop, the field should be ploughed for dibbling of next crops like horsegram, niger, greengram, blackgram and sesame which are considered ideal pre-*rabi* crops with residual moisture condition in uplands and well-drained medium lands

2.7.2 Contingency plan for flood

The coastal region of Odisha comprises about 15% of the geographical area of the state suffers from waterlogging and flood problems during crop growth. Eight coastal districts, namely, Balasore, Bhadrak, Jajpur, Kendrapara, Jagatsinghpur, Cuttack, Khordha, Puri, and a part of Ganjam district suffer from the flood. Breaking of riverbanks, poor drainage and tidal flow of sea preventing the river water to enter sea aggravate flood. The flood caused severe damage to *kharif* crops, for which preventive and ameliorative plans are needed. Contingency plan for flood includes fluvial flooding from rivers and other water bodies and short submergence (15 days) due to flash flooding associated with heavy rainfall.

2.7.2.1 Early-season flood (June-July)

Arable crops cannot withstand standing water and submergence. Being a semi-aquatic crop, rice plants can transport oxygen to root through aerial parts and hence may withstand standing water but cannot tolerate submergence for 7 days. Some varieties of paddy introgressed with *Sub 1* gene can withstand the submergence up to 15 days at rapid growth stages. Early floods mainly damage crops by hampering its growth through the sudden rise of water level, hypoxia, high water flow, and turbidity of water (Fig.2.9).



Fig. 2.9 Early flood situation in rice fields

Source: Authors' own collection

i. Preventive measures

- *Develop better flood warning systems:* Flood warning systems help to prevent or reduce crop damage, loss of livestock and human. An effective flood warning provides information on the possibility of flooding before 12-48 hours or earlier.
- *Protect the bank of wetlands/river:* Riverbank erosion is a major problem in which the stream cuts deeper into the foot of the bank when the water level is high. The riverbank is weakened and collapses into the stream. This way streams destroy establishments, crops and caused huge damage to the people residing nearby. There are several structures to control bank erosion by construction of concrete structures, gabions, wooden logs, live vegetation, coir mat, synthetic mat, coconut coir logs along river embankments.
- *Restore rivers to their natural courses:* Restoration of river courses increases the capability of the river to retain water, which effectively contributes to flood risk management. Effective flood risk management consists of reducing the damage if flood occurs and/or reducing the chance of flood to occur. High water levels in the rivers are managed by the river restoration improving the natural functions of the river at the same time, allowing to fulfill both functionalities of effective flood management.

- *Improve water storage areas:* Rapid urbanization causes a reduction in small ponds and other reservoirs that can store water locally and prevent pressures on streams and other larger water bodies. Less water storage increases the risk of higher discharge in streams and rivers during heavy rainfall, which causes flood.

ii. Ameliorative measures

Once flood occurs and damages due to flood are inevitable, ameliorative measures can mitigate the losses to some extent. This mainly comprises of selection of suitable cultivar, suitable intercultural operations, and effective nutrient management during the flood and contingent crop planning. The following points are considered as an effective method of early flood management.

- If transplanting is possible in time within July, select rice varieties (e.g. Durga, Sarala, Varshadhan, etc.) suitable for semi-deep low lands or varieties suitable for growing under submergence upto 14 days (Sub 1 series varieties). Rice varieties with medium duration (125-130 days) can be selected for transplanting if flood water recedes early and transplanting is possible by mid-August. If flood water recedes in the last part of August, short-duration rice varieties (90-105 days) can be transplanted. Transplanting with 6-8 seedlings per hill can be done upto the last part of August using 45-60 days old seedlings of traditional coarse-grain photosensitive varieties.
- If the damage is more than 50%, the rice crop may be re-transplanted from the community nursery.
- In partially damaged direct-seeded rice fields, rice plants should be allowed to stand upright. *Bushening* operation should not be practiced as it may further reduce the plant population.
- Once flood water recedes, weeding and gap filling should be initiated immediately.
- Proper nutrient management of rice in flash flood-prone area reduces the extend of loss by increase survival, early recovery of plants and subsequent growth. It is found that pre-submergence N application results in higher lodging and leaf senescence, higher depletion of chlorophyll and non-structural carbohydrate, which should be avoided. Application of 20% higher phosphorus dose as basal enhanced submergence tolerance. Post-submergence N application through the

foliar spray and basal P application can be recommended for high plant survival and grain yield in areas where untimely flooding is anticipated. Potassium application at higher levels improves survival and growth after submergence by regulating photosynthesis, reducing elongation and lodging. Similarly, the combined application of silica and nitrogen reduces the damage of flooding stress in rice.

- After receding of floodwater rice field encounters several pests and diseases. Spraying of chlorpyrifos or quinolphos @ 2 mL L⁻¹ needs to be done to check the infestation of the case worm and leaf folder in rice. In the case of bacterial leaf blight infestation in rice, top dressing of N- fertilizer should be avoided and K-fertilizer @ 10 kg ha⁻¹ as top dressing or 3% foliar spray may be applied. Rice swarming caterpillar in field bunds can be controlled by the application of chlorpyrifos or quinolphos @ 2mL L⁻¹.

2.7.2.2 Late -season flood

The late flood occurs during mid-August to early September which coincides with the late tillering or early reproductive stages of rice (Fig. 2.10). Submergence at the reproductive stage causes extensive damage and lowers the leaf area index, photosynthesis rate, biomass, survival and productivity as compared to that at the



Fig. 2.10 Late flood situation in rice field

Source: Authors' own collection

active tillering stage. If the rice plants are submerged at reproductive stages, the delay in maturity occurs due to a delay in flowering. Submergence delays flowering and maturity by 20 and 10 days when submergence occurs at panicle initiation and active tillering stages, respectively.

i. Preventive measures:

These measures are similar to the preventive measures discussed in the early flood section (2.7.2.1).

ii. Ameliorative measures:

- Transplanting aged seedlings of 40-65 days is recommended after flood water recedes. Community nursery should be raised in suitable upland areas to maintain a buffer nursery for gap filling and ensuring adequate plant population in the field after flood damage. Alternately, raise the Dapog method of nursery to transplant wherever possible. Plant population can be maintained by transplanting clonal tillers detaching from the old hills, wherever possible.
- Pulses like black gram, green gram, horse gram, and sesame can be sown in areas where the revival of rice is difficult.
- In flood-prone areas, sometimes the completely damaged rice fields remain fallow right from October till the next *rabi* crop is taken in December. It is possible to take an extra-rice crop during this October-December period with extra early rice variety like Heera, Vandana, Kalinga III, Dala Heera, (75-100 days), without sacrificing the *rabi* crop.
- Application of 20% additional dose of P and K as basal whereas skipping of nitrogen application is suggested. At the time of *beushening* moderate doses of NPK may be applied if not applied earlier. Apply phosphatic fertilizer to rice at the time of sowing to increase flood resistance.
- After receding of floodwater, rice field encounters several insect-pests and diseases, which can be managed as described for early flood situation (section 2.7.2.1)

2.7.3 Contingency plan for cyclone

Odisha faces moderate to very severe cyclonic storms at regular intervals as it shares large coast with the Bay of Bengal. The intensity and frequency of cyclone risk are high in eight districts in central and coastal Odisha viz., Gajapati, Ganjam, Nayagarh, Dhenkanal, and Keonjhar. Very often there is severe damage to standing crop, in addition to the colossal loss of life and properties in these districts. (Fig. 2.11). The following measures (preventive and ameliorative) may be followed to overcome the stress due to cyclones.



Fig. 2.11 Rice fields damaged by the cyclonic wind

Source: <https://sandhannews.com/>

i. Preventive measures

- Introducing better cyclone warning systems- This helps to relocate people and livestock from susceptible structures to comparatively safe structures. Early warning system helps for a quick harvest, threshing and drying the grains.
- Plantation and conservation of cyclone-resistant trees and other forest plants especially mangroves help to reduce the cyclone impact.
- Construction of water storage structures in cyclone-prone areas avoids flash flood after the cyclone.
- The vulnerability of rice at the grain-filling stage for lodging is very high and a cyclone during grain filling causes lodging of the crops and complete damage of the crop. Lodging resistant rice variety, like CR 1014 can withstand the wind gust to some extent.
- Rice variety (e.g. Hansaswari, Durga) with kneeing ability may be selected for those areas. These varieties keep the reproductive part above water even after lodging that helps in survival.
- Tailoring sowing and transplanting time may be made in such a way so that it can escape peak cyclone period at maturity stage (mid-October to mid-November).
- Post-harvest losses can be reduced by threshing in a covered threshing floor-cum-drying yard.
- Diaquat 0.05% or paraquat 0.1% or common salt 10% on the earhead at 20-25 days after 50% flowering enhances the maturity by 5 to 7 days facilitating in escaping peak cyclone period.

ii. Ameliorative measures

Post-cyclone contingent measures are provided depending on the nature of urgency and damage under different time frames. Ameliorative measures for cyclone disaster management can be made at four stages: immediate, short-term, medium-term and long-term.

(a) Immediate measures (day 1-7 of cyclone-hit)

- The supply of all agricultural inputs like seeds, fertilizers, plant protection chemicals, and farm machineries to farmers should be completed before planting season.
- Polythene sheets are to be supplied to the affected farmers to make low-cost poly houses for raising vegetable seedlings.

(b) Short-term measures (week 2-8 of cyclone-hit)

- The supply of all agricultural inputs like seeds, fertilizers, plant protection chemicals and farm machineries to farmers should be completed before planting season. The supply of agricultural inputs generally depends on the planting season of the crops in the affected area.
- In the coastal area, an intrusion of seawater induces salinity which may adversely affect crop productivity. The effect of soil salinity can be minimized by proper leaching of salts by storing post-cyclone rains in the field by raising the height of field bunds, the application of FYM, compost, and green manure.
- Activities like promoting an integrated farming system with horticulture, livestock, and fishery components promote livelihood initiatives to be encouraged.
- Capacity development programmes should be organized for providing training on the best utilization of available resources.

(c) Medium-term measures (month 2-6 of cyclone-hit)

- Damaged agricultural infrastructures should be rehabilitated on a priority basis.
- Farmers should be encouraged to resume their agricultural activities for a normal agricultural calendar.
- Various capacity building programmes should be initiated to train farmers on modern technology for improving livelihood for affected farmers. This training should encompass modern techniques for livestock and fish farmers.
- Providing financial support such as input subsidies through direct cash transfer for raising crops, livestock and post-harvest operations.
- Feed, fodder, and veterinary support should be provided to livestock farmers.
- In the poultry rearing sector, along with restocking of birds, feeds and medicines should be made available.
- Need-based availability of fish fingerlings and feed, boats, and nets should be ensured for fish farmers.

(d) Long-term measures (month 7-18 of cyclone-hit)

- Reclamation of degraded lands and damaged watercourses should be initiated.

- Restocking of fish fingerlings, livestock and animal feed/fodder, restoration of damaged orchards, agroforestry promotion, organizing capacity building programmes on crop production, livestock management and disaster preparedness should be initiated.
- Dams should be constructed to check flood. Flood tolerant crops and suitable varieties need to be promoted.
- Post-harvest losses may be avoided by the construction of *pucca* threshing floor, drying yard, mechanized farm operations.

2.8 Crop insurance

Drought, floods, and cyclone affect farmers through loss in crop production and income which are beyond their control. The risks to production, livelihood, and income of farmers from various natural and manmade events are very high and agricultural insurance is thought to be an effective system to address these challenges. The government of India has taken a major step in funding and initiating a market-based insurance program with actuarially sound premium rates. The private insurance companies are actively involved and bringing improved schemes. These insurance schemes are thought to provide noteworthy benefits to the farming community with the faster settlement of claims and more equitable allocation of subsidies.

Crop-specific insurance is required to compensate for income loss due to vagaries of weather. Various crop insurance schemes have been developed namely Comprehensive Crop Insurance Scheme (CCIS), National Agricultural Insurance Scheme (NAIS), Pilot Modified National Agricultural Insurance Scheme (MNAIS), Pilot Weather Based Crop Insurance Scheme (WBCIS) to help farmers to mitigate the stress. At present, Pradhan Mantri Fasal Bima Yojana (PMFBY) has been adopted in place of MNAIS/NAIS for implementation from *Kharif* 2016 season. PMFBY introduced by the government of India, integrates different stakeholders using a single platform. PMFBY aiming at increasing the crop insurance holders in India by creating an awareness campaign with attractive low premium rates. PMFBY aims to provide a comprehensive insurance cover against the failure of the crop, thus helps in stabilizing the income of the farmers. Local/ appropriate government authorities are assessing the loss due to crop failure and PMFBY covers these losses. The losses due to cyclone, flood, unseasonal rainfall, hailstorms as well as pre-sowing and post-harvest losses are also covered under this scheme.

The scheme provisions have been simplified for easy understanding. The maximum premium payable by the farmers will be 2%, 1.5% and 5% for all *kharif* food and oilseeds crops; *rabi* food and oilseeds crops; and for annual commercial/horticultural crops respectively. The difference between premium and the rate of insurance charges payable by farmers shall be shared equally by the Centre and State. An ‘area approach basis’ shall be implemented for the scheme with village/village panchayat as a unit of insurance for major crops whereas for other crops unit may be bigger than the level of village/village panchayat. Insured farmers will be eligible for indemnity claims upto a maximum of 25% of the sum insured when the majority of farmers in a notified area are unable to sow/plant the insured crops due to adverse weather conditions.

2.9 Non-farm employment

When climatic hazards like flood, cyclone and drought strike the state, it causes loss to life, and properties, damage of crops, loss of livelihood and employment. The central as well as the state Government employment guarantee programme, this program strengthen and well targeted in the area frequently effected by the climatic hazards. The feature of current employment guarantee scheme are presented below.

2.9.1 Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA)

The aim of launching the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) in 2006 was to ensure livelihood security and poverty reduction in the country. There is a provision for providing at least 100 days of employment to a willing adult member of any rural household at statutory wages in a financial. The work provided under this act are of manual and unskilled nature and are linked to agriculture and allied activities. The works like water conservation and water harvesting, watershed management, afforestation, land development *etc.*, creating infrastructure and assets in rural areas are mostly undertaken.

2.9.2 Odisha livelihood mission (OLM)

The entire livelihood activities of OLM are being implemented under “Mission Samrudhi”. Various livelihoods options for reducing the household vulnerability of women under Mission Samrudhi by engagement in multiple segments. OLM promotes existing livelihood options of the poor through vulnerability reduction and livelihood enhancement. The expansion in existing

livelihood options and tapping new opportunities in both farm and non-farm sectors is the main focus. OLM also promotes employment building skills for different jobs, and enterprises, facilitating self-employed and entrepreneurs for micro-enterprises. The scheme can be leveraged to provide household off-farm employment in the events of crop failure due to extreme events.

2.10 Household off-farm employment or investment

Agricultural farm holdings in India are less than two hectares for around 84% of farmers in India and are not viable, hence many farmers are either leaving agriculture or living in penury (NSSO 2005). To improve the economic status and farm viability of such households, off-farm sources should constitute a sizeable proportion of their household income. This will also shield the farm family from the shock of seasonal extreme climatic events. Across the developing countries, non-farm earnings account for 35-50% of rural household income. While landless households depend heavily on non-farm income for their survival, the agricultural households depend on the non-farm income for diversifying risk mitigation ability and increasing their agricultural input purchase capacity. Over a period of time, there has been a tremendous growth in the rural non-farm economy contributing considerably to employment as well as rural income growth. Over the years a shift has been observed in the occupational structure of rural people who have diversified from farm to non-farm activities. To create better off-farm opportunities for rural farm households, the off-farm income sources should be generated in the vicinity, generally referred to as the rural non-farm sector. The rural non-farm sector includes all non-agricultural activities such as mining and quarrying, household and non-household manufacturing, food processing, repairing, construction, trade and commerce, transport, and other services in villages and rural towns. These activities are undertaken by household own-account enterprises (OAEs) or by factories. The key component of the rural non-farm economy is agro-processing, in which raw agricultural produce is processed by milling, packaging, bulking, or transporting.

Both developmental (pull) and distress (push) factors are responsible for the increase in non-farm employment of the rural workforce. There exist several distress factors like poverty, unemployment, and frequent climatic stresses in Odisha, forcing the rural youths to migrate in search of non-farm activities for supplementing their farm income. In Odisha, shift from on-farm to non-farm employment is growing very fast. In comparison to male labourers, the employment of female labour, is much less. Income from non-farm activities

like construction, transportation, and shop-keeping has gone ahead compared to income from rice, which a few years before, was the main source of income and livelihood. Non-farm income is 2-3 times higher than the farm income for different categories of farmers. Being a significant contributor to the rural livelihood, the non-farm income should be promoted under various government schemes. Small scale industries and other infrastructure roads, tanks, etc. should be created for improving the non-farm income of the rural household. There should be training for skill and knowledge development, which in long run, shall help in income generation and improved livelihood. Recent agriculture farm Acts (2020) passed by parliament if implemented properly will attract investment and encourage non-farm economy that will ensure off-farm employment.

2.11 Weather-smart technologies for climate change adaptation, mitigation and higher productivity

Weather forecasting and early warning of extreme events influence agricultural crop production. Forecasting is one of the important adaption options that help the farming community to plan agriculture accordingly to adapt to the uncertainty associated with climate change and enhance productivity and farm income. Agricultural crop intensification for example including a legume in the rotations increases food production from existing land with lower environmental impact along with reducing GHGs emissions and improves soil organic carbon status. Agricultural intensification with a suitable crop with appropriate duration fitting the crop window has been proved to be an effective adaptation option in the context of climate change. Changing planting dates is a simple climate change adaptation strategy involving minimal cost and is currently practiced across the globe. Preponing of planting time of wheat in north India helps the crop to escape terminal heat, postponing of green gram sowing is done to mid-January in the coastal districts of Odisha to avoid cold stress at the germination stage. It has been reported that the sowing time of rice has already been delayed in *kharif* season in Odisha. Crop insurance scheme is one of the adaptation options that provide security to farmers against financial loss on account of crop loss due to weather abnormalities. Various weather smart technologies and their contribution to the three pillars of climate-smart agriculture are depicted in Fig 2.12.

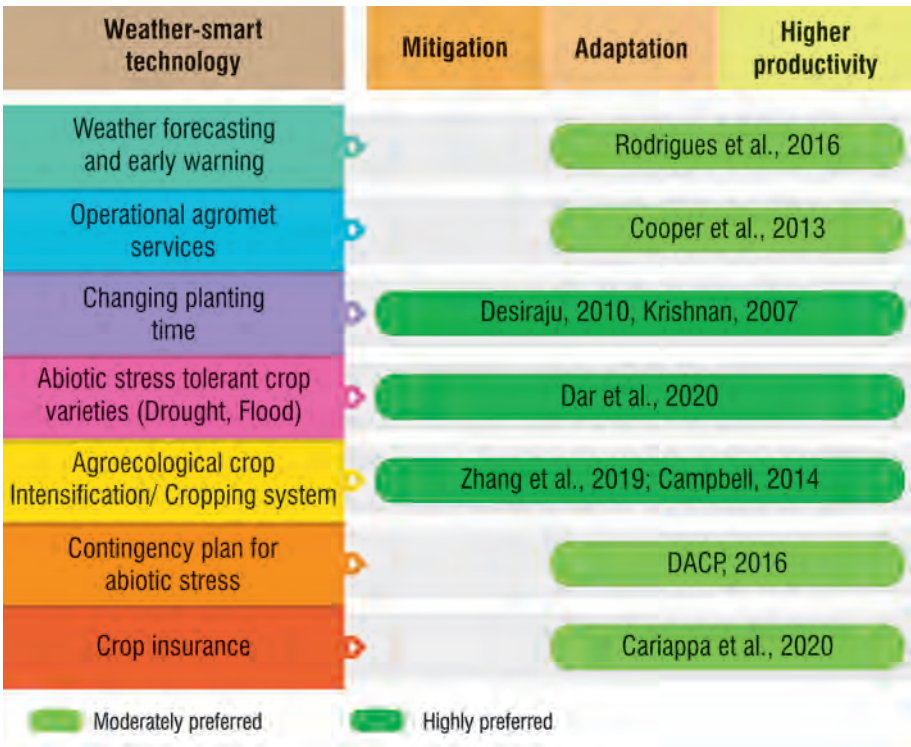


Fig 2.12. Contribution of different weather-smart technologies to three components of climate-smart agriculture
Source: Author's own analysis.

2.12 Government schemes/programmes generating non-farm employment to farmers

Weather-smart agricultural technology has attracted widespread attention by various schemes of both central and state Governments that support the weather-smart technologies discussed in the chapter. The various govt schemes for weather-smart technologies are mentioned in Table 2.21.

Table 2.21 Government policies supporting weather-smart technologies for farmers

S. No.	Policies	Schemes/ CSA Technologies	Refernces
1.	National Food Security Mission (NFSM)	Cropping-system intensification, Stress tolerant varieties	https://www.nfsm.gov.in/

S. No.	Policies	Schemes/ CSA Technologies	Refernces
2.	National Mission for Sustainable Agriculture (NMSA)	Crop insurance, Crop diversification	https://nmsa.dac.gov.in/
3.	Rashtriya Krishi Vikas Yojana (RKVY)	Stress tolerant varieties	https://rkvy.nic.in/static/index.html
4.	National Mission on Agricultural Extension and Technology (NMAET)	Climate resilient varieties	http://agricoop.nic.in/
5.	Pradhan Mantri Fasal Bima Yojana (PMFBY)	Crop insurance	https://pmfby.gov.in/
6.	National Innovations on Climate Resilient Agriculture (NICRA)	Stress tolerant varieties	http://www.nicra-icar.in/nicrarevised/
7.	Mahatma Gandhi National Rural Employment Guarantee Act”, MGNREGA)	Non-farm employment	https://nrega.nic.in/netnrega/home.aspx
8.	National Fund for Calamity Relief	Contingency plans	https://doe.gov.in/national-calamity-contingency-fund-nccf
9.	Odisha livelihood mission (OLM)	Contingency plans, Off-farm employment	http://olm.nic.in/
10.	Western Odisha Rural Livelihoods Project (WORLP)	Rural livelihood support for rural poors	http://www.worlp.com/

Source: Authors' own compilation

3. Water-Smart Technologies

3.1 Introduction

Water is essential for socio-economic progress, agriculture, healthy ecosystems, and human survival. The shadow of climate change looms over agriculture sector where water is the epicentre of sustainability and it is becoming scarcer. All the ingenuity of science needs to be deployed devising and applying smart technology to address the issue of water particularly in the field of agriculture. Agriculture uses 85% freshwater available in India. Irrigated area has to increase to 140-150 m ha to produce 450-500 mt food grains to feed 1.6 billion people by 2050 (Dhawan, 2017). In the next two decades, there is a need to produce around 25% more from 10-15% reduced share of water. To feed the ever-increasing population, efficiency of canal irrigation system is to increase by 40-60% and groundwater by 60-75%. An increase in 10% irrigation water use efficiency can bring 40% water availability for other uses and the country can gain about 50 mt additional food grains. Development of irrigation potential in the country *vis-a-vis* Odisha is a costly proposition and involves a lot of environmental issues (Anonymous, 2015).

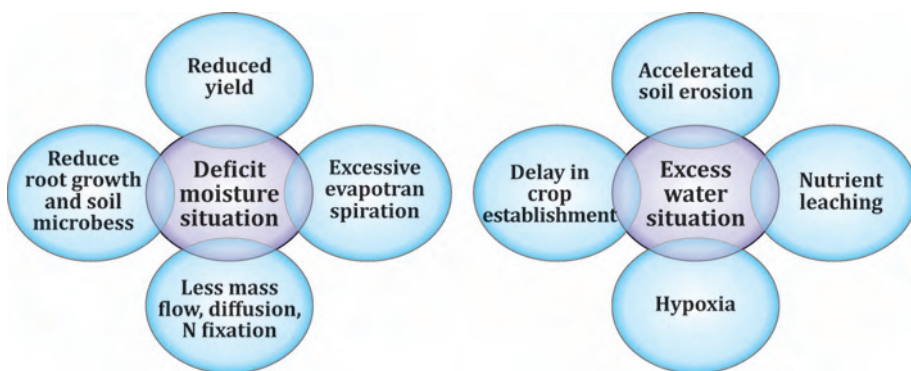


Fig. 3.1 (a) Deficit water situation, (b) Excess water situation

Source: Authors' analysis

A major impact of climate will be visible in the form of water stress due to prolonged dry spell or excess water situation due to prolonged wet spell (Fig. 3.1(a) and (b)). The complexity of managing water continues to escalate due to the adverse effect of climate change, leading to an abundance of water in some areas and water scarcity elsewhere. Deficit of water also causes negative impact on crop growth and yield. Excessive evapotranspiration in moisture

stress altered mass flow of nutrients to roots thereby affecting the availability of plant nutrients. The abundance of water/flooding caused by high-intensity rainfall events early in cropping season cause delay in crop establishment, accelerate the soil erosion leading to loss of nutrient-rich topsoil and surface applied fertilizers, and causing damage to the crop in the field due to hypoxic condition.

Water-smart technology in agriculture aims at identifying smart, innovative and scalable solutions and facilitating their co-implementation and scaling-up. The technologies that involve effective water management through the adoption of innovation in water harvesting and conservation of rainwater, farm-scale water management practices for improving productivity and resilience are considered as water-smart. The examples of water-smart technologies are water-efficient rice production system: aerobic rice, System of Rice Intensification (SRI), improved method of irrigations: check basin, border strip, drip irrigation, sprinkler irrigation, alternate wetting and drying, furrow irrigated raised bed planting, saturated soil culture, tensiometer based irrigation, supplemental irrigation, rainwater harvesting: farm ponds, check dam, *bandheras*; soil moisture conservation like mulching; and excess water management using proper drainage, groundwater recharge: raising the bunds in the paddy field, conservation of wetlands, contour bunding, dug out ponds, percolation tank and check dam, sub-surface dykes, recharge shafts, injection wells. Broadly, the climate-smart water management is classified as on-farm water management system and off-farm water management system (Fig. 3.2)

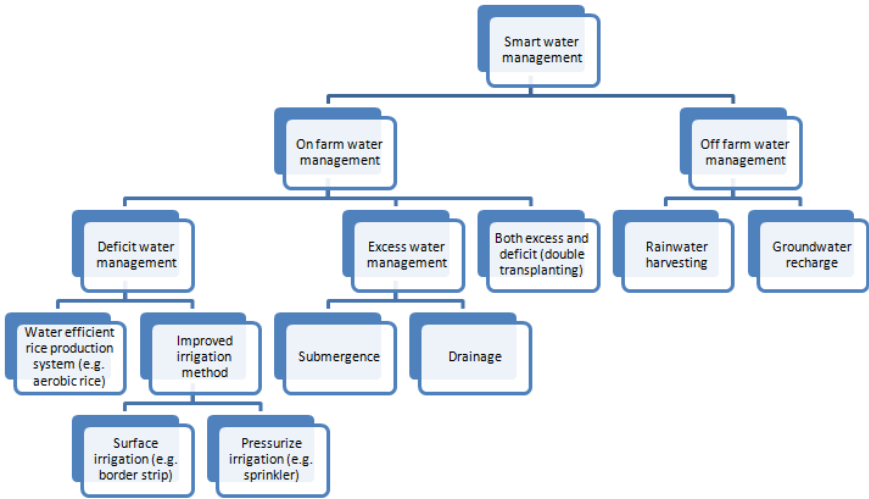


Fig. 3.2 Categories of climate-smart water management system

Source: Authors' own analysis

3.2 On-farm water management

On-farm water management refers to the water-smart technologies that enhance water use efficiency via managing deficit and excess water *in situ* through a water-efficient water management system, use of improved irrigation methods, soil and water conservation technologies, submergence and drainage management.

3.2.1 Deficit water management

Deficit water management is a way of maximizing water use efficiency for higher yields per unit of irrigation water applied. The crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season. Simply, this is growing crop with less application of irrigation water. This mainly relies on ‘more crop per drop’ principle.

3.2.1.1 Water-efficient rice production system

Rice consumes a large quantity of water. The share of irrigated rice is about 52% in India, while 43% in Odisha. Irrigated rice consumes 40% and 65% of all irrigation water resources in India and Odisha, respectively. In Odisha, rice is one of the dominant but the most inefficient user of water ($3.7 \text{ kg ha mm}^{-1}$), approximately requires 1 cm water each day duration. About 60-83% of total water applied to the rice field is lost as deep percolation. This scary situation is likely to be further aggravated in the context of climate change, some water-efficient rice production systems are available that involve growing of rice under less water than the conventional systems. Technologies like aerobic rice, system of rice intensification and dry direct-seeded rice need less water to the tune of 20-60% than the conventional method of cultivation.

Aerobic rice

Aerobic rice production technology involves growing rice in non-puddled and non-flooded conditions (Fig. 3.3). The irrigation water is given intermittently when the soil moisture content reaches a lower threshold at tensiometer reading in between 20 and 30 kPa. However, a thin film of water (1-2 cm) should



Fig. 3.3 Aerobic rice

Source: Authors' own collection

be maintained after panicle initiation. Being both water and energy-smart technology, this method could save about 37-60% of water as compared to the conventional flooded system. There could be a yield loss to the extent of 20-40%, which however could be minimized through improved crop management practices and selection of suitable short duration varieties like, Shabhagi Dhan, CR Dhan 200 (Pyari), CR Dhan 202, CR Dhan 203, CR Dhan 205, CR Dhan 206, CR Dhan 207 (Srimati), CR Dhan 209 (Priya), Apo and MTU 1010. Aerobic rice production system reduces continuous seepage, percolation losses, enhances water productivity, reduces the labour requirement, energy requirement, and GHG emission. However, aerobic rice is not suitable for high rainfall areas where water can't be controlled.

System of Rice Intensification

The system of rice intensification (SRI) is a package of improved practices for growing rice crop (Fig. 3.4 (a) and (b)). It was first conceptualized in Madagascar by Father Henri Laulanie in 1983. It is essentially a water-smart technology saving up to 20-50% water. Irrigated medium lands in the wet season and the dry season, rainfed shallow lowlands where water control (irrigation and drainage) is possible, irrigated boro/ *rabi* rice, favourable bunded uplands during the wet season are suitable for SRI. It encompasses a set of five simple principle works synergistically to enhance yield:



Fig. 3.4 (a) Square marking for transplanting under SRI

Source: Authors' own collection

- Transplanting at the early age, more preferably seedlings of 8-12 days are suitable, when the plant has only two small leaves, before the fourth phyllochron.
- Transplanting of a single seedling per hill and wider spacing in square fashioned is practiced. Seedling still attached with the seed, transplanted at 1-2 cm keeping roots at horizontal position planting at grid point demarcated by a marker.
- Mechanical weeding (rotary hoe/ conoweeder) for 2-3 times is

recommended. The first series of weeding to be completed at 10 DAT (days after transplanting) and others in a frequency of 10-15 DAT.

- Maintenance of moist soil under non-saturated conditions during the vegetative phase, which results in the development of more tap and primary roots.
- Application of organic manures for optimum biological activity and continual release of nutrients.

The major benefits of this technology are lower seed requirement (5 kg ha^{-1}), water-saving (20-50%), very high yields (35-40%), improved soil health, improved input use efficiency and lower methane emission (50-60%).

Direct seeded rice

Direct seeded rice (DSR) is an establishment technique for rice crop in which seeds are sown in the field directly in the main field rather than by transplanting seedlings from the nursery to the main field. Direct seeding is done by either sowing of pre-germinated seeds into a puddled soil (wet direct seeding, Fig. 3.5(a)) or well prepared non-puddled seedbed (dry direct seeding, Fig. 3.5(b)). Both the dry seeding and wet seeding are commonly practiced in Odisha. The main problem associated with DSR (more specifically in dry DSR) is the weed infestation. If proper weed management is not adopted the yield losses may go up to 85%. Seed priming using water and



Fig. 3.4(b) Transplanting single seedling

Source: Authors' own collection



Fig. 3.5 (a) Dry direct seeded rice

Source: Authors' own collection

KCI is one of the promising approaches to overcome poor crop establishment. Short and medium duration rice varieties are preferred for DSR in upland and medium land. Water stress must be avoided during critical stages of seedling emergence, active tillering, panicle initiation, and flowering. The overall duration of the crop is reduced by approximately 10 days. The other benefits include reduced labour requirement that is required for nursery bed raising and transplanting and less methane emission.



Fig. 3.5 (b) drum seeder for wet direct seeded rice

Source: Authors' own collection

Dry direct-seeded rice

In dry direct-seeded rice (D-DSR), dry seeds are sown directly in the main field (Fig. 3.6 (a) and (b)). Dry direct seeding is commonly practiced in rainfed uplands, medium low land, lowland and deepwater ecologies during the wet season. In D-DSR, land preparation is done by ploughing the soil twice by rotavator/ cultivator, followed by crop establishment using several methods, including (i) broadcasting of dry seeds on un-puddled soil after either zero tillage (ZT) or conventional tillage (CT) (ii) dibbled method in a well-prepared field and (iii) drilling of seeds in rows after CT, minimum tillage (MT) using a power tiller-tractor operated seeder, ZT or raised beds. In the case of both CT and ZT, a seed-cum-fertilizer drill is used, which,



Fig. 3.6 (a) Sowing in dry direct seeding method using manual seeder

Source: Authors' own collection



Fig. 3.6 (b) Tractor drawn dry direct seeder for sowing

after land preparation or in ZT conditions, places the fertilizer and drills the seeds. In this method of establishment weed is a major menace, which can be controlled by using post-emergent herbicide. The D-DSR saves water (up to 30%) over conventional transplanted rice. This method also helps in curbing CH_4 emissions ranging from 18-20% compared to conventional puddled transplanted rice. Additionally, this method reduces labour requirement, improves the emergence of seedlings, and reduces the chance of lodging.

Wet direct-seeded rice

Although wet direct-seeded rice (W-DSR) does not save much water compared to D-DSR, this practice is recommended when the late onset of monsoon rain does not allow farmers to sow the crop in time. Application of irrigation water and sprouted seeds can help to sow the crop through the direct seeding method on time and this method uses less water compared to the traditional transplanting. W-DSR involves sowing of pre-germinated seeds (radicle 1- 3 mm) on or into puddled soil through manual broadcasting or tractor-drawn drum seeder (Fig. 3.7 (a) and (b)). When pre-germinated seeds are sown on the surface of puddled soil, the seed environment is mostly aerobic and this is known as aerobic W-DSR. When pre-germinated seeds are sown/drilled into puddled soil, the seed environment is mostly anaerobic and this is called anaerobic W-DSR. The W-DSR under aerobic and anaerobic, seeds can either be broadcasted or sown in-line using a drum seeder or an anaerobic seeder with a furrow opener and closer. The yield in W-DSR rice crop is *at par* with that of transplanted rice when proper management practices are followed. It also increased water productivity by 0.3 to 0.4 kg rice m^{-3} water.



Fig. 3.7 (a) broadcasting of sprouted seeds



(b) power drawn drum seeder for sowing in WDSR

Source: Authors' own collection

3.2.1.2 Improved method of irrigation

Water is an essential input for crop growth. There are various ways (surface, pressurized, lift, and groundwater irrigations) in which the irrigation water can be applied to the fields. In surface irrigation, the soil is flooded with water, which is approximately followed in about 90% of the irrigated areas of the world. In pressurized irrigation, water is applied to the crop under pressure. About 5% of the area is irrigated by this method. In lift irrigation, water loss during conveyance is avoided. Groundwater irrigation is applied through tube wells where groundwater quality is suitable for irrigating the crop. Choosing the right method of irrigation depends upon several factors like availability of water, topography, climate, soil type, crops to be grown, economics, local traditions, and skills.

Surface irrigation

Surface irrigation is an age-old practice of providing irrigation water to the field and highly followed method of irrigation in the world. In this method water is applied through the action of gravity, sometimes the whole field is flooded (e.g. check basin) or the water is applied to small channels (e.g. channel to the field) or in strips (e.g. border strip). In these cases, irrigation application efficiency rarely exceeds over 45%- 60%.

Channel to field irrigation

In eastern India especially Odisha, canal irrigation is dominant in which water is flooded from field to field where farmers have less control over the flow of water. The water flows continuously through the fields, and the water distribution is quite irregular, with heavy percolation loss of applied irrigation water. The inclusion of field channels in existing flood irrigation system provides better control over water resulting in 15% saving of irrigation water (Fig. 3.8). The irrigation efficiency of this system is around 50%. However, channel to field method can achieve a considerable increase in water use efficiency (17% higher)



Fig. 3.8 Channel to field irrigation

Source: adapted from www.alamy.com

and grain yield (7-8% higher) of rice comparable to farmer's traditional practice of field to field irrigation.

Check basins

Check basins are necessarily rectangular or square areas measuring about 10-100 m² or even more with bunds surrounded by levees or checks, constructed around the area to control the irrigation water (Fig. 3.9). Construction of small irrigation channels in between two adjacent rows of beds helps the water to be conveyed to the field by the main irrigation channels and lateral field channels. This is a water-smart technology and scientifically designed check basins save about 10-30% water compared to conventional flooding. Check basin irrigation is suitable for many field crops including rice and fodder crops that prefer flooded water. Heavy soil with low infiltration rate is preferred for check basin irrigation.



Fig. 3.9 Check basins

Source: Authors' own collection

Border strip irrigation

In border strip irrigation, water is applied through controlled flooding of the surface (Fig. 3.10). The field to be irrigated is aligned into strips by parallel dikes or border ridges, and each strip is irrigated separately. Slopes of each unit should be uniform, with a minimum slope of 0.05% to facilitate suitable drainage and a maximum slope of 2% to limit the soil erosion. This water-smart technology saves about 10-30% of water compared to the conventional flooding. Yield is also increased by 25-35% in the border strip method of irrigation over the conventional flooding. Deep homogenous loam or clay soils with medium infiltration



Fig. 3.10 Border strip irrigation

Source: Authors' own collection

rates are preferred for such irrigation. It is suitable to irrigate crops like wheat, barley, fodder crops, and legumes, but not suitable for crops like paddy, where ponding of water is necessary.

Scheduling of canal irrigation

Canal irrigation is the cheapest and the most favourable source of irrigation in Odisha (Fig. 3.11). In the scheduling of canal irrigation, the flow of water in canal has to be maintained so that farmers can get water as per their requirement in an adequate, dependable, efficient, and equitable fashion. Proper scheduling of canal irrigation matches the supply with demand and saves about 40-60% water. However, difficulties in scheduling irrigation occur for the tail-end farmers due to inequitable distribution of water caused by the seepage loss or use of more water by farmers at the starting point that makes farmers at the tail end to get a lower volume of water compared to farmers at the privileged positions, particularly at the head of the watercourse. Water allocation on volumetric basis by the Pani Panchayat is an option for optimum utilization of available canal water uniformly. Additionally, canal water helps to raise the groundwater table by 0.3–0.4 m annually.



Fig. 3.11 Scheduling of canal irrigation

Source: Department of Water Resources,
Government of Odisha

Groundwater irrigation

Groundwater irrigation has emerged as a major source of irrigation water in agriculture. At present, about 60% of the irrigated area in India is occupied by groundwater irrigation. Irrigation water use efficiency of groundwater irrigation is about 64%. Extraction of groundwater is made through the use of shallow and deep tube wells. Attention is needed to avoid overexploitation of groundwater and saving it more for drinking purposes.

Shallow tube wells

Shallow tube wells are made to tap groundwater from a depth of 30-60 m and the water flow rate is 20 Ls⁻¹ (Fig. 3.12). Groundwater irrigation

through shallow tube wells is one of the alternatives, sometimes complementary method to irrigate the rice crop with surface water. The shallow tube well is used as supplementary irrigation to rice crop during a dry spell in the rainy season. One or two shallow tube well irrigation from a shallow tube well in the dry season can make it possible to take short duration pulse/ oilseed/ spices crop



Fig. 3.12 Shallow tube wells

Source: Department of Water Resources,
Government of Odisha

in coastal area supplementing the residual soil moisture carried over from the preceding rainy season. Installation of shallow tube wells may directly influence the cropping intensity by increasing the net sown area in the coastal rainfed area. This water-smart technology increases the grain yield of tropical lowland rice by 18-20% due to the timely availability of water. Accelerated exploitation of groundwater is not recommended in the coastal areas as it will facilitate the salinization of aquifer due to saltwater intrusion from the sea. Shallow tube wells are preferred in the coastal area adjacent to the sea for supplemental irrigation.

Deep tube well

Deep tube wells are of large diameter with depth ranges from 60-300 m (Fig. 3.13). In deep tube well, a powerful pump goes inside the well and operates in force mode to lift the water onto the surface. These types of tube wells possess a large discharge capacity of about 80-200 Ls^{-1} . With an increase in discharge capacity, the length and width of the water distribution channels need to be increased



Fig. 3.13 Deep tube well

Source: Department of Water Resources,
Government of Odisha

accordingly. This water-smart technology ensures higher water use efficiency as compared to the surface canal irrigation. It enhances resilience against water stress in the area where canal irrigation is not possible. However, adequate recharging of groundwater and proper crop planning needs to be ensured for arresting the rapid decline of groundwater.

Pressurized irrigation

In pressurized irrigation systems, irrigation water is applied through pipes more precisely to crops. These systems are superior to surface irrigation systems as they provide better farm distribution, time-saving, land area saving, less labour intensive and high water use efficiency. These systems are of two types: drip and sprinkler irrigation systems. Recently, low-cost water and energy-efficient device (LEWA) is getting attention because of its cost-effectiveness and lower energy use. The irrigation application efficiency of these systems ranges from 75%- 95%.

Drip irrigation

Drip irrigation is a pressurized irrigation system that can save water as well as nutrients by permitting the water to drip at very low rates ($2\text{--}20 \text{ L h}^{-1}$) to the roots of plants, either from the top of the soil surface (surface drip) or buried inside



Fig. 3.14 Drip irrigation

Source: adapted from 'Resilience project'

the surface (sub-surface drip) (Fig. 3.14). The main objective is to apply water directly into the root zone and minimize evaporation loss of water. Drip irrigation increases the crop water productivity (25%), irrigation water productivity (20%), net photosynthesis ($\sim 10\%$), and water use efficiency ($\sim 36\%$), while reduces the transpiration rate ($\sim 22\%$) compared to flood irrigation. The on-farm efficiency of the drip irrigation system is estimated to be over 90%. The grain yield of drip-irrigated rice is about 25% higher than rainfed rice. It is mostly recommended in the water scarcity area, growing high-value crops (cash crops) in protected cultivation and where recycled water is used for irrigation. This method of irrigation is highly successful for high-value horticultural crops. The major constraints associated with drip

irrigation are (i) initial cost of establishment and (ii) maintenance as the pipes/conveyance tubes are often clogged if good quality irrigation water is not used. The average cost for installing a drip irrigation system is 0.7 to 1 lakhs per acre.

Sprinkler irrigation

The system consists of sprinkler heads or nozzles, which are mounted on risers in lateral lines taken from the mainline, which is further connected to a pumping unit (Fig. 3.15). This system of irrigation is suitable for all types of soil and is used mostly when the soil is too porous,



Fig. 3.15 Sprinkler irrigation

Source: Authors' own collection

uneven and easily erodible which prevents good distribution by surface irrigation. This is a water-smart technology that saves 30-50% of irrigation water in comparison to the surface method of irrigation. Loss of water through evaporation is restricted to only 2-5% in this method. The overall efficiency of the system is above 80%. In this system, no land is wasted on making bunds and channels, and about 40-50% of saving in labour as compared to surface irrigation. A problem associated with this technology is the drifting of water during the high wind to the non-target areas. The cost of installation of the sprinkler system is around 0.50-0.70 lakhs per acre.

Low energy water application (LEWA)

LEWA is low-cost water and energy-efficient device (25-40% saving in water and energy) used as a replacement of overhead impact sprinklers to irrigate fields with higher efficiency, more specifically in row crops in smaller fields (Fig. 3.16). It is operated at a pressure range of 39-98 kPa at its nozzle head, with a discharge rate of 0.87–1.10



Fig. 3.16 Low energy water application

Source: adapted from www.asagriculture.blogspot.com

m^3h^{-1} , and throw diameter of 6–8 m. This system is not only cost-effective but also a water and energy-efficient pressurized irrigation system, that is appropriate for small and marginal farmers with small and fragmented landholdings. LEWA is more feasible for paddy crop compared to drip and sprinkler systems.

Lift irrigation

In lift irrigation, water instead of being transported by natural flow through the action of gravity requires external energy supplied through animal, fuel or electricity using pumps or other mechanical means (Fig. 3.17(a) and (b)). Lifting water from a source from lower elevation to higher elevation requires external energy. Lift irrigation involves carrying the water to the delivery chamber from the water source and distributing it to the required places.

The water is carried out by the help of pumps from the water source at the lower portion of the land from channels or ponds. Distribution is done by the gravitational method. For this, a contour map is prepared and the places to be irrigated are blocked according to their need. Pipelines of required diameter and suitable valves are placed for the distribution. This method allows farmers to irrigate crops at a higher elevation. Farmers can supply water to their crops as and when needed, this reduces the chances of excess irrigation. Besides, this irrigation technology reduces the conveyance loss as it is directly applied to the field resulting in higher irrigation water use efficiency (more than 60%).



Fig. 3.17 (a) Mega lift irrigation system



Fig. 3.17 (b) Application of water in vegetable field using lift irrigation

Source: Department of Water Resources,
Government of Odisha

3.2.1.3 Scheduling irrigation

Application of irrigation water with respect to time and space based on the evaporative demand of the crops is referred as scheduling of irrigation. In water-scarce areas, irrigation scheduling in rice is done using saturated soil culture (SSC), alternate wetting and drying (AWD), tensiometer based irrigation, and critical stage based lifesaving irrigation.

Rice has five critical stages (tillering, panicle initiation, booting, heading, and flowering/ anthesis). Moisture stress at active tillering phase and reproductive phase reduces yield by 30% and 50-60%, respectively. Application of water in AWD or SSC upto tillering followed by maintenance of 5-8 cm standing water saves about 50% of water as compared to continuous submergence without any yield loss. During *kharif*, the application of water could be delayed up to 3 days of complete disappearance of ponded water (5-7 irrigations), while in *rabi*, the application of water could be delayed up to 1 day of complete disappearance of ponded water (13-15 irrigations). This method saves about 9-27% of irrigation water.

Saturated soil culture

In saturated soil culture (SSC), the soil is kept as near to saturation as possible and it requires regular shallow irrigation (standing water depth 1 cm) on daily basis or once in every two days (Fig. 3.18). The best way of using SSC is in raised beds in which the soil can be kept around saturation effectively. The raised beds are used for growing rice and shallow irrigation is applied in furrows. About 5-50% water can be saved if SSC is used scientifically. However, the saving of water varies with soil type and groundwater table depth. On average, SSC can decrease water input by 23% from the continuously flooded condition with non-significant yield reduction upto 5-10%. This technology is a good alternative to flooded rice production in semi-arid tropical environment.



Fig. 3.18 Saturated soil culture

Source: Authors' own collection

Alternate wetting and drying

Alternate wetting and drying (AWD) is a method of controlled and intermittent irrigation (Fig. 3.19 (a) and (b)).

It is a water-saving technology that saves up to 15-30% water with no/little yield loss (upto 5%). In this process, irrigation water is applied from 10 DAT or 20 DAS only after the disappearance of ponded water from the soil surface. The most efficient and

accurate way to implement AWD is through the use of a 'field water tube' or 'pani pipe' of 30 cm length and 7-10 cm diameter to keep vigil the water depth. After a few days of application of irrigation, when the water level drops below 15 cm from soil surface, the field should be re-irrigated. However, during the sensitive stages (flowering) a thin layer of water of about 5 cm is always advocated. AWD improves water use efficiency (upto 1.2 kg m^{-3}) and reduces greenhouse gas emissions by 30-50%.

Tensiometer based irrigation management

In AWD method of irrigation in rice, effective irrigation scheduling can also be done based on soil water potential as measured by tensiometer (Fig. 3.20). Irrigation scheduling based on tensiometer saves irrigation water upto 50%.

Tensiometers continuously monitor soil water status, which is useful for practical irrigation scheduling, and are extensively used on high-value cash crops where low water tension is desirable. It is ideal for sandy loam or light-textured soils. The measurement range is limited to less than one bar tension, accurate measurement is obtained below 0.8 bar.



Fig. 3.19 (a) pani pipe (b) alternate wetting and drying method in rice field

Source: adapted from 'Resilience project'



Fig. 3.20 Tensiometer based irrigation management

Source: Authors' own collection

Coarse-textured soils require to be irrigated at 0.2 to 0.3 bar and finer soils at 0.3 to 0.4 bar soil moisture.

Supplemental irrigation/ lifesaving irrigation

Supplemental irrigation (SI) is small amounts of irrigation water given to essentially rainfed crops at their critical stages of growth, particularly when insufficient rainfall or low availability of irrigation water fails to provide adequate moisture for normal plant growth. When rainfall failed to meet water requirement of rainfed crops for stabilized production, SI is applied to prevent crop failure. The SI is not applied to get moisture-stress-free conditions throughout the growing season, rather ensure a minimum quantity of water for getting an optimal production by making moisture available at the critical stages of growth. For instance, about 2 to 3 supplemental irrigation of 5 cm each to rice during critical growth stages (tillering, panicle initiation, milking, and doughing) can enhance yield up to 50%. Water for supplemental irrigation comes mainly from the canal as well as lift irrigation, but shallow groundwater aquifers are also used. One or two supplemental irrigation to rice during dry spell can wipe out drought stress in most of the rice-growing areas of Odisha. If *rabi* crop is planted in time (by 30th November), the soil residual moisture is good enough to meet the crop's requirement. However, when *rabi* crop is delayed (20 January-15th February) supplemental irrigation may be needed. If 75-80% of the water requirement is fulfilled by soil moisture, 0-1 irrigation is sufficient. On the contrary, if 55-60% of the water requirement is fulfilled by soil moisture, two irrigations are required for growing low water requiring pulse or oilseed crops.

3.2.1.4 Agronomic practices for higher water use efficiency

Various agronomic practices like laser land leveling, field bund raising, furrow irrigated raised bed, and raised and sunken beds can increase irrigation water use efficiency and save a significant quantity of irrigation water, with marginal or no reduction of grain yield.

Laser land leveling

It is the process of leveling the land surface at an accuracy level of ± 2 cm from its mean elevation by using laser-equipped drag buckets (Fig. 3.21). Besides, this method creates a constant slope of 0-0.2% throughout the field, for which, irrigation water spreads uniformly in every part of the field with negligible loss from run-off or water-logging. Large horsepower tractors and soil movers equipped with global positioning systems (GPS) and/or laser-guided instrumentation are used in this method. The soils are moved either

by cutting or filling to make the land surface well leveled. Laser leveling increase water saving by approximately 20-25%, increases approximately 3 to 5% of cultivable land area, reduce GHG emission and increases the yield of crops.

Field bund raising

In lowland flooded paddy, water loss may occur mainly due to seepage, percolation loss and runoff (Fig. 3.22). Water flow through and over bunds around rice fields are primarily responsible for higher water loss, thereby reducing water productivity. For this, about 50 cm high earthen bund along with mud plastering allow the water to retain within the field boundary. These structures are



Fig. 3.21 Laser land levelling

Source: Authors' own collection



Fig. 3.22 Field bund raising

Source: adapted from www.rkmp.co.in

easy to build, reduce runoff and conserve topsoil. However, further raising of field bund from 50 to 75 cm reduces the runoff of water in heavy rainfall events and provide additional water for groundwater recharge. Increasing peripheral field bund by 18-20 cm in rice paddy can store 90% of the total rainwater *in situ* and simultaneously improve rice productivity.

Furrow irrigated raised bed planting

Furrow irrigated raised bed planting (FIRB) planting involves the planting of crops on raised beds or ridges and the application of irrigation water to the bottom of furrows (Fig. 3.23). For most of the soil types (sandy loam to loam soils) and crops, FIRB of 67cm width (top width of bed-37cm; furrow-30cm) is widely used. On the raised beds, two rows of crops like rice, maize, wheat, or chickpea are grown. This method of planting facilitates *in-situ* conservation of rainwater in furrows, better drainage of excess water and proper aeration in the

seedbed and root zone. FIRB increases water use efficiency and saves up to 25-30% of irrigation water. It saves 70-80% of time, labour, cost, diesel, and energy; produces higher yields (4-5%) and energy efficiency (20-25%) compared to conventional sowing.



Fig. 3.23 Furrow irrigated raised bed planting

Source: Authors' own collection

Sunken and raised bed

Alternate sunken and raised bed is made by excavating soil of a strip of 5 m, a depth of 20-30 cm and placing the soil in the adjacent strip (5 m) (Fig. 3.24). The height of the raised bed is 40-60 cm higher than the adjacent sunken bed. As the removal of top fertile soil from sunken bed creates poor fertility conditions, the application of FYM @ 10



Fig. 3.24 Sunken and raised bed

Source: Authors' own collection

t ha⁻¹ is recommended. Vegetables like chillies, brinjal, okra, amaranthus, cucumber, bitter gourd can be grown on beds during monsoon seasons and long duration paddy cum fish (singhi/ magur) can be practiced in furrows. To prevent soil erosion from the raised bed, planting of papaya at a distance of 1.5 m is useful. A higher rice grain yield of about 13-15% is obtained in this system compared to unmodified and conventional rice cultivation.

3.2.1.5 Soil and water conservation (SWC) technologies

Land and water are the most important natural resources to be conserved and sustained carefully for better crop production. Soil erosion is a serious threat, which is caused due to agricultural intensification, rolling topography, soil degradation and intense rain which is likely to be more aggravated in the context of climate change. Loss of rainwater and soil lead to loss of nutrient and organic carbon from the top layer of soil. Various measures can be taken for SWC, which are broadly categorized into agronomic and engineering measures.

Agronomic measures

Plant canopy has the capability to dissipate the splashing effect of raindrops and minimizes its impact on the soil particle to detach and erode. Agronomic measures involve a set of crop husbandry practices that do not involve any modification of the land surface. These measures are recommended for less rainfall areas with fairly erosion-resistant soils with a gentle slope of less than 2%.

Contour farming

A simple conservation practice of farming operation where the plantation is done along the contour and across the slope called contour farming. This is recommended for 4-6% slope (Fig. 3.25).



Fig. 3.25 Contour farming

Source: Authors' own collection

All the cultural practices such as ploughing, sowing, intercultural operations are

performed across the slope to reduce soil erosion (by almost 50%) and water loss. Because of ploughing and sowing across the slope, each ridge of plough furrow and each row of the crop act as a barrier to the runoff and offer extra time for water to enter into the soil, thereby reducing the loss of soil and water. Because of better saving of topsoil, water and nutrient loss, this method enhances 5-10% crop yield.

Mulching

Mulching is the practice of putting a protective layer of an organic or inorganic material that is spread on top of the soil. Mulches can either be organic, such as straw of paddy or wheat, stover of maize, crop residues of various leguminous crops, and grass clippings or inorganic, such as plastics of varying colour and thickness, stones, and brick chips. Plastic mulching performs better at relatively low temperature while straw mulching is



Fig. 3.26 (a) polythene mulching

more suitable for hot climate (Fig. 3.26 (a) and (b)). Straw mulching consists of placing a uniform layer of straw approximately @ 4-6 t/ha. Both organic and inorganic mulches have several benefits. In non-flooded rice systems, evaporation as well as percolation losses are reduced substantially by mulch which further increases WUE upto 60%. Besides, mulch ensures earlier crop establishment (3 weeks), add organic matter, increase yield (7-8%), increase nitrogen use efficiency (upto 20%), and suppress weed seed germination.



Fig. 3.26 (b) straw mulching

Source: Authors' own collection

Growing of erosion resisting crops

Crop species can be selected based on their ability to prevent erosion. Erosion permitting and erosion resisting crops should be grown alternately (Fig. 3.27). Cereal crops such as maize, rice come under erosion permitting and legumes under erosion resisting crops. The



Fig. 3.27 Growing of erosion resisting and erosion permitting crops

Source: Authors' own collection

The fast-growing and deep-rooted trees or shrubs like *Leucaena leucocephala*, *Erythrina* sp., *Gliricidia sepium* etc. are planted on the contour bunds of the hills to give it extra stability. The vertical spacing of these species should be maintained at 1.0–1.5 m and crops are planted between the two rows of hedge plants. By growing suitable erosion resisting and erosion permitting crops along with tree/shrub species on contour bund, sediment loss can be reduced to about 12-15%.

Engineering measures

Engineering measures are also known as mechanical measures as these measures target at preventing the movement of eroded soil by reducing either

the length and/or steepness of the slope. On contrary to agronomic measures, these measures are typically followed for the land with a slope higher than 2%.

Gully plugging

Gullies are formed because of inappropriate land use and formed as a result of severe soil erosion. Gully plugging is built to prevent erosion and to settle sediments (Fig. 3.28). A gully plug is a small earthen/stone dam constructed at one or more locations along the



Fig. 3.28 Gully plugging
Source: Authors' own collection

gully. Excess runoff is delivered to the downstream channel by a drop inlet structure. These structures are cost-effective as they can use locally available materials.

Bench terracing

Bench terracing transforms comparatively steep land into a series of leveled platforms across the slope to reduce the slope length and subsequently the soil erosion (Fig. 3.28). This method is suitable for soils having slopes 16 to 33%. A piece of sloppy land is transformed into a series of benches by digging soil from the top part and filling at the



Fig. 3.29 Rice cultivation in bench terracing
Source: Authors' own collection

lower part of the terrace. Bench terraces reduce both length and degree of slope and thus prevent soil erosion. Bench terraces provide permanent infrastructure for the cultivation of crops like paddy, potato, oilseeds, vegetables in double or multiple cropping annually. As a result, the productivity of the crop is increased by almost two-fold. The runoff loss of water in this system may be reduced to the extent of 8-13%. Besides, bench terracing reduces erosion rate to less than 1tha^{-1} on 25% slope. The main drawback of this technology is its high-cost involvement for its construction.

Contour bunding

Contour bunds are a typical bund constructed along the contour and across the slope (Fig. 3.30). The main objective of contour bunding is to create a mechanical obstruction to the runoff water for its slower movement during high rainfall. This structure attempts to retain the rainwater within the bunds and allow less water to flow as runoff. The vertical interval between two consecutive contour bunds is adjusted to 0.5-1 m depending on the slope, soil depth and land use type. This type of bund is suitable for lands with slopes lesser than 6%. This system is most suitable for a low rainfall area below 75 cm annually.



Fig. 3.30 Contour bunding

Source: www.agritech.tnau.ac.in/agriculture

Contour trenches

Contour trenches are made by excavating the soil to form an artificial depression/ pit on the steep land surfaces to reduce soil erosion and to absorb rainwater in the soil (Fig. 3.31). This type of engineering structure is advocated for the land with a slope higher than 15%. Most commonly, trenches are of 0.30 m x 0.30 m dimension at 1 to 2 m vertical interval. However, the continuous trenches may be as long as 100 to 200 m long across the slope depending on the land width. Trench protects the soil from erosion and reduces the run-off by absorbing the velocity of rainwater. The vegetation like broom grass can be planted on either side of the trenches to prevent erosion. It improves moisture status in soil, water yield, and increases crop production.



Fig. 3.31 Contour trenches

Source: Authors' own collection

Staggered trenches

This is a variant of contour trenches. Unlike continuous trenches, staggered contour trenches are made in a scattered pattern with a maximum length of 2-4 m (Fig. 3.32). These trenches are mostly trapezoidal or rectangular in shape. Flatter upstream side slopes are generally preferred to minimize the runoff.



Fig. 3.32 Staggered trenches

Source: Authors' own collection

Gabion structures in waterways

Gabion structures in waterways are made for soil stabilization (Fig. 3.33). Gabion structures can successfully stabilize the medium and deep gullies where the bed of the waterways is eroded by surface runoff. They are made from a galvanized hexagonal meshes and broken rock that are placed behind the meshes. These structures are low cost and an alternative solution for concrete structures for soil stabilization in waterways.



Fig. 3.33 Gabion structures in waterways

Source: www.icharity.in

Borrow pit in dryland area before plantation

Borrow pit and cluster of shallow depth pits are excavated to retain/ recharge rainwater during monsoon and later it is used for plantation in the post-monsoon season (Fig. 3.34). It facilitates the retention of rainwater which is used for planting trees later and helps in improving vegetation cover, soil erosion



Fig. 3.34 Borrow pit in dryland area before plantation

Source: Authors' own collection

control, rainwater recharge, and improvement in soil organic carbon.

Stone and vegetative bunds

This is an indigenous technical knowledge in which a structure with an embankment of stones, or soil and stones is made along the contour and the stone structure is stabilized using vegetation, such as fodder trees and grasses. Stone bund controls the soil erosion from the drainage basins and water gets more time to enter into the soil (Fig. 3.35). Apart from the above structure, planting of hedges, grasses, or shrubs on the contour can check the runoff velocity drastically and increase the time for water to infiltrate into the soil, facilitate sedimentation and deposition of eroded material by reducing the carrying capacity of the overland flow (Fig. 3.36). Because of the conservation of topsoil and water in this structure, the yield of the crops is improved and also, it increases the access to drinking water by increasing the water table.

Control of bank erosion

Streambank erosion happens due to a larger flow of river or stream water during the rainy season that cuts a chunk of soil from the river or stream bank (Fig. 3.37). Repeated cutting of chunks of soil weakens the banks and allow it to erode more



Fig. 3.35 Stone bund

Source: Authors' own collection



Fig. 3.36 Vegetative bund

Source: Authors' own collection



Fig. 3.37 Control of bank erosion of Subarnrekha river

Source: Department of Water Resources,
Government of Odisha

with complete demolishing of the embankments. There are several ways to control bank erosion by construction of concrete structures, gabions, wooden logs, live vegetation, coir mat, synthetic mat, coconut coir logs along river embankments.

Construction of runoff water collection ponds

This is similar to the farm pond, however, it is dug for more diversified purposes. In runoff water collection ponds, rainwater is harvested at the mid or lower slope of a sloppy land or hills for multiple uses including the supply of water for drinking, crop production and fish farming (Fig. 3.38).



Fig. 3.38 Construction of runoff water collection ponds

Source: Authors' own collection

On account of high water percolation and seepage due to higher permeability, harvested water may be unavailable within 1-2 months after rainfall recedes. Therefore, low-density polyethylene (LDPE) lining of the pond is advocated in areas with high soil permeability to extend its use for a larger period, preferably throughout the dry season.

3.2.2 Excess water management

Due to the uncertainty of rainfall, excess water may accumulate in the rhizosphere. Excess water may cause anoxia in the rhizosphere and plant roots do not get sufficient oxygen to respire. Turbidity associated with excess water also damages the crop. In rice, excess water accumulation at vegetative stages deters tillering. The crop growth stage in between flowering to maturity is more sensitive to excess water compared to the stage from maximum tillering to flowering. If fields remain flooded beyond the dough stage, the crop will show non-homogenous maturity and harvesting of the crop will be delayed. Management of submergence and drainage are two important options for the management of excess water.

3.2.2.1 Submergence management

In rainfed lowland, rice crop undergoes submergence for 10-15 days during the vegetative and reproductive stages of crop growth (Fig. 3.39). Most of the rice varieties are unable to withstand complete submergence for more than a week.

More than 16% of lowland rice is adversely affected by excess water stress with a time scale from a few days to 2 weeks. Upon complete submergence, the rice plants have to adapt themselves to two drastic environmental changes: the transformation of the aerobic environment to the hypoxic environment during the period of submergence followed by retransformation of the



Fig. 3.39 Submergence management

Source: Authors' own collection

hypoxic environment to the aerobic environment when the floodwater recedes. The turbidity, turbulence, pH, and temperature of floodwater and the stage of submergence are the main factors that affect crop growth. The major problems associated with submergence are reduced PAR and underwater photosynthesis, leaf senescence due to more ethylene production under submergence, cell wall damage and lodging, reduced tiller and leaf numbers, deposition of silts on the leaf surface in case of turbid water, reduced plant population and difficulties in crop establishment. Suitable management practices are recommended to cope with the submergence. Resilient varieties like Swarna-SUB1, IR64-SUB1, Samba Mahsuri-SUB1, CR1009-SUB1 can withstand submergence better than its parent cultivar. Agronomic approaches such as using higher seed rates, better seeding methods, skipping basal N application, post submergence application of N (both foliar and soil application), application of 20% more P and K and soil application of sodium silicate, foliar application of orthosilicic acid have been found to increase the productivity of both *sub 1* introgressed and non-introgressed HYV subjected to submergence of 14 days duration.

3.2.2.2 Drainage management

An agricultural drainage system refers to the methods by which excess water of harmful level and/or duration is removed from the soil for better production of crops. Lack of poor drainage may cause severe damage to crops. It may be classified into surface and subsurface drainage.

Surface drainage

Surface drainage refers to the removal of excess surface water through the use of land slope utilizing drainage channels/systems to take away the surplus water

from the field (Fig. 3.40). This is normally accomplished by shallow ditches, also called open drains. Surface drainage can be done in five ways:

- Random system: Small scattered depressions are connected by drains to one another and conveyed to the outlet
- Parallel system or field ditch: Fields can be graded for discharge into lateral drains bordering the field. Lateral drains are connected to the main drains
- Parallel open ditch system: It is resembling a parallel system excepting the drains which are replaced by open ditches
- Bedding system: Parallel beds are developed by shaping and smoothing the land surface so that the run-off drain laterally from the beds to dead furrows
- Interception system: Series of shallow open drains across the slope with a mild grade to intercept and remove surface runoff



Fig. 3.40 Surface drainage

Source: Department of Water Resources,
Government of Odisha

Subsurface drainage

Subsurface drainage removes the excess water which has infiltrated into the soil and that can be held there by capillary forces even against the gravitational force. This type of drainage is typically needed for the soils that contained impervious or



Fig. 3.41 Subsurface drainage

Source: Authors' own collection

slowly permeable rocks or a layer below the soil surface (Fig. 3.41). This impervious layer does not allow the water to move deeper into the soil so that the crop production does not hamper. Subsurface runoff systems include pipe/ tile drainage, mole drainage and drainage wells. The subsurface drainage system of 20 m spacing and 1.5 m depth can increase the cotton, wheat, and rice yield upto a great extent. The cost of making a subsurface drainage system is 2-2.5 times higher than the surface drainage system.

3.2.3 Practices for both deficit and excess water management

Rice cultivation largely depends upon the crop growing conditions like soil type and available water. Transplanting of rice requires a lot of water which may not be available during dry years or may be delayed due to the late onset of monsoon. Again, excess water or flood during certain stages hamper crop growth. Some climate-smart agricultural technologies are available that can tackle both drought and flood-like situations. Double transplanting is a crop establishment technique that is suitable for both situations. Additionally, the availability of healthy seedling in drought or flood years can be assured with the management of community nursery.

3.2.3.1 Double transplanting

This technology was evolved in eastern India especially in Bihar, West Bengal, Odisha, and then spread gradually to the eastern UP. Double transplanting is an indigenous crop cultivation system in rice where farmers transplant the seedlings twice during the season (Fig. 3.42). In the double transplanting method, farmers usually broadcast less quantity of seeds (6-8 kg ha⁻¹) in puddled fields during the middle of May using available surface or groundwater. After 25 days, the seedlings are transplanted in another small field where the seedlings are grown for 20 days. When the seedlings reach the age of about 50-55 days, they are again transplanted in the main fields. This method enhances the resilience of rice agro-ecosystems. Rice crop grown using this technique can withstand extended dry spells and prolonged water inundation in the low-lying fields. In comparison to puddled transplanted rice, this method delivers about 10-25% higher grain yield.



Fig. 3.42 (a) Double transplanting (b) Transplanting of aged seedling

Source: Authors' own collection

3.2.3.2 Community nursery

Establishment and management of community nurseries of high-quality seedlings at the well-aerated site with good water availability can serve as regular as well as a contingent source of seedling during aberrant weather years (Fig.



Fig. 3.43 Community nursery
Source: adapted from Resilience Project

3.43). Delay in the onset of monsoon often delays transplantation of *kharif* paddy in the eastern part of India resulting in lower productivity as over-aged seedlings suffer from the low tillering ability. The establishment of staggered community nursery could be a local adaptation strategy to combat the problems encountered during deficit rainfall seasons. Sometimes, rice crop is lost at its early stages due to droughts, insufficient rainfall, floods, pest, and disease incidence. Again, sometimes sufficient time is not available to start a new nursery or to arrange seedlings from other growers. During such circumstances, the farmer may lose a complete season. Such situations can be addressed by community nurseries managed by a group of farmers. The seedlings may be made available on commercial basis to the other farmers. The preferable place for growing nursery is either in protected structures like polyhouses or a lowland with irrigation facilities (in the drought-prone area) or an upland with suitable drainage facility (in the flood-prone area).

3.3 Off-farm water management

Off-farm water management refers to the collection and management of water outside the border of farm premises. However, the water collected in this method may be used in on-farm. Rainwater harvesting and groundwater recharge methodologies are coming under off-farm water management.

3.3.1 Rainwater harvesting

Rainwater harvesting refers to the process of capturing and storage of rainwater at its inception and simultaneously does not allow the water to loss through runoff, evaporation and seepage for its efficient utilization. Rainwater harvesting is broadly composed of two steps, firstly, the storage of rainwater on the surface for further use and secondly, recharge to groundwater. The rainwater is traditionally stored in tanks, ponds, and check dams. In high

rainfall areas, the water harvesting structure can act as a source of drinking and irrigation water during the times of the lean-period and dry spell. In 44 blocks and 27 urban areas of Odisha, the groundwater has started declining. The problem of groundwater decline has already been experienced in about 5 blocks where 70-90% of the groundwater development have been made. All the possible ways of rainwater harvesting and recharging needs to be explored to address these problems. Examples of some surface rainwater harvesting structures viz., farm pond, check dam and bandheras are discussed hereunder.

3.3.1.1 Farm ponds

Farm ponds are small reservoir constructed for storing the rainwater incepted in the catchment area (Fig. 3.44 a). The farm ponds supply of water for both on-farm use like irrigation, fishery, and off-farm use like drinking water, recharging groundwater. Due to the availability of protective irrigation facility from farm pond productivity of crops can be increased, viz., pigeon pea (35%) and green gram (20%), wheat (30%), sorghum (27%), and gram (20%) and vegetables (13%). Gross cropped area and cropping intensity can be increased by 8-10% after the construction of farm ponds in an area. In a broad sense, the farm ponds are divided into the following two general categories: embankment type and excavated or dugout type. Embankment type farm ponds are generally constructed across the stream or watercourse. Dugout type farm ponds are constructed by excavating the soil from the ground, relatively in flat areas. The lining of the farm pond is done with reinforced plastering or silpauline to prevent percolation loss in the area of high soil permeability (Fig. 3.44 b).



Fig. 3.44 (a) Farm pond with concrete lining

Source: Authors' own collection



Fig. 3.44 (b) Pond structures for rainfed uplands with silpauline lining

3.3.1.2 Check dams

A check dam is a temporary structure made of stone and wood or a permanent structure made of cement and concrete, constructed across a drainage basin

to prevent soil erosion by reducing water flow velocity (Fig. 3.45). Construction of check dams across first-order streams/ gullies serves as an effective water harvesting structure. Check dams control runoff, facilitate percolation of water and help to recharge nearby wells on both sides of the streams. These structures



Fig. 3.45 Check dam

Source: Department of Water Resources,
Government of Odisha

are suitable to conserve excess runoff water generated in seasonal streams of hill areas. Harvested water can be used for agricultural purposes during long dry spells. This technology reduces the velocity of runoff by 11%. For protecting soil erosion near the check dam, climbers like *Hedra helix*, *Smilux sp.*; grasses like hybrid napier and tree species like *Quercusincana* and *Morus alba* can be planted.

Besides its role as a rainwater harvesting structure in hilly terrain, a check dam is built on a stream with the help of ground material, stone and mud-filled wall to recharge the GW aquifer. It stops the runoff water and has a little storage. This dam should be constructed in a sequence at a proper distance in the stream. The flow of surface water is hindered, water remains on permeable soil and rock surface for a longer time to recharge the groundwater. This method of GW recharge is suitable for the region with an annual rainfall of 900 mm. This type of structure is recommended where the rock strata are sufficiently porous for groundwater recharge through ponded water.

3.3.1.3 Bandhera

Bandhera is a type of check dam that is built across rivers to impound water to form a large reservoir (Fig. 3.46). This technology is recommended for the plain areas. Bandhera increases the water level of the rivers allowing it to flow into smaller channels. Bandhera helps in water supply for a longer period even when monsoon is over.



Fig. 3.46 Bandhera on Bheema river

Source: www.commonswikimedia.org

3.3.1.4 Rooftop rainwater harvesting

This technique of rainwater harvesting involves the collection of rainwater from the roof through conduits to a reservoir (Fig. 3.47). A rainwater harvesting system is composed of three basic systems: a collection area, a conveyance system, and storage facilities. Generally, the collection area is the roof of a house. The area and constituent material of the roof impact the collection efficiency and water quality. A conveyance system is made of gutters or pipes and the water is stored in a plastic or cemented tank. This technology provides high-quality water, soft and low in minerals. The physical and chemical properties of rainwater are better than those of polluted or saline groundwater or surface waters. Using the harvested water, crop productivity is increased by two-three folds because of assured irrigation in the kitchen garden. Various vegetables viz., radish, french bean, carrot, coriander, etc. can be grown in the assured irrigated area during the lean period.



Fig. 3.47 Roof top rain water harvesting

Source: www.hyderabadwater.gov.in

3.3.2 Groundwater (GW) recharge

Groundwater recharge (subsurface water harvesting) is a hydrologic process that involves the downward movement of water from surface water to groundwater. Recharge occurs both naturally without any external intervention and artificially through anthropogenic processes where rainwater is routed to the subsurface.

3.3.2.1 Natural GW recharge

In natural recharge, rainwater enters the soil through voids through natural processes (Fig. 3.48). About 15–20% of seasonal rainfall contributes to groundwater recharge in the region with higher permeability, while that falls



Fig. 3.48 Natural GW Recharge

Source: Authors' own collection

to about 5–10% in the hard-rock regions. Sandy or permeable soil, rocky strata with fractures, perennial rivers and streams, forest land, paddy field, wetlands, and leveled lands are the most suitable natural condition for GW recharge. Application of additional irrigation @ 50 mm in each time over and above the normal irrigation is easily moved to the downstream and recharges the groundwater.

3.3.2.2 Artificial GW recharge

Artificial recharge is needed due to the overuse of water due to rapid industrialization, population increase, intensive agriculture, urbanization. Artificial GW recharge is needed in the area of overexploitation of GW, desaturation of the aquifer, poor quality of GW, saline water intrusion (coastal belt), and drying of wells and pumps during the lean period. Groundwater can be artificially recharged directly by redirecting water across the land surface through contour bunding, percolation tank, check dam, dug out pond; and indirectly through recharge shafts, injection wells and subsurface dykes.

Direct GW recharge

Direct GW recharge refers to the water added to the groundwater reservoir when it is in excess of soil moisture and evapotranspiration deficits, through direct vertical percolation of water. It may be done through contour bunding, percolation tank, dugout pond, and check dam.

Contour bunding for GW recharge

Contour bunding has already been discussed in the soil and water conservation section. Here we discuss its potential for GW recharge. Contour bunds comprise of narrow trapezoidal bunds to hold water behind them, which percolates through the soil and finally increase the groundwater level. This method of GW recharge is suitable for the low rainfall area (<900 mm) where internal subsurface drainage is good. They are not suggested for clayey soils with poor internal drainage.

Percolation tank

Percolation tanks are the most common runoff harvesting techniques, in which a series of dams are made for the storage of a suitable quantity



Fig. 3.49 Percolation tank
Source: Authors' own collection

of surface water that may percolate to recharge GW (Fig. 3.49). The area for establishment of such structure should be such that a significant quantity of water infiltrates through the bed towards the groundwater table. This method is effective in alluvial soils with higher permeability and hard rock area with many faults. It is useful for uninterrupted recharge even after the receding of the monsoon. The size of tank depends upon the percolation capacity of strata.

Dug well

Dug well is a hole dug out in the land surface, generally circular in shape that is used as structures to recharge the groundwater level (Fig. 3.50). This is mostly recommended in the alluvial region. These structures can be diverted stream water, canal water, tank water to recharge the dried aquifer. The recharged water flows through a pipe to the well and recharged through the well. It plays a significant role in water percolation in beneath collected from the surrounding land area.



Fig. 3.50 Dug well

Source: Authors' own collection

Dugout pond

Dugout ponds are made by digging the soil from a piece of land and the dugout soil is used to make embankment around the pond (Fig. 3.51). The pond is filled by surface runoff. In this technique of surface groundwater recharge, ponds are dug before the monsoon. During monsoon, the runoff water is stored in the pond not only for domestic and irrigation uses, but also percolate down gradually to recharge the groundwater.



Fig. 3.51 Dugout pond

Source: Authors' own collection

Indirect GW recharge

Indirect GW recharge refers to the percolation of surface water to the GW table through ponding of runoff in a natural depression, low lying areas and lakes, or indirectly through beds of surface watercourses like rivers, streams. Recharge shafts, injection wells, and subsurface dykes are examples of indirect recharge.

Recharge shaft

Recharge shafts are used when a poorly impervious layer at the surface recharge impedes the water to recharge the aquifer whose water table is deep below the surface (Fig. 3.52). If the layer is devoid of faults and non-caving type, it may be dug manually. By constructing recharge shaft in tanks, the additional water may be used to recharge GW. The recharge shaft is made up to the size of 2 m in diameter and it terminates at the permeable layer just below the top impervious layer. However, the shaft may not reach to the GW table. These shafts are highly impressive for ponds below which a shallow clay layer impedes the deep percolation of water to the aquifer.



Fig. 3.52 Recharge shaft

Source: Authors' own collection

Injection well

Injection wells are used to recharge GW with surface water directly (Fig. 3.53). Water for recharge is directed through a recharge pipe to the lowermost part of the well to evade entrapment of water bubbles in the GW aquifer. The quality of source water should be good enough, not to contain much silt in it. This method is costlier than the other indirect GW recharge method because of the boring of wells. However, sometimes abandoned tube wells are used for GW recharging using



Fig. 3.53 Injection Well

Source: Authors' own collection

this method. Hydraulically, the groundwater recharge in the injection well is determined by the permeability of the aquifer, rate of pumping, distance from the surface water source and well type.

Subsurface dykes

Subsurface dykes are built in an aquifer to obstruct the natural flow of GW, thus raising the GW level and increasing the quantity of water stored in the aquifer (Fig. 3.54). These are performing as an underground obstruction impermeable to water. These controls GW flow in an aquifer and increases the



Fig. 3.54 Subsurface Dykes

Source: Authors' own collection

GW table. These essentially comprise of brick masonry structures constructed on massive crystalline rocks, which are exposed in trenches of 1-2 m wide, dug across the breadth of the stream down to impervious bed. The space between the structure and the walls of the trench may be filled by impermeable clay. These are found to be cost-effective alternatives for providing sustainable drinking/irrigation water supplies to small communities in areas where construction of other artificial recharge structures cannot be attempted due to adverse geomorphologic conditions or constraints of space.

Groundwater skimming

Seawater intrusion occurs in the interface between GW and seawater. The density of seawater is higher than the fresh GW that allows seawater to push the GW. Due to excessive use of GW for industry, agriculture (especially rice cultivation), shrimp farming, and fisheries, saline seawater may intrude into the GW table. The wells with saline GW in the coastal region impedes its use as drinking water. Groundwater skimming is a technique that extracts relatively fresh GW from the upper zone of the fresh-saline aquifer (known as Dhorugu technology). Skimming wells play an important role in supply good quality drinking water, irrigation water and control the GW table to prevent its further degradation. The conventional single strainer well, multi-strainers wells, scavenger wells, radial collector wells, and dug wells are various types of skimming wells.

3.4 Watershed management

A watershed refers to a geographical area that drains to a common point. It is a viable unit for technical efforts for simultaneous conservation of soil along with maximization in the utilization of surface and sub-surface water for developing efficient production systems. Watershed management is a risk aversion management approach, aiming to protect the dwellers of the fragile ecosystems from severe distress caused by frequent droughts through development and supervision of land, water, and biomass resources with a focus on social and institutional aspects apart from bio-physical aspects following a participatory “bottom-up” approach. It aims at

- Conserving as much rainwater at the place of its inception, without distressing the natural hydrological system, increasing the GW level and maintaining it for sustainability and stabilizing the flow of water for a long period
- Preventing soil erosion and sediment production through suitable SWC measures
- Controlling the damaging runoff and moderate floods in the downstream areas
- Drain the excess water safely and avoiding gully formation
- Maximize the water storage capacity in the watershed, both in the soil and developing the existing and new water bodies

Watershed programmes are being implemented under an array of national schemes/programmes such as Integrated Wasteland Development Programme (IWDP); Drought Prone Area Programme (DPAP); Employment Assurance Scheme (EAS); Flood Prone River (FPR); National Watershed Development Programme for Rainfed Agriculture (NWDPA); National Bank for Agriculture & Rural Development (NABARD) Watershed Programmes; State-funded WSM programmes and various foreign-funded afforestation projects. Effective implementation of watershed management can be done by the community participation. Participatory management at micro-watershed level aims to achieve (i) involvement of local leadership, (ii) voluntary generation of ideas and interventions by community members, (iii) equity in decision making such as participation of women, (iv) community organizational structures for managing the interventions, (v) removal of obstacles to collaborate- attitude, belief, and behaviour, (vi) training of local communities.

3.5 Participatory irrigation management

Participatory irrigation management (PIM) may be defined as the participation of farmers in the management of irrigation to bring sustainability to the system. The main objectives of PIM are to promote equitable distribution of water among its farmers, adequate maintenance of irrigation system, and efficient utilization of water ensuring ecological balance. PIM was introduced in Odisha under the Odisha Water Resources Consolidation Project (OWRCP) during 1995 in which water users associations (WUA) were formed. Later on, the WUA has been renamed as Pani Panchayats. Odisha Pani Panchayat Act-2002 came into force to give this programme a legal framework. The basic four-tier structure of PIM in Odisha includes (Table 11.1): (i) Pani Panchayats (PP) at primary level consisting of several Chak Committees (CC) (ii) Distributary Committee (DC) at the secondary level (iii) A Project Committee (PC), at the project level, is a federation of all distributaries committees' (iv) A State-Level Committee (SLC) to lay down policies for implementation of the Pani Panchayat programme. However, in lift irrigation projects it is a single-tier system i.e. Pani Panchayat.

Table 11.1. PIM models varying with level of irrigation

Level of irrigation	PIM Model
Major	SLC-PC-DC-PP-CC
Medium	SLC-PC-PP-CC
Minor	SLC-PC-PP-CC
Lift	SLC-PP

PIM: Participatory irrigation management; SLC: State-Level Committee; PC: Project Committee; PP: Pani Panchayat; CC: Chak Committee; DC: Distributary Committee

Source: Authors' own compilation

3.6 Multiple use of water

Multiple-Use Water Services (MUS) is an innovative and holistic approach to sustainable water delivery that seeks to provide water services that reflect the multiple water needs of households. The more vulnerable users are provided with low-cost services for domestic water, irrigation water for agriculture, gardening, drinking water for cattle, water for aquaculture, and water supplies for rural enterprises. This technology increases productivity, income and sustainability of the farming as a whole.

3.7 Conjunctive use of multisource and multi quality water

The conjunctive use of multi-source/multi-quality waters is defined as a strategy by which waters are used in a combined manner such that the net output is more than the net output of the individual component. Increasing competition among urban, industrial, and agricultural uses of water resulted in opening a new dimension of conjunctive water use that involves the use of multisource (surface water + groundwater) and multi-quality (canal water + sewage water) water for agriculture. Conjunctive use of surface water and groundwater deals with overexploitation of groundwater, depletion of the water table, and surface water shortage during critical crop growth stages. About 70-80% of the total water supplied for domestic use turns into wastewater, which can meet approximately 4.5% of the total irrigation water demand. Application of two canal irrigations and one irrigation with sodic water cause insignificant yield reduction (1.5-4%) in the rice-wheat cropping system. Simultaneous use of tube well water and paper mill effluent in 1:1 ratio is observed to increase yield by 7-17%.

3.8 Integrated water resources management

Integrated Water Resources Management (IWRM) is a method that promotes the harmonized development and supervision of water along with land and related natural resources to exploit economic and social welfare reasonably without hampering the sustainability of the ecosystems and environment.

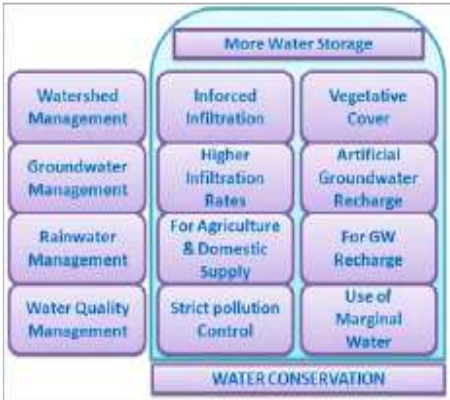


Fig. 3.55 (a) Demand management for IWRM



Fig. 3.55 (b) Supply management for IWRM

Source: Authors’ own analysis

IWRM is based on the three principles: social equity, economic efficiency and environmental sustainability. Considering these principles there are two-step processes to implement IWRM. The first step is demand management that is to bring higher efficiency in water use through conjunctive use of water coupled with pollution control measures (Fig. 3.55(a)). This step promotes multiple uses of water and water conservation through watershed management (infiltration, vegetative cover), groundwater management (higher infiltration and artificial groundwater recharge), rainwater management (agricultural and domestic supply, groundwater recharge), water quality management (pollution control and marginal water use). The second step relies on the use of untapped sources of water to provide a balanced supply-demand scenario in the use of irrigation water (Fig. 3.55(b)). Supply management tries to increase the available quantities of water by making the best use of all available sources of water through institutional reform (water rights and public-private partnership), market-based measures (price, taxes and pollution charges), non-market measures (incentives, licenses, restrictions) and direct interventions (research & development, training and education). Making of water harvesting structure for increasing supplemental irrigation during a dry spell and for pre-sowing irrigation during *rabi* season is a key driver for supply management. The gap between potential requirement of irrigation water and the potential utilization of water needs to be reduced. Demand management is heading for a decrease in water use by education, training, technological innovations and appropriate water pricing policies. The adoption of improved water management strategies is the key to the area where recharge potential is low. Loss can be minimized in the conveyance of water (lined channel, closed conduits *etc.*), optimizing cropping pattern and use of improved irrigation system.

3.9 Water-smart technology for climate change mitigation, adaptation and higher productivity

Water-smart technologies, like other climate-smart technologies, also fulfill the criteria of CSA pillars, *viz.*, mitigation, adaptation and crop productivity. The water-smart technologies satisfying all the three pillars are considered as highly preferred technologies for adoption; if two pillars are satisfied then it is called moderately preferred and if only one pillar is satisfied then it is considered as preferred water smart technology (Fig. 3.56). Technologies like SRI, improved method of irrigation, submergence and drainage management, soil and water conservation, rainwater harvesting and groundwater recharge are fulfilling all the three pillars. These technologies help to grow more crops, which in turn increase soil organic carbon and in the long run help in carbon

accumulation. Among these highly preferred technologies, some technologies are directly fulfilling the three criteria and others have co-benefits that fulfill the criteria for some of the pillar. For instance, an improved method of irrigation and submergence and drainage management had a direct impact on adaptation and crop productivity, however, these have adaptation-led mitigation as co-benefits. Similarly, soil and water conservation, rainwater harvesting and groundwater recharge have direct benefits on adaptation and mitigation, while crop productivity is their co-benefits. Technologies like AWD and Dry-DSR have zero or slightly negative impacts on crop productivity, for which they come under the moderately preferred category.

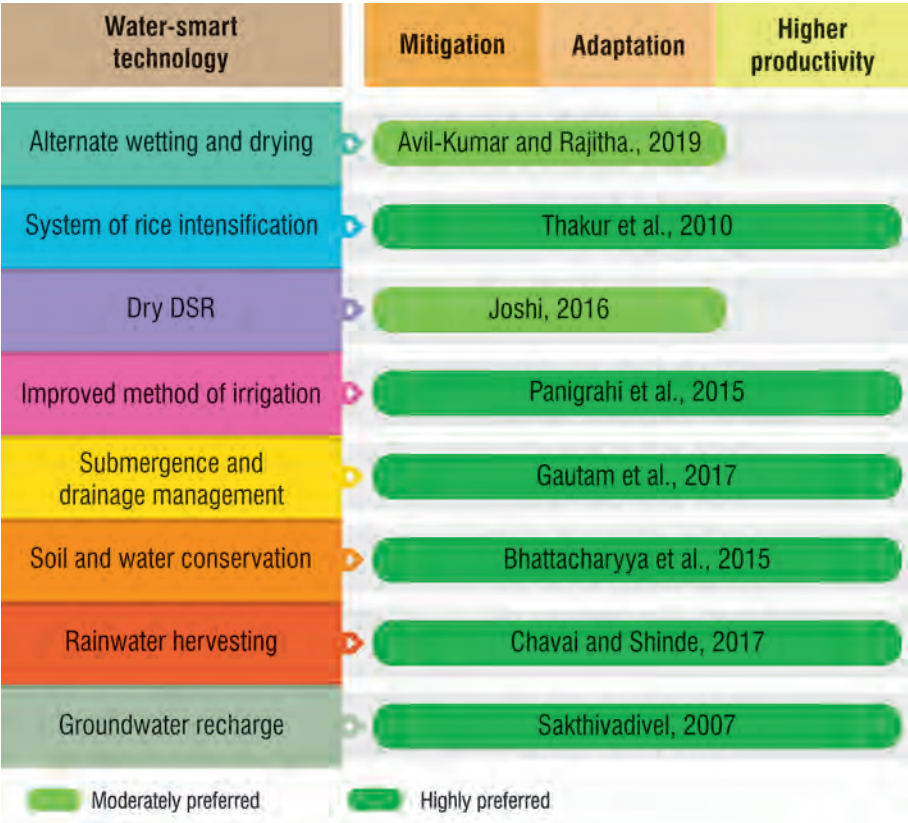


Fig. 3.56 Water-smart technologies and three pillars of CSA
Source: Authors’ own analysis

3.10 Government schemes promoting water-smart technologies

Small-holder farmers (<2 ha landholding) are vital for India's agriculture and rural economy. However, they are more exposed to water-related issues as they depend upon marginal areas with high water scarcity (drought-prone areas) or water in excess (flood plains). Moreover, they are less able to respond to these problems due to limited financial capability. Therefore, India needs strong policies for small farmers to increase their capacity to respond better to the extremes.

The Government of India and the Government of Odisha have launched schemes to promote water-smart technologies at the grass root level that can benefit smallholder farmers of marginal areas with higher vulnerability. The main purposes of these schemes are assured water supply for agriculture, mechanism for distribution of water, increasing water productivity, promoting micro-irrigation, promoting conjunctive use of lift irrigation and surface irrigation, developing watershed, encourage water harvesting and groundwater recharge. Various schemes and the WST supported by these schemes are listed in Table11.2.

Table11.2: Water-smart technology supported by Government Schemes

Sl. No	Name of Scheme/ Programme	Water-smart technology supported by the scheme	Reference
Central Government scheme			
1.	Pradhan Mantri Krishi Sinchayee Yojana (PMKSY-AIBP)	Drip and sprinkler irrigation, Rainwater harvesting, Soil and water conservation	https://pmksy.gov.in/
2.	National Food Security Mission (NFSM)	Alternate wetting and drying, Direct seeded rice	https://www.nfsm.gov.in/
3.	National Mission for Horticulture (NMH) (85% by GoI and 15% by GoO)	Drip/sprinkler irrigation, Rainwater harvesting, Water conservation.	https://hortnet.gov.in/
4.	National Watershed Development Project for Rainfed Areas (NWDPRRA)	Integrated watershed management and sustainable farming systems	http://agricoop.gov.in/sites/default/files/NWDPRRA8410.pdf

Sl. No	Name of Scheme/ Programme	Water-smart technology supported by the scheme	Reference
State Government schemes			
5.	Biju Krushak Vikash Yojana (BKVY)	Scheduling canal irrigation	http://www.dowrodissha.gov.in/Citizen/BKVY/BKVY.htm
6.	Odisha Integrated Irrigated Agriculture Water Management Investment Programme (OIIAWMIP) with assistance from Asian Development Bank	Lift irrigation, Canal irrigation (Rehabilitation and improvement)	https://www.adb.org/projects/38411-043/main
7.	Odisha Integrated Irrigation Project for Climate Resilient Agriculture (OIIP-CRA)	Improved methods of irrigation, Drainage, Water smart varieties	https://projects.worldbank.org/en/projects-operations/project-detail/P163533?lang=en
8.	Mukshyamantri Adibandha Tiari Yojana (MATY)	Rainwater harvesting, Groundwater recharge	https://www.odisha.gov.in/
9.	Deep Borewell Scheme	Deep tube well, Multisource irrigation water	http://www.dowrodissha.gov.in/Citizen/DBWELL/DBWELL.htm
10.	Water Sector Infrastructure Development Programme (WSIDP)	Irrigation management, Lift irrigation, Canal irrigation, Micro-irrigation	http://www.dowrodissha.gov.in/
11.	Renovation of Canal & Embankment	Scheduling Canal irrigation, Prevention of riverbank erosion, Soil and water conservation	http://www.dowrodissha.gov.in/
12.	Drainage Improvement Programme (DIP)	Drainage	http://www.dowrodissha.gov.in/
13.	Integrated Wasteland Development Programme (IWDP)	Implementation of micro-watershed project	https://soilodisha.nic.in/Home/InnerPage/48
14.	Rooftop Rainwater Harvesting & Groundwater recharge in urban areas	Rainwater harvesting, Groundwater recharge	http://www.dowrodissha.gov.in/Citizen/RRHS/RRHS.htm

Source: Authors' own compilation

4. Nutrient-Smart Technologies

4.1 Introduction

Modern-day agriculture uses high yielding varieties that need a significant quantity of nutrients for achieving their yield potential. The contribution of fertilizer accounts for approximately 50% of today's food production. Hence it is evident that global food security is not possible without fertilizers. On the other hand, agriculture is responsible for about 67% of global N_2O emissions that include direct emissions from fertilization and livestock manure (42%), runoffs and leaching (25%) (IPNI, 2015). Despite several decades of research, the average recovery efficiency of N, P, and K in agriculture has been quite low due to several factors including inappropriate and imbalanced use of fertilizer. This has led to several socio-economic and ecological consequences such as an increase in the cost of cultivation, fossil fuel burning, greenhouse gas emission, pollution of water bodies, *etc.* Climate change further presents multiple challenges to nutrient management by its effects on the crop growth and yield, crop nutrient demand, soil nutrient dynamics, and availability and uptake of nutrients (Table 4.1). Studies pointed out that climate change impacts both the availability and uptake of nutrients by modifying the soil environment that either enhance or reduce the nutrient acquisition and its utilization.

The major impact of climate change on nutrient dynamics and its plant availability will be through its effect on the dynamics of water in the agroecosystem. The complexity of managing water continues to escalate due to the adverse effect of climate change, leading to an abundance of water in some areas and water scarcity in others. Excess water from high-intensity rainfall events will lead to loss of nutrients from the topsoil due to accelerated soil erosion, it also hastens the process of nitrate loss through leaching and surface runoff. Waterlogging makes soil hypoxic that affects the oxygen-dependent active transport of nutrients adversely affecting the plant growth. Change in soil redox status caused due to waterlogging can lead to Mn, Fe, and Al toxicity and N loss through denitrification. Water deficit also causes a negative impact on crop growth. Excessive evapotranspiration in moisture stress alters the mass flow of nutrients to roots thereby affect the availability of NO_3^- , SO_4^{2-} , Ca, Mg, and Si. Drought hinders soil bacterial activity and hence inhibits N-fixation in legume crops and interrupts soil N cycling.

Despite its central role in sustaining the productivity of agricultural systems, plant nutrition has received little consideration in the context of climate change. Sustaining productivity and reducing GHGs emissions under such situation requires unhindered nutrient acquisition by plants and improvement in nutrient use efficiency. This can be possible through the deployment of nutrient smart technology that can help in improving the resilience of the production system by limiting the adverse effects of extreme weather events such as floods, drought, high temperature, *etc.* Piloting nutrient efficient varieties, soil test based fertilizer application, customized fertilizers, enhanced efficient N fertilizers, site-specific nutrient management, real-time N application, integrated nutrient management are some examples of nutrient-smart practices discussed in the following sections

Table 4.1: Effect of weather parameters on plant nutrient availability

Weather parameters	Influence on soil-plant interaction
Excessive moisture (flood, storm, heavy rainfall)	• Loss of surface-applied fertilizers and nutrient from topsoil • Hypoxic conditions following the stagnation of floodwater interfere with oxygen mediated nutrient dynamics and availability. • Decrease in soil redox status leads to Mn, Fe and Al toxicity
Deficit moisture (monsoon failure, elevated temperature)	• Altered availability of NO_3^-, SO_4^{--}, Ca^{++}, Mg^{++} and Si^{+4} • Retards soil bacterial activity and inhibits N-fixation in legume crops
High soil temperature	• Influences the microbial activities, which affects the availability of all nutrients like P and Zn
Elevated CO_2	• Influences root exudation which changes the nutrient dynamics • Altered plant nutrient requirement due to plant growth modification
Moisture stress and high soil temperature	• Alters the microbial activity, which affects N cycling through symbiotic and non-symbiotic processes
High air temperature	• Affects plant physiological and metabolic activity, which in turn affects the nutrient uptake from the soil

Source: Authors' own compilation

4.2 Principles of nutrient-smart practices

The nutrient availability in soil is influenced significantly by soil as well as weather conditions. The crop productivity is directly influenced by the

nutrient availability in the soil and their use efficiency. For ensuring higher crop productivity in an ecologically safe manner, efforts are to be made to enhance the nutrient use efficiency using 4R principles (Right source, right rate, right time, in the right place) of nutrient stewardship (Fig.1) and following improved crop management practices (Fig 2). The principles of governing efficient nutrient management in the context of climate change are not going to essentially change under a changing climate but the strategies to improve nutrient use efficiency may differ depending on past management practice. Some of the strategies for enhancing nutrient use efficiency include (i) appraise the soil nutrient status of the farm following standard laboratory testing method/sensing tools and GIS platform and prepare the soil fertility rating chart showing different categories of soil nutrient status *e.g.* deficient, sufficient and excess. If possible, as per the fertility rate chart, a soil variability map and variable applicator can be used for the application of nutrients, (ii) assess nutrient resources potential available from different sources at the farmer's field, (iii) application of decision support system to fill the gap between nutrient requirement and availability, (iv) short-term forecasting tool for agricultural nutrient management, which helps in predicting the nutrient demand by the crop under different changing weather, (v) recommend fertilizers by integrating soil test values, the nutrient requirement of the crops and available sources of nutrient supply by using decision support systems and (vi) use nutrient efficient crop varieties.

The 4R Nutrient Management

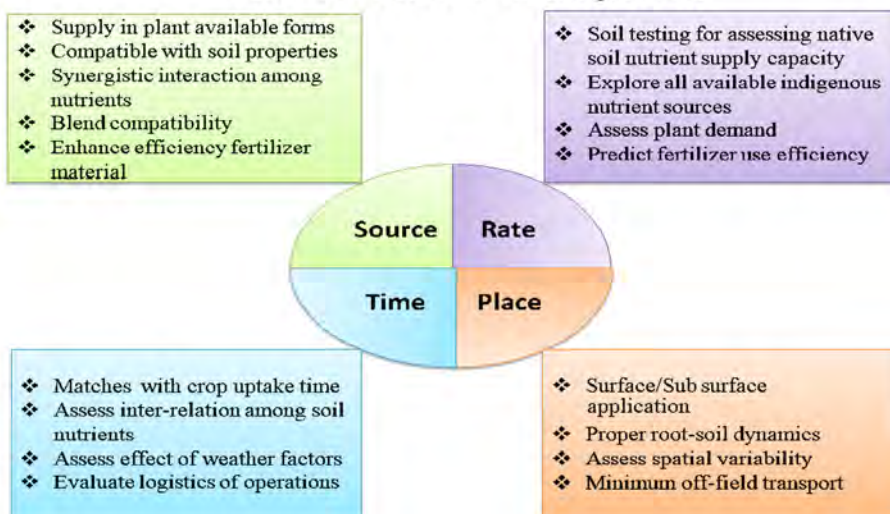


Fig.4.1. 4R nutrient management for optimum production

Source: Adapted and modified from IPNI (2012)

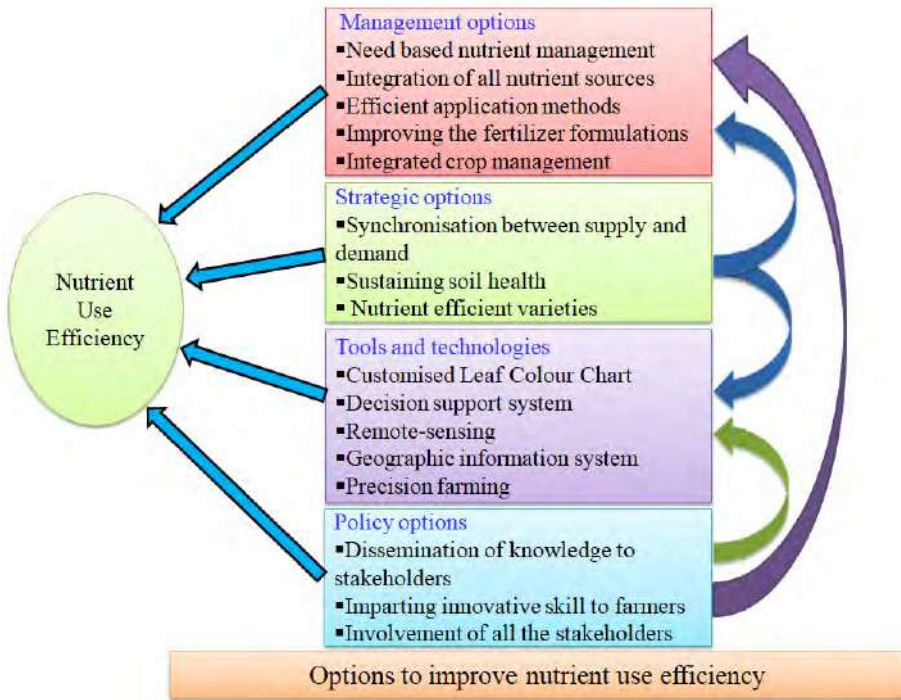


Fig.4.2. Options to improve the nutrient use efficiency

Source: Authors' own compilation and analysis

4.2.1 Piloting nutrient-efficient varieties

The crop varieties that perform well to lower doses of chemical fertilizer and are having both higher internal, as well as uptake use efficiency even under reduced soil nutrient conditions, are usually referred to as nutrient efficient. The reduced availability of nutrients in soil occurs due to either inherent nutrient deficiency in soil or the nutrient present is not available to plant due to prevailing unfavourable soil conditions. Under both the situation crop plant suffers nutrient starvation resulting in reduced growth and yield. In India, 50% of rice is cultivated in the rain-fed lowland rice soils that are naturally low in nutrient contents. Nutrient-efficient crop varieties are having the ability to withstand nutrient deficiency by deploying various mechanisms such as well-developed nutrient transporters, deeper and wider root systems, rhizosphere engineering through root exudation, and symbiotic association with microbes that promote nutrient availability. Phosphorus-starvation tolerance 1 (*PSTOL1*) gene from a traditional indica variety Kasalath and other quantitative trait loci (QTLs) have been used to develop low phosphorus

tolerant varieties. Similarly, QTLs for low nitrogen response have also been identified in several important field crops. Apart from this, genotypes and varieties tolerant to a reduced level of K, Fe and Zn have also been developed for rice (Table 4.2)

Table 4.2: Efficient genotypes of rice for nutrient stress situation

Stress	Genotypes
Low N	Swarna, Ranjit, Sarjoo-52, Bejhary, Pranava, Salivahana
Low P	Kasalath, Rasi, RPA 5929, MTU 2400, Vikramarya
Low Zn	CSR 10, Sarjoo-52, Vikas, IR-30864
Fe toxicity	Mahsuri, Phalguna, Dhanrasi

Source: Authors' own compilation

4.2.2 Soil health card

The nutrient use efficiency of most of the plant nutrients is very low in India. Out of the many reasons, lack of knowledge on the inherent soil fertility is one of them. In order to enhance their efficiencies ensuring higher productivity, reducing the cost of cultivation, and minimizing the environmental consequences of nutrient losses, the Government of India launched a Soil Health Card (SHC) scheme in February 2015. Soil Health Card is a printed report handed over to a farmer for each of his holdings. It contains information about the status of 12 parameters, namely N, P, K, S, Zn, Fe, Cu, Mn, Bo and pH, EC, OC. This information is important for fertilizer recommendations and soil amendments required for the farm. As per this scheme, the soil testing is done once every two years so that necessary management steps can be followed to improve the status of soil fertility. The SHC provides complete information on the fertility status of agricultural land enabling the farmers to apply major and micronutrients as per the target yield and crop need. During Phase-I (Years 2015 to 2017) of the SHC scheme, 10.74 crore cards, while under Phase-II (2017-19) 11.69 crore cards have been distributed among the farmers. In Phase-II, about 12.9 lakh SHCs were distributed to the farmers of Odisha. The adoption of SHC has helped the farmers to increase productivity by 5-6% and reduce the use of chemical fertilizer by 8-10%.

4.2.3 Customized fertilizers

Most of the Indian agricultural soil is suffering from the deficiency of one or more nutrients. Out of many factors, the imbalanced application of chemical fertilizer is one of the important factors. Unless managed, the problem of

nutrient deficiency will be further aggravated more so under a changing climate scenario. Site-specific and crop-specific customized fertilization practice that caters to the nutrient need of crops and correcting the deficiency of soil nutrients will help in addressing the nutrient management issues in the context of climate change. As per Fertilizer (Control) Order, 1985 customized fertilizers are “multi-nutrient carrier designed to contain macro and /or micronutrient forms., both from inorganic and/or organic sources, manufactured through a systematic process of granulation, satisfying the crop’s nutritional needs, specific to its site, soil and stage, validated by a scientific crop model capability developed by an accredited fertilizer manufacturing/marketing company”. These fertilizers are generally prepared by physical crushing and mixing of two or more than two fertilizers such as urea, diammonium phosphate, muriate of potash, ZnS, bentonite sulfur, and boron granules for supplying different macronutrients such as N, P, K, S and micronutrients in the desired proportion. Around 22.5% fertilizer reduction in paddy has been observed by using customized fertilizers *e.g.*, 16:22:14:4:1:0 and 8:15:15:0.5:0.15:0 *etc.* (N:P:K:S: Zn: B). Customized fertilizers are considered as one of the best available options to correct site-specific multi-nutrient deficiencies of soils and thus help to attain desired crop yield cost-effectively. These fertilizers cater to the nutritional demand of crops for a specific area, soil, and growth stage of the plant. The promotion of these fertilizers will enhance fertilizer use efficiency and become cost-effective.

4.2.4 Enhanced efficiency fertilizer (EEF)

Slow-release nitrogen fertilizer contains coatings made up of less permeable material and inhibitors (either nitrification or urease inhibitors or both) within the formulation or in the coating to regulate the process of transformation of urea to NH_4 or that of NH_4 to NO_3 or both *e.g.* neem coated urea, sulfur coated urea, *etc.* After the application of urea to the soil, it is broken into ammonium ions (NH_4^+), which is further oxidized to nitrite (NO_2^-) and, then, nitrate (NO_3^-) forms. When plain urea is applied to the soil, there is a rapid conversion from urea to nitrate,



Fig. 4.3. Urea pellets
Source: Authors' own collection

consequently, there is a rapid loss of nitrogen in the form of leaching loss as nitrate or in the form of gaseous emission as nitrous oxide. Several chemical and natural inhibitors for inhibiting or slowing down the hydrolysis of urea (urease inhibitors: NBPT - N-(n-butyl) thiophosphorictriamide (trade name -Agrotain), N-phenylphosphorictriamides (2-NPT), Hydroquinone (HQ), Phenyl phosphorodiamidate (PPD/PPDA)) and nitrification inhibitors: Nitrapyrin, DCD, N (2,5-dichlorophenyl) succinic acid monoamide (DCS), 3,4-dimethylpyrazole phosphate (DMPP), niminetc.) have been identified and found to enhance the use efficiency of nitrogen. Slow release or controlled release urea fertilizers are also prepared by coating urea prills with less soluble chemicals such as sulfur, polymers, and other products like plaster of paris, resins, and waxes. The coating of neem oil on urea slows down urea hydrolysis and nitrification and hence it regulates the release of nitrogen. The slow release of nitrogen increases its availability to the plant thereby increases the nitrogen use efficiency. Neem coated urea, urea briquette, urea + neem oil briquette, urea + karanja oil briquette showed 64-81% higher agronomic use efficiency (AEN) as compared to prilled urea (Nayak et al., 2017). Urea briquettes based N application showed 17-25% lower nitrous oxide emission compared to plain urea granule. The application of neem-coated urea prolongs the release of nitrogen and results in longer periods of greenness in the plants. In July 2004 the Neem Coated Urea was included in Fertilizer Control Order (FCO) by the Ministry of Agriculture. The application of NCU resulted in a decrease in $\text{NO}_3\text{-N}$ leaching and N_2O emission by 18% and 21%, respectively, and an increase in yield by 6% as compared to prilled urea (PU) (Mohanty et al., 2017). Improvement of nitrogen use efficiency through using efficient fertilizer material will simultaneously meet the productivity enhancement while contributing to mitigation. The efficiency of some natural and chemical nitrification inhibitors for enhanced nitrogen use efficiency and reduced N_2O emission are presented in Table 4.3.

Table 4.3. Efficiency of nitrification inhibitors for reducing N_2O emission.

Nitrification inhibitor	Mitigation (%)
Dicyndiamide (DCD)	13-42
Neem cake	10-21
Neem oil	15-21
Nimin	25-35
Coated Ca-carbide	12-29
Thiosulphate	15-20

Source: adapted from Pathak et al., 2014

4.2.5 Site-specific nutrient management

Site-specific nutrient management (SSNM) involved the use of principles and tools for supplying nutrients to plant to achieve higher yield synchronizing the demand and supply after considering climatic yield potential, yield target, and availability of nutrients from all possible indigenous sources which generally vary from site to site. The recommendations using SSNM ensure the application of the right amount of fertilizers at a time when it is required by the plant so that the losses are minimized. Field experiments conducted in several parts of south Asia indicated 30–40% increase in the N-use efficiency of irrigated rice following SSNM based N application. Site-specific nutrient management involves the use of decision support tools for nutrient recommendations and other tools such as leaf color chart, Soil Plant Analysis Development (SPAD) chlorophyll meter, green seeker for real-time nitrogen management for synchronizing the demand and supply.

4.2.5.1 Rice crop manager (RCM)

A web-based site-specific nutrient management tool, rice crop manager (RCM) which is based on the principles of site-specific nutrient management, has been developed jointly by International Rice Research Institute, Philippines; ICAR-National Rice Research Institute, Cuttack and Odisha University of Agriculture and Technology, Bhubaneswar for rice growers of Odisha which gives region-specific NPK recommendation based on crop history. Field evaluation showed that the RCM recommendation provided rice grain yield advantage of 3-14% over farmer's practice (Sharma et al., 2019). The use of RCM in farmers' fields increased rice productivity by 1 t ha⁻¹ than with traditional fertilizer application. In terms of income, there was an increase of around Rs 13000/- ha⁻¹ per season. Nutrient management recommendation based on the SSNM principle is now available through this online decision-making tool for different regions of India. It facilitates farmers and extension workers to take appropriate decisions with respect to fertilizer management for enhanced productivity.

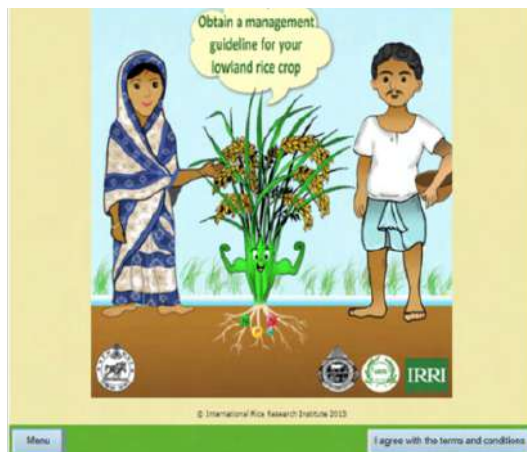


Fig. 4.5 Rice crop manager for SSNM

Source: <http://webapps.irri.org/in/od/rcm>

4.2.5.2 Real time nitrogen management using leaf color chart

Changes in rice leaf color is a sensitive indicator of leaf nitrogen status within a growing season. The change in leaf color can easily be determined by the leaf color chart (LCC), which is a low-cost and user-friendly real-time N management tool. This tool assists farmers in deciding the right time and dose of N fertilization. It contains four or more color panels that vary from yellowish-green to dark green. These color bands match the color range of rice leaves encompassing a continuum from leaf N deficiency to excessive leaf N concentration. A customized leaf color chart (CLCC) has been developed by ICAR-National Rice Research Institute, Cuttack for varieties grown in eastern India, and field trials showed CLCC based N recommendation could save 25% of fertilizer and also decrease N_2O emission by 13-21% in rice (Nayak et al., 2017 and Mohanty et al., 2017).

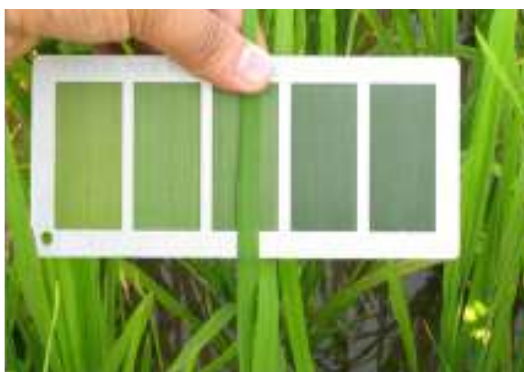


Fig. 4.6 Customized leaf colour chart for real time N management

Source: Authors' own collection

4.2.5.3 Real-time N management using RiceNxpert app

An android based N fertilizer recommendation app- "RiceNxpert" for rice has been developed by ICAR-NRRI (Fig 4.7). This app gives N fertilizer application recommendation as per the crop requirement at the right time and right dose on the basis of leaf color analysis. This app is very simple and easy to use. It provides direct recommendations in terms of urea. The protocol of the use of this app are: (i) capturing photographs of 10 fully expanded healthy rice leaves against the white



Fig. 4.7 RiceNxpert gets direct N recommendation in terms of urea

Source: Authors' own collection

background, (ii) cropping of the captured leaf image, (iii) extraction of R G B values from image, (iv) pantone extraction for corresponding R G B values, (v) comparison with four standard rice leaf colour categories, (vi) N fertilizer recommendation for different ecologies of rice if green color is less than critical standard leaf colour based on pantone. Farmer's field validation of RiceNxpert showed 7-27% enhancement



Fig 4.8 Farmer using RiceNxpert in field

Source: Photograph from Resilience project

in partial factor productivity from applied nitrogen following RiceNxpert recommendation over RDF (Fig 4.8).

4.2.6 Integrated nutrient management

Integrated nutrient management (INM) is the practice of combining both chemical fertilizer and organic manure judiciously and efficiently to supply nutrient to crop as per the requirement. The INM includes practices of green manuring, use of farmyard manure, compost, vermicompost, and other locally available well-decomposed manure, use of biofertilizers, and intercropping with legumes. The major goals of INM approaches are sustaining soil health, mitigating adverse environmental effects of nutrient use, and improving crop productivity in the long run.

4.2.6.1 INM practices for rice production system

Rice is the main crop of Odisha and mainly grown as a lowland crop, where 3-5 cm standing water is maintained. Due to the gaseous losses of N from rice fields, the nitrogen use efficiency is low. Proper integration of organic and inorganic nutrient sources is required for improving nutrient use efficiency and enhancing yield in an eco-friendly manner.

- Application of FYM @ 5 t ha⁻¹ yearly once during *kharif* season and fertilizer NPK @ 80:40:40 kg ha⁻¹ during both *kharif* and *rabi* season has been recommended for the rice-rice system of eastern Odisha for enhancing crop productivity and soil organic carbon sequestration and maintaining soil fertility.

- Green manuring with *dhaincha* and application of urea @ 15 kg N ha⁻¹ three weeks after rice transplanting and @ 15 kg N ha⁻¹ at panicle initiation is *at par* with the prilled urea applied alone in favorable lowland of eastern India.
- The INM practice that involved the application of 50% recommended doses (RD) of nutrients as chemical fertilizer along with 50% RD of nutrients through *dhaincha* green leaf manuring in the wet season and 100% RD of nutrients as chemical fertilizer in *boro* season produced a similar yield as that of 100% RD as chemical fertilizer in both wet and boro season in a rice-rice system.
- Application of *dhaincha* @ of 8 t ha⁻¹ + 100 kg N ha⁻¹ (urea) in three equal splits at basal, active tillering, panicle initiation to rice produced significantly higher grain yield over urea applied alone at the rate of 100 kg N ha⁻¹.
- Integrated application of 75% inorganic N + 12.5% N as FYM + 12.5% N as well decomposed poultry manure performed better in terms of yield than 100% N applied as chemical fertilizer.
- Application of soil-based BGA biofertilizer at the rate of 10 kg ha⁻¹ along with 90 kg urea produced 16% higher yield than 90 kg urea-N alone and *at par* with 120 kg urea-N alone.

4.2.6.2 INM practices for maize production system

Maize being a nutrient exhaustive crop, requires both micro and macronutrients to obtain high growth and yield potentials. Therefore a judicious combination of both organic nutrients and chemical fertilizers is required to attain higher yield and at the same time sustain the soil fertility and productivity. Few widely evaluated INM modules for maize have been mentioned below:

- Full dose of RDF (120- 60-40 kg N-P-K ha⁻¹) + 10 t ha⁻¹ FYM recorded highest cobs/ plant, 1000- grain weight, grain yield, and straw yields of maize.
- Application of 25% recommended dose of fertilizers (RDF) along with *Azotobacter chroococcum*, phosphate solubilizing bacteria, green manuring with *sunnhemp*, and compost at the rate of 10 t ha⁻¹ produced significantly higher grain yield than 100% RDF.

4.2.6.3 INM practices for cotton production system

Cotton, popularly known as ‘White Gold’ is grown as a commercial crop in upland rainfed conditions in the western and southern parts of Odisha. The

productivity of cotton has been stagnating for the last few years due to mono-cropping of cotton in the same land for years and less use of fertilizer and manures. Judicious INM modules for ensuring a higher and stable yield of cotton have been mentioned below:

- Application of 5 t ha⁻¹ FYM + 100% NPK produced higher yield as compared to 100% RDF(80:40:40)
- The INM module including 5 t ha⁻¹ FYM + 2.5 t ha⁻¹ phospho-compost + 50% recommended dose of N produced a comparable yield as that of standard INM practice mentioned above.

4.2.7 Legume-based crop rotation

One of the best and eco-friendly alternatives for plant nutrient management is to include legume in the crop rotation (Figure 4.9). This practice accelerates the soil microbial activity by changing the soil-root-microbe interaction. The crop residue left after harvesting legume crops decomposes and ultimately improves the



Fig. 4.9 Green gram crop after rice

Source: Authors' own collection

physical condition and fertility of soil. Crop rotation with legume crops doesn't need significant additional cost of cultivation and on the other side it fixes substantial amount of atmospheric N in the soil, which is available to the next crop in the cropping sequence. The legume based cropping system is found to be ecologically sound, economically viable and socially acceptable. Legumes are in symbiotic relationships with nitrogen fixing bacteria, and require less synthetic fertilizers. So, the inclusion of legumes within a crop rotation can help reduce overall fertilizer nitrogen use both as a result of reduced direct applications and also as the carryover effect from the legume crop to the following crop (through the decomposition of crop residues). Mung bean inclusion in rice-wheat rotation increased rice grain yield by 10–14% and soil organic carbon (SOC) by 35%. Mung bean inclusion in maize-wheat rotation increased wheat grain yield by 5–11% and SOC by 24%. Replacing wheat with chickpea in rice-wheat rotation increased rice grain yield by 5–8% and SOC by 6% (Ghosh et al., 2020).

4.2.8 Organic manures

Manures are sources of plant nutrients that originated mainly from plant and animal wastes. Organic manures may be bulky or concentrated. The examples of bulky organic manures are: farmyard manure (FYM), compost, green manure, while the example of concentrated organic manure is oil cakes. Besides increasing the availability of nutrients, organic manures improve soil physical properties like soil structure, water holding capacity, *etc.*

4.2.8.1 Farmyard manure(FYM)

Farmyard manure is formed after the decomposition of dung and urine of farm animals. It also consists of litter and left-over material from roughages or fodder fed to the cattle. Average composition of well-decomposed farmyard manure is 0.5% N, 0.2% P_2O_5 and 0.5% K_2O . However, all the available nutrients in FYM are not readily available to crops; about 30% of nitrogen, 60 -70% of phosphorus and 70% of potassium are available to the first crop.

Common methods of FYM (Fig 4.10) preparation are pit method, trench method and heap method. The suitable dimension for the preparation of FYM is 6 to 7.5 m lengths, 1.5 to 2.0 m widths, and 1.0 m depth. While preparing FYM, it must be protected from direct sunlight,



Fig. 4.10 Farmyard manures

Source: Authors' own collection

rain, and runoff losses. Gypsum and superphosphate can also be added during decomposition to reduce N-volatilization losses and enrich the nutrient (Ca, P, S) content in FYM. FYM can be directly be used for field application after 4-5 months of preparation. About 1 tonne of fully decomposed FYM is recommended to 20 cents nursery. Well decomposed FYM is recommended @ 5 t ha⁻¹ at the time of land preparation for rice crop in the main field before sowing in *kharif* season. The application of FYM increases rice grain yield by 11-20% (Shahid et al., 2013).

4.2.8.2 Brown manuring

Brown manuring is a technique of growing *Sesbania* (Fig 4.11) between two rows of standing rice crop and its knockdown with the help of herbicide for manuring. Generally, the seeds of *Sesbania* spp @ 20 kg ha⁻¹ are broadcasted three days after rice sowing and allowed to grow for 30 days, and then killed by spraying 2,4-D. Due to 2,4-D spray, leaves turn



Fig. 4.11 Brown manuring with dhanicha

Source: Authors' own collection

brown in colour because of loss of chlorophyll, and hence termed as brown manuring. Desiccated *Sesbania* crop is left standing in the field along with the main crop without incorporation/ *in-situ* ploughing till its residue decomposes itself in the soil. Hence it is simply a 'no-till' version of green manuring, where an herbicide is used to desiccate the crop before the flowering stage. This practice can supply upto 35 kg N ha⁻¹, and increase yield by 4 -5 q ha⁻¹ due to the addition of organic matter in low fertile soils (Sharma et al., 2014). Over and above its beneficial effect on soil fertility, brown manuring also helps controlling weed growth through its weed smothering effect at the early vegetative stage of rice.

4.2.8.3 Green manuring

Green manuring is practiced in two ways: by growing green manure crops on the field site and incorporation of the same after sufficient growth (*in-situ* green manuring) or by collecting biomass of green manuring crop grown elsewhere (*ex-situ* green manuring). Green manuring is the practice of growing N-fixing plants



Fig. 4.12. Green manuring with dhanicha

Source: Authors' own collection

like *sunnhemp*, dhaincha (*Sesbania aculeata* and *S. rostrata*), cluster beans and their incorporation into the soil. These crops are capable of biological

N-fixation, hence enrich soil fertility. Incorporation and decomposition of green manure have a solubilizing effect of N, P, K, and micronutrients (Zn, Fe, Mn, and Cu) in the soil (Saraf and Patil, 1995). A 6-8 weeks old green manure crop of sunnhemp or dhaincha accumulates about 3-4 t ha⁻¹ dry matter and 100-120 kg N ha⁻¹ and supplements up to 50% of the total N requirement of rice when these are incorporated *in-situ*, besides leaving a significant residual effect on the succeeding crop (Ghosh et al., 2007). Green manuring of *Sesbania rostrata* + 30 kg N ha⁻¹ gave maize yield *at par* with 90 kg N ha⁻¹ alone indicating 60 kg N saving through green manuring (Tiwari et al., 2004). In flooded rice fields, green manuring also reduces the gaseous losses of N as ammonia volatilization by 14-42% (Ghosh et al., 2007). Different crops suitable for green manuring are listed in Table 4.4.

Table 4.4. Different green manuring crops their seed rate, biomass, N accumulation and days of incorporation

Green manure crop	Seed rate	Biomass (t ha ⁻¹ dry basis)	N accumulation (kg/ha)	Days of incorporation
Sesbania	20-40	1.5-4	200-350	45-50
Cowpea	40	3-4	140-150	40-60
Clusterbeans	7-18	5-7	220	45-60
Sunnhemp	35-40	5.5-6	108	50-60

Source: Authors' own compilation

Co-culturing of dhaincha

This technology involves dry direct seeding of rice with dhaincha (paired row) @ 20-25 kg for *Sesbania aculeata* and *S. rostrata* @ 30-40 kg ha⁻¹.



Fig. 4.13 Pair row rice-dhaincha (2:1) ratio in additive series

Source: Authors' own collection

Incorporation of dhaincha by conoweeder is done in the same site when the plants are of 40–45 days old. Incorporation of dhaincha is possible only if adequate water is available in the field; alternatively, if the water is not available, knock down of *dhaincha* is done by the application of 2,4-D. This system of green manuring was found to be promising and increased yields upto 42% (Selvi and Kalpana 2008). The co-culture of *S. rostrata* with rice at 7:1 ratio contributed 16.3 kg N ha⁻¹ (Purushothaman and Padmavathy, 1994).

Green leaf manuring

Green leaves, twigs of trees, shrubs and herbs growing on wastelands and field bunds are collected and applied in the field is known as green leaf manuring. The important plant species useful for green leaf manuring are neem (*Azadirachta indica*, 2.83% N), mahua (*Madhuca longifolia*, 1.66% N), wild indigo (*Tephrosia purpurea*,



Fig. 4.14. Green leaf manure application

Source: Authors' own collection

2.9 – 3.2% N), calotropis (*Calotrophis gigantean*, 2.06% N), glyricidia (*Gliricidia sepium*, 2.76% N), karanj (*Pongamia glabra*, 3.31% N), subabul (*Leucaena leucocephala*, 3.83–4.25% N) and other shrubs. Green leaf manuring improves soil structure, increases water holding capacity, decreases soil loss by erosion, reduces weed growth. It is often recommended for the reclamation of alkaline soils. The application of green leaf manuring enhances rice grain yield by 9.5% (Prakash et al., 2019).

4.2.8.4 Compost

Composts are bulky organic manures prepared from the decomposed product of animal excreta and plant waste. It plays an important role in sustaining soil fertility and also improves soil physico-chemical and biological properties. As a result, it improves the soil water holding capacity, nutrient cycling, and dynamics which ultimately improves the uptake of plant nutrients. This improvement helps in sustaining higher yield, mitigating environmental risks, and enhancing farm income. Application of compost in conjunction with inorganic fertilizer (75% RDF + 25% compost) has been found to produce rice grain yield *at par* with 100% RDF, and thus it can save nitrogen up to 25%

(Kavitha et al., 2007). There are different kinds of compost namely NADEP, aerobic, anaerobic, and vermicompost.

NADEP composting

This method of organic composting uses a wide range of organic materials such as crop residues, weeds, forest litter, and kitchen waste with an end-product of a manure that serves as a good alternative to farmyard manure. This method of composting is best suited for moisture stressed areas during the dry season. The N, P, and K contents of NADEP compost are 0.66%, 0.79%, and 1.15%, respectively. The cost of construction of the tank with brickwork in cement mortar and light thatched roof has been estimated at Rs. 4000-5000/- per unit and the operational cost has been estimated at Rs.1000-1200/- per cycle per plant.

Aerobic composting

This process involves converting organic wastes into compost in aerobic conditions. In aerobic composting, the temperature inside the compost pile rises rapidly to 70-80 °C within the first couple of days. First, mesophilic organisms multiply and the pile temperature ranges between 20-45 °C. Then a few thermophilic fungi and several



Fig. 4.15. Preparation of anaerobic compost

Source: Authors' own collection

thermophilic bacteria carry out the process, raising the temperature of the pile to 65°C or higher. At this temperature, most of the pathogens and weed seeds are killed. This is called the active composting stage which is followed by a curing stage where the pile temperature decreases gradually. During the curing stage, thermophilic fungi start to grow and mediate the decomposition of plant cell-wall materials such as cellulose and hemicellulose. The curing process ensures that the produced compost is matured. The final product is dark brown to black in colour and soil-like in texture. In this process, the amount of humus increases, the ratio of carbon to nitrogen (C:N) decreases, pH neutralizes, and the exchange capacity of the material increases. In this method, the organisms utilized as inoculum for composting are mainly fungi such as *Trichoderma* sp. and *Pleurotus* sp.

Anaerobic composting

This process of compost preparation involves the decomposition of organic materials in anaerobic conditions. The N, P and K contents are 0.90%, 0.83%, and 0.65% in anaerobic compost. The method overcomes many of the disadvantages of aerobic composting, loss of top layer due to high wind, frequent turning, and nuisance of flies. The available refuse on the farm is collected and stored until it forms a sufficient mass for compost making. This utilizes weeds, crop stubbles, or straw, crop residues such as cotton stalks, ground nut husks, leaves, sugarcane trash, urine-soaked earth, and litter from cattle-shed, waste fodder, hedge clipping, *etc.* After three months of decomposition, the mass is taken out of the trench and formed into a conical heap above the ground, moistened with water if necessary, and covered with earth. After another month or two, the manure will be ready for land application.

Phospho-compost and Vermicompost

To enrich the compost with phosphorus, an insoluble source of phosphorus is added to the compost. During the composting process, the microbial activity solubilizes the phosphorus and enriches the compost. Phospho compost contains 1.5-2.0% N, 2.0-3.0% P with C: N ratio 16-18. Phospho-compost is prepared in *kuccha* or reinforced cement concrete (RCC) structure where the composting process is carried out. Waste material like FYM, poultry manure, pig manure, or goat manure is dumped in the structure and mixed properly with rock phosphate. Simply, rock phosphate + raw animal waste + water is used to prepare enriched phospho-compost. Generally in this process, rock phosphate is used @ 5 to 10% depending upon the availability.

Vermicompost is an excellent, nutrient-rich organic fertilizer and soil conditioner that is made through the decomposition of organic residues and animal dung in presence of certain species of earthworm. The vermicompost is not only enriched by nutrient from decomposition but also the activities of microflora in the gut of earthworm add mucus, hormones, enzymes which help in promoting the growth of the plants. The average nutrient content of vermicompost is 0.6–1.2% N, 0.13–0.22% P_2O_5 , 0.4–0.7% K_2O , 0.4% CaO, and 0.15% MgO. One vermiculture unit (12 m x 4 m x 2 m) having three numbers of vermibeds can produce about 3 tons of vermicompost, from which a net profit of Rs. 18300/- may be obtained in 100 days. Vermicompost is applied to rice crop @ 2 t ha⁻¹ and reported to decrease N₂O by 14 to 18% (Wu et al., 2019).

4.2.9 Biofertilizer

Biofertilizers are the substances that contain carrier-based (solid or liquid) microorganism's living or latent cells. They are useful in terms of nutrient mobilization to increase productivity. They increase the nutrient content of host plants when applied as a seed treatment or soil application by colonizing the rhizosphere of the plant. They are more cost-effective as compared to chemical fertilizers. Different types of biofertilizers are discussed below:

4.2.9.1 Free-living N-fixer for non-legume crops

Azotobacter

Azotobacter is a non-symbiotic free-living N-fixing bacterium that supplements the need for nitrogenous fertilizers in non-legume crops. *Azotobacter* inoculants usually contribute 20–30 kg N ha⁻¹ in soil and can save upto 60 kg urea. Efficient *Azotobacter* strains available in the market are *A. vinelandii* and *A. chroococcum* for crops like wheat, sorghum, maize, cotton, mustard, etc. *Azotobacter* is applied through seed treatment, seedling treatment and soil application. In seed treatment, 600 g ha⁻¹ of *Azotobacter* formulation is mixed with water in which the seeds are soaked overnight and then sown in the nursery bed. In seedling treatment, the slurry can be prepared by mixing *Azotobacter* @ 1000 g ha⁻¹ in 40 L of water and rice seedlings are dipped in the suspension for 15–30 minutes before transplanting. For soil application, 3 L in 1000 kg of field soil has to be applied uniformly in the soil and watered well. *Azotobacter* synthesizes auxins, cytokinins, and gibberellic acid-like substances, and these growth promoting materials are the primary substances that control and enhance plant growth, increase crop yield, and maintain soil fertility. Yield increase ranges from 2–45% in vegetables, 9–24% in sugarcane, 0–31% in maize, sorghum, and mustard on *Azotobacter* inoculation under different situations. Inoculation with *Azotobacter* in these crops is reported to decrease global warming potential by 9–13% (Sharma et al., 2016).

Azospirillum

Azospirillum is a gram-negative, non-fermentative, micro-aerophilic, N-fixing bacteria for rice and non-legume crops and used as biofertilizers. *A. brasilense* is an example of an efficient strain of diazotrophic *Azospirillum*. This is most suitable for sugarcane, maize, wheat, rice, and pastures such as *Brachiaria*. *Azospirillum* inoculants usually contribute 20–30 kg N ha⁻¹ in soil. Inoculation with *Azospirillum* benefits plants due to its capacity to fix atmospheric nitrogen and to synthesize phytohormones like indole-3-acetic acid and gibberellins that helps in better root proliferation. Some strains of *Azospirillum* has the

capacity to solubilize fixed phosphorus, and thus enhances its uptake by the plant. Some strains of *Azospirillum* help in the mitigation of abiotic stresses like salinity and drought, by triggering induced systemic tolerance. It is applied through seed treatment, seedling treatment, and soil application. The application method is similar to that of *Azotobacter*.

4.2.9.2 Symbiotic N-fixers

Rhizobium fixes nitrogen symbiotically with legumes, by fixing atmospheric nitrogen in the root nodules and reduce it to ammonia. *Rhizobium* fixes 100-300 kg N ha⁻¹, meets 80% N of crop demand, and increases 10-25% of yield. However, the strains of *Rhizobium* are host-specific, and among crops, the most common symbiotic fixation happens with alfalfa, clovers, peas, beans, etc. For seed treatment *Rhizobium* @ 200 g for 10 kg of seed is recommended for pigeonpea, green gram, black gram, cowpea, groundnut, and soybean. A 10% jaggery (*gur*) solution is used as a sticker. For soil application, 2-3 kg *Rhizobium* is mixed with 40-60 kg manure/soil and applied in 1 acre. The application of *Rhizobium* strains increases yield in groundnut by 11% (Basu et al., 2011), in green gram by 12% (Srivastava et al., 2006).

4.2.9.3 Azolla and blue-green algae (BGA) for low land paddy

Azolla

Azolla is a freshwater fern (pteridophyte) that lives in symbiosis with a diazotrophic cyanobacterium (Fig 4.16). It is found in ponds, lakes, swamps, and streams. After its incorporation into the soil, it can fix atmospheric N into ammonia in association with a blue-green alga. The fixed atmospheric N can be utilized by rice plants.



Fig 4.16. Azolla , azolla nursery and rice –azolla dual culture

Source: Photograph from NRRI rice field

Azolla as green manure (pure crop) is recommended @10-15 t fresh wt ha⁻¹. Less than 5% of the nitrogen sequestered by *Azolla* is available immediately to the growing rice plants, while the rest 95% remains in the *Azolla*'s biomass

(contains 2–5% N, 0.3–6.0% K on a dry weight basis) until the plant dies. *Azolla* can be taken as a dual crop in rice crops which enriches soil nitrogen by 50 kg ha⁻¹ and reduces nitrogen requirement by 20–30 kg ha⁻¹.

Blue Green Algae (BGA)

Blue-Green Algae (Cyanobacteria), are the photosynthetic prokaryotes that are frequently considered as predominant diazotrophs in wetland rice systems. Its recommended application rate is 10–15 kg ha⁻¹ after 7 days of transplanting with 2.5 cm of standing water. By the process of exudation or autolysis and microbial decomposition, nitrogen fixed by these organisms is made available to the rice plants. Potential nitrogen-fixing BGA species in the rice fields of India are: *Aulosira*, *Anabaena*, *Nostoc*, *Anabaenopsis*, *Calothrix*, *Camptylonema*, *Cylindrospermum*, *Fischerella*, *Hapalosiphon*, *Microchaete*, *Westiella*, *Westiellopsis*, and *Tolypothrix*. Apart from biologically fixed nitrogen and adding organic matter to the soil, these organisms excrete growth-promoting substances, solubilize insoluble phosphates, and improve the fertilizer use efficiency of crop plants. BGA has ameliorating effects on saline and saline-alkali soils, and helps increasing soil stability and aggregate size, and narrowing down the C:N ratio of soil. BGA inoculation in the rice field increased yield by 12–19% (Mishra and Pabbi 2004). Its application in rice fields along with inorganic fertilizers saves around 50% of commercial N fertilizer (Paudel et al., 2012). Blue-green algae in association with *Azolla* decrease the N₂O emission by 18–27% from rice fields (Malyan et al., 2019).

4.2.9.4 Phosphate solubilizing microorganisms

Many fungi (*Aspergillus*, *Penicillium*, *Mucor*, *Fusarium*, *Candida* etc.), bacteria (*Bacillus*, *Pseudomonas*, *Micrococcus*, *Flavobacterium*), and actinomycetes (*Streptomyces*) are capable of solubilizing phosphate in the soil. The application of phosphate solubilizing microorganisms increases rice grain yield by 2–10% (Biswakarma et al., 2018). These inoculants save 25% of phosphate fertilizers depending upon the native phosphorus status. Besides saving phosphorus, seed inoculation leads to early germination, augments growth, and also increases the lateral root formation and the volume of roots.

4.2.9.5 Mycorrhizal fungi

These symbiotic fungi colonize the plant roots and play a major role in improving plant growth through nutritional and non-nutritional effects. It enhances the uptake of nutrients such as P, Zn, Cu, and nitrogen and is also known to produce a wide array of plant growth-promoting substances like IAA, IBA, GA that can influence plant growth beneficially. Generally, mycorrhizal

infection increases water transport in host plants due to increase in surface contact of roots through mycorrhiza associated with it. This further helps mobilization of nutrients and enhanced nutrient uptake of mycorrhizal plants, grown in low nutrient soils. Due to higher transpiration rates of mycorrhizal plants, the water uptake and mass flow of soil solution to the root surface are about twice as high as in nonmycorrhizal plants. For inoculating arbuscular mycorrhizal fungi (AMF), de-husked rice seeds are surface-sterilized twice with 5% sodium hypochlorite for 15 minutes and washed with sterile water thoroughly. Then seeds are allowed to germinate on petri dishes. Germinating seedlings are transplanted to 150 mL-cones containing a mix of 63.3% quartz sand, 31.6% soil, and 5% of granular inoculums at a concentration of a minimum 10 propagules per gram of granular inoculum. After 3 weeks of AMF inoculation, seedlings are transplanted in the main field. Inoculation of AMF in rice plants results yield benefit by 28-41% as compared to non-inoculated plants (Campo et al., 2020).

4.2.9.6 Zinc solubilizing bacteria (ZSB)

Zinc is found as a limiting factor in rice production in many agro-climatic zones of the country. Zinc availability may be altered by the microscopic inhabitants of the soil. Increased availability and uptake of zinc in rhizosphere due to the liberation of inorganic ions from the complexed form by microorganisms have been observed.

Few bacterial species in soil have the potential to solubilize insoluble zinc compounds like ZnO , ZnCO_3 , ZnS and sphalerite ore. A zinc solubilizing bacterium (*Bacillus* sp.) isolated from sphalerite ore enhanced the available zinc content of soil and plant uptake upon inoculation. For plant inoculation, bacterial inocula are prepared by growing pure cultures of Zn solubilising bacteria in a suitable nutrient broth. The final concentration of the bacterial suspension is adjusted to 10^8 cfu mL^{-1} . The roots of rice seedlings are thoroughly washed with tap water; surface sterilized in 2% NaOCl for 15 minutes and finally rinsed with sterile distilled H_2O and is inoculated by soaking them overnight in different bacterial inocula maintained at 10^8 cfu mL^{-1} . Inoculation with ZSB increased grain yield by 17% as compared to uninoculated rice plants (Vaid et al., 2014).

4.2.9.7 Silicate solubilizing bacteria (SSB)

Silicon is a beneficial nutrient that imparts mechanical resistance to insect, pest, and disease. The Si nutrition enhances the number of spikelets per panicle, spikelet fertility, and enhances yield. Most of the Si in soil present in

the form of primary silicate minerals. But plants absorb Si in mono-silicic acid form. Silica tends to maintain erectness of leaves and culms thereby increasing photosynthesis. It also increases resistance against pests and diseases. The oxidizing power of plant roots and accompanying tolerance to a higher level of iron and manganese are found to depend on silicon nutrition. Application of silica through silicate minerals and siliceous rice residues increased the grain yield under both upland and waterlogged conditions. The plant could absorb mono-silicic acid and this could arise in soil solution only when depolymerization occurs in soil silicates. Few rhizosphere bacterial isolates were isolated with the capability to solubilize silicates. The organic acid production and polysaccharide production are supposed to create conditions favourable for silica solubilization. For plant inoculation, bacterial inoculum is prepared by growing pure cultures of silicate solubilizing bacteria in a suitable nutrient broth. The final concentration of the bacterial suspension is adjusted to 10^8 cfu mL⁻¹. The roots of rice seedlings are thoroughly washed with tap water, surface-sterilized in 2% NaOCl for 15 minutes, and finally rinsed with sterile distilled H₂O and are inoculated by soaking them overnight in different bacterial inocula maintained at 10^8 cfu mL⁻¹. Silicate solubilizing bacteria can also be applied with siliceous rice residues like straw, husk, and husk ash leading to a rapid breakdown of these residues in the soil. Application of SSB results in an increase in grain yield by 11 % as compared to uninoculated rice plants (Janardhan et al., 2014)

4.3 Nutrient management under abiotic stress

4.3.1 Nutrient management under submergence condition

Single and multi abiotic stress-tolerant rice cultivars have been developed that can withstand drought, submergence, or both to some extent. The advent of submergence tolerant varieties e.g. Swarna Sub1, IR-64 Sub 1, etc. makes it necessary to devise appropriate nutrient management strategies to enhance productivity and reduce yield loss. Some attempt has



Fig. 4.17. Post submergence nitrogen application for enhancing yield

Source: Authors' own collection

been made to develop nutrient management recommendation for submerged rice of flood-prone areas of eastern India and found that application of 20% additional P as basal and post submergence (48 h after de-submergence) application of N, either as soil broadcasting or foliar spray along with additional potassium enhanced the submergence tolerance of high yielding variety introgressed with *Sub-1* (Gautam et al., 2014).

4.3.2 Nutrient management under drought condition

Yield loss in rice due to drought is a serious threat to sustainable rice production. Drought induces oxidative stress in rice crop because of stomatal closure, reduction in dry weight, and formation of reactive oxygen species that damage lipids, proteins, enzymes, and nucleic acids in plant cells. Phosphorus plays a significant role in improving the drought-resistant capacity of crop by enhancing the formation of different antioxidant metabolites such as catalase and peroxidase. Application of P also improves water use efficiency by promoting better root growth in rice plant. Silicon improves the spikelet number, spikelet fertility, and grain weight and enhances yield. Application of P (50% more than the recommended dose), Fe (30 kg ha⁻¹), and Si (200 kg ha⁻¹) under water deficit stress condition resulted in a significant increase in grain yield by 7, 9, and 12%, respectively (Kumar et al., 2019).

4.3.3 Nutrient management under high-temperature stress condition

High-temperature stress is a constraint to rice production and the most detrimental effect is on spikelet sterility. It increases cell damage and thus affects water, ion, and organic solute movement across plant membranes. Spikelets that are exposed to temperatures above 35°C during anthesis for about 5 days during the flowering period remained sterile and set no seed.

External application of boron helps to mitigate the negative effects of high temperature during both vegetative and reproductive crop growth stages. Boron application at 1 and 2 kg ha⁻¹ and 0.2% foliar spray enhanced the rice grain yield by 8-20%, respectively over no boron application (Shahid et al., 2018). Application of N, K, Ca, and Mg increases the concentration of antioxidants such as superoxide dismutase, catalase, and peroxidase in the plant cells, and hence reduce the toxicity of reactive oxygen species (ROS). Potassium and Ca improve the water absorption capacity of plants which in turn regulates the stomatal activity and maintains the temperature leading to enhance temperature stress tolerance in plants. Manganese and Selenium (Se) alleviate the adverse effects of temperature stress by regulating the physiological, biochemical and metabolic processes in the plants.

Application of Se and Salicylic acid can induce temperature stress tolerance by accelerating activities of antioxidant enzymes and preventing damage of membrane by ROS.

4.4 Nutrient-smart management for climate change mitigation, adaptation and crop productivity

Mitigation and adaptation measures and productivity enhancement due to the application of nutrient-smart technologies offer solutions that respond to climate change. Integrated nutrient management and site-specific nutrient management mobilizes nutrients from other sources in addition to chemical fertilizer, thereby reduces GHGs emissions on account of its release during the production process. These techniques rely on the local resources hence help in the adaptation process and enhances productivity by better use efficiency

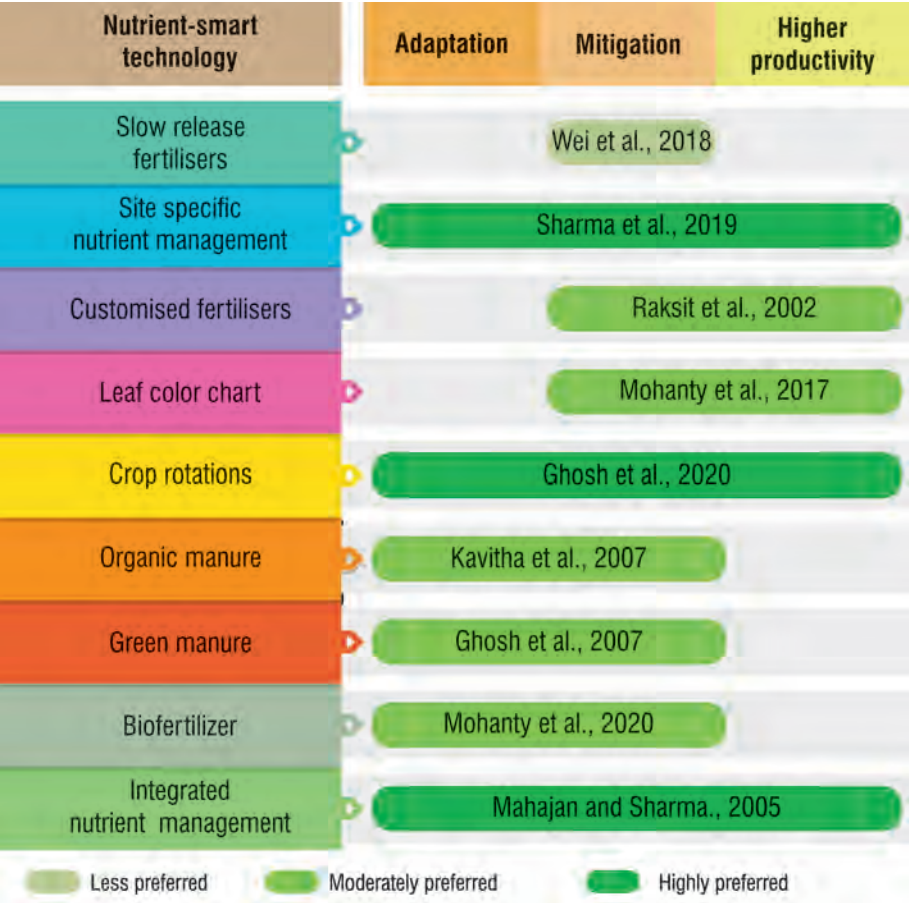


Fig. 4.18. Nutrient-smart technologies and three pillars of CSA
Source: Authors' own analysis

and synchronizing supply and demand. However, the techniques like slow-release fertilizer do not contribute much to adaptation but significantly reduce the N_2O emission from soil. Nutrient-smart management strategies that promote optimal crop production along with its contribution to mitigation and adaptation are presented in Fig 4.18.

4.5 Government schemes promoting nutrient-smart technologies

Both central and state Governments have launched schemes to promote nutrient-smart technologies at the grass-root level that can benefit smallholder farmers of marginal areas with higher vulnerability (Table 4.5). The main purposes of these schemes are to promote nutrient management strategies for sustainable yield in an environmentally safe, economically viable, and socially acceptable manner.

Table 4.5. Nutrient-smart technology supported by Government Schemes

Sl. No	Name of Scheme/ Programme	Nutrient management technology supported by the scheme	Reference
1.	National Mission for Sustainable Agriculture (NMSA)	Soil Health Card	https://nmsa.dac.gov.in/
2.	Integrated Scheme of Oilseeds, Pulses, Oil Palm and Maize (ISOPOM)	Bio fertilizers like Rhizobium culture/Phosphate Solubilizing Bacteria, Azotobacter and Azospirillum culture.	http://dpd.dacnet.nic.in/npdp/default.htm
3.	National Food Security Mission (NFSM) on Pulses, including Accelerated Pulses Production Programme (A3P)	Integrated Nutrient Management and Bio fertilizers.	https://www.nfsm.gov.in/
4.	Mission for Integrated Development of Horticulture	Biofertilizers like Rhizobium/ Azospirillum/Azotobacter, Phosphate Solubilising Bacteria (PSB) and Potash Mobilizing Bacteria (KMB)	https://hortnet.gov.in/
5.	Nutrient Based Subsidy (NBS) Policy (w.e.f. 1.4.2010)	Chemical Fertilizers	http://fert.nic.in/page/fertilizer-policy
6	Soil Health Card Scheme	Soil Health Card	https://www.soilhealth.dac.gov.in

5. Carbon-Smart Technologies

5.1 Introduction

Enhancing food security along with maintaining the natural resource base necessitates the transition of agricultural production systems that are more productive, input efficient, and are more resilient to climate change. With intensive agriculture, there is a clear indication of a decline in the soil organic carbon contents at various places. Carbon-smart farming represents a better method of land management as part of the climate solution. It harnesses the power of soil to sequester atmospheric carbon into underground storage. It offers multiple benefits, is relatively easy to implement, and can positively engage the agricultural sector in climate solutions. Good agricultural practices viz., balanced fertilization and utilization of crop residues could thus promote soil carbon sequestration instead, reversing the role of soil from a carbon source to a carbon sink. Storage of carbon below the ground in the form of soil organic matter may enhance agricultural productivity and resilience to climate change. Converting harvested biomass in the form of recalcitrant carbon instead of completely burning it offers a new avenue to terrestrial carbon sequestration and is called biochar or biomass carbonization. Disruption

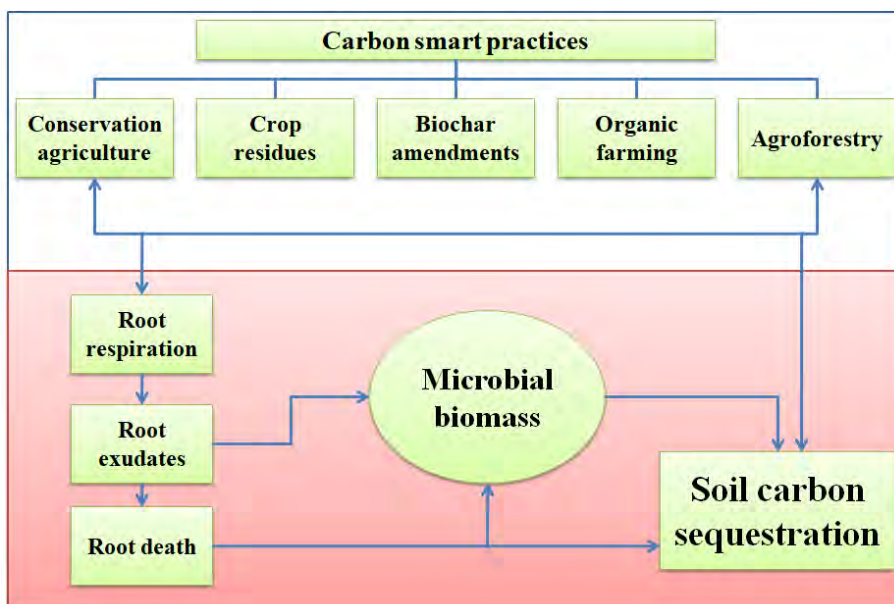


Fig. 5.1 Schematic diagram of carbon sequestration by carbon-smart practices

Source: Authors' own compilation and analysis.

from tillage causes organic carbon material to ascend aboveground, whereby carbon reacts with atmospheric oxygen to form carbon dioxide. Minimizing tillage thus allows carbon to stay within the soil. From research findings, it is evident that improved nutrient management, residue incorporation, compost application, green manuring, crop rotation, reduced tillage, improved irrigation method, organic farming, wasteland restoration, and agroforestry enhance soil carbon content (Fig. 5.1). These practices besides promoting sustainable agriculture, also help to mitigate the harmful effects of climate change by enhancing carbon sequestration and minimizing the emissions of GHGs.

5.2 Conservation agriculture

Conservation agriculture (CA) refers to such management practices that improve and sustain agricultural productivity, increases profits and food security while preserving and enhancing the resource base and the environment. It is characterized by the principles of holistic management of soil, water, and other natural resources to fulfill the objectives of sustainable agricultural production. CA is based on three major principles.

- Minimal soil disturbance (minimum- or zero-tillage) by direct sowing into the soil cover without seedbed preparation.
- Keeping soil permanently covered by residue retention or growing cover crops to protect the soil surface.
- Diversification and adaptation of crop rotations and intercropping for annual and perennial crops.

Conservation agriculture helps to reduce the carbon footprint of the production system, improves productivity, and enhances adaptability. It provides a wider window for sowing operation because of moisture availability for a longer period. The components of CA are briefly described below.

5.2.1 Minimum tillage

Minimum tillage involves minimal soil disturbance compared to conventional tillage. Tillage can be minimized by omitting some of the operations that do not give a reasonable benefit. For example, nursery bed raising can be eliminated and rice seeds can be directly sown in the main field or combining the agricultural operations viz., seeding, and fertilizer application using seed cum fertilizer drill. The minimum tillage is suitable for coarse- and medium-textured soils and the benefits are usually evident after two to three years of practice. However, such practices require specialized equipment. Minimum

tillage reduces soil erosion, increases the soil carbon and nutrient build up in the soil, results in higher macro aggregate content, and increases soil infiltration rate. In maize cultivation, it reduced CO₂ emission by 30% and N₂O emission by 18% as compared to conventional tillage (Forte et al., 2017). Minimum tillage operations also reduce GHGs emissions, save energy, and enhance energy productivity.

5.2.2 Zero tillage

Zero tillage is a form of minimum tillage that completely avoids the primary tillage and secondary tillage is restricted to the opening of furrow/ drilling/ dibbling in the row zone for placing the seeds (Fig. 5.3). Zero tillage accomplishes four tasks such as clean a thin line across the crop row, open a narrow slit for insertion of seed, drop the seeds, and cover the seeds. Major constraints associated with zero tillage are the weed infestation, both in-season and off-season. This needs to be controlled by the sequential application of suitable broad-spectrum herbicides (total killer) before sowing and subsequent application of pre-emergence or post-emergence herbicide after crop establishment. The effect of zero tillage on yield over conventional tillage is highly variable and it was observed that zero tillage in combination with mulching resulted in initial yield decline, and later on increase over the subsequent period, eventually giving higher yields than conventional tillage-based agriculture. Zero-tillage with little soil disturbances



Fig. 5.2 Minimum tillage operation in field

Source: Authors' own collection



Fig. 5.3 Zero till green gram with standing residue

Source: Authors' own collection

enhance and stabilize the soil organic carbon. Besides, it helps in reducing GHGs emissions, saving in energy, and increasing energy productivity. In rice – maize system, practice of zero tillage resulted in 56% reduction in energy consumption, 39% less carbon footprints and 20% less N_2O emission as compared to conventional tillage (Lal et al., 2019).

5.2.3 Mulch tillage

Mulch tillage is a form of conservation tillage that maintains at least 30% of the soil surface covered with crop residue. With the advent of the second-generation farm machineries like “Happy Seeder” (Fig. 5.4), the management of rice straw in the field becomes easy. By using this machine, the rice straw is cut, lifted, the seed is sown and straw is spread over the seeded area as mulch. It is attached to the three-point linkage of the tractor. It has the capability of sowing in the field has a straw load upto $\sim 9 \text{ t ha}^{-1}$. The happy seeder needs to be calibrated and adjusted as per the requirements of seed and fertilizer rate, sowing depth, and as per the crop and field conditions. This technology avoids the need for burning and prevents



Fig. 5.4 Happy Seeder
Source: Authors' own collection



Fig. 5.5 Use of rotavator in a straw anchored soil before sowing of green gram
Source: Adapted from Resilience project

air pollution. It also brings many other benefits including enhancing the soil organic matter, suppression of weeds, and *in-situ* soil moisture conservation. The average cost of field preparation for wheat sowing is Rs. 7,288 ha^{-1} using conventional methods. On the contrary, the cost is only Rs. 1625 ha^{-1} if Happy Seeder is used through custom hiring. The average yield of wheat was 43.3 q ha^{-1} when the Happy Seeder was used compared to the average yield

in conventional method which was nearly equal to 43.8 q ha⁻¹ (Gupta and Somanathan, 2016).

The rotavator can also be used to incorporate the crop residue by chopping it into small pieces and mixing into the soil (Fig. 5.5). The operation of the rotavator with the shield in the lowered position results in a maximum (99%) extent of residue incorporation. The average field capacity of the rotavator was found to be 0.27 ha h⁻¹. This method of sowing with higher residues at the surface reduces number of tillage and pre-sowing irrigation usually required for sowing of succeeding *rabi* crops. The minimum tillage makes little soil disturbances. The direct drilling (zero tillage) operation saves labour input, conserves soil water, reduces energy requirement and cost of cultivation, and maintains soil health. It also facilitates preponing of planting times, thereby ensures escape of reproductive and maturity stages from the terminal heat usually coincides with these stages. This helps to enhance yield and quality of the produce.

5.2.4 Cover crops and crop residues

One of the fundamental principles of the CA is to keep the soil surface covered. This can be achieved either by growing cover crops or retention of previous crop residues at the soil surface (Fig. 5.6 & 5.7). Residues retention is linked to tillage and under no-tillage systems, by definition, residues cover more than 30% of the soil surface while in reduced tillage systems, more than 15% of the soil surface remains covered.



Fig. 5.6 Horsegram - Pre-monsoon cover crop

Source: Authors' own collection



Fig. 5.7 Horsegram cover crop after maize

Source: Authors' own collection

The soil surface may also be covered by raising cover crops. The crops that grow in intervals between two main crops, to cover the soil all the time are called cover crops. Cover crops serve many purposes viz., erosion control, reduction in surface runoff, improvement in soil organic status, better soil structure,

fixation of atmospheric N, weed control, enhancement in soil productivity, and ecosystem biodiversity. Some studies have found that recycling of crop residues in the rice-wheat system increased the rice as well as wheat yields by 13 and 8% and energy efficiency by 13 and 6%, respectively with a decrease in the cost of production, compared to residue retrieval.

5.2.5 Diversification/efficient crop rotation

Crop rotation is considered an essential component of conservation agriculture for achieving higher diversity in crop production. Growing diverse crops in a sequence not only maintains the higher soil microbial diversity but also helps to recycle the nutrients from the deeper layers. One important aspect of crop rotation is it interrupts the pest habitat and pest cycles from a successive monocrop, thus reduces pest and weed infestations. Crop rotation of diverse crops having different rooting patterns in combination with minimum- or zero-tillage promotes macro-pores in the soil, which helps in water infiltration to deeper soil layers and supports extensive channels of root proliferation. Diversification/efficient crop rotation can increase soil C storage under no-tillage. The inclusion of pulses in the rice-rice cropping system helps in improving the soil structure, enhancing the soil organic carbon, increasing biological nitrogen fixation, etc.

5.2.6 Conservation agriculture for rice-green gram cropping system

After rice, greengram is cultivated in a large part of Odisha mostly cultivated under residual soil moisture. This system can be brought under CA by following zero tilled rice and greengram. The detailed package of practices for the zero tillage rice-greengram cropping system is given in Table 5.1. Puddled transplanted rice has harmful effects on the soil condition for the subsequent crops. Zero tillage direct-seeded rice (ZT-DSR) avoids land preparation (dry ploughing or puddling) and reduces the drudgery of transplanting. This practice provides an option to enhance the sustainability of rice-based cropping system (Fig. 5.8). Puddling operation requires lots of water which is a scarce resource and destroys soil structure which adversely affects soil productivity. ZT-DSR solves the problem of seasonal labour shortage for raising nursery and transplanting of seedlings. It also enables the timely establishment of rice and succeeding winter crops (Fig. 5.9). Contrary to the puddled field, ZT-DSR reduces water loss by preferential flow through soil cracks. Surface residue retained in the ZT system moderate the seasonal extreme soil temperature, conserve soil moisture, reduce the emergence of the weeds, and add organic matter & nutrients to the soil. This system of cultivation helps to prepone the

sowing time of subsequent greengram crop thus reduces the cost of tillage and irrigation required for preparatory tillage. Additionally, it helps the crop to avoid terminal heat by maturing 20 days earlier than that under the conventional system. System productivity of rice greengram under CA is *on par* with conventional (CT) system. However, it saves 28.4% of labour and improves 21% of energy productivity. The soil carbon build-up is increased by about 10.7 % after three years of CA over the conventional system



Fig. 5.8 Zero tillage sowing of green gram in standing rice residue
Source: Authors' own collection



Fig. 5.9 Timely establishment of greengram in a zero tilled system
Source: Authors' own collection

Table 5.1 Details of conservation agriculture package of practices for rice-greengram cropping system

Crop Management	Technology
Rice (kharif)	
Seed treatment	Bavistin @ 2 g kg ⁻¹ seed Imidacloprid 70 WS @ 5 g kg ⁻¹ seed
Field preparation	Pre-sowing weed management: glyphosate @ 1.20 kg ai ha ⁻¹ applied at 3 weeks before sowing
Sowing	Seed rate: 40 kg ha ⁻¹ Spacing: 20 cm apart rows Machinery: Zero till seed-cum-fertilizer drill
Fertilizer application	80:40:40 kg ha ⁻¹ NPK Basal application of full dose of PK and 25% of N; 50% N at max. tillering and 25% at PI stage.
Water management	Assured water supply for the first 2 weeks after sowing for establishment. Apply light irrigation with repeated draining. Maintain 3-5 cm standing water during active tillering, heading and grain filling stages.
Weed management	Pendimethalin @ 1000 g ai ha ⁻¹ as pre-emergence after sowing Fenoxaprop-p-ethyl @ 60 g ai ha ⁻¹ as late post emergence (PoE) or, Cyhalofop butyl @ 100 g ai ha ⁻¹ as late PoE

Harvesting	Manual, leaving stubble 30 cm from the ground
Greengram (rabi)	
Seed treatment	Trichoderma (1×10^8 cfu g ⁻¹) @ 5–10 g kg ⁻¹ seed or, thiram 2.5 g kg ⁻¹ seed or, carbendazim 2.5 g kg ⁻¹ seed. Rhizobium culture @25 g kg ⁻¹ seed
Field preparation	Application of glyphosate @ 1.20 kg ai ha ⁻¹ 7 days before sowing
Sowing	Seed rate: 25 kg ha ⁻¹ Spacing: 25 cm row to row, 4-5 cm deep Machinery: seed drill on residue retained plot
Fertilizer application	20:40:20 kg ha ⁻¹ NPK as basal
Water management	1-2 supplemental irrigation if required. Avoid water logging in the field.

Source: Authors' own compilation.

5.2.7 Conservation agriculture for rice-maize cropping system

In most of the irrigated areas of the Odisha, rice is cultivated as *rabi* crop. Transplanted rice-rice system takes a heavy toll on soil structure, reduces soil organic carbon, and increases the pest load in the succeeding crop. This system can successfully be brought under CA by following zero tilled rice-maize systems. The detailed package of practices for zero tillage rice-maize cropping system is given in Table 5.2. It is reported from the experiment at NRRI, Cuttack that under the rice-maize CA system, the overall grain yield of rice is lower (7.5%) compared to conventional practices in the initial years and the difference narrows down over the year and *at par* after 3-4 crop cycle. Maize yield under CA was about 10% higher than the conventional system from the beginning. Conservation agriculture increased energy use efficiency by 19.2%, energy productivity by about 18%, and water use by 80 cm as compared to conventional practices. The annual N₂O flux was reduced by 20% and soil carbon build-up increased by about 17% under CA compared to conventional practices (Lal, 2019).

Table 5.2 Details of conservation agriculture package of practices for rice-maize cropping system

Crop	CA practices
Rice (<i>kharif</i>)	Same as in table no. 5.1
Maize (<i>rabi</i>)	
Herbicide application before sowing	Glyphosate was sprayed @ 1.23 kg ai ha ⁻¹ before 15 days of sowing to clearweeds from the field

Sowing and seed rate	Maize was sown using multi-crop planter/zero till seed drill with rice residue in the field. Maize seed rate of 30 kg ha ⁻¹ was used.
Herbicide application	Atrazine was sprayed @ 0.5 kg ai ha ⁻¹ within 4-5 days after sowing to control the weeds.
Nutrient management	NPK fertilizer (120:50:50 kg ha ⁻¹) with N in three equal splits at sowing, knee-high stage, and tasseling stage. The entire content of phosphorus and potassic fertilizers were applied as basal.
Harvesting	Manual harvesting with and no maize residues in the field.

Source: Authors' own compilation.

5.3 Rice residue management

Crop residues (CRs) comprise the largest part of agriculture's harvest and cereals contribute about 66% of total crop residues. Rice residue is one of the predominant lignocellulosic resources, more than 90% of rice residue is produced in Asia. India generates about 150 Mt of paddy straw annually with 1.0-1.5 kg of residue produced from every kg of harvested grain. Paddy straw contains cellulose (32-40 %), hemicelluloses (16-24%), lignin (5-12%), ash (10-16%) and extractives (8-14%). In general, these residues contain 0.5% nitrogen, 0.2% phosphorus and 1.5% potassium (Singh and Nain, 2014). It is assumed that, if only 50% of crop residues are used as cattle feed and fuel, the remaining residue may have the nutrient potential of about 6.5 Mt of NPK per annum.

Burning of crop residues emits GHGs, causes problems of air-pollution, health hazards, and loss of nutrients and thus is a matter of serious concern. Therefore, CRs should be managed judiciously. About 16% of CRs are burnt on farms, of this 60% is paddy straw and 22% is wheat straw. Recent data showed that during the months of November-December, about 70% source of air pollution in New Delhi and its surrounding cities was due to straw burning. Not only Punjab and Haryana, residue burning is also spreading rapidly over other states of India including Odisha. Primarily, burning causes emission of CO₂, CO, SO_x, NO_x, particulate matter, and CH₄ which increases air pollution and GHGs/ Carbon footprint.

Given the growing problems associated with the burning of crop residues, many steps have been taken to ensure its proper use. Different studies at various institutions advocate alternative uses of residues rather than burning. The rice residue can be used as cattle feed, as bio-energy in bio-thermal power plants,

a basal substrate for cultivation of mushrooms, bedding material for cattle, biofuel production, paper production, biogas, and *in-situ* decomposition. Further, it can also be used in the application of soil and energy technologies. Out of the five different energy conversion technologies which are applicable for rice residue, the combustion technology alone is commercialized, while others are at different stages of development. Conversion of crop residues to biofuel is one of the mitigation options that additionally provides value to farmers. Now, such technologies are available for the proper management of the residues.

5.3.1 Use of residues as a source of soil carbon

Retention and /or incorporation of the crop residues protect the soil surface from the direct impact of wind and raindrops and helps in reducing wind and water erosion, thereby conserving soil moisture. Besides, it adds nutrients to the soil and helps in building soil organic carbon.

5.3.1.1 Mulching

For other crops such as wheat, sugarcane, corn, potato, soybean, sunflower, chili *etc.* rice straw can be used as mulch (Fig. 5.10). On one side, it would improve crop yield in dry land and water stress conditions by conserving soil moisture and on the other hand, could save irrigation water of about 7 to 40 cm. Wheat sowing in residual moisture with rice straw mulching could save around 20% of irrigation water, which is equivalent to 80 kWh of energy (Singh and Sidhu, 2014).



Fig. 5.10 Mulching of rice straw

Source: Authors' own collection

However, on a short-term basis, the addition of rice straw causes elevated emission of CH_4 from the succeeding crop, immobilization of available N, and accumulation of toxic materials in the soil. Generally, neither mulching nor incorporation of straw has recorded a consistently significant effect on N_2O emission, but an enhanced field-based emission of N_2O with mulching was noticed in rice-based cropping system as compared to incorporation. Bhattacharyya et al. (2012) has observed that the use of chemical fertilizers along with rice residue resulted in the buildup of carbon, an increase in

productivity, and enhanced C-sequestration; however, it causes higher emission of GHGs. They suggested using urea fertilizer with rice straw (1:1 N basis) to buildup soil carbon (1.39 Mg ha^{-1}) and improving crop yield besides reduction in the emission of GHGs as compared to using rice residue alone.

5.3.1.2 Rice residue incorporation in soil

After the harvest of rice, the residue left in the field obstructs the sowing of the next crop and residue immobilizes the nutrients and the crop continuously suffers. Handling of rice residues, before sowing wheat crop is considered as a key management problem of the farmers. As a common practice, farmers simply burn the residues in the field to enable the conventional tillage operation for field preparation and sowing of wheat crop. The burning of CRs is not only harmful to soil biota but also affect sustainable crop production and cause atmospheric pollution. The best substitute is to recycle the CRs into the agricultural field for soil health improvement and crop productivity enhancement. To avoid the practice of residue burning in the field, the better alternative would be to cut it into small pieces and mix in the soil. Incorporation of these residues will help in faster decomposition that will increase the availability of the nutrients. It is noticed that maximum residue incorporation was obtained while operating the rotavator with the shield in the lowered position. Farmers of Punjab, Haryana, and Uttar Pradesh have been provided straw management machines at a subsidized price by the Government. The deposition of organic carbon from the incorporation of rice residue into the soil is significant since nearly half of the total carbon is within the straw and stubble (although root C contributes most SOC) of the residue. The major challenge of incorporation of rice residue is the immobilization of soil inorganic N that may cause N-deficiency; however, the combined use of residue and inorganic fertilizer can increase the yield of the subsequent crop.

5.3.1.3 Composting

The crop residues can be applied in the field through *in-situ* and *ex-situ* composting process to improve the nutrient availability and fertility of soil. Due to the high lignin content in the paddy straw, there is limited enzymatic and microbial contact to the cellulose hence requires appropriate composting methods for the preparation of manure. Many composting technologies are available and it requires nearly 60-75 days for complete decomposition of paddy straw (Fig. 5.11).

The composting of agricultural wastes high in lingo cellulose like paddy straw generally takes five to six months to get good and mature compost. The

cultures used for composting are consisting of cellulose-degrading microbes which accelerate the biodegradation of crop residues, even though the time for composting is too long.



Fig. 5.11 Ex-situ decomposition of rice straw
Source: Authors' own collection

5.3.1.4 Mushroom cultivation

Cultivation of edible mushroom is one of the cheapest and economically viable processes for the bioconversion of lingo-cellulosic residues. Mushrooms can convert nutritionally less valued substances like paddy straw into valuable and nutritious human food and animal feed. Various studies recommend the use of paddy straw for cultivating mushrooms of different kinds viz., oyster mushroom (*Pleurotus* spp.), button mushroom (*Agaricus bisporus*), and paddy-straw mushroom (*Volvariella volvacea* and *V. diplasia*) in India. The highest biological and economic yield of Oyster mushroom was obtained from rice straw as compared to other substrate materials tested (Mondal et al., 2010). The highest yield obtained was due to the relatively better availability



Fig. 5.12 Paddy straw mushroom cultivation
Source: Authors' own collection

of carbon, nitrogen, and minerals from the substrate. The rice straw could be used to substitute other substrates in a ratio 1:4 in planted media of oyster mushroom production without any reduction in productivity of white oyster mushrooms (Utami and Susilawati, 2017). It is one of the most suitable substrates for the cultivation of milky white mushrooms (Fig. 5.12).



Fig. 5.13 Training on production of mushroom

Source: Authors' own collection

Paddy straw mushroom is considered to be the third most dominant cultivated mushroom in the world and this mushroom utilizes a wide variety of cellulosic materials preferably having 40 to 60 C:N ratio. Eastern Indian states viz., Odisha, West Bengal, Jharkhand, part of Bihar and North Eastern states have tremendous potential and scope for the cultivation of paddy straw mushrooms due to easy availability of straw. Use of rice straw for cultivation of *Volvariella* spp. decreases the environmental problem and provides a sustainable means of adding value to rice farmers. Cultivation of *Pleurotus florida* on rice straw has a beneficial effect on digestibility, degradability and increases the nutritional values for animal feed. Even the leftover rice straw after mushroom harvesting may be used again in other crops as manure (after composting) which can further save costs on chemical fertilizers. The spent rice straw owing to its proteinaceous nature and low lignin content has a potential quality feed for ruminants either solely or in combination with other feedstuffs.

5.3.1.5 Biochar amendment

Crop residues can also be used for the production of biochar. The biochar is produced from the crop residues after controlled pyrolysis. This biochar when added to soil as an amendment, not only reduces GHGs emissions but at the same time sequester C for a longer period in soil. However, technical options and the spatial data on field level are needed to fully exploit or understand the potential of the technology for mitigation/adaptation options. Biochar due

to its reactive surfaces and recalcitrant aromatic structure acts as a trap for atmospheric CO₂.

When pyrolysis of rice straw is done, around 50% carbon of the residue is released in the form of gas or volatile compounds that can effectively be utilized as a source of energy for various purposes. Whereas the rest of the carbon in biochar remains in highly recalcitrant form and may contribute towards carbon sequestration upon its application in the soil and creates a win-win situation. Within 10 years of application of fresh crop residue, about 80-90% of the carbon is emitted as carbon dioxide. However, the biochar derived from the crop residue offers the prospects for sequestration of 40-50% of original crop residues thus can be a potential mitigation option (Fig. 5.14). India produces only 1.7 million tons of biochar year⁻¹ (Srinivasarao et al., 2013).

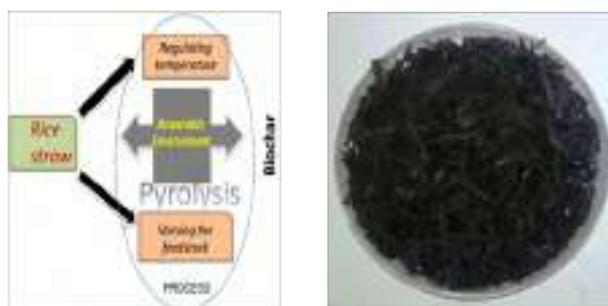


Fig. 5.14 Biochar
Source: Authors' own collection

5.3.2 Rice straw as animal feed

In India, paddy straw is used as fodder since time immemorial. In the eastern part of the country, it is the traditionally most popular form of dry biomass that is given to animals after they are chopped and mixed with green fodder or as a basal diet at animal sheds. It is relatively a poor-quality feed in terms of protein and mineral content which are the two important components of a fodder crop. On average, the crude protein content in rice straw is less than 4%. Although the crude fiber content is approximately 37% and the total ash content is nearly 18%, the major fraction of them is lignocellulose and insoluble ash. Due to these reasons, paddy straw is poorly palatable and thus its intake by animals is low. Different processes involving machines discussed below are now being used to utilize the rice residue as animal feed which needs to be popularized.

5.3.2.1 Rice straw-based animal feed block

Feed block making machine is useful for making animal feed blocks of size 20 cm x 20 cm by mixing rice straw with essential nutritional elements. The machine is powered by a 25 hp electric motor and has a capacity of 250 kg h⁻¹.

It is also available in 125 kg h⁻¹ capacity with a block size of 10 cm x 10 cm operated by 10 hp electric motor. The self-life of the feed blocks is more than one year, very economical to transport to distant places.

The rice straw collected from farmers' field is passed through chaff cutter machine (15 hp capacity) and straw are made into pieces of about 1 to 2-inch size. The essential mineral mixtures (*i.e.* splitted



Fig. 5.15 Mixing unit

(Rice Straw + other ingredients)

Source: Adapted from Indramani et al., 2017

maize grain, green gram, black gram, horse gram, and jaggery) for increasing its nutritional quality and chopped rice straw placed in the mixing machine (5 hp size) (Fig. 5.15 and 5.16). The mixture output from the mixing machine is then passed through the feed block making unit (25 hp size) which then makes feed blocks of 3.5 kg each. And those are ready for selling which is used for animal feeding (cow/buffalo).



Fig. 5.16 Feed block making machine and feed block ready to use

Source: Adapted from Indramani et al., 2017

5.3.2.2 Straw chopper cum bailer

Combine harvesters are gaining popularity day by day in India for the timely harvesting of rice. The combine harvested fields leave high stubbles and straw in the field. For the timely sowing of the next crop without burning of these loose straws, the paddy straw collector cum chopper (Fig. 5.17) is used to pick up it and conveyed to the serrated blade for chopping cylinder, and then the chopped straw is spread in the field.

Straw baling in paddy field harvested by combine harvester is considered as technically and economically beneficial for use as animal feed, biofuel, and other industrial applications. Straw baling technology is very useful for mechanized straw processing and can be achieved in less time. Straw bales are much more efficient and cost-effective for handling, transport, and storage.



Fig. 5.17 a) Combined harvester, b) Straw chopper, c) Straw baler, and d) Paddy straw collector-cum-chopper

Source: Adapted from Indramani et al., 2017

5.4 Organic farming

Organic farming is a production method that avoids the use of inorganic fertilizers, synthetic pesticides, growth regulators, genetically modified organisms, antibiotics, and livestock feed additives. The use of resources from natural sources such as organic manures and bio-pesticides are recommended for the cultivation of crops under organic farming. Organic farming reduces air, soil, and water pollution, and enhances the health and sustainability of the interdependence of plant, animal, and human populations. Organic farming is practiced in an eco-friendly way to produce crops with high nutritional value.

The success of the organic farming system depends on the efficient use of organic manure and other crop wastes, symbiotic nitrogen fixation with

legumes, suitable crop rotation, effective biological pest control, and effective integration of crop and animal husbandry in the system (Fig. 5.18). Organic farming improves soil health and preserves biodiversity. Organic farming also has the potential to mitigate climate change by decreasing the emission of GHGs from the production of chemical fertilizers and enhancing soil carbon sequestration in the system. Energy use



Fig. 5.18 Components of organic farming
Source: Authors' own compilation and analysis.

is also considerably less (about 50% less) under organic than conventional management. The establishment of organic farms requires an inspection and certification by accredited agencies to ensure that the farm meets the minimum standards specified for organic farming and the product has been grown organically. Odisha is the 8th largest organic farming states in India having 118,000 ha covering 2% of the net sown area in the state under organic farming (Khurana and Kumar 2020). The state targets to bring 2 lakhs ha area under organic cultivation in the next 5 years. Though pulses and millets are having natural advantages in the state, there is a tremendous scope for export oriented organic production of turmeric, ginger, coffee, and short grain aromatic rice in the state. Another potential area is organic production of vegetables such as tomato, brinjal, chilli, and pumpkin, which are having demand in the supermarkets. The package and practices for growing some crops organically is given below.

5.4.1 Organic cultivation of rice

5.4.1.1 Seeds treatment

- Dilute 500 mL cow urine in 2.5 L water and soak the seeds tied in small bags for half an hour and then dry in shade.
- Mix 0.5 kg fresh cow dung and 2L cow urine (2L) in 5L of water.
- Soak 10-15 kg seeds firstly in water for 10-12 hours thereafter in the solution of cow dung for 5–6 hours. Dry in shade.

- Treat the seeds with a mixture of *Azospirillum/Pseudomonas/PSM* (200 g 10 kg^{-1} of seed) and 1 L of cooled rice gruel. Dry in the shade for 30 minutes.
- For direct sowing, treat the seeds with a mixture of Beejamrut (200 g kg^{-1} seed) and *Trichoderma viride* (8 g kg^{-1} seed) and then dry in the shade.
- Treat the seeds with *Azospirillum* and PSB bio-fertilizer (each 10 g kg^{-1} seed) and dried again in shade. Sow the treated seeds within 6–8 hours of their treatment.

5.4.1.2 Nursery bed application

Apply 8-10 kg neem cake and 10-15 kg vermi-compost in 800/sq m area during the last land preparation. Pests in the nursery can be managed by application of 4-5 kg ha^{-1} bio-control agent mixture (mixed with well-decomposed farmyard manure) 10-12 days before sowing.

5.4.1.3 Nutrient management

- Sowing of *dhaincha* should be done towards end of May either with pre sowing irrigation or after pre monsoon rainfall. It should be incorporated in the field at vegetative stage around 40-45 DAS or *ex-situ* green manuring with glyricidia leaves @5 t ha^{-1} .
- Apply groundnut or neem cake @ 15 q ha^{-1} as basal manure or
- Apply 5-10 q ha^{-1} vermicompost or
- Apply 1.25 t ha^{-1} goat droppings or 1.25 t ha^{-1} poultry manure.
- The co-culture of *Azolla* (10-15 t fresh weight per ha) with rice can be done.
- 10 kg ha^{-1} blue-green algae can be applied at 6-7 days after transplanting.

5.4.1.4 Insect-pests and disease management

- Variety selected should be well adapted to soil and climatic conditions and possibly be inherently resistant to pests and diseases of the area.
- Application of suspension (2 L 10-12 days old cow urine, extraction of 2 kg fresh cow dung with 2 kg crushed neem leaves or 2 L vermiwash in 10 litres of water) will help in controlling rice blast and sucking insect-pests.
- Spray of 5% neem seed kernel extract or 2 L ha^{-1} neem oil can be done to control leaf-eating caterpillars and leaf folder.
- Rope method along with the spreading of chopped pieces of *Colacasia* and *Citrus grandis* all over the field is used to control rice case worm.

- Light traps can be used to control brown plant hopper and yellow stem borer.
- Frequent drying and flooding practices of the field helps to prevent the incidence of soil-borne pathogens and the incidence of devastating false smut.
- Spreading of fresh leaves of *Cleistanthus collinus* @ 10 kg leaves per 100 m² area all over the field can control gall midge.
- To manage rice blast 1 kg of tulsi leaves is boiled in 2L of water; the solution is strained and sprayed (2 mL L⁻¹ of water) twice at 15 days interval or 10% cow urine extract is applied twice in 10 days interval.
- Rice brown leaf spot can be managed by spraying a mixture of 10% vermin wash or 5% cow urine.
- To manage bacterial leaf blight, prepare a slurry of 50 kg of cow dung in 500 L of water for 1 ha area; and then spray the aliquot.

5.4.1.5 Cropping systems under organic farming

Following cropping systems may be adopted under the organic farming

- Rice- Dolichos bean/ Tomato/ Cucumber/ Red pumpkin/ Carrot - Green manure crops (for seeds)
- Basmati rice- Lentil / Vegetable pea/ Potato / *Brassica napus*/ Chickpea - Sesbania
- Rice- Black gram - Sesame
- Rice- Ground nut

5.4.2 Organic cultivation of vegetables (tomato, brinjal, chilli, and pumpkin)

5.4.2.1. Seed treatment

Before sowing, the seeds are treated with *Trichoderma viride* (4-5 g kg⁻¹ of seed) or *Pseudomonas fluorescens* (10 g) for 24 hours and with *Azospirillum* @ 4 g 100 g⁻¹ seed just before sowing.

5.4.2.2 Nutrient management

Incorporation of 45 days old dhaincha (green manure crop) into the soil is recommended before sowing. Use basal application of FYM @ 25 t ha⁻¹ before the last ploughing of the field. Add admixture of *Azospirillum* and PSB @ 2 kg ha⁻¹ and *Pseudomonas* @ 2.5 kg ha⁻¹ along with FYM @ 50 kg and neem cake @ 100 kg.

5.4.2.3 Insect-pests and disease management

The need-based application of biocides is done to effectively manage insect-pests and diseases. The crop-specific recommendations are given in Table 5.3.

Table 5.3. Crop specific pest and disease management options under organic farming

Crops	Insect-pest and disease management options
Tomato	Fruit borers: Gather and destroy the grown-up larvae on the plants and the fruits which are infected. Plant the American tall marigold of 40 days old and tomato seedling of 25 days old at the ratio of 1:16 in rows. Install pheromone trap (12 in number per hectare) with Helilure. Application of <i>Trichogramma pretiosum</i> @ 1 lakh no./ha/release at the interval of 7 days beginning from initiation of flowering (based on ETL of 10% damage). <i>Helicoverpa armigera</i> is controlled by HaNPV 1.5×10^{12} Polyhedral Occlusion Bodies (POBs)/ha i.e. NPV of <i>H. armigera</i> 0.43% AS @ 3.0 mL L⁻¹ or 2 % AS @ 1.0 mL L⁻¹ and <i>Spodoptera litura</i> is controlled by SI NPV 1.5×10^{12} POBs ha⁻¹. Serpentine leaf miners: Collection and destruct mined leaves. Spray neem seed kernel extract (5%). Leaf eating caterpillars: Plough the field to expose the pupae for killing. Grow trap crop (castor) along border and irrigation channel. Set up a light trap (1 number ha⁻¹) and pheromone traps (Pherodin SL) (15 number per ha) to attract the male moths. Collect and destruct the egg masses and grown-up larvae from castor and tomato. Spray admix of SI NPV @ 1.5×10^{12} POBs ha⁻¹, crude sugar (2.5 kg) and teepol (0.1 %). Thrips: Uproot the diseased plants and destroy them and apply yellow sticky traps @ 15 numbers ha⁻¹. Tomato leaf curl virus: Grow nursery in greenhouse/net house. Use yellow sticky traps @ 12 numbers per ha to control whitefly. Grow barrier crops-cereals around the field. Remove weed host. Tomato mosaic virus: Use healthy seeds from disease free plants. From nursery infected seedlings should be isolated carefully and dumped at far away distance. Rotate the crop in the main field other than tobacco, potato, chili, capsicum, brinjal, etc. Damping-off disease: Use raised seedbed. Provide light and frequent irrigation with well drains. Seed treatment by fungal culture <i>Trichoderma viride</i> (1 g 250 g⁻¹ seed) controls the pre-emergence damping off. Early blight disease: Remove and destruct the crop debris and rotation of crops minimizes the disease incidence. Bacterial wilt management: Rotation of crops (cowpea-maize-cabbage, okra-cowpea-maize, maize- cowpea-maize and finger millet-egg plant) can reduce the wilt.

Crops	Insect-pest and disease management options
Brinjal	• Nematodes can be controlled by the application of 1-2 q acre⁻¹ neem powder. • To control root diseases, dip the seedlings into the mixture solution of 2L cow urine, 1 kg termite soil, 1 kg cow dung into 10 L of water. • Sucking pests can be managed by using yellow and blue colour sticky traps @ 10-25 per acre. • Plant trap crops like marigold, onion, and garlic. • Place <i>Trichogramma</i> eggs @ 20,000 acre⁻¹. • Spray 5% neem seed kernel extract at every 20 days interval to control sucking pests. • To manage fruit and shoot pests, fix pheromone traps in the field immediately after transplanting upto harvesting. • Plant marigold seedling in between brinjal @ 200 acre⁻¹ to control soil-borne diseases.
Chilli	• Root dipping in Beejamrut before transplanting. • Three lines barrier crops like maize, jowar and bajra. • Trap crops like marigold, onion, and coriander to control sucking pest. • Datura leaf decoction can be sprayed for controlling aphids. • Plant 10-12 plants/acre castor plant to control fruit borer. • Use yellow and blue colour sticky traps to control the whitefly pest. • Use pheromone traps to control Spodoptera and Helicoverpa. • Remove weeds at crop surroundings. • Control whitefly and midge fly with the application of 5% extract of neem seed kernel. • Cow dung + cow urine + Ingua mixture application will reduce thrips incident in chilly. • Trichogramma cards @ 5 cards per acre • Fully fermented buttermilk @ 6 L in 100L water spray will reduce bacterial leg spot disease • Spraying of aloe vera + custard apple leaf mixture will reduce the shoot and fruit rot disease in chilly. Spray this mixture at an interval of 10 days two times.
Pumpkin	• Powdery mildew: Mix one tablespoon baking soda, one-and-half teaspoon of non-detergent soap liquid in one gallon of water and spray informally on plants. • Downy mildew: Downy mildew can be controlled by spraying Neem oil 25-30 mL L⁻¹ with emulsifier two times at ten days interval.

Source: Authors' own compilation.

5.4.3 Organic cultivation of root and tuber crops (Sweet potato, ginger, and turmeric)

5.4.3.1 Seed/planting material treatment

Select varieties that are resistant/tolerant to insect-pest, diseases, and nematode infection. Soak the cuttings of sweet potato in a solution of *Azospirillum* (400 g) mixed with water. Use *Trichoderma harzianum* or *T. viride* @ 5 g kg⁻¹ of rhizome for 30 minutes before storage as well as before planting of turmeric. Alternatively, seed treatment can also be done with 1 L cow urine + 100 mL neem oil + 5 L water and soaking of 10 kg seeds in the prepared solution for 30 minutes. A mixture of 1 kg well-decomposed cattle manure/compost with 10 g of *Trichoderma harzianum* is used for ginger.

5.4.3.2 Nutrient management

FYM (25 t ha⁻¹) and *Azospirillum* (20 kg ha⁻¹) can be used for nutrient management in sweet potato. In turmeric, FYM @ 40 t ha⁻¹ along with vermicompost @ 5-10 t ha⁻¹ can be applied at 45 days intervals followed by mulching with green leaves @ 12-15 t ha⁻¹. Oil cakes can also be used @ 2 t ha⁻¹ in turmeric. A study suggests that integrated application of coir compost @ 2.5 t ha⁻¹ with FYM; *Azospirillum*; neem cakes @ 2 t ha⁻¹, compost coir pith @ 5 t ha⁻¹, and PSB enhances the soil quality/health and turmeric yield. For ginger, apply FYM @ 10-12 t ha⁻¹ and vermicompost @ 5 t ha⁻¹ or apply neem cake @ 0.5 t ha⁻¹.

5.4.3.3 Insect-pests and disease management

The need-based application of biocides is done to effectively manage insect pests and diseases. The crop-specific recommendations are given in Table 5.4.

Table 5.4. Crop specific pest and disease management options under organic farming

Crops	Insect-pest and disease management options
Sweet potato	- Sweet potato weevil can be controlled by removing the previous crop residues and destroying the alternate host (<i>Ipomoea sp.</i>). Use healthy planting materials. Loosened the soil at 50 days after planting. At maturity, harvest the crop immediately and destroy the crop residues. - Soft rot can be controlled by seed treatment with <i>Trichoderma</i> @ 5 g kg⁻¹ seed and main field application of <i>Trichoderma</i> incorporation in FYM application to the main field.

Crops	Insect-pest and disease management options
Turmeric	• Leaf blotch and rhizome/root rot can be prevented using healthy planting materials and treatment of <i>Trichoderma harzianum</i> along with neem cake @ 1 kg/bed. • Use of Neem gold (0.5%) or neem oil (0.5%) is effective to control the shoot borers. Spraying should be done during July-October (at 21day intervals). • To control the nematode population, the use of neem cake with the bio-agents like <i>Pochonia chlamydosporia</i> can be beneficial.
Ginger	• To manage shoot borer, use neem kernel powder (0.5%) or neem oil (0.5%) at 21 days interval during the months of September-October. Use formulation of <i>Bacillus thuringiensis</i> (0.3%) during July - October at the same intervals. • Rhizome rot is managed by planting healthy rhizomes. Use soil solarization and <i>Trichoderma harzianum</i> for seed treatment and apply biocontrol agent like <i>Trichoderma viride</i> and <i>Pseudomonas fluorescens</i> during sowing to control the rhizome rot. Apply <i>Trichoderma harzianum</i> along with neem cake @ 1kg/bed to prevent the diseases in the field.

Source: Authors' own compilation.

5.5 Agroforestry

Agroforestry is defined as ‘the integration of woody perennials with herbaceous crops and/or animals over space or time, on the same land management unit’ (Steppler and Nair, 1987). For mitigating the adverse effects of climate change, the adoption of agroforestry systems can also be a viable option for specific situations. It provides timbers and fuelwood which provides a long-term and stable income to the farmers. It acts as a carbon sink and can benefit the poor smallholders the benefits of carbon credits if it is incorporated in a suitable carbon scheme projects. Agroforestry is a realistic and low-cost alternative for implementing many types of integrated land management (which aims to minimize the impacts of human on land), and it adds to a green economy by promoting long-term, sustainable, and renewable forest management, particularly for small-scale producers. About 1500 farmers in Andhra Pradesh and Odisha claimed to be the first in Asia and the second in the world to gain substantial revenue by selling carbon credits. P. Narsimharaju of Garudabili is one such farmer who has received Rs 1.63 lakh (USD 2.960) planting eucalyptus trees on his 60 acres of degraded land (Source: <http://www.worldagroforestry.org/news/indian-farmers-cash-carbon>).

Based on the nature of the components, the agroforestry system in India is classified as agri-silviculture, silvi-pasture, agri-horticulture, agri-silvipasture,

agri-horti-silviculture, homestead agroforestry, and other common agroforestry systems such as agro-psici-silviculture, silvi-apiculture, and pisci-silviculture.

5.5.1 Agri-silviculture system

In this system, crops are intercropped in the interspace of the trees. The food-grain crops can be profitably be taken for up to four years of the plantation. Some shade-loving crops like fodder and shallow-rooted crops can be cultivated economically, beyond four years of plantation. Without compromising the tree population, wider spacing can be adopted that will facilitate inter-cultural activity and bring more sunshine to the intercrops.



Fig. 5.19 Agri-silviculture system
Source: Authors' own collection

5.5.2 Horti-pastoral system

Horti-pastoral system is defined as one of the agroforestry systems which involves the integration of fruit trees with pasture. When a fruit tree is replaced with a top-fed tree, it is called a silvi-pastoral system. The tree species for this system may be chosen so that they are complementary or less competitive for understorey plants. In a horti-pastoral system, fruit trees like mango, guava, and custard apple are planted and seeds of *Stylosanthus hamata* and *Cenchrus ciliaris* are



Fig. 5.20 Horti-pastoral system
Source: Authors' own collection

broadcasted one year later to ensure the good establishment of fruit trees. In a continuous grazing system, a custard apple is an ideal option as livestock does not browse it and it is hardy too. Fruit trees like ber will go very well in combination with pasture, as the foliage is very nutritious.

5.5.3 *Silvi-horti-pastoral system*

In this system grass and legume mixtures along with fruit trees are grown in the interspace between trees. The grass and legume species suitable for this system include *Dicanthium*, *Cenchrus*, *Lasiurus*, *Chloris*, *Panicum*, *Pennisetum*, *Chrysopagon*, *Paspalum*, *Digitaria*, *Heteropagon* etc. Of these *Cenchrus* was found to be good in all areas. Among the legumes *Dolichos*, *Clitoria*, *Centrosema*, *Glycine*, *Vigna*, and *Stylosanthus* were found to be more suitable. Horticultural crops are selected based on their synergy with the plantation crops. For example, incidence of pest and diseases on orange was minimal when grown with *Casuarina*.



Fig. 5.21 Silvi-horti-pastoral system

Source: Authors' own collection

5.5.4 *Agri-horticulture*

Agri-horticulture system is a form of agroforestry in which the fruit trees/vegetables are grown with crops. Intercropping of vegetables in the initial growth stages in the interspaces of fruit trees is a profitable venture. Most of the fruit plants develop full canopy after several years and some of them require regular pruning thus permitting an intercrop. Specifically for the period when crops are not grown, during the off-season, the system helps to generate more employment. Economic return from this system is more as compared to sole cropping system (Malik and Butola 2010). Custard apple, aonla, ber, citrus are some examples of suitable fruit trees. Peas, beans, cauliflower, cabbage are some examples of vegetables grown well in the agri-horticultural system.

The crops like horse gram, cluster bean, green gram, black gram, cowpea, groundnut are grown with tree crops like custard apple, ber, guava grown with the spacing of 5-6 m and mango, jamun, aonla are grown with 8-10 m.



Fig. 5.22 Agri-horticulture systems a) Rice+Guava+Anola, and
b) Anola+Guava+Groundnut
Source: Authors' own collection

It gives an additional yield of $400 - 500 \text{ kg ha}^{-1} \text{ year}^{-1}$ from field crops while prunnings of fruit trees yield fuelwood of around 1 t. However, fruit yields compensate for the decrease in crop production under agri-horticulture compared with sole agriculture.

5.5.5 Silvi-pastoral system

Silvi-pastoral system involves the integration of top-fed tree species with pasture. The trees and shrubs supply livestock fodder, fruit, fuelwood and timber. This system is preferable for the dry area to meet the fodder demand throughout the year. In poor degraded soils, fodder grass including legumes can be planted in the interspace of trees for soil improvement. Trees should be multipurpose, and drought-tolerant and provide, fodder and fuel at regular intervals. *Acacia*, *Dalbergia*, *Leucaena*, *Prosopis*, *Populus*, *Sesbania*, *Tamarix*, etc. are the most suitable top-fed trees under this system. *Stylosanthes hamata* and *Cenchrus ciliaris* were the most suitable under



Fig. 5.23 Silvi-pastoral system
Source: Authors' own collections

the pasture system. The grass-legume mixture is grown along with trees simultaneously to conserve soil moisture and improve soil fertility status.

Agro-climatic zone wise recommended agroforestry system for Odisha is given in Table 5.5 and recommended agroforestry technology for Odisha is provided in Table 5.6.

Table 5.5. Agro-climatic zone wise recommended agroforestry system

Agro-climatic zone	Districts covered	Suitable agroforestry technologies
North-western Plateau	Sundergarh, Deogarh	i. <i>Acacia mangium</i> based silvipasture system ii. <i>Acacia mangium</i> based agri-silvicultural system iii. <i>Acacia mangium</i> + Guava based horti-silvipasture system iv. <i>Acacia mangium</i> + Guava based agri-horti-silvicultural system
North-Eastern Plateau	Mayurbhanj, Keonjhar,	i. <i>Acacia mangium</i> based agri-silvicultural system ii. <i>Acacia mangium</i> based silvipasture system iii. <i>Acacia mangium</i> + Guava based horti-silvipasture system iv. <i>Acacia mangium</i> + Guava based agri-horti-silvicultural system v. Guava + Teak based agri-horti-silvicultural system
North-Eastern Coastal Plain	Balasore, Bhadrak, Jaipur	i. <i>Acacia mangium</i> + Guava based horti-silvipasture system ii. <i>Acacia mangium</i> based agri-silvicultural system iii. Field bund plantation of <i>Acacia mangium</i> / <i>Acacia auriculiformis</i> / Teak
East and South-Eastern Coastal Plain	Cuttack, Kendrapara, Jagatsinghpur, Puri, Khurda, Nayagarh	i. <i>Acacia mangium</i> + Mango based agri-horti-silvicultural system ii. <i>Acacia mangium</i> based agri-silvicultural system iii. <i>Acacia mangium</i> + Guava based horti-silvipasture system iv. <i>Acacia mangium</i> + Guava based agri-horti-silvicultural system v. Field bund plantation of <i>Acacia mangium</i> / <i>Acacia auriculiformis</i> / Teak

Agro-climatic zone	Districts covered	Suitable agroforestry technologies
North-Eastern Ghat	Ganjam, Phulbani, Rayagada, Gajapati,	i. <i>Acacia mangium</i> + Guava based agri-horti-silvicultural system ii. <i>Acacia mangium</i> + Mango based agri-horti-silvicultural system iii. <i>Acacia mangium</i> based agri-silvicultural system iv. Guava + Teak based agri-horti-silvicultural system
Eastern Ghat Highland	Koraput, Nawarangpur	i. <i>Acacia mangium</i> based silvipasture system ii. <i>Acacia mangium</i> based agri-silvicultural system iii. <i>Acacia mangium</i> + Guava based horti-silvipasture system iv. <i>Acacia mangium</i> + Guava based agri-horti-silvicultural system v. Guava + Teak based agri-horti-silvicultural system
South-Eastern Ghat	Malkangiri, parts of Korapur	i. <i>Acacia mangium</i> based agri-silvicultural system ii. Field bund plantation of <i>Acacia mangium</i> / <i>Acacia auriculiformis</i> / Teak
Western Undulating Zone	Kalahandi, Nuapada	i. <i>Acacia mangium</i> based silvipasture system ii. <i>Acacia mangium</i> based agri-silvicultural system iii. <i>Acacia mangium</i> + Guava based agri-horti-silvicultural system iv. Field bund plantation of <i>Acacia mangium</i> / <i>Acacia auriculiformis</i> / Teak
Western-Central Tableland	Bolangir, Boudh, Sonepur, Sambalpur, Bargarh & Jharsuguda	i. <i>Acacia mangium</i> based silvipasture system ii. <i>Acacia mangium</i> based agri-silvicultural system iii. <i>Acacia mangium</i> + Guava based horti-silvipasture system iv. <i>Acacia mangium</i> + Guava based agri-horti-silvicultural system v. <i>Acacia mangium</i> + Mango based agri-horti-silvicultural system
Mid-Central Tableland	Angul, Dhenkanal,	i. <i>Acacia mangium</i> based silvipasture system ii. <i>Acacia mangium</i> based agri-silvicultural system iii. <i>Acacia mangium</i> + Mango based agri-horti-silvicultural system iv. <i>Acacia mangium</i> + Guava based horti-silvipasture system v. <i>Acacia mangium</i> + Guava based agri-horti-silvicultural system

Source: Authors' own compilation.

Table 5.6 Recommended agroforestry technology for Odisha

i. <i>Acacia mangium</i> based Silvipasture System	
Tree Component	<i>Acacia mangium</i>
Boundary/ Block/ in field	In field
Spacing	6 x 2 m ²
Pit size	0.5 x 0.5 x 0.5m ³
Any other management requirement	Basal: DAP-50g, MOP-50 g pit ⁻¹ Chloropyriphos-100 g pit ⁻¹ Top dressing: Urea- 50 g pit ⁻¹ (post monsoon up to 4 years) Pruning: maintained up to 1/3rd plant height.
Intercrop	Guinea/Thin Napier
Planting time	June
Seed rate	2.5 kg ha ⁻¹ (40,000 slips)
Fertilizer	FYM: 5 t ha ⁻¹ , 50:40:40 kg N, P ₂ O ₅ , K ₂ O ha ⁻¹ as basal and 40 kg N ha ⁻¹ after each cut.
Any other management requirement	Spacing: 50cm x 50 cm After planting, first cut at 70-80 days, and subsequent cutting at 45 days interval.
Return / Outcome	Fodder Grass: Guinea/Thin Napier 18-20 t ha ⁻¹ year ⁻¹ with yield recovery of 80-85 % and BCR: 2.17 <i>Acacia mangium</i> Tree (at end of 12 years): Av. 5.0 cft of timber and 0.4 t firewood per tree (Rs 4000-4500/tree). (from 1.0 ha out of 833 trees 600 trees are expected to be survived till harvest)
Any other information	It is suitable, in addition to supplying fodder and timber, for unbunded uplands and waste land. It is capable of improving soil physical condition and soil productivity.
ii. <i>Acacia mangium</i> based agri-silvicultural system	
Tree Component	<i>Acacia mangium</i>
Boundary/ Block/ in field	In field
Spacing	8 x 2 m ²
Pit size	0.5 x 0.5 x 0.5 m ³
Any other management requirement	Basal: DAP-50 g, MOP- 50 g pit ⁻¹ Chloropyriphos-100g pit ⁻¹ Top dressing: Urea-50g pit ⁻¹ (post monsoon up to 4 years) Pruning: maintained up to 1/3rd plant height.
Intercrop	Sesame (1-4 years)
Planting time	June-July, Spacing-30cm x 10 cm
Seed rate	10kg ha ⁻¹

Fertilizer	FYM: 5t ha ⁻¹ ; Fertiliser dose- 30:20:20 kg ha ⁻¹ Basal: 50% N, full of P ₂ O ₅ and K ₂ O, rest 50% N at 1 st hoeing and weeding
Any other management requirement	Turmeric/Arrowroot (5-8 years) Turmeric: Spacing- 30cm x 25cm Seed rate– 2t ha ⁻¹ , FYM– 10t ha ⁻¹ Planting size- 20 to 25g sprouted bits. Planting time- May N: P ₂ O ₅ :K ₂ O - 60:30:90 kg ha ⁻¹ 50%N at 45 DAP, Full P ₂ O ₅ & 50% K ₂ O at planting. Rest 50% N and 50% K ₂ O at 90 DAP. Mulching-Twice (45 & 90 DAP) Arrowroot: Spacing FYM- 5 t/ha, Fertiliser Dose- 100:60:60 kg ha ⁻¹ Azotobacter and PSB -5 kg ha ⁻¹ Pineapple(9-12 years): Planting time: July-Aug, Spacing:75cm x 60 cm Pit: 10 cm deep holes FYM: 5t ha ⁻¹ Basal: 12g N(6 split), 4g P ₂ O ₅ and 12g K ₂ O (2 split)
Return / Outcome	1-4 years: Sesame: 0.6-0.7 t ha ⁻¹ year ⁻¹ with yield recovery of 80-85 %, BCR: 1.62 5-8 years: Arrowroot: 5.5-6.5 t ha ⁻¹ with yield recovery of 85-90 %, BCR: 2.07 / Turmeric: 6-7 t ha ⁻¹ year ⁻¹ with yield recovery of 85-90 %, BCR: 2.24 Colocasia: 6.5-7.0 t ha ⁻¹ year ⁻¹ with yield recovery of 85-90 %, BCR: 1.96 9-12 years: Pineapple: 9-10 t ha ⁻¹ year ⁻¹ with yield recovery of more than 100 %, Net return 1.0 lakhs/ha/year and BCR: 2.45 <i>Acacia mangium</i> Tree (at end of 12 years): Av. 5.0 cft of timber and 0.4 t firewood per tree (Rs 4000-4500/tree). (from 1.0 ha out of 625 trees 500 trees are expected to be survived till harvest)
Any other information	This agroforestry system ensures food security besides providing fuel wood and timber helps in maintaining better soil health.
iii. <i>Acacia mangium</i> + Guava based horti-silvi-pasture	
Tree Component	<i>Acacia mangium</i>
Boundary/ Block/ in field	In field
Spacing	6 x 6 m ²
Pit size	0.5 x 0.5 x 0.5m ³

Any other management requirement	Basal: DAP-50g, MOP-50g pit ⁻¹ Chloropyriphos-100g pit ⁻¹ Top dressing: Urea-50g pit ⁻¹ (post monsoon up to 4 years) Pruning: maintained up to 1/3rd plant height. Guava: Spacing-6mx6m, Pit- 75cmx75cm Planting: July-Aug, FYM: 2 baskets Basal: N-60g, P ₂ O ₅ - 30g and K ₂ O- 60g pit ⁻¹ (July) Top dressing- -do- (October)
Intercrop	Guinea/Stylo
Guinea	
Planting time	June
Seed rate	2.5 kg ha ⁻¹ (40,000 slips)
Fertilizer	FYM: 5 t ha ⁻¹ , 50:40:40 kg N, P ₂ O ₅ , K ₂ O ha ⁻¹ as basal and 40 kg N ha ⁻¹ after each cut
Any other management requirement	Spacing: 50cm x 50 cm After planting, first cut at 70-80 days, and subsequent cutting at 45 days interval.
Stylo (<i>S. hamata</i>)	
Planting time	June-Sept
Seed rate	6kg (line), 10 kg (broadcasting)
Fertilizer	FYM: 5 t ha ⁻¹ , Dose: 20 :60:20 kg ha ⁻¹ N: P ₂ O ₅ : K ₂ O first cut at 70-80 DAS & subsequent cut after 60-70days.
Any other management requirement	Spacing: 30cm x 15cm
Return / Outcome	Fodder: Guinea: 18-20 t ha ⁻¹ year ⁻¹ with yield recovery of 80-85 % and BCR 1.8 Stylo: 8-10 t ha ⁻¹ year ⁻¹ with yield recovery of 80-85 % and BCR 1.4 Guava: 3.0 t ha ⁻¹ year ⁻¹ , BCR:1.88 <i>Acacia mangium</i> Tree (at end of 12 years): Av. 5.0 cft of timber and 0.4 t firewood per tree (Rs. 4000-4500/tree). (from 1.0 ha out of 275trees 200 trees are expected to be survived till harvest)
Any other information	It is suitable, in addition to supplying fodder and timber, for unbunded uplands and waste land. It is capable of improving soil physical condition and soil productivity.
iv. <i>Acacia mangium</i> + Guava based agri-horti-silvicultural system	
Tree Component	<i>Acacia mangium</i>
Boundary/ Block/ in field	In field
Spacing	6 x 6 m ²

Pit size	0.5 x 0.5 x 0.5m ³
Any other management requirement	Guava: Spacing-6m x 6m, Pit- 75cmx75cm Planting: July-Aug, FYM: 2 baskets Basal: N-60g, P ₂ O ₅ -30g and K ₂ O- 60 g pit ⁻¹ (July) Top dressing- -do- (October)
Intercrop	Turmeric/Arrowroot (In between 5-12 year old plantation)
Turmeric	
Planting time	May
Seed rate	2 t ha ⁻¹ Planting size- 20 to 25g sprouted bits
Spacing	30cm x 25cm
Fertilizer	FYM-10 t ha ⁻¹ , N: P ₂ O ₅ : K ₂ O-60:30:90 kg ha ⁻¹ 50% N at 45 DAP, Full P ₂ O ₅ & 50% K ₂ O at planting. Rest 50% N and 50% K ₂ O at 90 DAP. Mulching – Twice(45 &90 DAP)
Arrowroot	
Spacing	50cm x 20cm
Fertilizer	FYM- 5 t ha ⁻¹ , Fertiliser Dose- 100:60:60 kg ha ⁻¹ <i>Azotobacter</i> and PSB -5 kg ha ⁻¹
Return / Outcome	<i>Acacia mangium</i> +Guava+Turmeric: Net return Rs.46000/ha/year with BCR 2.31 <i>Acacia mangium</i> +Guava+Arrowroot: Net return Rs.42000/ha/year with BCR 2.20 and <i>Acacia mangium</i> Tree (at end of 12 years): Av. 5.0 cft of timber and 0.4 t firewood per tree (Rs 4000-4500/tree). (from 1.0 ha out of 275 trees 200 trees are expected to be survived till harvest)
Any other information	This agroforestry system ensures food security besides providing fuel wood and timber helps in maintaining better soil health.
v. Guava + Teak based agri-horti-silvicultural system	
Tree Component	Teak
Boundary/ Block/ in field	In field (in between two Guava tree)
Spacing	6 x 6 m ²
Pit size	0.5 x 0.5 x 0.5m ³
Any other management requirement	Guava: Spacing-6m x 6m, Pit- 75cmx75cm Planting: July-Aug, FYM: 2 baskets Basal: N-60g, P ₂ O ₅ -30g and K ₂ O- 60g pit ⁻¹ (July) Topdressing- -do- (October)
Intercrop	Ginger or Turmeric
Ginger	
Planting time	May-June

Seed rate	1t/ha; Planting size- each seed piece should have one or two sprouted bits.
Spacing	25cm x 15cm
Fertilizer	FYM-10 t ha ⁻¹ , N:P ₂ O ₅ :K ₂ O-100:50:50 kg ha ⁻¹ Full P ₂ O ₅ & 50% K ₂ O at planting. 50% N and 50% K ₂ O at 45 DAP, Rest 50% N at 75 DAP.
Any other management requirement	Mulching-Twice (at planting & 60 DAP) with 10 t ha ⁻¹ and 5 t ha ⁻¹ green leaves or straw respectively.
Turmeric	
Planting time	May
Seed rate	2 t ha ⁻¹ ; Planting size- 20 to 25g sprouted bits
Spacing	30cm x 25cm
Fertilizer	FYM – 10 t ha ⁻¹ , N:P ₂ O ₅ :K ₂ O-60:30:60 kg ha ⁻¹ Full P ₂ O ₅ & 50 % K ₂ O at planting. 50% N at 45 DAP, Rest 50% N and 50% K ₂ O at 90 DAP.
Any other management requirement	Mulching-Twice (at planting & 50 DAP) with 10 t ha ⁻¹ green leaves or straw
Return / Outcome	Ginger: 10 t ha ⁻¹ / Turmeric: 19 t ha ⁻¹ + Guava (fruits): 2-3 t ha ⁻¹ from 4 th year onwards Teak: To be harvested after 20-25 years
Any other information	This agroforestry system provides higher income and profit from limited area and due to diversified income minimises risk.
vi. <i>Acacia mangium</i> + Mango based agri-horti-silvicultural system	
Tree Component	<i>Acacia mangium</i> : Top dressing- -do- (September)
Boundary/ Block/ in field	In field
Spacing	6 x 6 m ²
Pit size	0.5 x 0.5 x 0.5m ²
Any other management requirement	Mango: Spacing-6mx6m, Pit- 1m x 1m Planting: July-Aug, FYM: 4 baskets Basal: N-60g, P ₂ O ₅ - 20g and K ₂ O- 60g (July)
Intercrop	Sesame (1-4 years), Turmeric/Arrowroot (5-8 years) and Pineapple (9-12 years)
Sesame (1-4 years)	
Planting time	June-July
Seed rate	10 kg ha ⁻¹
Spacing	30 x 10 cm ²

Fertilizer	FYM – 5 t ha ⁻¹ , N: P ₂ O ₅ : K ₂ O 30:20:20 kg ha ⁻¹ Basal: 50%N, Full of P ₂ O ₅ and K ₂ O, Rest 50% N at 1st hoeing and weeding
Turmeric (5-8 years)	
Planting time	May
Seed rate	2 t ha ⁻¹ ; Planting size- 20 to 25g sprouted bits
Spacing	30cm x 25cm
Fertilizer	FYM – 10 t ha ⁻¹ , -60:30:90 kg ha ⁻¹ 50% N at 45 DAP, Full P ₂ O ₅ & 50% K ₂ O at planting. Rest 50% N and 50% K ₂ O at 90 DAP. Mulching – Twice (45 & 90 DAP)
Arrowroot (5-8 years)	
Spacing	60cm x 50 cm
Fertilizer	FYM – 5 t ha ⁻¹ , N: P ₂ O ₅ :K ₂ O- 100:60:60 kg ha ⁻¹ Azotobacter and PSB – 5 kg ha ⁻¹
Pineapple (9-12 years)	
Planting time	July-Aug
Spacing	75cm x 60 cm
Pit	10 cm deep holes
Fertilizer	FYM – 5 t ha ⁻¹ Basal 12 g N (6 split), 4g P ₂ O ₅ and 12g K ₂ O (2 split)
Return / Outcome	1-4 years: Sesame: 0.6-0.7 t ha ⁻¹ year ⁻¹ with yield recovery of 80-85 %, BCR: 1.62 5-8 years: Arrowroot: 5.5-6.5 t ha ⁻¹ with yield recovery of 85-90 %, BCR: 1.73 / Net Return Rs 22,00 ha ⁻¹ Turmeric: 6-7 t ha ⁻¹ year ⁻¹ with yield recovery of 85-90 %, BCR: 1.60 and Net Return Rs. 20,00 ha ⁻¹ year ⁻¹ 9-12 years: Pineapple: 9-10 t ha ⁻¹ year ⁻¹ with yield recovery of more than 100%, Net return Rs. 87,000 /ha/year and BCR: 2.12 Mango: 1-1.5 t ha ⁻¹ year ⁻¹ (three years onwards, higher yield expected with increase in age of mango tree) <i>Acacia mangium</i> tree (at the end of 12 years): Av. 5.0 cft of timber and 0.4 t firewood per tree (Rs. 4000-4500/tree) (from 1.0 ha out of 275 trees 200 trees are expected to be survived till harvest)
Any other information	This agroforestry system ensures food security besides providing fuel wood and timber helps in maintaining better soil health.
vii. Field bund plantation of silvi trees	
Tree Component	<i>Acacia mangium</i> / <i>Acacia auriculiformis</i> / Teak
Boundary/ Block/ in field	In field bund
Spacing	2m distance from tree to tree in east west direction bunds

Intercrop	Other field crops: (rice, pulses, oilseeds, vegetables, etc.)
Seed rate, fertilizer, irrigation Any other management requirement	With normal package of practices
Return / Outcome	Teak: To be harvested after 20-25 years <i>Acacia mangium</i> to be harvested in 10-12 years <i>Acacia auriculiformis</i> to be harvested in 6-8 years

Source: Authors' own compilation.

5.6 Carbon-smart management practices for climate change mitigation, adaptation, and productivity

Mapping of carbon smart agriculture for their potential synergy with productivity, climate change mitigation and adaptation is required for prioritization of potential CSA. Some of the management practices may not always be having all these three benefits because of the tradeoffs. Carbon smart agriculture technology having one or more than one benefit of CSA such as sustainable food production and climate change mitigation

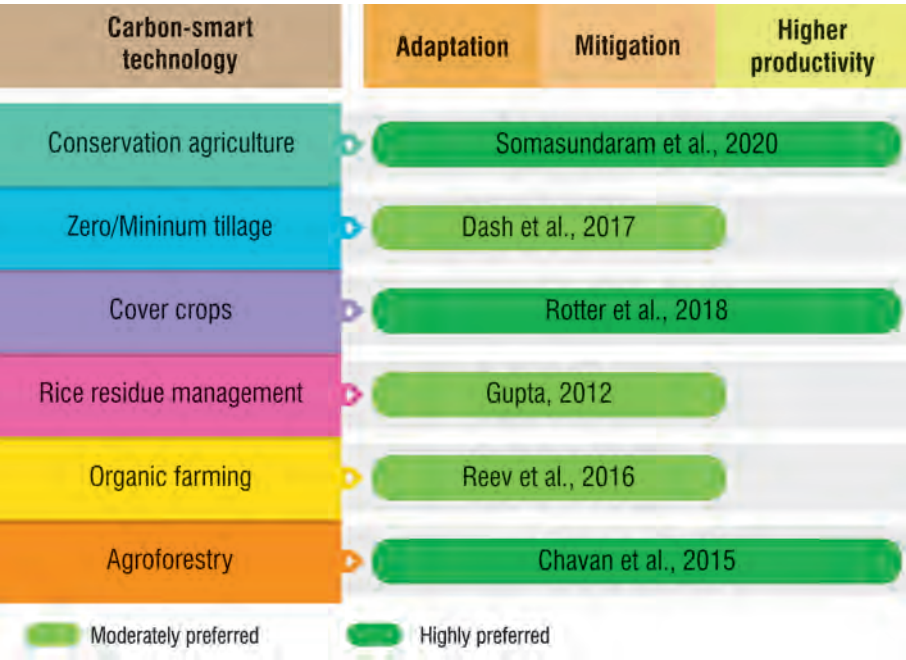


Fig 5.23 Contribution of different Carbon-smart technologies to three components of climate-smart agriculture

Source: : Author's own analysis.

and adaptation is presented in (Fig. 5.23). These practices address the challenges of climate change through several mechanisms that aim to increase photosynthetic and SOC sequestration potential; decrease GHGs emissions and SOC losses; and increase crop production by improving soil properties and natural resources use efficiency. Organic farming, conservation agriculture, and zero tillage/minimum tillage perform the function of both mitigation and adaptation, however, in the initial days there is little decline in the productivity which is made up as time passes.

5.7 Government schemes for supporting carbon-smart technologies

Schemes run by both central and state governments on various aspects related to economics, development, environment, social, *etc.* also deal with some of the aspects of the carbon-smart practices (Table 5.7). The Government of Odisha formulated an Organic Farming Policy to make farming climate-resilient, reduce the risk of farmers and enhance farm income (Odisha organic farming policy 2018). These schemes give incentives and support to adopt some sustainable agricultural practices discussed in this section that led to an increase in carbon sequestration and reduce the emission of GHGs along with an increase in productivity.

Table 5.7 Government schemes for supporting carbon-smart technologies

Scheme/Sub scheme	Carbon smart technologies supported by scheme	Reference
National Food Security Mission (NFSM)	• Crop residue management • Zero tillage • Diversification	https://www.nfsm.gov.in/
National Mission for Sustainable Agriculture (NMSA)/Soil Health Management (SHM) and Sub-Mission on Agroforestry (SMAF)	• Resource conservation technologies • Setting up of state-of-the-art liquid/carrier-based Bio-fertilizer/Bio-pesticide units • Setting up of mechanized compost production unit • Stimulating the growth of agroforestry	https://nmsa.dac.gov.in/
Paramparagat Krishi Vikas Yojana (PKVY)	• Promotion of organic farming in all states and union territories	https://pgsindia-ncof.gov.in/pkvy/index.aspx

Scheme/Sub scheme	Carbon smart technologies supported by scheme	Reference
Mission for Integrated Development of Horticulture (MIDH)/ National Horticulture Mission	- Organic farming - Paddy straw mushroom production	https://midh.gov.in/
National Programme for Organic Production (NPOP) certification	Third party certification of organic products for export and domestic markets	http://apeda.gov.in/apedawebsite/organic/index.htm
Participatory Guarantee System of certification for India (PGS-India)	Certify organic producers (group) for domestic market	https://pgsindia-ncof.gov.in/
National Project on Organic Farming (NPOF)	Promote production and use of organic and biological sources of nutrients and alternative bio-pesticides for organic farming	http://agricoop.nic.in/sites/default/files/gnpof11511.pdf
National Centre of Organic Farming (NCOF)	Nodal quality-control laboratory for analysis of biofertilizers and organic fertilizers	https://ncof.dacnet.nic.in/RTI/RTIASection4.pdf
Sub-Mission on Agroforestry (SMAF) Under National Mission for Sustainable Agriculture (NMSA)	Promote agroforestry for different agro ecological regions and land use conditions	https://nmsa.dac.gov.in/
Odisha State Organic Certification Agency(OSOCA)	Regulatory mechanisms for ascertaining the quality of organic inputs and products	https://www.ossopca.nic.in/Downloads.aspx

Source: Authors' own compilation.

6. Energy-Smart Technologies

6.1 Introduction

Farm productivity depends considerably on power availability and its efficient use. The energy requirement of the agriculture sector is usually fulfilled from fossil fuels, electric power, fertilizer, insecticides, irrigation water, machinery, human and animal energy, seed, manure, *etc.* (Fig 6.1). The energy requirement of the agriculture sector is mostly driven by the size and quality of land holding, extent of mechanization, cropping sequence, and agro-climatic conditions. In various farm operations, agricultural production can be made energy efficient by proper utilization of energy inputs involved. Energy use efficiency in farming is directly or indirectly linked with greenhouse gas (GHG) emissions.



Fig. 6.1 Forms of energy used in agriculture

Source: Authors' own compilation.

Over the decades, there has been a rapid change in farm power use from manual to mechanical. Farm power availability of Indian agriculture increased from 0.25 to 1.84 kW ha⁻¹ from 1951 to 2012 and is projected to increase up to 2.2 kW ha⁻¹ by 2020 (Mehta et al., 2014). The present farm power availability in Odisha is about 1.68 kW ha⁻¹ and it is targeted to increase to at least 2 kW ha⁻¹ in the next five years. The increase in farm power availability has led to several ecological consequences such as increase in fossil fuel burning, GHGs, *etc.* The adoption of mechanized cultivation and the use of heavy machinery lead to higher initial investment, higher energy consumption, and an increase in emission of GHGs. Although the increased power consumption and mechanization are desirable in Indian agriculture, still a higher energy use efficiency is required for enhanced farm energy productivity and the reduced GHGs emissions. Deployment of energy-efficient farm machinery

will reduce fossil fuel needs in the farm sector. Less dependence on fossil fuel and reduction in energy costs lower the cost of cultivation, and increases the farm income, thus perform both adaptation as well as mitigation actions.

6.2 Energy-efficient management practices

Different agricultural operations employ different forms of energy. Tillage operations are highly energy-intensive; heavy tillage operations not only require higher fossil fuel but also results in damage to soil structures causing loss in soil organic carbon and plant nutrients. The farming practices such as conservation tillage involving zero-, minimum- and mulch-tillage are considered energy-efficient farm operations. Similarly, the use of non-conventional energy operated farm machinery such as solar-operated machinery involved for pumping water, spraying pesticides, *etc.* can be used as an energy-saving technology. Other resource conservation technologies *viz.*, permanent raised beds, residue management, *etc.* are also practiced to conserve energy and to increase energy use efficiency. Most of these technologies are both energy as well as carbon-efficient, some of them *e.g.*, minimum-, zero- and mulch-tillage are already discussed in section 5.

6.2.1 Conservation tillage

It includes tillage practices which maintains at least 30% of the soil surface covered with crop residues after planting. Tillage is generally done to create a favourable soil environment by a physical operation to optimize soil conditions for better seed germination, seedling establishment, and optimum crop growth. The conventional practices involve 3-4 tillage operations to split and reorganize the whole topsoil structure to prepare a soil tilth favourable for seed sowing, germination, and optimum seedling establishment. There are many undesired effects of tillage such as higher energy consumption, a decline in soil structural stability, higher surface runoff, and an accelerated water or wind erosion, and a drop in soil organic matter content. These problems favoured the practice of conservation tillage, a system that consumes less energy, and conserves soil and water as compared to conventional tillage. Conservation tillage helps to reduce the carbon footprint of the production system, improves the productivity, and enhances the adaptability providing a wider window for sowing operation because of the better moisture availability for a longer period. Conservation tillage is considered as both carbon-and energy-smart technology. Different types of conservation tillage are minimum-tillage, zero-tillage, and mulch-tillage (discussed in section 5). In rice–maize system, the practice of zero-tillage resulted in a 56% reduction in energy consumption,

39% lesser carbon footprints, and 20% less N_2O emission as compared to conventional tillage (Lal et al., 2019).

6.2.2 *Permanent raised beds*

Alternate ridges and furrows are a system of cultivation where the land is ploughed, harrowed, levelled and then ridges and furrows are formed with the help of furrow openers (Fig. 6.2). 75 to 100 cm wide ridges are formed between furrows. For better drainage of the excess rainwater, the furrows are made along the natural slope of the field (Fig. 6.3).

The preparation of raised beds is done with the help of a disc harrow after preparatory tillage. The raised bed planter opens furrows and makes raised beds simultaneously. After permanent beds are formed, it can be maintained permanently with the minimal need-based reshaping. As per the need of crop to be sown/planted and tire spacing of



Fig. 6.2 Raised bed planter in operation
Source: Jat 2012



Fig. 6.3 Rice planted in furrows and vegetables on raised bed
Source: Mani et al., 2017

tractor, the geometry between raised beds is adjusted. The depth of furrows can be kept at 15 cm. With the help of a planter for permanent raised beds, it is possible to reshape beds and place seeds and fertilizer nutrients in a single operation. If reshaping is not required, the shaper can be removed or raised.

Furrow irrigation is more efficient than flat surface irrigation, and the plant roots inside ridges are well-supplied with moisture and adequate aeration for the plants to grow robust and healthy. Fertilizers are placed on the sides of ridges which gives the higher nutrient use efficiency. Ridges and furrows system is most useful to drain excess flood water during the periods of heavy

rainfall especially in areas with high rainfall. The excess water can be stored in a farm pond strategically located and the water can be used for irrigating crops in the following dry season. Ridges are also useful in semiarid areas when modified to collect rainwater in small pockets. Bed planting encourages water saving, intercropping, and diversification. It also helps in mitigating losses due to abiotic stresses like salinity and submergence. Raised beds with tide ridges play a significant role in *in-situ* soil moisture conservation and also improve crop productivity. Raised beds saved about 15%–24% of irrigation water (Naresh et al., 2014). In lowland ecology of eastern India alternate ridges and furrows system of cultivation is suitable for planting vegetables in ridges and rice in furrows.

6.2.3 Non-puddled transplanting

In absence of well-designed irrigation and drainage system, farmers do have limited control over the decision of irrigation to or drainage from their field. In the lowland rice areas, the rice is usually cultivated either through direct seeding or transplanting. Uncertainty of rain at the sowing time causes water deficit situation or standing water, both interfere in the decision of crop establishment method by the farmers. Lowland rice farming faces the risk of: (i) water deficit stress (if there is lack of timely rain); or (ii) prolonged submergence in fields due to lack of proper drainage. The later situation makes it difficult to practice dry direct sowing, under such situation farmers are forced to go for puddled transplanting which is energy-intensive and destructive tillage practice. Non-puddled method of rice transplanting has been developed and validated that involves the use of broad spectrum herbicide for controlling weeds and reduced tillage (RT) or zero tillage (ZT) with manual or mechanized transplanting (Fig. 6.4). This system can also be practiced under irrigated situation. In rice cultivation, non-puddled transplanting saved fuel and water consumption by 31-76% and 25-26% respectively, compared to conventional tillage (Islam et al., 2012).



Fig. 6.4 Transplanting in non-puddled condition

Source: Authors' own collection.

6.2.4 Energy plantation

It is the practice of planting trees, purely for their use as fuel. In this practice selected trees and shrub species are grown so that they can produce biomass in the shortest possible time (generally 5-10 yrs) and at a minimal cost. The produced biomass satisfies the energy need of the local population. This helps in minimizing the pressure on the consumption of non-renewable sources of energy and also prevents the destruction of the main forest. Trees absorb the greenhouse gas in quantities broadly equivalent to the amount emitted when plant material decay or burned. They are thus called “Carbon neutral” fuel sources. Moreover, planting energy crops helps in creating a “carbon sink” which includes storing carbon in the underground soil through the tree root system.



Fig. 6.5. Different energy plantations on the field bunds

Source: Authors' own collection



Fig. 6.6. Different energy plantations on the dykes

Source: Authors' own collection

Under energy plantation, annual or perennial plants are grown on the field bunds of rice field (Fig. 6.5) or on the dykes of pond based farming system (Fig. 6.6) in lowland to meet the energy demand. The species to be planted should have the following characters: (i) fast growth, (ii) resistance to biotic and abiotic stress, (iii) not preferred by the cattle and other animals for grazing, (iv) high calorific value, (v) absence of deleterious volatiles when smokes come out and (vii) high yield of biomass. In Odisha, the species like *Acacia auriculiformis*, *Acacia mangium*, etc. can be grown on the field bunds. The advantages of such trees are: soil carbon sequestration, less or no emission of

sulphur and less nitrogen dioxide than fossil fuel, lower energy cost per unit area as lower inputs are required as compared to agriculture crops, aesthetic value, windbreak, and shelterbelts, fodder, *etc.*

6.2.5 Energy from rice residue (Biofuel/biogas/bioethanol)

Rice straw being a ligno-cellulosic material considered as a potential source of renewable energy. It can be used for the synthesis of bio-ethanol. This bio-ethanol can be blended with the petroleum fuels in different proportion. The government of India has targeted 10% blending of bio-ethanol with petrol by 2022 and 20% by 2030. The Bharat Petroleum Corporation Limited (BPCL) has established a plant at Bargarh in Odisha for conversion of paddy straw to bio-ethanol. There is a tremendous potential to offset use of fossil fuel with efficient commercial technologies by producing ethanol from bulk crop residues (CRs) in general and rice straw in particular. In the 4th and 5th assessment, Inter Governmental Panel on Climate Change (IPCC) has identified CRs as a source of feed stock for energy to replace fossil fuel (IPCC, 2007; IPCC, 2014).

From each metric ton of dry CRs about 250-350 litres ethanol could be produced. Considering only 20% of the world's rice residue for this purpose, annually 40 billion litres of ethanol can be produced, which is capable of replacing about 25 billion litres of fossil fuel-based gasoline (Jeffery et al., 2011). As a result, about 70 mt of CO₂ equivalent GHGs emission could be reduced per year. But for the exploitation of this ability, large-scale and small-scale commercial machinery/technologies need to be developed. However, this technology would remove the crop residues from the field rather than its return to the soil (against the concept of conservation agriculture). For that harvesting, threshing and transportation mechanism need to be modernized. Additionally, varieties with desirable straw properties should be grown for the production of bio-fuels. Presently, in India about 10% of the total residues of rice is used for the production of bio-energy (NAAS, 2012).

In rice growing tropical world, the production of biogas from rice residue in combination with animal excreta is an age old practice. But over the years its usage has decreased, though it has numerous other advantages. When fermented/composted biogas residue is applied as manure in rice fields, it reduces CH₄ as compared to that of organic manure applied fields. Various studies have demonstrated that bio-energy from the residues has sufficient potential for sustainable energy production and it could cover a considerable amount of the future demand for biomass for energy production.

6.2.6 Solar energy-based equipment

Solar Photovoltaics (Solar PV) can be used in agriculture in a number of ways such as, pumping systems for lifting water from pond, rivers and groundwater, operating the pressurized irrigation system, sprayer, duster, mechanical weeder. Solar heater can be used to dry crops, livestock buildings, and poly-houses used for vegetable farming. Some of the post harvest operations such as threshing and winnowing can be done by using solar PV. Being renewable source of energy, use of solar energy in agriculture reduces pollutions/ GHGs and cost-effective in long run. Odisha receives an average incident solar radiation between 5.4 to $5.6 \text{ kWh m}^{-1} \text{ day}^{-1}$ with 300 clear sunny days every year having 6.65 sunshine hours day^{-1} . This can be effectively used in some of the above mentioned operations.

6.2.6.1 Solar water pumps

For the agricultural purpose, the government of India has launched different schemes to encourage the harnessing of solar power by the installation of solar power operated water pumps (Fig. 6.7). Solar-powered water pumps an excellent alternative to diesel-powered pumps because of the geographical position of India. The solar water pumps require very low maintenance.



Fig. 6.7 Solar Pump

Source: <https://www.economicstimes.indiatimes.com>

They are eco-friendly, as they do not release any harmful gases that pollute the environment. Government support is extended to individual farmers, cooperative groups, farmer producer organizations (FPO), etc. for installation of solar power plants whose capacity ranges from 500 kW to 2 MW . *Sourajalanidhi* scheme is already in operation in the state targeting distribution of 5000 solar pumps to the farmers with upto 90% subsidy.

6.2.6.2 Solar sprayers

Pesticide spraying equipment plays an important role in the application of pesticides. Generally, the power required for spraying is met out from either alone or a combination of human source and mechanical power. Sometimes the

batteries are used for running the motor which operates the pump for discharging the chemicals. But these batteries require electricity for charging them. Because of the inadequate supply of electricity in rural areas, there is greater scope for solar-powered sprayers (Fig. 8). They reduce drudgery and are eco-friendly. These can be quite economical and can be easily afforded by small and marginal farmers.

6.2.6.3 Solar weeders

Removing weed can be an uphill task and also an expensive affair for the agrarian community. It often forces them to explore control measures including the use of hazardous chemicals, risking their lives and health. An alternative to this, solar power operated weeders (Fig. 6.9) can be used. Solar weeding machine is the machine that operates on solar energy. The effective properties of solar-powered weeding machines are suitable for weeding purposes and have no side effects. It avoids the use of any chemicals and hence protects the soil and crops from harmful chemicals. The field capacity of the solar power weeder was reported as 0.175 ha day⁻¹ (Kumari et al., 2019).



Fig. 6.8. Solar Sprayer

Source: <https://www.toolsvilla.com/solar-sprayer-3-in-1.html>



Fig. 6.9 Solar Weeder

Source: <https://www.telanganatoday.com>

6.3 Energy-smart management practices for climate change mitigation and adaptation higher productivity

In the era of climate change, developing countries prefer technologies that offer mitigation and adaptation measures along with productivity enhancement.

These countries are having priorities in securing food and nutritional security, livelihood protection of their people against the impact of climate change. The technologies that address all these three components (Fig. 6.10) are most preferred in such countries. Energy-efficient management practices reduce GHGs emissions as compared to conventional management practices.

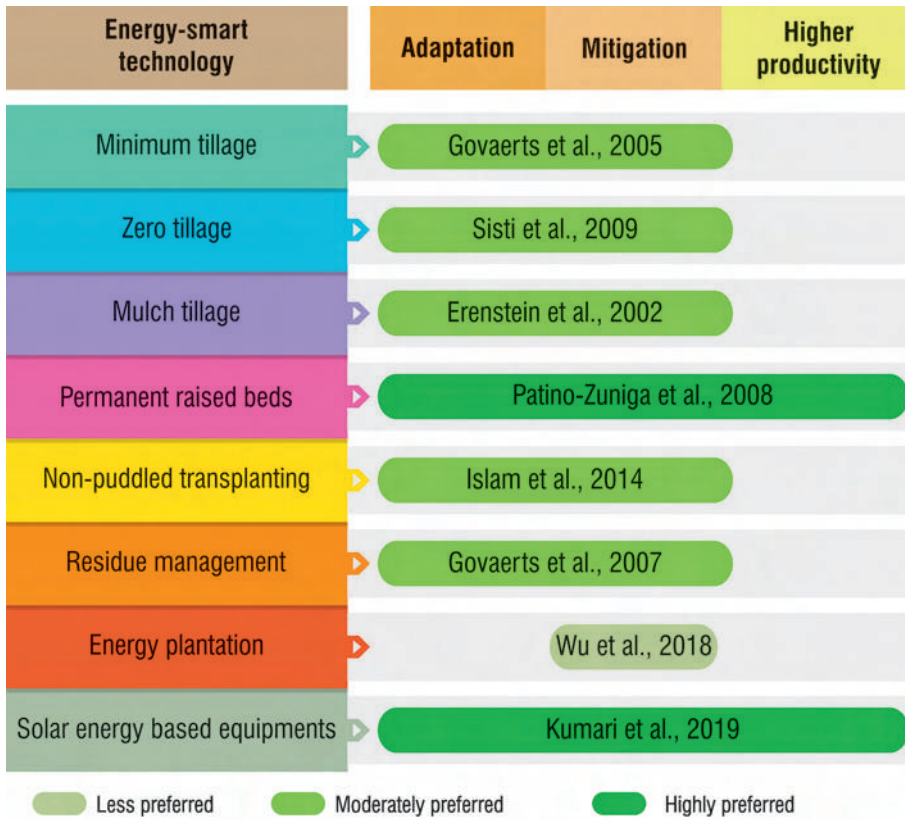


Fig. 6.10 Energy-smart management strategies that promote optimal crop production through climate change mitigation and adaptation.

Source: Author's own analysis.

6.4 Government schemes promoting energy-smart technologies

Both central and state governments have launched schemes to promote energy-smart technologies (Table 6.1) at the grass root level that can benefit smallholder farmers of marginal areas with higher vulnerability. The main purposes of these schemes are to promote management practices for sustaining yield in an environmentally safe, economically viable, and socially acceptable manner.

Table 6.1. Energy-smart technologies supported by government schemes

Sl. No	Name of Scheme/ Programme	Energy-efficient technology supported by the scheme	Reference
1.	Rashtriya Krishi Vikas Yojana (RKVY)	Minimum Tillage, Residue management	http://www.rkvy.nic.in/
2.	National Mission on Agricultural Extension and Technology (Sub-Mission on Agricultural Mechanization)	Minimum Tillage, Residue management	https://agrimachinery.nic.in/GraphReport/SMAMFmtti/SMAMFmtti.aspx
3.	National Food Security Mission (NFSM)	Minimum Tillage, Residue management, Solar energy based equipments	https://www.nfsm.gov.in/
4.	Mission for Integrated Development of Horticulture (MIDH)	Minimum Tillage, Residue management	https://midh.gov.in/
5.	Special Central Assistance to Scheduled Castes Sub- Plan	Minimum Tillage, Residue management	https://vikaspedia.in/social-welfare/scheduled-caste-welfare-1/schedules-caste-sub-plan-scssp
6.	Sourajalanidhi	Promote Solar Photo Voltaic Pump Sets in the remote farming areas	https://odishasolarpump.nic.in

7. Knowledge-smart technology

7.1 Introduction

Knowledge-smart technologies are integrations of promising knowledge and approaches for increasing adoption and developing innovative mechanisms for adaptation and mitigation of climate change. The primary target of the knowledge-smart technologies are small and marginal farmers who are highly vulnerable and have a lesser ability to cope with the impact of climate change. Knowledge-smart technologies like seed bank, fodder bank, crop and cropping system, cropping system intensification, ecology specific varieties need no extra input, rather need to reorient the traditional knowledge to an improved one. Creation of awareness about these technologies by making local management committees or groups by taking diversified stakeholders like farmers, extension officials like agriculture officers, horticultural officers, subject matter specialists from KVKs, and members of active NGOs, SHGs is the primary step for its implementation. Conducting on-farm demonstration, successful field visits and conducting frequent capacity building programs for farmers, and rural youth about these new technologies/practices can prepare them for managing the adverse situation. Technologies like mechanical transplanting and mechanical harvesting of rice help to quickly cover a large area, save the time of operations, utilize effectively the narrow windows of operation thrown by the untimely climatic extremes, and help to prepone the crop establishment during the succeeding season that helps to the effective utilization of residual moisture and escape from the terminal heat. Such operations require equipment that is costly at times and can be made available by subsidizing the purchase on a custom hiring basis. When the crop encounters moderate to severe drought, flood, or cyclone; contingent crop planning helps to either minimize the loss or ensuring quickly making up the loss with appropriate alternate crop planning. Contingent planning suggests the measures for the partially damaged current crops and the planning of next crops in case of complete failure. Knowledge of weed and insect pests management is now available on the digital platform on the website or mobile app and can be accessed over smartphones. These applications enable the farmers to get the right information at right time and make them aware of these smart technologies. Krishi Vigyan Kendras and Village Knowledge Centers (VKC) can be strengthened for the dissemination of knowledge-smart technologies. Detailed discussion on some knowledge-smart technologies are given below.

7.2 Seed treatment and seed priming

The seed is the integral factor in crop production. Seed treatments help to increase germination and ensures uniform seedling emergence, and protect the seedlings from primary soil and seed-borne infestation. Seed treatment involves treating or subjecting seeds to various physical and chemical treatments to safeguard the seed from the soil-borne pathogens and increase the load of beneficial microorganisms in the rhizosphere of the plant to stimulate plant growth. The details of seed treatment for control of insects-pests and seed-borne diseases are discussed under the IPM section. While seed priming is a regulated hydration technique in which seeds are imbibed in water or low osmotic chemical solution and re-dried to its original state in such a way so that the germination related metabolic activities start, but radical emergence does not initiate. Seed treatment and seed priming help the seedling to perform better under adverse condition such as extreme temperature and excess moisture. Different types of seed priming are discussed below.

- (a) *Hydro priming*: Soaking of seeds in water for a certain time. It is suitable for dryland farming. This technique increases vigour, germination percentage, water use efficiency, and uniform seedling growth.
- (b) *Halo priming*: Soaking of seeds with NaCl, KCl, etc. help in germination, seedling vigour under adverse effects of salinity, anaerobic condition, and high temperature.
- (c) *Osmo priming*: Soaking of seeds in an osmotic solution like potassium nitrate, polyethylene glycol (PEG), mannitol, sorbitol, glycerol, etc., for better germination.
- (d) *Solid matrices priming*: It is done with moist sand, diatomaceous earth, vermiculite for a certain period that allows slow imbibition.
- (e) *Natural product priming*: Soaking seeds with water and 2% Jamun (*Syzygium cumini*) leaf extract, mint leaf extract, etc., It improves seedling establishment under flooding. Seed pretreatment with this extract results in accelerated growth with longer seedling and greater accumulation of biomass.
- (f) *Amendment priming*: Priming with liming materials give almost similar effect of liming. Such type of coating in pulse seeds needs the use of stickers like gum acacia and sago for better attachment and it helps in increasing productivity in acid soils.
- (g) *Nutri priming*: Priming the seeds with plant nutrients. It benefits plant by increasing shoot growth, number of leaves, number of tillers, plant

light also helps to cope better with flooding, *etc.*

- (h) *Bio-priming*: Seed treatment with inoculums of beneficial microorganism and regulation of seed hydration for biotic and abiotic stress (Bisen et al., 2015). Seed treatment with microorganisms for nutrient acquisition and availability is presented under the nutrient smart section.
- (i) *Hormonal priming*: Seed treatment with different hormones that encourages growth and development of seedlings. Commonly used hormones are abscisic acid, auxin, ethylene, gibberellins, polyamines, kinetin, and salicylic acid, *etc.*

7.2.1 Seed treatment techniques for cereals

Rice

- For improving germination and seedling vigour, sun-dried seeds are kept in a gunny bag and imbibed in water for 12 h before sowing
- Subject the seeds to biofertilizers like *Azospirillum* / Phosphobacteria / *Pseudomonas* treatment one day before sowing and shade dry for 30 minutes. The recommended rate of biofertilizer is 200 g for every 10 kg of seed.
- Soak the seeds in 10 and 20 ppm aerated solutions of spermidine, putrescine, and spermine (polyamines) for 48-h at 28 ± 2 °C for better germination, early seedling growth, and drought tolerance.
- In P deficit soils, seed treatment with P benefits to seedling shoot growth, larger number of leaves, taller plant, larger number of tillers, and higher P concentration.
- Priming rice seed with CaCl_2 with osmotic potential -1 MPa reduces the injurious effect of salinity stress.
- For imparting resistance against seed-borne pathogens, soak the seeds in cow urine solution (mix 500 ml of urine in 2.5 l of water) for half an hour and shade dry it before one day of sowing.
- For control of *Helminthosporium* leaf spot disease, paddy seeds are soaked in 20% mint leaf extract for 12 h before sowing.

Maize

- Seeds are soaked in 2% *Panchagavya* for 2 h before sowing produce healthy seedlings.
- Biofertilizer (*Azotobacter* & Phosphobacteria) treatment before sowing at the rate of 200 gm each per 10 kg of seed

- Presoaking of seeds for 24 h helps better germination when soil moisture is low, under low temperature
- Seed treatment of maize with the fungicides captan, or etridiazole, or thiram @ 1.5 g kg⁻¹ seed, or combinations of various chemicals like captan + benodanil, or, captan + metalaxyl, or benomyl + fenaminosulf (0.75 + 0.75 g kg⁻¹) is recommended for control of seed born diseases.

Sorghum (Jowar)

- To prevent ergot disease in sorghum, treat the seeds with asafetida solution (10%) before sowing.
- Mix one kg of seed with the extract prepared from 250 g of Ashwagandha, 50 g of Datura leaves before sowing for producing healthy and disease-free seedlings. Sow the seeds after subjecting it to shade dry.
- The sorghum seeds are treated with the sulfur powder @ 4 g of S (particle size 300 mesh) kg⁻¹ of seeds for controlling the smut disease.

Pearl Millet and Finger Millet

- For the production of disease-free seedlings soak seeds in 3-4% Panchagavya solution for 7-8 h before sowing.
- Biopriming with *Pseudomonas fluorescens* enhances plant growth and resistance against downy mildew disease

7.2.2 Seed treatment techniques for pulses

Chickpea

- Soaking the seeds in water before sowing enhances seed germination.
- For enhancing the disease resistance of the crop, coat the seeds with turmeric and sweet flag mixture and sow after 10 minutes. For one kg seed, use 50 g turmeric and 15 g sweet flag with 10 mL of water.
- Before sowing, seeds are coated with mustard oil @ 100 mL 40 kg⁻¹ of seeds to impart resistance against wilt disease.
- Priming of seed with 225 ppm gibberellic acid increases the number of seeds per pod and grain yield.
- Treat the 10 kg of seeds with 250 g *Rhizobium* biofertilizer/phosphate solubilizing bacteria.
- 5 g of *Trichoderma* per kg chickpea can control wilting.

Bengal gram

- Treating the seeds with well-fermented buttermilk before sowing reduces the wilt and dry root rot diseases due to its acidic pH
- Treat 10 kg of seeds with 250 g *Rhizobium* biofertilizer/phosphate solubilizing bacteria for N fixation.

Blackgram and Greengram

- For protection against disease-causing microorganisms, seeds are treated with *Trichoderma viride* @ 4 g kg⁻¹ of seeds or *Pseudomonas* @ 10 g kg⁻¹ of seeds
- Treat 10 kg of seeds with 250 g *Rhizobium* biofertilizer/phosphate solubilizing bacteria for N fixation (Fig. 7.1).
- In acidic soils (pH <5.5) treat seeds with molybdenum (0.1%) for 20 h in the form of ammonium molybdate to encourage nitrogen fixation and nodule formation
- In acidic soil coat the seed with lime (4 kg CaCO₃ for 25 kg seed) using gum acacia or sago as a sticker.



Fig. 7.1 Seed treatment of greengram and blackgram

Source: Authors' own collection

7.2.3 Seed treatment techniques for oilseeds

Groundnut

- Seed soaking in water for 6 h followed by 14 h shade dry and then *Rhizobium* treatment improves germination and maintaining optimum plant population. Treated seed should be sown within 1 or 2 days.

7.2.4 Seed treatment techniques for vegetables

Lady'sfinger

- Soak the seeds with 5% or 10% cow's urine to increase germination percentage, for 12 h before sowing.
- Treat the seeds with *Azospirillum* and Phosphobacteria, each applied @ 60 g in 60 mL of rice gruel utilized for a kg of seeds. It is dried in shade for half an hour before sowing.

Brinjal

- Soak the seeds in 20% cow urine for 30 minutes before the sowing to inhibit seed-borne diseases viz., fruit rot and dieback.
- Treat the seeds with *Trichoderma viride* @ 4 g kg⁻¹ of seeds just before 24 h of sowing.
- Treat the seeds with *Pseudomonas* @ 10 g kg⁻¹ of seeds one day before sowing.

Tomato

- Soak the seeds in milk (20%) for 6 hours prevent seed-borne diseases infection and enhancing germination percentage.
- Treating the seeds with *Trichoderma viride* and *Pseudomonas fluorescens* @ 5 g per 100 g of seeds control early blight and other pathogens.
- Treat the seed with KNO₃ (5%) and NaCl (5%) for enhancement in seedling vigour in tomato.

Banana

- Before planting dip the banana suckers in medium hot water for 30 minutes to prevent root rot and root borer attack.

Bottle Gourd

- Soak the seeds in water one-day before sowing to break the dormancy and to speed up the germination.
- For inhibiting the seed-borne diseases, seeds are soaked in 20% cow's urine for 30 minutes one-day before sowing.
- Seeds are treated with *Trichoderma viride* @ 4 g kg⁻¹ of seeds 24 h before sowing.

7.3 Mechanization in rice cultivation

Mechanized cultivation increases agricultural productivity because of uniform operation within the stipulated time. Timely finishing of agricultural operations, *i.e.*, timely sowing and timely harvesting reduce the loss that occurred due to delayed operations. Presently farm mechanization is in high demand by farmers. Farm power use in agriculture has increased from 0.25 to 1.84 kW ha⁻¹ from 1951 to 2012 and is projected to increase at a rate of 3.5% per annum. Rice being the dominate crop cultivated in almost all the ecology of India. Around 50% of rice farming is rainfed, this makes it more difficult to cover the farming operation within the narrow window that the monsoonal climate provides. Thus, the mechanization of rice farming is an important adaptation option in the context of climate change. Additionally, it reduces production costs by 25-30% and increases profits by 30-35%. Crop establishment, weeding, and harvesting are the operations that require greater attention for mechanization.

7.3.1 Mechanized direct seeding

Mechanized direct seeding of rice is a cost-effective and efficient approach for rice cultivation and it is gaining popularity among farmers mainly because of labour shortages and increasing costs of agricultural production. With the technology advancement in the rice production system, more tools have been introduced to the farmers, which helps them to minimize the cost and time requirement. With the varietal improvement in rice, precision seeding and transplanting of rice are much needed. Precision seeders for the sowing of rice crops are getting worldwide popularity due to their cost-effectiveness and efficiency. Roller type metering unit in precision seeders is most simple, low cost, and easy to adjust during the varying speed of operation (Yoo et al., 2005). The spiral grooved metering device enhances the uniform seeding of paddy seeds (Maleki et al., 2006). Various types of precision seed drills were developed mostly for bold grain crops to get the optimum seed rate, proper line of sowing for better crop establishment, higher yield, and higher returns as compared to traditional systems. The different seeders developed for dry direct sowing and wet direct sowing of rice with different metering units are shown in Table 7.1.

Table 7.1 Different rice sowing machinery with there seed rate and operating parameters

Establishment method	Type of machinery	Metering unit	Rice varieties	Seed rate (kg ha ⁻¹)	References
Dry Direct Seeded Rice	Seed cum fertilizer drill	Fluted roller type	Basmati/ HYV	25 -30	Jat et al., 2009; Saharawat et al., 2010
	Inclined plate planter	Inclined plate metering unit	HYV	15-20	Gopal et al., 2010; Kamboj et al., 2013; Sahu and Verma 2016
	Multi-crop planter	Cup type/ Vertical plate	HYV	15-20	Gopal et al., 2010; Kamboj et al., 2013
Wet Direct Seeded Rice	Drum seeder	Drums	HYV	25- 30	Saharawat et al., 2010; Ratnayake and Balasoriya 2013
	Precision direct seeding machine (Kubota)	Roller type	Hybrid/ HYV	15-25	Zhang et al., 2018
	Precision rice hill drop drilling machine	Combined hole type	Hybrid/ HYV	15-25	Zhang et al., 2018
	Simple type rice direct-seeder	Combined hole-type	HYV	30-40	Zhang et al., 2018
	Vacuum disc rice direct-seeder	Vacuum disc	Hybrid	15	Zhang et al., 2018
	Vacuum drum rice direct-seeder	Vacuum drum	Hybrid	15	Zhang et al., 2018

Source: Authors' own compilation; HYV- High yield variety.

7.3.2 Mechanical transplanting of rice

Rice production is labour, water, and energy-intensive process and is generally grown by transplanting seedlings in the puddled fields. Land preparation and transplanting require about one-third of total man-power needed for rice production (Fig. 7.2). Mechanical transplanting reduces labour requirements and helps timely completion of the crop establishment operations. This helps to adapt



Fig. 7.2 Mat nursery of rice
Source: Authors' own collection.

to the narrow window of crop establishment imposed by climate change. Mechanical transplanting of rice is the process of transplanting young rice seedlings, which have been specifically raised in a mat type nursery, using a rice transplanter. In conventional manual transplanting, 8-12 labourers are required to transplant one acre, whereas mechanical transplanter could transplant up to four acres in a day with 3 labourers. Seedlings are established in a layer of soil: compost mixture arranged on a firm surface (concrete floor/ polythene sheet/ seedling trays). Rice seeds are sown on a thin layer (1.5 - 2.0 cm) of soil and FYM or compost or vermicompost mixture (4:1) in a specifically designed frame or fields by using polythene sheets. The frames or polythene sheets prevent the seedling roots from penetrating the underlying soil and a dense mat is created. The mat raised on the frames is of the desired shape which fits well into the transplanter, however, the seedlings grown on polythene sheet in the field need to be cut into desired shapes and sizes to fit into the trays of the transplanter. The mat nursery needs less land area, can be prepared nearer to the house than traditional field nurseries. Seedling raised in 100 m² (2.5 cents) is sufficient to transplant one hectare. Seedlings are ready for planting within 14-20 days after seeding (DAS). The seedlings are transplanted in the well prepared (puddled) field using the rice transplanters. A rice transplanter is a specialized machine used for transplanting the rice seedlings onto the paddy field. In the transplanter, specially prepared mat-type of nursery is used and the nursery prepared through conventional means is not suitable. The rice transplanter is generally of two types manual and self-propelled (Fig. 7.3). The manual transplanter is walking type and manually

driven, however, self-propelled transplanter can be walking type or riding type and requires mechanical energy. Just before transplanting, seedlings are uprooted like a mat and can be rolled and transported to distant places.



Fig. 7.3 Mechanical transplanting of rice

Source: Authors' own collection.

7.3.3 Mechanical weed control

Weeds competition with rice is higher during the initial stages of crop growth (2-6 weeks after planting). Controlling weeds during this period is very essential for realizing maximum crop yield. Weeding is mostly done manually, which is time-consuming and labour-intensive (Wei et al., 2010) and, therefore, the mechanical weed control method is rapidly gaining ground in the country due to low operational costs and lesser operational time. Details of mechanical weeding are discussed in integrated weed management section 7.4.

7.3.4 Mechanical harvesting

Harvesting and threshing are important operations in crop production which involves a lot of labour and time if done manually. In the event of untimely rain and storm at the time of harvesting the crop is damaged unless harvested and carried to the threshing floor or kept at an elevated place. Sometimes early and quick harvesting is required for making the land free for the field preparation

for succeeding crops. Mechanical harvesting employing reaper, the combined harvester can not only reduce the cost of harvesting on account of less wages due to labour force required but also saves the crop due to untimely storm by quickly harvesting the crop upon forecasting by the weather department. In rainfed farming, the success of the second crop depends on the early sowing harnessing the residual soil moisture. The combined harvester can perform the operations of harvesting, threshing, winnowing, and bagging in one go. These machines enhance the adaptation of farming to climate change hence qualifies as climate-smart agricultural technique.

Mechanical Reaper

Reapers are either hand-driven or mounted on the front of a tractor (Fig. 7.4). It is gaining popularity where labour shortages have occurred. Most reapers lay the crop in a window, which allows easy pick-up of the harvested crop. It reduces the labour requirement and ensures a timely harvest of the crop. Less dependent on field size. However, it is not suitable for the harvesting of the lodged crop. It saves 90% labour and 30% of the harvesting cost. At the speed of operation of 1.2 km h^{-1} the field capacity of self-propelled vertical conveyor reaper having cutting width of 1.2 m is 0.29 ha h^{-1} for cutting of rice crop. The fuel consumption was 5.7 L ha^{-1} and harvesting loss was only 0.98% (Murumkar et al., 2014). For efficient use of reapers, fields need to be leveled and water drained at least 10–15 days before harvest.



Fig. 7.4 Mechanical Reaper
Source: Authors' own collection.

Combine Harvester

A combine harvester is a machine used to efficiently harvest a variety of grain crops. It combines three separate operations viz., reaping, threshing, and winnowing into a single process. It chops the straw into small pieces and spread it back in the field. It is the most economical and labour saving method of harvesting. There are two types of combine harvester i) wheel type and

ii) walk type (Fig 7.5). The machine can harvest 0.64 to 0.81 ha h⁻¹ with a field efficiency of 67.02 to 76.83%. The losses during harvest range from 2.88 to 3.60%. It saves the harvesting cost by 60 to 65% over manual harvest. The cost of this machine ranges from 15 to 20 lakhs. The long-distance moment of the combine harvester is not easy. It is inefficient and not suitable in small size plots and high soil moisture levels.



Fig. 7.5 Different type of combine harvester

Source: Authors' own collection

7.4 Integrated weed management

Integrated weed management (IWM) combines preventive, physical, chemical, biological, and cultural methods of weed control to keep the weeds below the economic threshold level with minimum cost. It is a long-term and system approach, to manage weeds. Herbicide-based weed control or integration of herbicide and mechanical/manual weed control not only reduce the weed thrust but also bring substantial yield improvement. IWM works by preventing seed production, depleting seed bank and destroying vegetative propagules.

The IWM provides a competitive advantage to crop over weeds. Manipulating the crop environment by exploiting the biological variation between crops and weeds through suitable cultural practices that discourage the germination and growth of weeds. *e.g.*, crop rotation, stale bed techniques, and a combination of chemical and mechanical weed control measures. IWM practices are adjustable to new methods and skills of progressive farmers. Herbicides are considered as the last option in IWM. Recently, the use of herbicide mixtures (ready mix/ or tank mix) is mostly promoted. Herbicides can differentiate rice and weeds easily even at the seedling stage, where it is very difficult for people to see the difference.

7.4.1 Climate change and integrated weed management

The variation in response of C3 and C4 plants including weeds to elevated CO₂ and temperature is one of the important aspects in crop/weed competition as most of the weeds and crops are C4 and C3, respectively. Climate change may bring changes in the weed population and their phenology, change in time and duration of crop weed competition, and shift in weed flora. For example, *Ischaemum rugosum* was a common weed in tropical rice-growing areas, but now it has become an important weed in northern states. Thus, alteration in climate particularly in rainfall conditions would alter the occurrence of various weeds. For example, it has been suggested that *Lantana camara* a perennial weed, mostly occurs in wastelands may expand to a new area where high rainfall is received. In the Kaveri delta of Tamil Nadu, due to higher rainfall, the alien invasive weeds, *Leptochloa chinensis* and *Marsilea quadrifolia* dominated over the indigenous weeds, such as *Echinochloa* spp. and some other weeds by virtue of their amphibious adaptation to alternating flooded and residual soil moisture conditions. Thus, IWM practices developed for different crops and ecosystems based on a foundation of knowledge of weed biology and ecology are presented below.

7.4.2 Integrated weed management for different crop

Integrated weed management (IWM) deals with the control of weeds using several weed management techniques such as physical, chemical, biological, and cultural controls. The main advantage of IWM is that it does not allow the weed to grow resistance towards certain chemicals if used for the long-term. Moreover, IWM is designed in such a way so that it can emphasize economically effective control of the weeds keeping all ecological considerations in mind. Besides, IWM is a long term approach that reduces the weed seed bank in the soil. The IWM of different crops are discussed below:

Rice

Preventive measures

- Use certified seeds or clean seed from a known source free from admixture of weed seeds.
- Avoid application of un-decomposed organic manures as it contains viable weed seeds.
- Cleaning seeds by dipping in 2% brine solution (salt solution) helps in the selection of high-density seeds and separation of floating weed seeds.

- Clean all the implements and machinery properly after their use in infested areas and before using them in new areas.
- Off-season ploughing after rice harvest reduces weed seed replenishment.
- Deep summer ploughing once in three years not only exposes the vegetative propagules of certain weeds but also buries the weed seeds at a depth that inhibits germination.

Cultural practices

- Plough the field by rotavator or cultivator to get a fine tilth.
- Remove the weeds and crop stubbles before proper leveling for uniform germination and crop stand.
- In heavily infested areas, adopt a stale seedbed technique.
- Sow either by seed drill or behind plough in rows 20 cm apart with a seed rate of 35-40 kg ha⁻¹ for DSR to ensure optimum crop stand and better canopy cover, thereby suppress the weed growth. For mechanical weed control by power weeder, the spacing between the rows should be 25 cm.
- Avoid basal N application in high weed-infested areas as it stimulates weed growth. Apply the recommended N fertilizer in 3-4 equal splits depending upon the duration starting from 15-20 days after emergence (DAE), and rest at 15-20 days interval, i.e., 35-40 and 55-60 days after sowing.

Chemical measures

- Pre-emergence application of pendimethalin 3 DAE followed by mechanical weed control using finger weeder at 25-30 DAE is found useful in rainfed uplands. However, weeder can be used only in the line-sown crop and enough moisture should be available in the soil during operation.
- Spray bispyribac sodium @ 30 g ha⁻¹ at 8-10 DAE (two-three leaf stage of weeds) to control early emergence grassy weeds and sedges in lowland rice. Sometimes, the efficacy of herbicides is reduced because of the continuous rain or dry spell following their application. If there are new flashes of grassy weeds, spray fenoxaprop-p-ethyl (60 g ha⁻¹) at 25-28 DAE (3-4 leaf stage of weeds).
- In shallow lowland or irrigated areas, tank-mix application of fenoxaprop-p-ethyl + ethoxysulfuron (50+15 g ha⁻¹) at 15-18 DAE (2-4 leaf stage of weeds) is effective against mixed population of grassy weeds, sedges, and broadleaved weeds.

Herbicides used for transplanted rice, dry direct-sown rice, wet direct-sown rice are listed in table 7.2, 7.3, and 7.4, respectively.

Table 7.2 Herbicide option for transplanted rice

S. No.	Herbicide options	Schedule of application
1.	Bispyribac sodium @ 30 g ai ha ⁻¹ (Early post-emergence)	10-12 days after transplanting/ 2-4 leaf stage of weeds
2.	Fenoxaprop-p-ethyl @ 60 g ai ha ⁻¹ (Late post emergence)	25 days after transplanting
3.	Ethoxysulfuron @ 20 g ai ha ⁻¹ (Late post-emergence)	25 days after transplanting
4.	Cyhalofop butyl @ 100 g ai ha ⁻¹ (Late post-emergence)	20 days after transplanting

Source: Authors' own compilation.

Table 7.3 Recommended herbicides for dry direct-sown rice*

S. No.	Name	Target weeds	Time of application	Dose (g a.i. ha ⁻¹)
1.	Bispyribac Sodium (Nominee gold)	Early emergent grassy weeds and few sedges	8-10 days after sowing (DAS) / at 2-3 leaf stage of weeds	30
2.	Fenoxaprop-p-ethyl (Rice star)	Late emergent grassy weeds	18-20 DAS (at 3-5 leaf stage of weeds)	60
3.	Cyhalofop-butyl (Clincher)	Grassy weeds	12-15 DAS (2-4 leaf stage of weeds)	100
3.	Ethoxysulfuron (Sunrise)	Sedges and broadleaved weeds	15 DAS (at 2-4 leaf stage of weeds)	20
5.	Fenoxaprop-p-ethyl + Ethoxysulfuron (Tank-mix)	Mixed weed population	15-20 DAS (3-4 leaf stage of weeds)	50 + 15

*Combination of stale bed (total killer) + Early post-emergence + late post-emergence herbicide gives the best result

Source: Authors' own compilation.

Table 7.4 Recommended herbicides for wet direct-sown rice

S. No.	Name	Target weeds	Time of application	Dose (g a.i. ha ⁻¹)
1	Pyrazosulfuron ethyl (Sathi)	All types of weeds	0-3 DAS	20
2.	Bensulfuron methyl + Pretilachlor (60+600) (Lona dax power / Eraze Strong)	Grassy weeds and sedges	7-10 DAS	60+600 (10 kg ha ⁻¹)
3.	Bispyribac Sodium 10 SC (Nominee gold/ Narkis)	Early emergent grassy weeds and few sedges	10-12 DAS (at 2-3 leaf stage of weeds)	30
4.	Ethoxysulfuron (Sunrise)	Sedges and broadleaved weeds	15 DAS (at 2-3 leaf stage of weeds)	20
5.	Metsulfuron methyl+ chlorimuron ethyl (Almix)	broadleaved weeds	15-20 DAS (at 3-4 leaf stage of weeds)	8

Source: Authors' own compilation.

Mechanical weed control

- Integration of chemical weed control by spraying bispyribac sodium at an early stage followed by mechanical weed control by operating power weeder at 30 DAE is also found very effective in lowlands/irrigated areas. Under this management option, the crop should be established at 25 cm apart rows. The mechanical weeder also increases soil aeration and consequently tiller production.
- Manually-operated cono-weeder or push type rotary weeder can also be operated at a late stage (30-35 DAE) with 3-5 cm depth of water. However, power weeder is found more effective and also it needs less time for operation and reduces drudgery than manual weeder. Various types of machinery for weeding in rice are shown in Fig. 7.6.



Fig 7.6 Mechanical measures

Source: Authors' own collection.

Sorghum

- Intercropping of sorghum with cowpea
- Pre-plant incorporation isoproturon 0.5 kg ha^{-1} / pendimethalin spray as pre-emergence herbicide @ 1.0 kg ha^{-1}

Maize

- For irrigated maize, application of atrazine @ 0.5 kg ha^{-1} 3 DAS + hand weeding on 45 DAS provide effective weed control, improved crop growth that results in higher grain yield and net return or
- Use of twin wheel hoe weeding on 20 DAS + hand weeding on 40 DAS.

Pearl millet

- Apply pre-emergence herbicide viz., atrazine @ 0.5 kg ha⁻¹ followed by one hand weeding is effective in controlling weeds. It also saves approximately 30 kg N ha⁻¹.

Finger millet

- For rainfed direct sown crop post-emergence application of 2,4-D Na salt at 15 days after sowing @ 0.75 kg ha⁻¹ provide better weed control as well as higher grain yield.

Red gram

- Pre-emergence application of metalachlor @ 1.0 kg ha⁻¹ on 3 DAS followed by one hand weeding at 40 DAS provide better weed control, higher pods per plant and grain yield.

Black gram

- Pre-emergence application of isoproturon @ 0.5 kg ha⁻¹ or pendimethalin @ 1 kg ha⁻¹ followed by one hand weeding effective control weeds effectively, increased the grain yield and the protein content under irrigated condition.

Greengram

- Pre-plant incorporation of fluchloralin @ 1.0 kg ha⁻¹ followed by one manual weeding or
- Pre-emergence application of pendimethalin @ 1 kg ha⁻¹ followed by one manual weeding or
- Pre-emergence application oxyfluorfen @ 0.1 kg ha⁻¹ followed by one manual weeding

Chick Pea

- Pre-plant incorporation of fluchloralin @ 1.0 kg ha⁻¹ followed by one manual weeding if needed or
- Pre-emergence application of pendimethalin @ 1 kg ha⁻¹ followed by one manual weeding.

Lentil

- Pre-plant incorporation of fluchloralin @ 1.0 kg ha⁻¹ followed by one manual weeding or
- Pre-emergence application of pendimethalin @ 1 kg ha⁻¹ followed by one manual weeding.

Sunflower

- Ploughing the field with disc plough followed by cultivator to kill all the weeds and fine tilth for sunflower crop
- Pre-emergence application of pendimethalin @ 0.50 kg ha⁻¹ + metolachlor 0.50 kg ha⁻¹ or
- Pre-emergence application of atrazine @ 0.25 kg ha⁻¹ followed by a hand weeding on 40 DAS for maize crop in sunflower - maize cropping system or
- Two hand weedings (20 and 40 days after sowing) or
- Pre-plant incorporation of fluchloralin @ 0.75 kg ha⁻¹ with one late manual hand weeding.

Rapeseed and mustard

- Pre-emergence application of pendimethalin @ 1.5 kg ha⁻¹ followed by one hand weeding at 30 DAS or
- Pre-emergence application of oxadiargyl @ 0.180 kg ha⁻¹ followed by one hand weeding on 30 DAS.

Sesame

- Per-emergence application of alachlor @ 1.5 kg ha⁻¹ followed by one hand weeding on 35 DAS or
- Per-emergence application of metolachlor @ 1.0 kg ha⁻¹ followed by one hand weeding on 35 DAS or
- Pre-emergence application of clomazone @ 0.25 kg ha⁻¹ followed by hand weeding on 20 DAS or
- Pre-emergence application of pendimethalin @ 0.75 kg ha⁻¹ with one hand weeding at 20 DAS.

Linseed

- Pre-emergence application of pendimethalin @ 1 kg ha⁻¹ followed by one hand weeding at 20 DAS.

Cotton

- Pre-sowing application of glyphosate followed by two hand weedings.
- Pre-emergence application of pendimethalin @ 1.0 kg ha⁻¹ followed by one manual weeding.
- Pre-sowing application of glyphosate @ 2.0 kg ha⁻¹ to prepare the stale seedbed.

- Pre-emergence application of tank mix (oxyfluorfen @ 0.2 kg ha⁻¹ + metolachlor @ 1.0 kg ha⁻¹) on 3 DAS followed by manual weeding at 40 DAS.
- Application of 2-mercapto-6-chlorobenzonitrile (trade name GOD H001) @ 75 g ha⁻¹ on 5 DAS followed by one hand weeding on 30 DAS.
- Pre-emergence application of oxyfluorfen @ 0.1 kg ha⁻¹ followed by earthing-up or fluchloralin @ 1.0 kg ha⁻¹ followed by earthing-up for both single cotton crop or cotton intercropped with onion.

Groundnut

- For irrigated groundnut, pre-plant incorporation of fluchloralin @ 1.0 kg ha⁻¹ followed by one earthing up using hoes or working star type weeder.
- For irrigated groundnut, pre-emergence application of oxadiazon @ 0.8 kg ha⁻¹ followed by earthing up using hoes or working star type weeder.
- Three deep ploughing at an interval of 15 days for each ploughing with disc plough and application of glyphosate @ 1.0 kg ha⁻¹ twice on 15 DAS and 35 DAS provide good control of *Cyperus rotundus*.
- Pre-emergence application of pendimethalin @ 0.75 kg ha⁻¹ followed by one hand weeding at 45 DAS and earthing up.
- Pre-emergence application of metolachlor @ 1 kg ha⁻¹ followed by one hand weeding and earthing up.

7.5 Integrated pest management (IPM)

The IPM is the mutual incorporation of available insect pest control strategies to keep the insect infestation below the economic threshold levels (ETL) with an aim of least or no damage to the environment. About 800 insect species damage rice, of which many species have little damage to the rice crop. The majority of rice insect-pests are managed by a complex and rich web of predators and parasitoids that live in or on the rice plant, rice water, or soil. Proper management of biotic stresses in rice resulting in enhancement of production by 30-35%. The major practices of IPM for the management of rice insect-pests are based on four major strategies: (i) cultural control, (ii) host plant resistance, (iii) biological control, and (iv) selective insecticides

7.5.1 Climate change and integrated pest management

Climate change has brought uncertainty with respect to variability in the various weather parameters and its peak (temperature, rainfall, wind, sunshine, radiation, *etc.*) thereby influence the physiology, distribution, phenology, and abundance of the insect pests (Bale et al., 2002; Dukes et al., 2009; Laštůvka 2009). The abundance in the population of an insect pest is influenced by the host plant, natural enemies, and extreme weather events (Chu and Chao 2000; Bale et al., 2002). There are reports some of the pest which is earlier considered as minor pest becoming major pest due to changing climate. Changing in planting time due to climate change has also impacted the pest complex and their dynamics. It has been reported that the virulence of some of the insect pest has already been magnified because of climate change. Under such a situation, IPM is going to be one of the CSA technology having a greater potential for adaptation and productivity enhancement. It is a knowledge-intensive method for the management of pests by conjoining harmonious cultural, biological, chemical, and physical tools to minimize economic, plant health, and environmental risks.

7.5.2 IPM for rice

Rice is a staple food and the foundation of national food security and the economic growth of India. The crop is susceptible to biotic stress throughout the crop growth period from diverse pests such as insects, diseases, weeds, rodents, *etc.* Climate change has brought another dimension to insect pest management. Their effective management and maintaining ecological balance by maintaining pest-predator- parasite equilibrium in rice ecology through IPM will help in adaptation to climate change. The various IPM strategies of rice are discussed below.



Fig. 7.7 riceXpert

Pest identification

The identification of insect pests is a crucial step for its management. Many complex processes/ diagnostic tools are available for the identification of insect pests. NRRI developed the riceXpert – a mobile app that can be used to identify rice insect pests (Fig. 7.7). Similar applications are available for other crops. These tools facilitate farmers for accurate identification of rice insect pests and serve as a handy tool on a real-time basis. There are inbuilt provisions in some app through which the farmers can also send the picture, text message, or recorded voice to the expert for further clarification if any.

Pest monitoring

a. Survey/field scouting

For this, farmers need to monitor the occurrence of insect pests and disease at stipulated intervals. The plant protection measures are essential when insect pests and diseases exceed Economic Threshold Level (ETL).

- i. Roving survey: This is implemented at every 10 km distance in about 7-10 days intervals. Every day at least 20 spots are to be observed.
- ii. Field scouting: This is done for pests and bio-control fauna. The interval of taking this type of observation is once in 3-5 days to workout ETL.

b. Pheromones/light trap

The majority of the insect population can be supervised by fixing pheromones or light traps or through a sweep net at an appropriate stage of the crop.

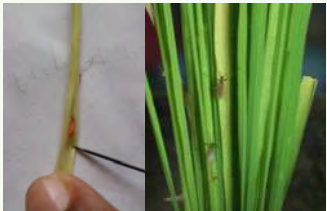
- i. Pheromone trap: 8 traps ha^{-1} may be used to monitor the yellow stem borer moth population.
- ii. Light trap: Alternate energy (solar) light trap is functioned for 2- 3 h in the evening to monitor photo-tropic insect pests (Fig. 7.8).



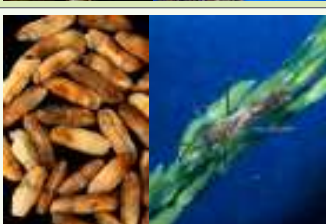
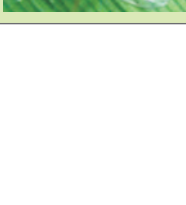
Fig. 7.8 Light trap
Source: Authors' own collection

iii. Sweep net: Sweep nets are used to evaluate the population of insect pests and biocontrol agents. This is mainly done to determine the type of pesticides to be recommended. Some of the visuals of the rice insect pests and the damages caused by them are given in Table 7.5.

Table 7.5 Insect-pest in rice and nature of damage

Name of the pest	Symptom	Picture
Paddy stem borer (<i>Scirpophaga incertulas</i>)	- Drying of central shoot or ‘dead heart’ at vegetative stage - Drying of panicle or ‘white ear’ in reproductive stage	
Gall midge (<i>Orseolia oryzae</i>)	The central shoot produces a long tubular structure called onion shoot, silver shoot instead of producing leaf	
Swarming caterpillar (<i>Spodoptera mauritia</i>)	- Caterpillars completely graze the nursery in overnight - Severly infested crop appear like grazed field - Stunted plant growth	
Caseworm (<i>Nymphula depunctalis</i>)	- Stunted plants - Hanging of caterpillars on leaf edges in a tubular case and often float in water - Ladder like appearance of leaf due to scrapping of leaf tissues by the larva inside the tubular cases	

Skipper (<i>Pelopidas mathias</i>)	- Folding of leaves longitudinally or transversely - Scrapped, white patches	
Leaf folder/ roller (<i>Cnaphalocrocis medinalis</i>)	- Leaves folded longitudinally or transversely with silk and scrapped patches in such places. - Larvae stay within the folded leaf and scrape off the green portion of the leaves.	
Horned caterpillar (<i>Melanitis ismene</i>)	It feeds on the margin of the leaf which gradually becomes week and final defoliated.	
Grasshoppers Large grasshopper (<i>Hieroglyphus banian</i>) Small grasshopper (<i>Oxya nitidula</i>)	The nymphs and adults fragment leaves and earheads at an early stage.	
Spiny beetle/ rice hispa, (<i>Dicladispa armigera</i>)	- The mining of leaf by grubs - White parallel line on the leaves	
Thrips, (<i>Stenchaetothrips biformis</i>)	- Presence of yellow (or) silvery streaks on the leaves of young seedlings - Terminal rolling and drying of leaves from tip to base	

Green leafhopper (GLH) (<i>Nephotettix virescens</i>)	- Pale yellow colour and stunted plant - Heavy infestation results in withering and complete drying of the crop	 
Brown plant hopper (BPH) (<i>Nilaparvata lugens</i>)	- Nymphs and adults can be detected congregating just above the water level at the plant base. - Circular burnt up appearance (hopper burn). - Besides, this pest is the carrier of many viral diseases in rice, e.g., ragged stunt, wilted stunt, and grassy stunt diseases.	 
Mealybug (<i>Brevinnia rehi</i>)	Stunted, circular patches in the fields. It is more common in upland and rainfed environments, and quite rare under an irrigated situation.	 
Earhead bug/ Gundhi bug (<i>Leptocorisa acuta</i>)	- Shriveling of grains and the presence of brownish spots on grain/ feeding site - Sucking of the milky sap causes ill filled/ partial filled and chaffy grains	 
Whorl maggot, (<i>Hydrellia sasakii</i>)	Discoloured margins of flag leaf with small punctures/ pinholes in the middle are seen	 

Source: Authors' own collection.

*Some of the photographs are adapted from Parthiban et al. 2017

Methods of pest management in rice

Cultural methods

- Wider spacing (30 × 20 cm) usually helpful in controlling the population of caseworms.
- To avoid the peak caseworm activity period, planting should be done early.
- To control caseworm larvae and gall midge, the field may be drained for 5-7 days.
- Split applications of nitrogen reduce the abundance of rice caseworm.
- To prevent rice whorl maggot infestation the water surface should be covered with *Azolla* and *Salvinia molesta*.
- Removal of weeds not only in the field but also on the bunds eradicates the favoured grassy hosts for various insect pests.
- Eradication of grassy weeds and wild rice (alternate hosts) from the paddy field and the adjacent areas can diminish the gall midge occurrence.
- Clipping of the top three-fourths of the leaves of extremely infested crops with eggs and grubs at the early vegetative stage followed by its destruction can check the yellow stem borer and rice hispa populations.
- Time to time collection and killing of adults by sweep net can check the populations of various insect pests and reduces damage.
- Rice fields should be drained if brown plant hopper (BPH) infestation starts. It is effective in reducing initial infestation levels of BPH. However, draining for a larger period of time (3 - 4 days) is needed when heavy infestations occur.
- Harvesting should be done close to ground level to destroy insect pests existing in the internodes/stubbles. Additionally, this will expose the insects to the natural predator (*e.g.* birds) which helps to control them naturally.

Mechanical control

- Collection and destruction of eggs and larvae of the insect pest.
- Removal and burning/burying of diseased/pest-infested plant parts.
- Use of coir rope dipped in kerosinized water passing over the rice crop helps to dislodge swarming caterpillar, cutworm case worm, and leaf folder larvae.

Biological Control

- *Trichogramma japonicum* and *T chilonis* may be released @ 1 lakh ha⁻¹ when egg masses/ moth of yellow stem borer and leaf folder are detected in the field.

- Natural biocontrol agents such as damsel flies, water bugs, mirid bugs, spiders, drynids, meadow grasshoppers, dragonflies, carabids, staphylinid beetles, *Apanteles*, Coccinellids, *Telenomus*, *Tetrastichus*, *Bracon*, *Trichogramma*, *Platygaster*, etc. should be conserved and apply when needed.
- Collection of egg masses of borers and putting them in a bamboo cage-cum-percher till flowering will allow egg parasites to escape in nature which may trap and kill the hatching larvae in the next season. Besides, this structure would allow the sitting of predatory birds.
- Rice bunds may be utilized to grow crops like marigold and sun hemp may increase the population of beneficial natural enemy and also reduce the occurrence of root-knot nematodes.
- Keeping of refuge like straw bundles sometimes help in buildup of spider population and to provide the perch for birds.
- Mass trapping of yellow stem borer male moths by fixing pheromone traps @ 20 traps ha⁻¹ at 20 days after transplanting.

Chemical control

In this method, a chemical formulation containing the active ingredient of the insecticide is sprayed to control insect-pest in rice crop when the insect-pest population exceeds ETL (Table 7.6).

Table 7.6 Spray recommended chemical if the infection exceeds ETL

Insect pests	ETL	Recommended chemical
Stem borer	1 moth or egg mass/sq meter or 1-2 dead heart / white earhead/sq meter	Apply chlorantraniliprole 0.4G @ 10kg ha ⁻¹ or imidacloprid 0.3 G @15kg ha ⁻¹ or cartap 4 G @ 25 kg ha ⁻¹ or fipronil 0.3 G @ 25 kg ha ⁻¹ .
Leaf folder	2 folded leaf/ hill	Spray lambda-cyhalothrin5EC@ 250ml ha ⁻¹ or chlorpyriphos 20 EC @ 1,250 mL ha ⁻¹ or cartaphydrochloride 50 WP @ 1000 g ha ⁻¹ or acephate 75 WP @ 1000 g ha ⁻¹ or fipronil 5 SC @ 600 ml ha ⁻¹ .
Brown plant hopper and White backed plant hopper	5-10 hoppers/hill	Spray triflumezopyrim 10SC@ 234g ha ⁻¹ , pymetrozine 50 WG @ 300g ha ⁻¹ or flonicamide 50WG@150g ha ⁻¹ or dinetofuran 20SG@150g ha ⁻¹ or clothianidin 50WDG @20g ha ⁻¹ or imidacloprid 200 SL @ 125 mL ha ⁻¹ or thiamethoxam 25WG @ 100 g ha ⁻¹

Green leafhopper	10 adults/hill	Spray acephate 50 WP @ 700 g ha ⁻¹ or ethofenprox 10 EC @ 500 ml ha ⁻¹ or imidacloprid 200 SL @ 125 ml ha ⁻¹ or thiamethoxam 25 WG @ 100 g ha ⁻¹ . Alternatively, apply fipronil 0.3 G @ 25 kg ha ⁻¹ .
Gall midge	1 silver shoot/sq meter	Fipronil 0.3% GR @ 25 kg ha ⁻¹ or carbofuran 3% CG @ 25 kg ha ⁻¹ at 20 days after transplanting.
Hispa	1-2 adult/hill	Spray chlorpyrifos 20 EC @ 1,250 mL ha ⁻¹ or quinalphos 25 EC @ 1,200 mL ha ⁻¹ or ethofenprox 10 EC @ 450 ml ha ⁻¹ or fipronil 5 SC @ 600 mL ha ⁻¹
Caseworm	2 folded leaf/hill	Drain water from the field and spray carbaryl 50 WP @ 1000 g ha ⁻¹ or apply carbaryl 10DP @ 25 kg ha ⁻¹
Ear-cutting caterpillar/cut worm	2 larvae / sq meter or 1 damage tiller / hill	Spray quinalphos 25 EC @ 1,000 ml ha ⁻¹ or chlorpyrifos 20EC @ 1,250 mL ha ⁻¹ or carbaryl 50 WP @ 1,500 g ha ⁻¹
Mealybug	-	Spot application of phorate 10 G granules
Gandibug	2 bugs/hill	Spray ethofenprox 10 EC @ 500 ml ha ⁻¹
Whorl maggot	1 damage leaf/sq meter	Apply fipronil 0.3 G @ 25 kg ha ⁻¹ or chlorpyrifos 20 EC @ 1,500 mL ha ⁻¹
Termite	-	Soil application of chlorpyrifos 20% EC @ 10 L ha ⁻¹ along with 10% solution of gum arabica or seed treatment of imidacloprid 200 SL (20%) @ 0.25 L 100 kg ⁻¹ seed along with 10% solution of gum arabica in 3.75 L of water just before sowing for upland rice.

Source: Authors' own collection.

IPM for various rice ecology

i. Rainfed upland ecology

The major insect-pests and nematodes in upland ecology are root-knot nematode, gundhi bug (*Leptocoris oratorius* and *L. acuta*), and termite (*Odontotermes obesus* and *Micotermes obesi*) especially in red, light-textured soils with low water holding capacity under prolonged drought conditions. *In-situ* moisture conservation like increasing the height of bunds and summer ploughing are useful to control termites under upland ecology. Growing pulses in rotation like blackgram (urdbean), pigeonpea, greengram or sesamum

reduces the chances of infestation of nematodes in upland rice. Seed treatment with chlorpyrifos can effectively control termites, gundhi bug, and root-knot nematode. Use only healthy seeds and infested seeds are separated by using 2% brine solution.

ii. Rainfed lowland ecology

This ecology can be classified into 3 major categories: shallow drought-prone, shallow favourable and medium-deep waterlogged based on the moisture stress and depth of water. Persistent warm and humid climate is conducive for the growth of many pests, and cause a heavy toll in rice production. Stem borer, gall midge, leaf folder, hispa, BPH, mites, and WBPH are the major insect pests. Improved stress-tolerant varieties like Gayatri, Moti, Swarna, Pooja, Rajshree, Monoharsali, Ranjit, Pankaj, Savitri, Mashuri, and Sambha Mahsuri are commonly grown in this ecology. Pest monitoring and mass trapping of yellow stem borer using pheromone traps have been found promising. Cultural practices like ploughing after paddy harvest and burning of stubbles in extreme cases are also advisable for the management of stem borers. In deep water ecology, ufra nematode occurs in a severe form. The most important insect-pest of deep waterlogged rice are yellow stem borer, causing more than 50% of stem damage. Other insect pests of importance are rice hispa, mealybug, leaf folder, and whorl maggot.

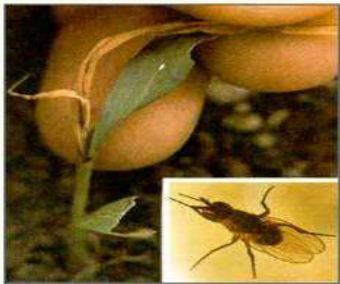
7.5.3 IPM for maize

Climate change is contributing towards the evolutions of new strains of insect pests of maize that require careful attention for future pest management programmes. Many minor pests are now becoming major, imposing a serious threat to crop productivity. For example, fall armyworm, which was a minor pest earlier, creating devastation in maize crop in recent years. This pest is now reported from about 20 states of India.

Identification of insect pest in maize

The first step in the IPM is identifying the pest and its economic threshold limit for need-based pesticide application over and above the cultural, biological, and mechanical methods of pest control. The field survey, monitoring the pest of maize can be made by following the process that was discussed as in pest identification in rice. Some of the visuals of the maize insect pests and the damages caused by them are given in Table 7.7.

Table 7.7 Insect-pest in maize and nature of damage

Name of the pests	Symptom	Pictures*
Stem borer (<i>Chilo partellus</i>)	• Oval punctures in leaves of the unfolding whorl. • Larvae damage the growing point "dead heart" through tunnel into the leaf midribs.	
Shoot fly (<i>Atherigona orientalis</i>)	• Maggots bore into shoots of seedlings and kill the growing point. • Presence of "dead hearts". • Infected plant produce tillers and gets a bushy look.	
Corn earworm (<i>Helicoverpa armigera</i>)	• Damaging of leaves, tassels, silks and kernels.	
Pink stem borer (<i>Sesamia inferens</i>)	• Presence of larvae on the backside of the leaf sheath in group. • Severe damage causes the stem to break.	

Aphid (<i>Raphalosiphum maidis</i>)	• Nymphs and adults draw the sap from plants mainly from the leaves. • Stunted plant growth under heavy infestation. • Exuding of sap which later crystallizes into sugary material upon drying.	
Maize shoot bug (<i>Perigrinus maidis</i>)	• Yellowing of leaves • Stunted plant growth • Reduced vigour • Girdling/ twisting of top leaves	
Two-spotted spider mite (<i>Tetranychus Utricae</i>)	• Reduced plant growth • Yellow to brown colour leaves	
Termite (<i>Microtermes</i> spp.)	• Presence of mud/ soil on the growing point. • Partial or total defoliation. • Mainly causes damage to the matured plant.	
Army worm (<i>Mythimna seperata</i>)	• Pinholes on leaves and shoot, scrapping of leaves. • Loss of growing point. • Presence of faecal pellets in leaf whorl.	

Fall Armyworm (<i>Spodoptera frugiperda</i>)	• The young caterpillars spin silken threads that they use to move from one plant to another aided by wind. • Newly hatched caterpillars are green in colour during the 1st- 2nd instars and turn brown to black from 3rd - 6th instar. • Caterpillars have a dark head with a pale upside down Y-shaped mark on the front • Big caterpillars have four raised dark spots that form a squared pattern on the second to last segment when seen from above • Caterpillars can live for 12-20 days depending on temperature and other environmental conditions	
Grasshopper (<i>Melanoplus spp.</i>)	• Presence of infestation on the border. • Defoliation and grazing of the plant.	

Source: Authors' own collection and compilation.

* Photographs are adapted from Parthiban et al., 2017

Methods of insect pest management in maize

Cultural practices

- Ploughing during summer season exposes pupa/ larvae to their natural enemies and heat.
- Crop diversification especially legume intercropping (maize-cowpea/ maize-green gram) reduces borer incidence.

- Application of well rotten farmyard manure (FYM) decreases the termite population.
- Proper plant spacing of 60 cm x 15 cm in *kharif* season and 45 cm x 15 cm in *rabi* season should be followed.
- The optimum dose of fertilizers in balanced quantity @ NPK 120:60:40 kg ha⁻¹ and supplement of micronutrients are useful to reduce the incidents of various insect pests.
- Grow tolerant varieties.

Mechanical Practices

- Elimination of dead hearts and its destruction will reduce next-generation infestation.
- Installation of resting places for birds invites natural predators of insect pests.
- Gathering and destruction of white grub and chaffer beetle manually during adult emergence decreases the pest population.

Bio-pesticide/botanicals

- Application of neem cake in soil controls nematode and chaffer beetle.

Biological control

- Preservation of naturally occurring biocontrol agents such as Carabids, *Cotesia flavipes* Cameron, *Trichogramma chilonis*, Coccinellids, *Chrysoperla* spp, spiders and wasps, and reduction in the use of chemical pesticides.
- Release of *Trichogramma chilonis* @ 1,60,000 ha⁻¹ on 7 and 15 days old crop.

Chemical control

- Granular application of 33.3 kg carbofuran 3% CG ha⁻¹ of land in whorls of infested plants to control stem borer, thrips and shoot fly.
- A spray of 1764 g carbaryl 85% WP per litre of water against borer at 15-18 days after germination.
- Spray 1000 mL of oxydemeton – methyl 25% EC ha⁻¹ or 1155 mL of dimethoate 30% EC ha⁻¹ or 30 kg phorate 10% CG ha⁻¹ for the management of shoot fly.

7.5.4 IPM for pulses

Integrated pest management (IPM) for pulses includes the use of resistant or tolerant varieties, crop rotation with non-host crops, *etc.* in addition to pesticide application at the minimum doses. Agronomic practices like intercropping of chickpea + linseed/ mustard or chickpea + coriander encourages natural enemies of pod-borers. The use of bio-pesticide NPV (Nuclear polyhedrosis virus), neem-seed-kernel extract and sex pheromone trap are also helpful in controlling pod-borers in pulses. Conservation agriculture carries additional benefits, such as improved soil nutrient availability and eradication of certain soil-borne pests, such as nematodes. Integrated insect-pest management components for the pulse crops are given below:

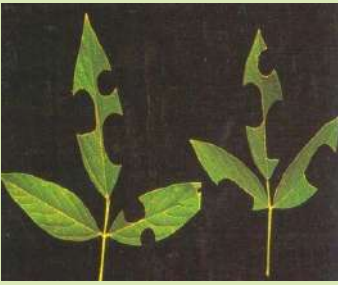
Identification of insect pest in pulse

The identification of the pests can be done by using a field survey, monitoring the pest by following the process that was discussed as in pest identification in rice. Some of the visuals of the insect pests of pulses and the damages caused by them are given in Table 7.8.

Table 7.8 Insect-pest in pulse crops and nature of damages

Name of the pests	Symptom	Pictures*
Bean aphid or black aphid (<i>Aphis craccivora</i>)	- Cupped or crinkling irregularly distorted, shoots stunted and malformed - Sooty mould. - Stunting- withering and reduced vigour.	
Whitefly (<i>Bemisia tabaci</i>)	- Presence of white round hardy scales and ants on young branch. - Wilting, drying and stunted growth of the plant.	
Thrips (<i>Caliothrips indicus</i>)	Leaves are mottled with characteristic silvering	

Scales (<i>Ceroplastodes cajani</i>)	• Tender branches are covered with white round hardy scales which are attended by ants • Wilting and drying of plants results in stunted growth of plants	
Pod bug (<i>Riptortus pedestris</i>)	• Unfilled pods and shrivelled grains • Yellow spot on infected pods • Shedding of green pods	
Lablab bug (<i>Coptosoma cribraria</i>)	• Weak and deformed, stunted in growth that results in poor yield	
Tobacco caterpillar (<i>Spodoptera litura</i>)	• Grazing and defoliation by larvae • Scrapping leaves from the backside	
Redgram leaf webber (<i>Grapholitha critica</i>)	• Fold or web leaves with tender shoots and feed within folded leaves • Infested leaves dry up	
Leaf miner (<i>Aproraema modicella</i>)	• Larva folds leaves together twisting near the tip. • Webbing scrapping and distortion of leaves	
Redgram bud weevil (<i>Indozocladus asperulus</i>)	• Boreholes on bud • Bud drop	

Leaf cutting bee (<i>Megachile anthracina</i>)	• Presence of semi-circular cut out on leaves	
Blister beetle (<i>Mylabris pustulata</i>)	• Buds and flowers are eaten completely • Orange and dark brown or black coloured beetles with red cross bands on the elytra are visible	
Stem fly (<i>Melanagromyza phaseoli</i>)	• Wilting and drying of seedlings • Swollen and rotten collar region • Stem tunneling and discoloration • Adults puncture leaves	
Stem borer (<i>Sphenoptera indica</i>)	• Stem tunneling • Wilting and drying • Boreholes at the basal stem	
Gram caterpillar (<i>Helicoverpa armigera</i>)	• Defoliation • Boreholes on pod • Empty pods	
Blue butterfly (<i>Lampides boeticus</i> , <i>Euchrysops cnejus</i>)	• Caterpillars burrow in buds, bore tender pods and feed on seeds in association with ants • Green flat slug-like larva imbibed in secretions are detected	

Spotted pod borer (<i>Maruca vitrata</i>)	• Webbing shoots and shoots boring • Flower bud damage and drop • Boreholes with excreta	
Spiny pod borer (<i>Etiella zinckenella</i>)	• Pods with granular excreta and greenish pink larva • One caterpillar/ pod boreholes on dry pods • Seed damage	
Plume moth (<i>Exelastis atomosa</i>)	• Small pinhole on pods • Seed damage	
Pod borer (Field bean) (<i>Adisura atkinsoni</i>)	• Pods with boreholes	
Redgram pod fly (<i>Melanagro-myza obtuse</i>)	• Small round boreholes (ring-like) on pods • Dark brown encrustation on the pod wall • Burrowing of tender seeds	
Pod wasp (<i>Tanaostig-modes cajaninae</i>)	• Small borehole on basal locule • Distorted pods	
Pulse beetle (<i>Callosobru-chus maculatus</i>)	• Grubs feed on seeds • Round boreholes on dry pods and seeds	

Source: Authors' own collection and compilation.

* Some photographs are adapted from Parthiban et al., 2017

Methods of pest management in pulse crop

The pest management in pulse crops like chickpea, pigeon pea, mungbean, urdbean, peas, cowpea, French bean, cluster bean is discussed in the following section.

Chickpea

Cultural practices and mechanical measures

- Deep summer ploughing to expose and kill pupae
- Early sowing of chickpea on mid-October to avoid attack of stem fly
- Higher seed rate to ensure optimum plant population in stem fly prone areas
- Soil raking through weeding reduces soil grubs
- Adoption of closer spacing (20×10 cm) and application of potash fertilizer (50 kg ha^{-1}) to reduce stem fly and pod borer incidence
- Collection and destroying egg masses and pupae
- Installing light trap to monitor, attract and kill pod borer moths
- Installing pheromone traps @ 12 numbers ha^{-1} to control gram pod borer
- Applying FYM/ neem-cake
- Marigold as a trap crop
- Planting of trap crop (castor) along the border and irrigation channels to control tobacco caterpillar *Spodoptera litura*
- Intercropping with linseed/ coriander/ mustard/ wheat
- Using tolerant varieties
- Application of balanced fertilizers
- Thinning the excess plant population
- Erecting bird perches @ 50 ha^{-1} helps in bird sitting to locate the larvae

Biological /botanicals control

- *Rhizobium* treatment 200 g ha^{-1} for effective nodulation
- Seed treatment with *Trichoderma viride* @ 10 g kg^{-1} seed
- Seed treatment with Carbosulfan 25 EC @ 3%.
- Use of bioagents like *Trichogramma* and *Chrysoperla*
- NPV 250 LE ha^{-1} or NSKE (neem-seed-kernel extract) @ 5% to control bruchid beetle
- *Trichogramma* spp; egg larval parasitoid *Chelonus blackburnii* for control of *H. armigera*

- Applying neem/ castor cake @ 1 t ha⁻¹ at the time of land preparation for nematodes.

Chemical control

- Seed pelleting with chlorpyiphos @ 4 mL kg⁻¹ of seed to control stem fly
- Seed dressing with dimethoate @ 4 mL kg⁻¹ of seeds at planting
- Applying insecticide spray (methyl-oxy-demeton 25 EC @ 500 mL ha⁻¹ (or) dimethoate 30 EC @ 500 mL ha⁻¹ in 250 L ha⁻¹) to control sucking pests.
- For pod bores control, apply quinalphos 4D, carbaryl 5D @ 25 kg ha⁻¹
- Poison bait with rice bran 5 kg, jaggery 500 g, carbaryl 50 WP 500g, water 3 L ha⁻¹ -spread bait in evening hours to control tobacco caterpillar *Spodoptera litura*
- Spray NSKE 5% twice followed by triazophos 0.05 %

Pigeonpea

Cultural practices and mechanical measures

- Growing trap crops like marigold and sunflower
- Following ridge planting
- Include cover crops like urdbean, mungbean, soybean, cowpea
- Destroying the alternate host plants
- Seed treatment with *Rhizobium* and arbuscular mycorrhizae each @ 240 g acre⁻¹
- Install yellow sticky traps @ 4–5 traps acre⁻¹ to manage sap feeders
- Destroying sources of sterility mosaic inoculum
- Encourage coccinellid predators to control sap feeders

Biological control

- Spray *Bacillus thuringiensis* 5% WP in 500 L of water ha⁻¹.

Chemical control

- Benfuracarb 40% EC @ 1,000 mL in 200 L
- Spray chlorantraniliprole 18.5% SC @ 60mL acre⁻¹ in 200 L water to control *H. armiger* or, profenophos 50 EC @ 2.0 mL or thiodicarb 75 WP @ 0.6 g or methomyl 40 SP @ 0.6 g in one L of water
- For *H. armiger* second spray of neem seed kernel extract at the rate of 5% or chilli 0.5% + garlic 0.25% extract or novaluron 10 EC 0.75 mL L⁻¹

- For spotted pod borer/ webber spray profenophos 50 EC @ 2.0 mL + dichlorvos @ 0.5 mL L⁻¹ or methomyl 40 SP @ 2.0 mL + dichlorvos @ 0.5 mL L⁻¹ or neem seed kernel extract 5% + dichlorvos @ 0.5 mL L⁻¹
- For pod bugs and pod fly management, spray dimethoate 30 EC @ 1.7 mL L⁻¹ or oxy-demeton methyl 25 EC @ 1.5 mL L⁻¹ or acephate 75 SP @ 1.0 g L⁻¹

Mungbean and urdbean

Cultural practices and mechanical measures

- Growing resistant /tolerant varieties.
- Hot water treatment of seeds at 52°C for 10 minutes to control anthracnose and bacterial leaf blight.
- Collect and destroy disease-infested plants
- Use yellow sticky traps @ 4–5 traps acre⁻¹

Biological/botanicals control

- Seed treatment with *Trichoderma viride* 1% WP @ 4 g kg⁻¹ seeds
- Removal of yellow mosaic virus affected plants at 30 DAS followed by the application of NSKE (5%) spray.

Chemical control

- Seed treatment with imidacloprid (5 mL) + carbendazim 2 g kg⁻¹ of seed
- Spraying of 2 mL rogor + wettable sulphur 4 g L⁻¹ of water at 40 DAS
- Quinalphos 25% EC 600 mL or phenthoate 50% EC 320 mL in 200–400 L acre⁻¹
- Soil application of phorate or carbofuran granules @ 20 kg a.i. ha⁻¹

Peas, cowpea, french bean, cluster bean

Cultural practices and mechanical measures

- Grow resistant /tolerant varieties.
- Apply 200 kg ha⁻¹ neem cake at the time final land preparation.
- In nematode endemic area grow marigold as intercrop.
- Crop rotation with cereals
- Roughing of the infected plants
- Install 5 Pheromone traps ha⁻¹
- Erect 50 bird perches ha⁻¹

Biological control

- Use of *Trichogramma chilonis* (1 lakh eggs ha⁻¹), conserves *Telonomus remous* parasitoids

Chemical control

- Application of phorate / carbofuron granules @ 20 kg ha⁻¹ or
- Spray of NSKE @ 5%

Pesticides recommended for pulses pod borer complex are given in Table 7.9.

Table 7.9 Pesticides recommended for pulses pod borer complex

Pest	Chemical name	Dose (ha ⁻¹)	
		a.i.	Formulation
<i>Helicoverpa armigera</i>	Flubendiamide 480 SC	48 g	100 mL
	Spinosad 45 SC	75 g	167 mL
<i>Maruca vitrata</i>	Indoxacarb 14.5 SC	75 g	517 mL
<i>Exelastis atomosa</i>	Chlorantraniliprole 20 SC	30-40 g	150-200 mL
	Emamectin benzoate 5 SG	11 g	220 g

Source: Authors' own collection.

7.5.5 IPM for Oilseed

The IPM for oilseeds deals with the major insect pests of oilseed crops and their management through the exploitation of various integrated pest-management tactics such as cultural, mechanical, use of potential biocontrol agents, and chemical methods for increasing the quality and productivity of oilseed crops. The IPM for important oil crops such as groundnut, mustard, sunflower safflower, sesame, sunflower *etc.* which are mainly grown in Odisha are discussed below.

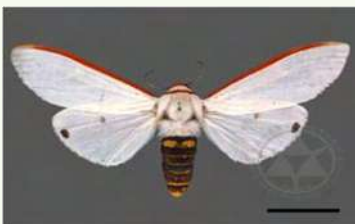
7.5.5.1 Identification of insect pest in oilseed

The identification of the pests can be done by using a field survey, monitoring the pest by following the process that was discussed in pest identification in rice.

Groundnut

Some of the visuals of the insect pests of groundnut and the damages caused by them are given in Table 7.10

Table 7.10 Insect-pests in groundnut and nature of damage.

Name of the pests	Damaging stages	Pictures*
Groundnut leaf miner (<i>Aproaerema modicella</i>)	- Larva after hatching mine into the leaves and produces white blotches - Later stage larva webs the leaves together and feeds on them remaining inside the fold	
Red hairy caterpillar (<i>Amsacta albistriga</i> A. moorei)	Larva is a voracious feeder and acts as defoliator	
Bihar hairy caterpillar (<i>Spilarctia Oblique</i>)	Larva feeds voraciously on leaves and defoliates the plants.	
Tobacco caterpillar (<i>Spodoptera litura</i>)	Larva defoliates the plants	
Jassid (<i>Empoasca kerri</i>)	- Presence of nymphs and adults under the surface of the leaf - Yellowing of leaves due to sucking of plant sap	

Aphid (<i>Aphis craccivora</i>)	Adults and nymph suck cell sap from tender parts of plants	
Thrips (<i>Frankliniella schultzei</i> <i>Thrips palmi</i> <i>Scirtothrips dorsalis</i>)	Adults and nymphs lacerate and feed on the leaf surface	
Termites (<i>Odontotermes obesus</i>)	Feed on pod leading to the invasion of soil fungi resulting in rotting of the pods.	
Root grub (<i>Holotrichia consanguine</i>)	- Older grubs eat the entire taproot - Root is completely damaged in infected plants	
Pod bug (<i>Elasmolomus sordidus</i>)	Both adults and nymphs suck the sap from pods both in field and stores	

Source: Authors' own collection.

*Photo courtesy: S. Sheeba Joyce Roselyn and C. Durairaj

Methods of pest management in Groundnut

Cultural practices

- Grow trap crops such as cowpea/ soyabean (for leaf miner and leafhopper)
- Grow castor as border crops for *Spodoptera* control
- In *kharif* groundnut sowing should be synchronized in rainfed and irrigated areas by planting between 10-20th June

- Sow spreading and semi-spreading varieties in leaf miner endemic areas since bunch varieties are highly susceptible
- Collection and destruction of egg masses, and early and late instar larvae of tobacco caterpillar
- Intercrop groundnut with cumbu (*Pennisetum glaucum*) @ 6:1 ratio or cowpea @ 4:1 ratio or castor 6:1 ratio enhance natural parasitoid like *Goniozus* spp. for leaf miner
- Pigeon pea, mung bean, and soyabean intercropping increase the population of spiders
- Application of straw mulch within 10 days after germination if possible
- Growing tall crops like pearl millet, sorghum, or maize as the border crops to reduce the incidence of thrips, vector for peanut stem necrosis disease
- Prevent moisture stress to avoid leaf miner infestation in irrigated crop
- Maintain fields and bunds free from weeds
- Vegetative trapping of red hairy caterpillar with twigs of jatropha or calotropis; neem branches for trapping adult white grubs
- Plough twice during May-June to expose the beetles resting in the soil to control *Holotrichia* spp
- Deep summer tillage after the *kharif* crop, expose the pupae to predatory birds
- Practice crop rotation with sorghum/pearl millet or maize
- Planting of cowpea or soyabean as trap crops
- Use resistant/tolerant varieties
- Use well-rotten FYM and other organic manures
- Eradication of host plants
- Collection and killing white grub adults from host trees nearby the field.
- Destruction of the termitaria and destruction of the queen is needed
- To avoid termite damage, harvest the groundnuts as soon as they are matured.
- Application of rice straw mulch reduce the incidence of leaf miner

Mechanical/physical control

- Manual picking and destruction of egg masses (mesh like leaves with larvae), early instar larvae of *Spodoptera*, *Spilosoma*; late instar larvae of *Helicoverpa*

- Up-root and destroy severely infected plants.
- Switching on/off light traps (1 ha⁻¹) between 7-10 pm to attract leaf miner moths and tobacco caterpillar moth
- Pheromone traps @ 15 ha⁻¹ to attract male moth of tobacco caterpillar
- Collection and destruction of egg masses during the manual inspection of the fields.
- Installation of bird perches @ 10-12 ha⁻¹ (sunflower act as bird perches)
- Collecting and dipping the infested leaves in kerosenised or insecticide treated solution. (for brown hairy caterpillar)

Botanical and Biological Control

- Pheromone traps @ 10 traps ha⁻¹ for *Spodoptera* and *Helicoverpa* and 25 traps ha⁻¹ for leaf miner or light trap for red hairy caterpillar
- Spraying of NSKE 5% or commercial neem formulations or neem oil @ 5 mL L⁻¹ with Nirma powder 1 g L⁻¹ for defoliators and sucking pests
- Spraying of SINPV/HaNPV 250 LE ha⁻¹ or *Bacillus thuringiensis* @1g L⁻¹ against *Spodoptera litura* and *H.armigera*
- Spraying of *Nomuraea rileyi* @ 2x10¹¹ conidia L⁻¹ for *Spodoptera*
- Releasing *Cheilomenes sexmaculata* @ 1250 ha⁻¹
- Safeguarding and promoting the regeneration of bioagents or natural enemies like flower bugs, ladybird beetles, praying mantis, dragonflies, hoverflies, green lacewing, long-horned grasshoppers, green muscardine fungus and spiders
- Release *Bracon hebetor* twice at an interval of 7-10 days @ 5000 ha⁻¹
- Release *Trichogramma chilonis* twice at an interval of 7-10 days @ 50000 ha⁻¹ or *Telenomus remus* four times at an interval of 7-10 days @ 50000 ha⁻¹ based on pheromone trap catches
- Application of *Nomuraea rileyi* spray, an insect pathogenic fungus @ 10¹³ spores ha⁻¹ to control early instars
- Release of *Apanteles africanus* (larval parasitoid) @ 5000 ha⁻¹

Chemical control

- Leaf miner, Defoliators and Hairy caterpillars: Spraying quinalphos 2 mL L⁻¹ or chlorpyrifos 2.5 mL L⁻¹ or thiodicarb 1.5 g L⁻¹; Dusting with quinalphos 1.5% @ 25 kg ha⁻¹
- Sucking pests (aphid, jassid, thrips): Seed treatment with imidacloprid @ 2 mL kg⁻¹; Spray imidacloprid or acetamiprid @ 0.3 mL L⁻¹

- White grub: Seed treatment with chlorpyrifos 20 EC @ 6 mL kg⁻¹; Soil treatment with phorate 10G @ 15 kg ha⁻¹.
- Insecticide spray is recommended only if the insect population crosses the ETL. The recommended dose of insecticides for various pest is given below

Pesticide recommendation for different pests of groundnut is given in Table 7.11.

Table 7.11 Pesticide recommendation for different pest of groundnut

Insecticides	Insect Pests	Dosage
Diflubenzuron 25%WP	Tobacco caterpillar, Leaf webber	0.75 mL L ⁻¹
Indoxacarb 14.5% SC	Red hairy caterpillar	1 mL L ⁻¹
Quinalphos 20% AF	Spodoptera	1.8 mL L ⁻¹
Malathion 50% EC	Leaf miner	1.25 mL L ⁻¹
Deltamethrin 2.8% EC	Leaf miner	1 mL L ⁻¹
Phosalone 35% EC	Leaf webber	1.5 mL L ⁻¹
Phenthoate 50% EC	Leaf webber	1 mL L ⁻¹
Quinalphos 25% EC	Leaf miner, Leaf hopper, Thrips	1.4 mL L ⁻¹
Lambda-Cyhalothrin 5% EC	Leaf miner, Thrips, Leaf hopper	0.6 mL L ⁻¹
Oxydemeton – Methyl 25% EC	Leaf miner, Aphid	1 mL L ⁻¹
Imidacloprid 17.8% SL	Aphid, Jassid	0.3 mL L ⁻¹
Dimethoate 30% EC	White flies	1.7 mL L ⁻¹
Carbofuran 3% CG	Pod borer, Whitegrub	33 kg ha ⁻¹
Phosalone 4% DP	Leaf Webber	20 kg ha ⁻¹
Quinalphos 1.5% DP	Thrips, Jassids, Redhairy Caterpillar	23 kg ha ⁻¹

Source: Authors' own compilation.

Sunflower

Some of the visuals of the insect pests of sunflower and the damages caused by them are given in Table 7.12.

Table 7.12 Insect-pest in sunflower and nature of damage.

Name of the pests	Damaging stages	Pictures*
Leaf eating caterpillars (<i>Spodoptera litura</i>)	Caterpillars eat leaves and soft portions of the stems	
Cotton bollworm (<i>Helicoverpa armigera</i>)	It feeds on foliage and tender flower heads and developing seeds	
Leaf hopper (<i>Amrasca biguttula</i>)	- Curling of leaves - Hopper burn - Leaves dry up and drop	
Bihar hairy caterpillar (<i>Spilarctia oblique</i>)	- Defoliation - Mostly occurs during <i>rabi</i> season	
Thrips (<i>Scirtothrips dorsalis</i> <i>Frankliniella dampfii</i>)	- Leaf curl - Damage to capitulum and floral parts	
Parakeet (<i>Psittacula krameri</i>)	Green parakeet with the typical short, heavy, deeply hooked, red bill	

Source: Authors' own compilation.

* Photographs are adapted from Parthiban et al., 2017

Methods of pest management in Sunflower

Cultural control

- Intercropping sunflower with groundnut in the ratio 1:4 reduce jassids and whitefly attack.
- Install yellow sticky traps, to control whiteflies
- Under heavy rainfall conditions, narrow spacing reduces jassids infestation.
- Collection and destruction of egg masses, early and late instar larvae
- Grow castor as a trap crop
- Intercropping sunflower with pigeonpea, groundnut, finger millet and soyabean reduce tobacco caterpillar and head borer
- Install light trap @ 1 ha^{-1} and pheromone traps @ 15 ha^{-1} for insect pest severity monitoring as well as to catch the male moths
- Follow ridge sowing (6-8 cm height) in cutworm endemic areas
- Removal of alternate weed host through weeding out at periodical interval will prevent and slow down the aphids infestation
- Promote the multiplication of natural predators and parasites of aphids like lacewings, ladybugs, and syrphid fly
- Flooding the field in October and ploughing in November kill the eggs and control mealybug
- Collect and destroy the fallen leaves infested with scales during July and August
- Two to three pre-sowing summer ploughing helps in controlling Bihar hairy caterpillar through exposing hibernating pupae to sunlight and predatory birds.
- Timely sowing and clean cultivation reduce hairy caterpillar infestation
- Use of bird proof nets or bird scarer
- Pruning of perching and breeding places
- Installation of bird scare instrument and scaring tape/ribbon, distract the birds and minimize the bird pest damage in sunflower. Scare the birds by bursting crackers and carbide guns, during morning and evening times.

Biological/Botanicals control

- Spray neem oil (5%) or NSKE (5 kg acre⁻¹) with any sticky material before egg-laying preferably in the evening control head borer
- Release *Trichogramma chilonus* @ 20000 acre⁻¹ to control cutworm

- Release 10-15 grubs of coccinellid predator, *C. montrouzieri* per plant to control mealybug
- Spray *Clerodendrum inerme* dust (25%) and plant extracts (10%) to control head borer
- Apply SINPV 250 LE ha⁻¹ + cotton seed oil
- Release predators like coccinellids, *Chrysoperla carnea* @1 larva head⁻¹, parasitoides like *Trichogramma* spp. @ 20,000 acre⁻¹ for head borer control
- Spray HaNPV 250 LE ha⁻¹ +1 kg jaggery + 200 mL Sandovit or teepal mixture in the evening hours only to control the head borer

Mechanical control

- Carry out earthing up operation to expose the eggs to natural enemies and sun, control weeds.
- Collection and destruction of infested leaves with eggs and early instar larvae will reduce the population to a great extent.

Chemical control

- Seed treatment with imidacloprid 48% FS @ 5-9 mL kg⁻¹ seed or imidacloprid 70% WS 7 mL kg⁻¹ seed or spray imidacloprid 17.8% SL @ 40 mL acre⁻¹ or malathion 50% EC @ 400 mL acre⁻¹ in 200 L of water to control whitefly and jassid.
- Spray profenophos (2 mL L⁻¹) in 200 L of water for whitefly control.
- The use of synthetic pyrethroids increases the intensity of whitefly
- Spray insecticides like carbaryl/chlorpyrifos 20% EC/quinalphos 25% EC/phosalone 35% EC @ 2 mL L⁻¹ water for cutworm control .Avoid strictly the second spray of chlorpyrifos within 10 days of the first application.
- Spraying of quinalphos 3 mL L⁻¹ or propenophos 2 mL L⁻¹ or chlorophyriphos 2.5 mL L⁻¹ of water for head borer control.

Mustard/rape seed

Some of the visuals of the insect pests of mustard and the damages caused by them are given in Table 7.13.

Table 7.13 Insect-pest in mustard/rape seed and nature of damages

Name of the pests	Damaging stages	Pictures*
Mustard aphid (<i>Lipaphis erysimi</i>)	Both adults and nymphs suck the sap from under the surface of leaves, tender twigs	
Sawfly (<i>Athalia lugens proxima</i>)	Larvae feed on leaves i.e. early instars nibbles the leaves, as a result, there is slight curling	
Pea leaf miner (<i>Chromatomyia horticola</i>)	Maggots make small punctures in the leaf epidermis and whitish, irregularly linear mines	
Painted bug (<i>Bagrada cruciferarum</i>)	Both adults and nymphs suck the sap from the leaves and tender parts including pods	

Source: Authors' own collection and compilation.

* Photographs are adapted from Parthiban et al., 2017

Methods of insect-pest management in mustard

Cultural practices

- Summer ploughing
- Timely sowing
- Clean cultivation

- Application of irrigation during seedling stage is very crucial for sawfly management
- Collection and destruction of sawfly grubs
- Intercropping of mustard+linseed, mustard+fenugreek, mustard+gram, mustard+potato
- Apply balanced / recommended dosages of fertilizers.
- Use mustard aphid tolerant varieties
- Immediate threshing of the harvested crop
- Burn the remains of mustard crop
- The bugs usually congregate on the leaves and stem which can be shaken to dislodge them or killed in kerosinized water.
- Harvest the crop at the golden stage.
- Removal of alternate host plants from the surroundings of the field is beneficial

Mechanical practices

- Collection and destruction of larvae of sawfly in morning and evening hours
- Use of bitter gourd seed oil emulsion as an antifeedant
- Set-up yellow sticky trap to monitor the aphid population
- Installing pheromone trap @ 5 traps acre⁻¹ to monitor the moth activity.
- Collection and destruction of the larvae at the gregarious stage at least twice a week.
- Collect and destroy the gregarious form of larvae in 5% kerosinized water (cabbage butterfly).

Biological control

- Ladybird beetles (adult @ 5000 ha⁻¹) viz., *Coccinella septumpunctata*, *Menochilus exmaculata*, *Cheilomenes vicina* feed on average of 10-15 adult insects per day
- Several species of Syrphids, viz., *Eristalis* spp., *Metasyrphus* spp., *Xanthogramma* spp., *Syrphus* spp. are effective in controlling insect pests in mustard
- Conserve *Perilissus cingulator* (parasitoids of the grubs), and the bacterium *Serratia marcescens* which infect the larvae of sawfly
- The green lacewing, *Chrysoperla cornea* predaes on mustard aphid colony

- The braconid parasitoid *Diaretiella rapae* is very active biocontrol agent that causes the mummification of aphids
- Several entomophagous fungi like *Cephalosporium aphidicola*, *Entomophthora coronate*, *Verticillium lecanii* are very effective
- Conserve *Cotesia plutellae* an important parasitoid for diamondback moth, *Diadegma insulare* is also the most important parasitoid for the diamond back moth.

Chemical control

- Spray the crop with chlorpyriphos 20% EC 200 mL in 200 L of water acre⁻¹ or dimethoate 30% EC @ 264 mL in 200 L of water acre⁻¹, when the aphids infestation reaches ETL or
- Treat the seed with imidacloprid 70% WS@ 7 g kg⁻¹ for control of paint bug
- For controlling mustard sawfly, spray the crop with 1000 mL of malathion 50 EC ha⁻¹ or 625 mL of quinalphos 25 EC ha⁻¹ or 264 mL in dimethoate 30% EC in 200 L of water acre⁻¹ or 480 mL of quinalphos 25% EC in 200 L of water acre⁻¹.
- For control of grown-up larvae of diamondback moth, apply 37.5 kg of 5% malathion dust ha⁻¹.
- For control of grown-up larvae cabbage head borer apply 37.5 kg of 5% malathion dust ha⁻¹.

Sesame and linseed

Some of the visuals of the sesame insect pests and the damages caused by them are given in Table 7.14.

Table 7.14 Insect-pest in sesame and nature of damages

Name of pests	Damaging stages	Pictures*
Til leaf and pod caterpillar (<i>Antigastra catalaunalis</i>)	• Young larvae roll together a few top leaves and feed on them.	
Sesame gall fly (<i>Asphondylia sesame</i>)	• Maggots feed inside the floral parts and cause malformation of buds	

Safflower bud fly (<i>Acanthiophilus helianthi</i>)	• Maggots feed inside the floral parts	
Linseed gall fly (<i>Dasinura lini</i>)	• Maggots feed inside the floral parts	
Capitulum head borer (<i>Helicovera armigera</i>)	• Larvae feed voraciously on the capsules	
Safflower aphid (<i>Dactynotus carthami</i>)	• Nymph and adult suck the sap from tender parts of the plant	
Til hawk moth (<i>Acherontia styx</i>)	• The larvae feed voraciously on the leaves and defoliate the plant	

Source: Authors' own compilation.

* Photographs are adapted from Parthiban et al., 2017

Methods of pest management in Sesame

Cultural practices

- Avoid delay in sowing of sesame, practice timely or early sowing (before the first week of July)
- Intercropping of sesame with pearl millet, mungbean, and groundnut.
- Deep summer ploughing
- Collect and destroy the webbed leaves and infested pods
- To control sesame hawk-moth plough field during winter to expose hibernating larvae, hand-pick larvae in initial stages of the attack and kill them using kerosene oil
- Clip galls and burn the shredded buds for gall fly control

Biological/botanical control

- Safeguard and promote the multiplication of larval parasitoids like *Eurytoma dentipectus* and *Bracon hebetor* for gall fly control
- Spray neem oil @ 5% 2-3 rounds from 15 DAS at 10 days interval
- Release *Trichogramma chilonis* as a biocontrol agent

Chemical control

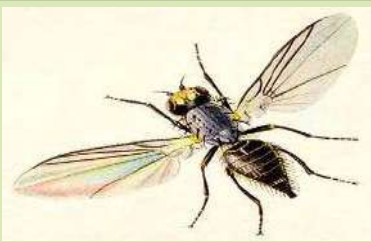
- Spray 2.5 kg of carbaryl 50 WP ha⁻¹ if the infestation is beyond ETL to control gall fly.
- Spray dimethoate 0.03% at bud initiation stage
- Spray quinalphos 0.05% or dichlorvos 0.75% at pest appearance, during flowering, and pod formation or
- Dusting twice with phosalone 4%. The first dusting should be done at 30 DAS and the second dusting at 45 DAS.

Safflower

Some of the visuals of the safflower insect pests and the damages caused by them are given in Table 7.15.

Table 7.15 Insect-pest in safflower and nature of damages.

Name of pests	Damaging stages	Pictures*
Safflower caterpillar (<i>Prospalta conducta</i>)	• Larvae defoliate the crop and damage the young capsules	

Gram caterpillar (<i>Helicoverpa peltigera</i> , <i>Helicoverpa armigera</i>)	Feed on leaves and also bores into flower heads (capsules) and devours the developing seeds	
Stem fly (Agromyzid fly) <i>Melanagromyza obtusa</i>	Maggots bore into the stem and girdle the plants	
Safflower Aphid (<i>Uroleucon carthami</i> <i>U. Compositae</i>)	Both nymphs and adults suck the sap from shoots, leaves, flowers and capsules and affected plants remain stunted	
Safflower bud fly (<i>Acanthiophilus helianthi</i>)	Eats the soft part of the capsules larva	
Cotton bollworm (<i>Helicoverpa armigera</i>)	Caterpillar feeds on leaves and also feed flower florets, bracts and bores into the capsules and feed on the seed	
Tobacco cutworm (<i>Spodoptera litura</i>)	Caterpillar feeds on the leaves and thus defoliates the plant.	

Source: Authors' own compilation.

* Photographs are adapted from Parthiban et al., 2017

Methods of insect-pest management in safflower

Cultural practices

- Grow non-host crop like wheat and barley as an intercrop and avoid intercropping with chickpea
- Avoid application of overdose of nitrogen and late sowing to control aphid attack
- Grow 2 or 3 rows of maize and sorghum in the fields

Mechanical practices

- Early removal and destruction of infested buds is helpful in checking the spread of the pest

Biological control

- Release of *Chrysoperla* eggs/ grubs @ 1-2 plant⁻¹ to control aphids.
- Protect and promote the multiplication of natural bioagents like *Enicospilus* spp, *Micromus cinearis*, *Aphidencyrus aphidivorus*, *Harmonia octomaculat* *Campoletis chloridae*, *Ischiodon scutellaris*, *Aphelinus* spp, etc.
- Encourage natural enemies, release larvae parasitized by *Apanteles flavipes* *Chelonus blackburni*, and *Rogas percurrans*.
- Spray HaNPV @ 250-300 larval equivalents ha⁻¹

Chemical control

- Spray 2.5 - 3.00 kg carbaryl 50 WP ha⁻¹ or 250 mL fenvalerate 20 EC ha⁻¹ to manage safflower caterpillar.
- Application of 500 mL dimethoate 30 EC ha⁻¹ or 1.00 L malathion 50 EC ha⁻¹ or 150-200 mL of phosphamidon 100 EC ha⁻¹ diluted in 600 to 650 L of water to control bud fly. Go for the second spray if needed.

7.6 Integrated disease management (IDM)

The disease is the function of the host (crop), pathogen, and environment. Integrated disease management is a combination of measures to prevent and manage crop diseases. It allows adopting a certain measure that reduces the interaction of host and pathogen through preventive measures/cultural methods and if the disease occurs then use of biological and chemical measures to reduce the intensity of the disease. In the following sections, we will discuss the IDM of various crops grown in Odisha.

7.6.1 *Climate change and integrated disease management*

Climate change impacts the occurrence; severity and prevalence of plant diseases as it affects the interaction between crops and pathogens in numerous ways (Zayan 2019). Thus disease management is continuously varying with respect to preference, timing, and efficacy of physical, chemical, and biological measures of control (Zayan 2019). IDM is highly location and crop-specific and it is developed for major crops and diseases especially to suit the changing climate scenarios.

7.6.2 *IDM for Rice*

Cultural methods

- Treat seeds in 54°C hot water for 10 minutes before sowing in the nursery after presoaking for six hours to kill seed-borne pathogens
- Do not use the seeds collected from disease affected fields
- 5 days of sun-drying of seeds during summer
- Summer ploughing to eradicate soil-borne pathogen
- Grow tolerant/resistant varieties
- Avoid using high doses of nitrogenous manures/ fertilizers
- Weed-free rice fields to destroy the shelter of pathogens
- Destroy crop residues and stubbles to eliminate inoculum sources.
- Ensure timely planting.
- Ensure optimum P availability to rice crop to control the incidence of brown spot disease.
- Drain excess water once the field is infected with the bacterial leaf blight (BLB) and avoid water stagnation once the infection is detected
- Apply K fertilizer in two splits at tillering and PI stages
- Application of neem cake @ 2.5 q ha⁻¹
- Crop rotation with black gram, potato, wheat, and groundnut.

Chemical Control:

- Seed treatment with thiram / captan / vitavax powder @ 2 g or carbendazim @ 1.5 g kg⁻¹ seed for both blast and brown spot control
- Spray with copper oxychloride/ mancozeb @ 1250 g ha⁻¹ or contaf/ carbendazim @ 500 g ha⁻¹ for brown spot control
- For controlling BLB the seeds are soaked with 10 g of plantomycin or 1.5 g of streptocyclin and 25 g of copper oxychloride in 10 L of water

- Spray propiconazole @ 500 mL ha⁻¹ or validamycin @ 1.5 L ha⁻¹ for sheath blight control
- Spray copper oxychloride @ 1 kg ha⁻¹ in 500 L of water at boot leaf stage twice at 7 days interval to control false smut
- Nursery soil treatment with carbofuran 3G before seeding for root knot nematode control.

Biological method

- Seed treatment with 10 g of *P. fluorescens* powder for kg⁻¹ of seed or seedling root dip with 20 g of *P. fluorescens* powder mixed litre⁻¹ of water for 1 h before transplanting or
- Foliar spray of 1 kg *P. fluorescens* powder ha⁻¹ for 2 times at 10 days of interval.

7.6.3 IDM for pulses

Successful integrated disease management (IDM) strategy involves reducing grain legumes losses due to diseases to tolerable levels while minimizing health and environmental risks on long-term sustainability basis, allowing agriculture to remain a productive and profitable enterprise. The IDM involving individual agronomic practices, careful use of fungicides, pesticides, bio-pesticides for pathogen control has complementary effects and can be applied together in farmers' fields mutually to provide farmers with the maximum economic return. Uses of healthy seed, alteration in sowing dates, use of short duration variety, destroying ratoon, destruction of infected plants, crop rotation are various tools used in IDM to reduce inoculum levels and vector populations. Various chemical methods like seed treatment with fungicide and spraying acaricides or insecticides to control the vector in the early stages of plant growth are quite effective. Location-specific components of IDM are needed to be evolved by identifying, evaluating, and integrating good agronomic practices. Various disease management options for different pulse crop are discussed below.

Black gram and green gram

- Use of disease-free seeds.
- Cultivate yellow mosaic virus resistant varieties like IPM 2-3 for green gram.
- Application of neem cake @ 150 kg ha⁻¹ for the control of dry root rot disease

- Seeds are to be treated with talc formulation of *Trichoderma viride* @ 4 g kg⁻¹ of seed. Alternately, it may be treated with *Pseudomonas fluorescens* @ 10 g kg⁻¹ of seed or chemicals like carbendazim or thiram @ 2 g kg⁻¹ of seeds.
- *P. fluorescens* can be applied @ 2.5 kg ha⁻¹ (applied with 50 kg FYM at 30 DAS) to control root rot.
- Removal of plant parts infected with leaf crinkle, yellow mosaic, and leaf curl
- Drenching of soil
- Management of vector
- Cleaning of weeds
- Collection of seeds from disease-free planting materials

Recommended chemicals for green gram and black gram disease control are listed in Table 7.16.

Table 7.16 Recommended chemicals/botanicals for green gram and black gram disease control

Name of the disease	Control measure
Yellow mosaic Leaf crinkle Leaf curl Powdery mildew	Spray methyl demeton @ 500 mL ha ⁻¹ or monocrotophos @ 500 mL ha ⁻¹ . Spray should be repeated after 15 days to control insect vector. Spray NSKE 5% or neem oil 3% twice at 10 days interval. Alternately, spray carbendazim 250 g ha ⁻¹ or wettable S @ 2.5 kg ha ⁻¹
Rust	Spray mancozeb @ 1 kg ha ⁻¹ or wettable S @ 2.5 kg ha ⁻¹
Leaf spot	Spray carbendazim @ 250 g ha ⁻¹

Source: Authors' own compilation.

Cowpea

- Removal of infected plants upto 30 days of sowing
- Spray methyl demeton 500 mL ha⁻¹ or monocrotophos 500 mL ha⁻¹ twice at fortnightly intervals to control insect vector of viral disease
- Spot soil drenching of carbendazim 1 g L⁻¹ or soil application of *Pseudomonas fluorescens* @ 2.5 kg ha⁻¹ (applied with 50 kg FYM at 30 DAS)

Bengal gram

- Seed treatment with *T. viride* culture applied at the rate of 4 g kg⁻¹ or *P. fluorescens* talc formulation @ 10 g kg⁻¹ seed before sowing or
- Application of *P. fluorescens* at the rate of 2.5 kg ha⁻¹ in soil at the time of final land preparation or
- Application of peat culture mixed with FYM or sand at the time of sowing, 30 days and 60 days after sowing

Red gram

- Remove the infected plants from the field.
- Spot soil drench with carbendazim @ 1 g L⁻¹ near to the base of the infected plants as well as healthy plants for wilt and root rot or soil application of *P. fluorescens* @ 2.5 kg ha⁻¹ (applied with 50 kg FYM at 30 DAS).
- To control wilt and dry root rot seed treatment with *T. viride* 1% WP @ 8 g kg⁻¹ seed/carboxin 37.5% + thiram 37.5% DS @ 4 g kg⁻¹ seed or soil application of *T. viride* 1% WP @ 500 g/ carboxin 37.5% + thiram 37.5% DS @ 500 g ha⁻¹.

7.6.4 IDM for Groundnut

Cultural methods

- Uproot volunteer groundnut plants and destroy infected plant parts.
- Practice crop rotation to avoid early season infection.
- Use good quality disease free certified seeds.
- Remove the weeds periodically and grow groundnut and pearl millet in 7:1 ratio.
- Deep summer ploughing (soil solarization) and removal of plant debris minimize disease occurrence and root knot nematode infestation.
- Timely sowing and adoption of proper spacing.
- Early sowing in the first fortnight of June to avoid disease incidence.
- Stop the spread of rust in disease free areas through strict plant quarantine regulations.
- Intercropping of pearl millet or sorghum with groundnut (7:1) reduce rust infection.
- Crop rotation with wheat, maize and soya bean to minimize stem rot incidence.
- Application of castor cake or neem cake @ 10 q ha⁻¹ in soil.

- Seed treatment using carbendazim/ thiram/ captan @ 2-3 g kg⁻¹ seed.
- Avoid sowing of seed deep in the soil.
- Prevent mechanical damage to crop plants during intercultural operations.
- Balanced fertilization, timely irrigation and pest management encourage good crop growth and reduce the disease incidence.
- Maintain adequate plant population.
- Rogue out bud necrosis affected plants up to 6 weeks after sowing.

Biological/botanical methods

- For rust control spray neem extract @ 5% to control insect vector.
- Seed treatment using 4 g *T. viride* followed by soil application of 2.5 kg mixed with 100 kg FYM before sowing.

Chemical methods

- Seed treatment with carbendazim 50% WP @ 2g kg⁻¹ or captan 80% WP 3 g kg⁻¹ seed or thiram 75% WP @ 5 g kg⁻¹ or or mancozeb 75% @ 3 g kg⁻¹ to control the seed borne disease.
- Spray carbendazim 1 g or mancozeb 2 g or chlorothalanil 2 g or hexaconazole 2 mL L⁻¹ water two to three times at 15 days interval to control leaf spot.
- Spray of tridemorph 2 g L⁻¹ of water three to four times at 15-20 days interval to control rust.
- Apply nematicides like carbofuran 3G @ 3 g m⁻² or aldicarb and phenamiphos (Nemacur) before sowing in furrows to control root-knot nematodes in endemic areas.
- Spray copper oxychloride and mancozeb 2 g L⁻¹ water for alternaria leaf spot control.

7.6.5 IDM for mustard/rape seed

- Summer ploughing of the field.
- Early sowing (first fortnight of October) avoid disease incidence, especially white rust, and blight.
- Adopt plant geometry of 30 x 10-15 cm row and plant distances.
- Defoliation of 50% of lower leaves at 60 days of crop age prevents the secondary spread of diseases.
- Removal of stag heads from white rust and downy mildew affected plants.
- Seed treatment with metalaxyl @ 6 g kg⁻¹, thiram or carbendazim @ 2 g kg⁻¹ seed.

- Follow balanced fertilization.
- Application of 25-40 kg S along with NPK.
- Spray of aqueous extract of bulb of garlic or leaf extract of eucalyptus @ 2% w/v or mancozeb 75 WP @ 0.2% twice at 50 and 70 days after sowing to control blight, white rust, etc.

7.7 Agro-ecological crop intensification for rice fallow

To minimize the risk of long dry spell induced crop failures, there is need of strong emphasis on water harvesting, runoff water collection for supplemental irrigation, inter cropping of rice with arhar/ green gram/ black gram in *kharif* season in the upland area. Agroecological intensification of bringing *rabi* fallow area can be made under pulses green gram, black grams, lentil and lathyrus as paira crop/relay crop/sequence crop using improved varieties, seed priming with P and molybdenum (Mo), seed pelleting on lime in acidic soil and seed treatment with fungicides, insecticides, and rhizobium treatment. The residual soil moisture can be harnessed if short duration pulses or oilseed can be planted in quick succession after *kharif* rice. Ensuring one or two supplemental irrigation can bring substantial *rabi* fallow under cropping in Odisha. Pulses are legume crops rich in protein that ensures food and nutritional security for poor people who cannot afford fish, meat, and milk.

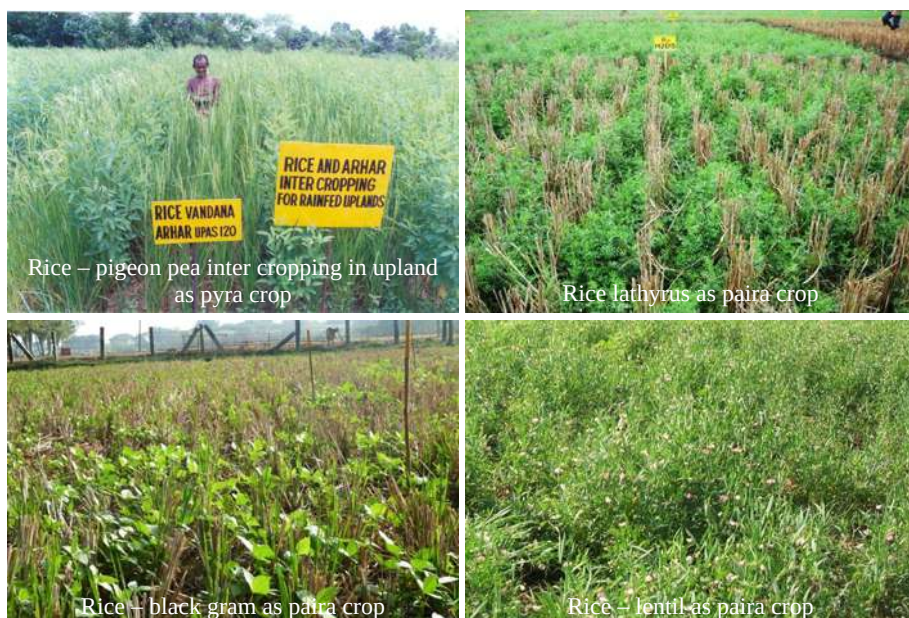


Fig. 7.9 Intensification of rice with pulses

Source: Authors' own collection.

It also improves soil health through atmospheric nitrogen fixation (Fig. 7.9). Pulses are the most important traditional crop of the state cultivated in all the districts. Green gram, black gram, horse gram, and arhar together account 87% of total pulse area and 84% of total production. The total area under rice fallow in Odisha is 12.2 lakh ha which is 10% of the total rice fallow of India (11.65 M ha). These areas can be brought under crop intensification by suitable strategies

Table 7.17 Rabi pulse varieties for rice fallows

Land type	Rabi pulse variety
Uplands	Green gram: TARM 1, PDM 54, Pusa1572, IPM 2-3 Black Gram: PU 30, 35, T-9, CO6, Prasad Lathyrus: Prateek, Bio L 212, Ratan, Mahateora
Medium lands	Chickpea: JG14 KWR 108, KAK2 Lentil: KLS218, HUL57 Green Gram: TARM 1, PDM 54, Pusa1572, IPM 2-3, IPM 2-14 Black gram: PU 30,31 35, T-9 Field pea : DDR23, HUDP 15
Shallow low lands	Chickpea: KPG59, JG14, KAK2, HK94-134 Lentil: K75, KLS218, HUL57 Green Gram: TARM 1, PDM 54, Pusa1572, IPM 2-3 Black gram: PU 30, 35, T-9, Prabha

Source: Authors' own compilation.

Table 7.18 Strategy components for rice fallow in Odisha

Action points	Interventions required
Variety	Improved varieties (cold and terminal heat tolerant) availability
Seed conditioning	Seed priming with Ammonium molybdate @ 3 g 10 kg ⁻¹ of seeds <i>Rhizobium</i> treatment @ 50 g kg ⁻¹ of seed
Seed treatment	Carbendazim (2 g kg ⁻¹ of seed) or thiram (3g kg ⁻¹ of seed)
Crop establishment	Zero tillage machines / line sowing
Diseases	Wilt and mosaic resistant varieties
Insects (Pod borer)	IPM responsive (bio-agent)
Fertilizers	2% DAP foliar spray or 1% DAP + 1% MOP at 20 and 40 days after sowing
Micronutrients	Foliar spray of 0.2% boron using borax at flower initiation stage in boron deficient soil

Weed management	Apply post emergence herbicides quizalofop ethyl @ 50 g a.i ha ⁻¹ at 20 DAS to control grassy weeds or imazethapyr @ 75 g a.i ha ⁻¹ at 15-20 DAS to control broad leaved weeds in pulses
Transfer of technology	Cluster demonstrations in hot-spots
Seed systems	Village level seed system/seed hub
Water management	Water harvesting structures, micro-irrigation, lift irrigation, shallow tubewell

Source: Authors' own compilation.

7.8 Farming system

Farming system is a system of growing crops with allied components of agriculture which is inter-related in terms of soil, implements, labour, capital, energy, and other inputs. Theoretically, it encompasses various components that are interrelated and interact among themselves. It is a resource management strategy to accomplish economic and sustained production to meet various requirements of farm households while conserving resources and sustaining environmental quality. Integration of farm enterprises such as crops/cropping systems, animals, pisciculture, agroforestry, poultry, sericulture, *etc.* enhances resources exploitation promoting resource flow from a system to another through residue recycling, increases resource use efficiency, curtails risk, diminishes the production cost, ensure ecological balance, deliver livelihood options and ensure food and nutritional security of poor and marginal farmers.

IFS enterprises depend on several factors like climatic conditions, farmers' preferences, soil type, knowledge, size of the farm, skill and technology, storage, transport and marketing, resource mobilizing power, credit facilities availability, socio-economic conditions, and customs, sentiments, and believes. In Odisha, small and marginal farmers constitute 90% of the total number of holdings and an average size of holding is 1.25 ha, about 40% of people are below the poverty line, varied agro-climatic condition, recurrent natural disasters, and the presence of well-equipped extension support system such as Krishi Vigyan Kendras enhance the scope of the integrated farming system (IFS) as climate-smart agriculture.

7.8.1 Integrated farming system and climate change

The IFS has enormous potential to make marginal and small farmer climate-smart through enterprise diversification on the same land and using farm resources sustainably. A higher degree of diversification of an agricultural system increases its ability to adapt to climate change. Instead of concentrating

the farm on one type of production system (crops or animals or agroforestry), IFS associates them into combinations like crops and livestock; livestock and forestry; crops and forestry; or crops, livestock, and forestry. Implementation of IFS generates food, energy, fodder, fiber, timber, and non-timber forest products in the same area, at the same time, or in rotation. Integrated farming system modifies micro-climate by altering local temperature; increasing water availability; and decreasing the effect of extreme weather events on crops, livestock, and other products; reducing soil erosion; enhancing productivity. Additionally, it provides socio-economic benefits by delivering multiple products for livelihood and income. IFS encourages the maximum use of land by integrating crops with agroforestry, dairy animals, birds, and fish within the same land space at the same time. The practice of rearing livestock, fish, and birds generate extra income, employment opportunities for the male and female farmers. This system also ensures equity by providing an opportunity to the women members of the farm family to access the produce. Being a multi-enterprise entity, IFS is one of the potential climate change adaptation options that reduce the impact of drought, flood, cyclone, heat waves. If one enterprise is impacted, the other enterprise compensates for the loss incurred. It has been reported that methane emission is reduced in rice-duck-fish based farming system as compared to rice monocropping. The aerated environment created due to the movement of ducks and fish slows down the methane formation through anaerobic decomposition by methanogens and oxidation of methane already produced by methanotrophs. The selection of enterprise and their size/area has to be done by using optimization techniques involving synergy and trade-off analysis among the enterprises. Farming system models along with their enterprises suiting to different agro-climatic zones of Odisha (Table 7.9) are discussed below.

Table 7.19 IFS identified for different agro-climatic zones of Odisha

Agro-climatic zones	Farming system modules
North western plateau (Sundargarh, Deogarh)	Crop (rice-mustard/greengram) – dairy – goatery – poultry-agroforestry
North central plateau (Keonjhar, Mayurbhanj)	Crop (rice/maize-pulse/mustard) – dairy – goatery – poultry – apiculture-agroforestry
North eastern coastal plain (Balasore, Bhadrak, Jajpur)	Crop (rice-pulse/oilseed) – dairy – pisciculture – mushroom Vegetable + pisciculture + poultry + dairy Rice + vegetable + duckery + apiculture + banana Rice + fish + horticulture + duckery + agroforestry + mushroom + goatery system

East & south-eastern coastal plain (Jagatsinghpur, Khurda, Kendrapada, Puri, Nayagarh, Cuttack)	Crop (rice + pulse/oilseed/veg) + dairy + pisciculture + mushroom Banana + paddy + dairy + vegetables + vermicompost + bee keeping + mushroom + fishery Paddy + groundnut + greengram + betel vine + fodder + azolla + dairy + goatery + poultry + vermicompost system Chili + baby corn + cauli flower + tomato + vermicompost + honey bee Pisciculture + horticulture + poultry Rice + vegetable + duckery + apiculture + banana Rice + fish + horticulture + duckery + agroforestry + mushroom+ goatery system
North east Ghat (Rayagada, Gajapati, Kandhamal, Ganjam)	Crop (rice/millet-pulse/oilseeds/veg) – goatery – sheep – poultry – agroforestry Rice + vegetable + duckery + apiculture + banana Rice + fish + horticulture + agroforestry + duckery
Eastern ghat highland (Nawarangpur, part of Koraput)	Crop (rice/millet-pulse) – goatery – sheep – agroforestry Field crops + vegetables + dairy + goatery + poultry
South eastern Ghat (Malkangiri, part of Koraput)	Crop (rice/maize/ragi/til-veg) – poultry – goatery – sheep – agroforestry
Western undulating zone (Nuapada and Kalahandi)	Crop (rice/cotton-pulse/oilseeds) – dairy – poultry – piggery – goatery Crop – animal – poultry – pisciculture system
Western central table land (Bolangir, Baragarh, Boudh, J.suguda, Sonepur, Sambalpur)	Crop (rice/groundnut/arhar/til-pulse/oilseed/veg) – dairy – poultry – piggery – goatery
Mid-central table land (Dhenkanal and Angul)	Crop (rice/groundnut/arhar/til-pulse/oilseed) – poultry – dairy – apiculture – goatery – mushroom

Source: Authors' own compilation.

7.8.2 Details of farming systems recommended for different agro-climatic zones of Odisha

i. Rice + fish + horticulture + duckery + agroforestry + mushroom + goatery system

The field design of the model includes wide bunds all around, a pond connected with trenches on two sides, and a guarded outlet (Fig. 7.10). The approximate area allotment is, 65% for the main rice field, 20% for bunds, and 15% for pond refuge and trenches. Rice and field crops in the main field in succession, fish in pond refugees and trenches, vegetables, fruits, floriculture, and agroforestry

on pond dyke. The intervention of 10 goats (Black Bengal breeds), 50 ducks (Khakhi Campbell), 50 poultry birds (Vanraj, Black rock), 4 honey bee boxes on the pond dyke, and growing of 400 beds of mushrooms (paddy straw and oyster) on pond dyke by using the paddy straw in one-hectare area. Suitable rice varieties are Varshadhan, Durga, CR Dhan 505/500. Fish species like catla, rohu, mrigal, common carp, silver carp, freshwater prawn (*M. rosenbergii*) are suitable. Tree species like *Acacia mangium*, *A. auriculiformis* used as agroforestry. In the tree shade crop like *Amorphophallus*, yams, colocasia, ginger, turmeric are grown. Marigold and tuberose are also suitable.

The system can annually produce around 16 -18 t of food crops, 0.55 t of meat, 0.6 t of fish and prawn, 8000 - 12,000 eggs, 600 kg of mushroom apart from fuelwood flowers, and animal feed. The net income in the system is about Rs. 76,000 in the first year. Subsequently, this increases to around Rs.1.3 lakh in the sixth year with B: C ratio of 2.2-2.4. Fifteen times increase in farm productivity and 20 times increase in net income is obtained over the traditional rice farming in rainfed lowlands. The rice-fish system also generates employment of around 250 to 300 man-days hectare⁻¹ year⁻¹. This production system is suitable for adoption in the rainfed lowland ecosystem of East and South-Eastern Coastal plain (Jagatsinghpur, Khurda, Kendrapada, Puri, Nayagarh, Cuttack) and North Eastern Coastal plain (Bhadrak, Jajpur, Balasore), agro-climatic zones of Odisha. In a similar system in Khurda, about Rs. 3,75,920 (gross income) from an area of 1.87 ha, crop-based farming system adopting paddy-vegetables based farming system over a period of 13 months was reported (Dash et al., 2015).



Fig.7.10 Rice+fish+horticulture+duckery+agroforestry+mushroom+goaterysystem

Source: Authors' own collection.

ii. *Multi-tier rice + aquaculture + horticulture + agroforestry + duckery system*

The model includes land shaping in the form of uplands (Tier I and tier II) covering about 15% of field area followed by rice field area of 40% as rainfed lowland (tier III) and deep water (tier IV). This rice field is connected to micro watershed cum fish refuge (pond) of 20 % area for growing of fish and prawn with the rice crop. Raised and wide bunds are made all around using 25% of the farm area. Interventions include fruits (Mango, Banana, Papaya, Sapota, Guava, Pineapple), vegetables, root and tuber crops in tier I and II, rice-vegetables/ field crops (Sunflower, Groundnut, Sweet Potato) in tier III and IV, composite fish culture with freshwater prawn (1:1) in pond refuge, silviculture plants, 50-100 ducks on pond dyke (Fig. 7.11). The annual productivity of the system is rice 8 t ha⁻¹ (rice-rice), fish and prawn 1 t ha⁻¹, vegetable 20-25 t ha⁻¹, and tuber crops 8.5 to 51.7 t ha⁻¹. The cropping intensity in this system increases to 170 % in the field and 360 % in the raises upland/dyke.



Fig. 7.11 Multi-tier rice + aquaculture + horticulture + agroforestry + duckery system

Source: Authors' own collection.

This model improves soil fertility, the pond provides life-saving irrigation to crops during mid-season drought facilitate biocontrol of weeds and other pests. This system has been adopted in some areas of Odisha. This production system is suitable for adoption in the rainfed lowland ecosystem of East and South-Eastern coastal plain (Cuttack, Jagatsinghpur, Khurda, Puri, Kendrapada, Nayagarh) and North-Eastern coastal plain (Bhadrak, Balasore, Jajpur) agro-climatic zones of Odisha.

iii. *Integrated rice + fish + horticulture + agroforestry + duckery system*

This system includes one-acre irrigated lowland land, developed to an integrated rice + fish + horticulture + agroforestry farming system. Allocation of the area to different components includes 30% of the area to two rice + fish fields (600 m² each with a refuge of 15% area) and another 30% area to two nursery fish ponds for fingerlings rearing. The remaining 40% (1500 m²) area is utilized as bunds for growing vegetables, horticultural crops, and silvicultural trees (Fig. 7.12). The interventions include growing rice, fruits, vegetables, root and tuber crops, silvicultural crops on field bunds, rearing of fish fingerlings, and grow-out fish in respective pond refuges. Mushroom, honey bees, and vermicompost on field bunds throughout the year. Teak as an agroforestry crop was planted only on one of the dyke.



Fig. 7.12 Integrated rice + fish + horticulture + agroforestry + duckery system
Source: Authors' own collection.

Two rice crop yields 1000-1200 kg of grain, 1.5-2.0 t of rice straw, fish fingerlings worth of Rs. 4000- 5000 and grow out fish of Rs. 20,000 per year. From the bird unit, 40-50 kg of meat is produced every two-three months which gives a net return of Rs. 8000-10000 per year besides mushrooms, vegetables, pulses, and fodders. This system in establishment years provides net earnings of Rs. 1,500-3,300 per month besides, high employment generation of 450-500 man-days per year. Agroforestry reduces soil loss through erosion drastically. The production system is suitable for adoption in rainfed lowland ecosystem of North Eastern Coastal plain (Bhadrak, Balasore, Jajpur), East and South-Eastern Coastal plain (Jagatsinghpur, Khurda, Puri, Kendrapada, Nayagarh, Cuttack) and North Eastern Ghats (Gajam, Rayagada, and Gajapati) agro-climatic zones of Odisha.

iv. *Field crops + vegetables + dairy + goatery + poultry system*

This integrated farming system model has been designed for one-hectare area with an allocation of 50% area to field crops (rice, maize, millets, pulses, and oilseeds), 40% area to vegetables, and rest 10% area to livestock (dairy 2-3 cross breed cows + 50 back yard poultry birds + 5-10 goats) (Fig. 7.13). The contributions of field crops, vegetables, and livestock are 25%, 40%, and 35% of the total income, respectively from the system. With optimum management the system gives a net income of Rs. 1.1 lakh annum⁻¹ ha⁻¹ with B: C ratio of 2.4. Fodder crops are intercropped or grown as border crops to ensure the availability of fodder for livestock like cows, sheeps, and goats. The production system is suitable for adoption in the Eastern Ghats High land Zone (Nawrangapur and parts of Koraput) of Odisha.



Fig. 7.13 Field crops + vegetables + dairy + goatery + poultry system

Source: Authors' own collection.

v. *Field crops + horticulture + poultry + goatery + mushroom system*

This integrated farming system model has been designed for one-hectare area with allocation of 70% area for field crops (rice, toria, green gram, black gram), 20% area for horticulture (fruits, vegetables, root and tuber crops) and the rest 10% area for livestock (50 back yard poultry birds and 5-10 goats) and 100 beds of mushroom in 2 cycle (Fig. 7.14). With optimum management, the system gives yield of 3.5 t of paddy, 4.0 t of paddy straw, 0.5 t of oilseed

and pulses, 250 kg of mushroom, 2 t of vegetables and fruits besides eggs and meats. The system gives a net income of Rs. 1.0-1.5 lakh annum⁻¹ ha⁻¹ with B: C ratio of 2.6. The production system is suitable for adoption in the Eastern Ghat Highland Zone (Nawrangapur and parts of Koraput) of Odisha.



Fig. 7.14 Field crops + horticulture + poultry + goatery + mushroom system

Source: Authors' own collection.

vi. *Field crops + vegetables + dairy + poultry + piggery + goatery system*

This integrated farming system model has been designed for one-hectare area with an allocation of 70% area for field crops (rice, maize, millets, pulses, and oilseeds), 20% area for vegetables and the rest 10% area for livestock (dairy-2-3 cross breed cows, 50 back yard poultry birds + 4-5 goats + 4-5 pigs) (Fig 7.15). The contributions of field crops, vegetables, and animal husbandry are 40%, 35%, and 25%, respectively of the total income from the system. With optimum management, the system gives a net income of Rs. 1.2 lakh annum⁻¹ ha⁻¹ with B: C ratio of 2.6. The waste collected from livestock is used as an organic nutrient supplement to field crops and vegetables. Similarly, the green and dry matter (straw) of vegetables and field crops are used as forage for livestock. It decreased the use of off-farm external inputs and increased farm income through the inclusion of allied components. It ensures a stable income on regular basis through the selling of eggs, meat, milk, and vegetables. The integration of allied activities guaranteed the accessibility of food enriched

with vitamins, minerals, protein, carbohydrates, and fat. The production system is suitable for adoption in Western undulating zones (Kalahandi and Nuapada) of Odisha.



Fig. 7.15 Field crops + vegetables + dairy + poultry + piggery + goatery system

Source: Authors' own collection.

vii. *Field crops + vegetables + livestock + silviculture system*

This integrated farming system model has been developed for one-hectare area with the allocation of 50% area for field crops (rice, maize, ragi, til), 40% area for horticulture (fruits, vegetables, root and tuber crops), and the rest 10% area for livestock (50 back yard poultry birds, 5goats, 5 sheep) and 50-100 silvicultural trees on field bunds (Fig 7.16). The contributions of field crops, vegetables, and animal husbandry are 25%, 40%, and 35%, respectively of the total income from the system. Under optimum management the system gives a net income of Rs. 1.1 lakh annum⁻¹ ha⁻¹ with B: C ratio of 2.4. The production system is suitable for adoption in South-Eastern Ghat zones (Malkangiri and parts of Koraput) of Odisha.



Fig. 7.16 Field crops + vegetables + livestock + silviculture system

Source: Authors' own collection.

viii. Crop + horticulture + livestock + apiculture + silviculture system

This integrated farming system model has been designed for one-hectare area with an allocation of 60% area for field crops (rice, maize, mustard, pulses), 30% area for horticulture (fruits, vegetables, root and tuber crops), and the rest 10% area for livestock (50 back yard poultry birds, 5 goats, 2-4 cross breed cows) and 50-100 silvicultural tress on field bunds (Fig. 7.17). The contributions of field crops, vegetables, and animal husbandry are 30%, 50%, and 20%, respectively of the total income from the system. Under optimum management, the system gives a net income of Rs. 1.2 lakh annum⁻¹ ha⁻¹ with B: C ratio of 2.24. The production system is suitable for adoption in North Central Plateau zones (Keonjhar, Mayurbhanja) of Odisha.



Fig. 7.17 Crop + horticulture + livestock + apiculture + silviculture system

Source: Authors' own collection.

ix. *Field crops + horticulture + livestock + apiculture + mushroom system*

This integrated farming system has been developed for one-hectare area with allocation of 35% area for field crops (rice, groundnut, red gram, til, mustard, green gram), 55% area for horticulture (fruits, vegetables, root and tuber crops) and the rest 10% area for livestock (50 back yard poultry birds, 5 goats, 2-4 cross breed cows, 5-10 pigs) and 4-6 honey bee boxes and 200 beds of oyster mushroom in 2 cycles on field bunds (Fig. 7.18). The contributions of field crops, vegetables, animal husbandry, apiculture, and mushroom are 15%, 44%, 35%, 3%, 3%, respectively of the total income. Under optimum management, the system gives a net income of Rs. 1.2-1.5 lakh annum⁻¹ ha⁻¹ with B: C ratio of 2.3. The production system is suitable for adoption in Western Central Tableland (Boudh, Baragarh, Bolangir, Jharsuguda, Sonepur, and Sambalpur) of Odisha.



Fig. 7.18 Field crops + horticulture + livestock + apiculture + mushroom system

Source: Authors' own collection.

x. *Pond based Crop + fishery + livestock + horticulture + vermicompost system*

This integrated farming system has been developed for one-hectare area with an allocation of 33% area for field crops (rice, green gram, maize), 24% area for horticulture (fruits, vegetables, root and tuber crops), 41.5% area for fishery (composite fish), 0.9% area for the dairy (2 crossbreed Jersey cow) and the rest 0.5% area for poultry 400 poultry birds. The contributions of field crop, horticulture, dairy, poultry, and fishery are 8.1%, 30.6%, 38.4%, 11%, and 11.9%, respectively of the total income. Water productivity in this system is very on account of its multiple-use in raising crops, fruits, and vegetables (Fig. 7.19). Under optimum management, the system gives a net income of Rs. 2.9-3.0 lakh annum⁻¹ ha⁻¹ with B: C ratio of 2.46. The production system is suitable for adoption in the South-Eastern coastal plain (Kendrapada, Jagatsinghpur, Khurda, Puri, Nayagarh, Cuttack) of Odisha.



Fig. 7.19 Pond based crop + fishery + livestock + horticulture + vermicompost system

Source: Authors' own collection.

xi. *Pond based field crop + fishery + horticulture + livestock + mushroom system*

This integrated farming system has been designed for one-hectare area with an allocation of 24% area to field crops (rice, pulses and oilseeds), 32% area to horticulture (fruits, vegetables, root and tuber crops), 34% area to fishery (composite fish), 1.5 % area to dairy (3-4 cross breed), 0.5% area to mushroom and 0.5% area to poultry (400 poultry birds). The contributions of field crop, horticulture, dairy, poultry, fishery, and mushroom are 6.1%, 26 %, 24 %, 11.9%, 38.4%, and 11.9%, respectively of the total income.

4.5%, 34%, and 5% of the total income. The fish pond was surrounded by a strong dyke for growing papaya, root/ tuber crops, and banana. The residue of crops is used as fodder, thatch, and medium for growing mushroom. Water productivity in this system is very high on account of its multiple-use in raising crops, fruits, and vegetables (Fig. 7.20). Under optimum management, the system gives a net income of Rs.3.0-3.3 lakh annum⁻¹ ha⁻¹ with B: C ratio of 2.42. The production system is suitable for adoption in North-Eastern Coastal plain (Balasore, Bhadrak and Jajpur) of Odisha.



Fig. 7.20 Pond based field crop + fishery + horticulture + livestock + mushroom system

Source: Authors' own collection.

xii. Field crops + horticulture + goatery + poultry system

This system has been designed for one-hectare area with an allocation of 40% area to field crops (rice, pulses, millets, and oilseeds), 50% area to horticulture (fruits, vegetables, root and tuber crops, spices), 1% area to goatery (50 goats), and 0.5% area to poultry (100 poultry birds) and rest of area to silvicultural plants (Fig. 7.21). The contributions of field crop, horticulture, goatery, and poultry are 12%, 49%, 33%, and 6%, respectively of the total income. Under optimum management, this system provides a net income of Rs. 2.0 lakh

annum⁻¹ ha⁻¹ with B: C ratio of 2.5. The production system is suitable for adoption in North East Ghat (Kandhamal, Rayagada, Gajapati and Ganjam) of Odisha.



Fig. 7.21 Field crops + horticulture + goatery + poultry system

Source: Authors' own collection.

xiii. *Field crops + horticulture + poultry + dairy + apiculture + goatery + mushroom system*

This system has been developed for one-hectare area with an allocation of 60% area to field crops (rice, groundnut, pigeon pea, til, pulses and oilseeds), 25% area to horticulture (fruits, vegetables, root and tuber crops) 5% area to livestock (10 goats, 2 cross breeds, 50 backyard poultry birds) and 2-4 honey bee boxes (Fig. 7.22). Various components of this system viz., field crop, horticulture, livestock, and honey bee contribute 35%, 49%, 15%, and 1%, respectively of the total income. The nutritional security is ensured by the inclusion of the horticultural and vegetable crops to this farming system.

Similarly, additions of poultry, bee-keeping, dairy, growing mushroom, goatery components conserve land space and provide high energy food without reducing food grains production. The crop residue is used as fodder, thatch, and medium for growing mushroom. Water productivity in this system is very high on account of its multiple-use in raising crops, fruits, and vegetables. Under optimum management, the system gives a net income of Rs 1.0-1.2 lakh annum⁻¹ ha⁻¹ with B: C ratio of 2.25. The production system is suitable for adoption in Mid Central Tableland (Angul and Dhenkanal) of Odisha. In research in Dhenkanal district, it was reported that the maximum oyster mushroom production is 766 kg annum⁻¹ which is due to optimum temperature regime of 14- 27°C with relative humidity of 70-80% prevail in that area (Sahoo and Behera, 2017).



Fig. 7.22 Field crops + horticulture + poultry + dairy + apiculture + goatery + mushroom system

Source: Authors' own collection.

xiv. *Pisciculture + horticulture + poultry-based farming system*

This model is developed in 0.94 ha area with an allocation of 0.8 ha area for pisciculture, 0.14 ha area for horticulture, and 540 number of poultry birds. Banana is grown on dykes (Fig. 7.23). With optimum management, the system provides Rs 2.4 lakhs gross return per year, net income of Rs. 1.45 annum⁻¹ with B: C ratio of 2.56. With respect to individual components the highest B:C ratio is obtained from horticultural crops (4.38) followed by pisciculture (3.83). The maximum net profit (69%) is obtained from pisciculture. This model is most suitable for Nayagarh district.



Fig. 7.23 Pisciculture + horticulture + poultry based farming system

Source: Authors' own collection.

xv. Vegetable based farming system

This model (Fig. 7.24) is developed for one ha area with allocation of 0.36 ha area for vegetable, 0.64 ha area for pisciculture, 6 numbers of dairy animals, and 150 numbers of poultry birds provide Rs 3.4 lakh gross return per year. This system recorded a net monetary return of Rs 2.13 lakh annually with B:C ratio of 2.72. Among the components, vegetable cultivation resulted in maximum net profit (61%) and B:C ratio of 5.25. It is most suitable for Tihidi, Bhadrak district.



Fig. 7.24 Vegetable based farming system

Source: Authors' own collection.

xvi. Crop + animal + poultry + pisciculture system

This model in 5.2 ha area is developed with an allocation of 5 ha area for crop (rice/ sugarcane/ banana/ wheat/ maize/ vegetable), 0.2 ha area for pisciculture, 5 numbers of dairy animal, 40 numbers of duckery and 40 numbers of poultry birds provide Rs 7.53 lakh gross return annually (Fig. 7.25). This system earned a net profit of Rs 4.99 lakh against Rs 6120 in conventional systems. A maximum net profit (Rs 4.54 lakh) was obtained from crop components. This system is suitable for Kalahandi district. Banana, mango, and teak lemon were grown on dykes.



Fig. 7.25 Crop+animal-poultry+pisciculture system

Source: Authors' own collection.

xvii. Paddy + groundnut+ greengram + betel vine + fodder + azolla + dairy + goatery + poultry + vermicompost system

This model (Fig.7.26) in 1.32 ha area earned a net profit of Rs 2.35 lakh with B: C ratio of. 2.7. It also generated additional employment of 422 mandays (321 male + 101 Female). This system is suitable for coastal area in Puri district.



Fig.7.26 Paddy + groundnut+ greengram + betel vine + fodder + azolla + dairy + goatery + poultry + vermicompost system

Source: Authors' own collection.

xviii. *Farm pond based system for coastal degraded lands*

The farm ponds in coastal/degraded lands contain either fresh or brackish water due to soil salinity and backwaters. Farm pond based multi-enterprise production system developed to ensure water harvesting and multiple uses of water. Saline tolerant fodders are grown on the bunds of farm pond to support cattle and goat production. The production of brackish water prawn in coastal farm pond provides additional income to the farmers. During the dry period, water in the pond can be used for irrigation after testing its quality. Similarly, the inclusion of bee-keeping, fisheries supply high energy food without lowering the production of food grains. Rice + vegetable + duckery + apiculture + banana based farming system model (Fig.7.27) in 4.2 ha area gave net income of Rs. 3.4 year⁻¹. It also generated additional employment of 804 man-days. Additional return of Rs. 4000/- from 600 m² pond can be obtained from the duck component within four months through the sale of eggs. This model is most suitable for the Astaranga block of Puri district especially in the disadvantaged areas having coastal salinity as a constraint.



Fig. 7.27 Farm pond based system for coastal degraded lands

Source: Authors' own collection.

xix. *Vegetable Based Integrated farming system*

Chili + baby corn + cauliflower + tomato + vermicompost + honey bee integrated farming system model (Fig. 7.28) in 2 ha area earned a net profit of Rs. 1.87 with B: C ratio of. 2.7. It also generated additional employment of 605 mandays (295 male + 310 female). This system is suitable for Pipili block of Puri district.



Fig. 7.28 Vegetable Based Integrated farming system

Source: Authors' own collection.

xx. Pond based integrated farming system

Banana - paddy - dairy - vegetables - vermicompost - beekeeping - mushroom - fishery model is designed for pond based IFS for favourable lowland ecology (Fig. 7.29) in 2.87-acre area with an allocation of 0.67 acre for banana, 1 ac for paddy, 0.2 acre for vegetables, 1 acre for fishery, mushroom (1800 beds year¹), poultry (1000 birds), vermicomposting (3 units), beekeeping. This system provides Rs. 4.53 lakh of net return annually and generated additional employment of 804 mandays. The excavated soil from the pond and side trenches was used for building dykes. Fishes were grown in the refuge pond, trenches, and also in the rice field. This system is suitable for Nimapada block of Puri district. Banana, papaya, and teak were grown on dykes.



Fig. 7.29 Pond based integrated farming system

Source: Authors' own collection.

xxi. *Raised and sunken bed (RSB) based rice + fish + vegetable + fodder system for coastal waterlogged areas*

It is a practice of land management to grow vegetables, fodder, and fish right in the center of rice fields. It involves making of raised broad beds and sunken furrow alternatively. RSB system can serve as climate-proof technology in the rice-based farming systems particularly in the coastal ecosystem wherein the inundation of rice fields are occurred due to the sea level rise and heavy rainfall during monsoon (Fig. 7.30).



Fig. 7.30 Raised and Sunken Bed (RSB) based rice

Source: Authors' own collection.

Beds of 4 m and furrows of 6 m with a minimum 1 m depth are appropriate for the coastal area having high-intensity rainfall. The length of beds and furrows can be according to the length of the field. In one ha area of flat paddy field, 10 beds of 4 m × 100 m × 1 m and 10 furrows of 6 m × 100 m × 1 m can be made which envisages 60% area of furrows and 40% area of beds. On the downside of the slope of the furrow, 6 m × 3 m × 1 m (from furrow bottom) trenches are made to shelter the fishes during water-scarce conditions or intermittent dry spells. An outlet can be provided to drain out the excess water from the furrows. The raised broad beds are stabilized by planting two rows of hybrid Napier grass on the edges on either side. In the RSB, the low area is utilized for growing rice and the raised bed area, which is above the water level present in the paddy field, are used for growing of seasonal vegetable or fodder crop during monsoon season. The 40% area of

beds can be utilized to grow high-value vegetables during monsoon season. Vegetables like chillies, brinjal, okra, amaranthus, cucumber, bitter gourd can be grown on beds during monsoon seasons and long duration paddy cum fish (grass carp / singhi/ magur) can be practiced in furrows. During off-season, vegetables like cowpea, French bean, chillies, tomato, cluster bean capsicum can be grown successfully on bed, and pulses or oilseed crops can be grown in furrows. This provides a net return of Rs. 1.2 lakhs $\text{ha}^{-1} \text{year}^{-1}$ and B:C ratio: 4.78. The gross water productivity and net water productivity of the system is Rs. 8.96 m^{-3} , and Rs. 6.9 m^{-3} . This system is highly suitable for the coastal districts of Odisha.



Fig. 7.31 fish + vegetable + fodder system for coastal water logged areas

Source: Authors' own collection.

xxii. *Three-tier system of fish + rice + vegetable farming*

Three-tier systems involve the shaping of the low lying area into three equal portions as a pond, original or middle land, and raised land. The pond area should be the downward side of the slope. The excavated soil from the pond is taken to the upper side of the slope for raising the land. The pond



Fig. 7.32 Three tier system of fish + rice + vegetable farming

Source: Authors' own collection.

is used for water harvesting during monsoon season for pisciculture, and life-saving irrigation. Stored freshwater in midland and pond keep field relatively salt free in the coastal area. The pond facilitates better drainage to the mid /raised land to prevent damages of crops due to occasional heavy rains in the dry season. During the wet season, paddy can be grown in the midland along with vegetables on the raised bed. The system is in practice in coastal areas wherein water logging is the major limitation for crop production (Fig. 7.32).

xxiii. Field crop+ horticulture + dairy + goatery + poultry + silviculture system

This system is developed for one-hectare area with allocation of 40% area for field crops (rice, maize, mustard, greengram), 50% area for horticulture (fruits, vegetables, root and tuber crops) and rest 10% area for livestock (50 back yard poultry bird, 5 goats, 2-4 cross breed cows) and 50-100 silvicultural trees on field bunds. Various components like field crops, vegetables, and animal husbandry contribute 20%, 50%, and 30%, respectively to the total income. Under optimum management, the system gives net income of Rs. 1.05 lakh annum⁻¹ ha⁻¹ with B: C ratio of 2.25. The production system is suitable for adoption in North-Western Plateau zones (Sundergarh and Deogarh) of Odisha.

xxiv. Rice based IFS model for irrigated ecology

A model of one-acre area (Fig. 7.33) with the allocation of 30% area (1200 m²) for field crops (rice-rice + fish), 30% area (1200 m²) for a fish pond, 200 m² area for the trench of 0.8 m depth, 1000 m² area for bunds and rest 400 m² area for agroforestry provides 11 q of food crops, 1.0 q of fish, 0.5 q of meat, 14 q of vegetables and 0.9 q of fruits besides 15 to 20 q of rice straw annually.

This system generates employment of 200-250 mandays acre⁻¹ year⁻¹. During *kharif* long-duration varieties (160 days) & in *rabi* short (120 days) duration varieties of rice are grown. Suitable pulse crops for dry season are cowpea, green gram, black gram,. Fruit crops like papaya, banana, pineapple, guava, mango; plantation crops like areca nut, teak, and neem; spices & condiments like onion, chilli, ginger, garlic, turmeric can be taken in the system. In pond, fish species like rohu, mrigal, catla, common carps are raised. Under optimum management, the system gives a net income of Rs. 36000 to 60000 acre⁻¹ month⁻¹.



Fig. 7.33 Rice based Integrated Farming System model for irrigated ecology

Source: Authors' own collection.

7.9 Protected Agriculture

Crops are grown under polyhouse/green house under the controlled environmental condition such as temperature, humidity-controlled by the equipment fixed in the polyhouse (Fig. 7.34). The crops like vegetables, flowers and nurseries are grown under protected structures. The crops can be taken around the year under a protected structure. Generally, tomato, cucumber, capsicum, chili, and flowers like rose, chrysanthemum, gerbera, and carnation are being grown under protected structures. Crops grown in the poly house are protected from bright sunlight, intense heat wave, hail storm, cold waves. Every factor controlling crop growth can be controlled in a poly house. High tech poly houses even have a heating system to decontaminate the soil from pathogens. Year-round availability, less infection of disease and pests, less use of pesticides in the fruits and vegetables grown under protected structures that enhance nutritional security. Production and quality parameters are reported to be high in the fruits and vegetables grown under protected structures. Various

designs are available suiting different climatic conditions. Bureau of Indian standards has formulated different standards for poly houses/ greenhouses that are used by the national horticulture board for promoting protected horticulture in the countries. The following materials commonly used to build frames for the greenhouse are (i) Galvanized iron pipe, (ii) bamboo, (iii) steel, (iv) wood, (v) aluminum and (vi) reinforced concrete (RCC). The choice of the above materials depends upon their physical properties, requirements of design strength, shelf-life and cost.



Fig 7.34 Protected Agriculture

Source: Authors' own collection

7.9.1 Hydroponic fodder production

Hydroponics is growing plants in nutrients rich solutions under controlled conditions instead of open field soil cultivation. It takes the pressure off the land to produce high quality nutritious green fodder crops such as maize, sorghum, etc. for the livestock. Fodder grown in hydroponics comprises of grass with grains, leaves, stem, and roots as compared to the only stem and leaves part in conventionally grown fodder (Fig. 7.35). Non-availability of quality fodder, higher labour cost, and small landholdings has left dairy farmer with many challenges for milk production. The problem is more aggravated during extreme situations like flood, drought. Rashtriya Krishi Vikas Yojana and various state government schemes supporting hydroponic fodder cultivation in India.

Requirements for hydroponics fodder cultivation

- Small landholdings.
- Non-availability of productive land for fodder.
- Less access to irrigation, and other land preparations facilities.
- Limited area for fodder production in the mining and coastal areas.
- Damage of fodder crops by wandering cattle and wild animals.
- Labour cost for cultivation practices.
- Less interest showed by educated unemployed youths for fodder farming.
- The demand for green fodder is very high.

Production processess

- Remove the floating seed from the warm water.
- Add 50 - 100 gm salt in the water to minimize the chance of fungus growth.
- Allow this seed to soak water for around 12 hours after that drain the water and then wash the seeds with clean water.
- Transfer this washed seed in a gunny bag and allow them to sprout. In a hot climate the seed will take about 24 hours to germinate while in a cold climate, it will take more than 24 hours.
- Transfer the sprouted seeds from the gunny bags to clean trays and evenly spread them and place this tray on the rack.
- Sprinkle water daily to sprouted seeds using watering cans or sprinklers system.
- In hot weather give water after every two hours and in cold weather after 4 hours to maintain moisture.
- Always maintain cleanliness in the shed, it helps to reduce fungus, and mould development.
- Do not disturb the sprouted seeds from the trays until they are harvested as this influences the growth of the fodder.
- Within seven days from one tray containing one kilogram of maize seed, you can produce about eight kilograms of fodder.



Fig 7.35 Hydroponic fodder production

Source: Adapted from Kanak news

7.9.2 Vertical farming

Vertical farming has the potential to sustain ever-increasing world population especially in the urban areas with nutritional supplement thus providing food security. Vertical production of mushrooms, hydroponic green fodder, some vegetables and fruits and even poultry birds are either already in vogue or at advanced stage. Vertical gardens in ornamental horticulture, a component



Fig 7.36 Vertical farming
Source: www.globuswarwick.com

of vertical farming are also known as green walls, living walls, bio walls or vertical garden (Fig 7.36). It is a free-standing space or part of a building that is partially or completely covered with attractive vegetation luxuriantly growing in an organic or inorganic medium and in some cases soil also.

Important features of vertical farming

- Round the year food production
- Prevent risk to the crop from extreme weather events
- Recycling of used water, saving of irrigation water upto 90%, avoid runoff and percolation
- Employment generation in urban areas
- Reduce the dose of pesticides/fertilizers/ herbicides and increase its use efficiency
- Extreme reduction and dependency on fossil fuels
- Check the crop loss during storage/shipping/ transportation

Growing medium

The success of vertical farming is largely determined by type of growing media, providing needed nutrition. Field soils are generally unacceptable for the production of plants in vertical farming. Mixing coco peat, vermiculite and perlite in the ratio of 3:1:1 on volume basis was observed to be one of the best growing media. However, to bring down cost locally available inert media needs to be standardized. For quality production, irrigation water needs to be

free from undesirable chemicals and pathogens, while fertigation can save as much as 60% fertilizers. Essentially the drainage and recirculation of water/nutrients solution needs to be monitored for its electrical conductivity (EC) and pH.

7.8.2.1 Vertical farming ventures in India

i. Mushroom Production

Mushroom producers have been using vertical farming much longer than the plant producers since it does not require lots of light to grow. It is successful, economical and sustainable. It can be practiced in all the metros and peri-urban areas.

ii. Poultry Production

Poultry birds, both layers (egg producers) and broilers (meat bird), are reared either in multi-storey buildings on floors or in battery cages. However, battery cages found more profitable since it houses more number of birds per unit area. It is popular both in urban and rural areas, though animal welfare organizations opposing it for long time.

iii. Crops in Vertical Farming

It is possible to grow and produce all the plant completely under indoor but this technology is not economically viable for all the crops. Small size plants like amaranths, green leafy vegetables, and prolific producers (tomato, cucumber, bottle gourd, sponge gourd, ridge gourd, snake gourd, and bitter gourd) and perishable nature plants which are sold rapidly (fruits and vegetables) are highly suitable. At present crops like lettuce, broccoli, spinach, chard, chive, palak (beet leaf), mustard greens, amaranths, parsley, coriander, mint, kale, basil and other herbs (rosemary, fennel, thyme, oregano and others), strawberries, mushrooms, micro greens and sprouts, summer squash, peppers, egg plants, tomatoes, cucumbers, muskmelon, algae, crop nurseries, ornamental foliage and flower plants are produced commercially under vertical farming.

iv. Garden Wall/Bio Wall

Vertical garden (garden wall/bio wall) most famous in many tourist spot and public places like metro station, airport throughout the world including India. Multi-colour evergreen foliage plants are highly preferred for garden wall. Its maintenance require huge investment and found not economical and sustainable in long run. Plants having short growth habit, shallow fibrous root

system and longer life cycle are best suited for this purpose. Garden walls with seasonal leafy vegetables are the best option for indoor gardens.

v. Micro Greens

Micro greens becoming more popular in vertical farming due to growing conscious over nutrient diet among urbanites and the round the year demand. Vertical farming of micro greens facilitates production in indoor, outdoor, on and off season, in home and on farm. These crops consist of vegetables and herbs that are consumed at a young growth stage and preferred by cooks and consumers to enhance the flavour, colour, and texture of a dish. The genus *Brassica* mainly broccoli have become popular due to their ease of germination, relatively short production time (7 to 21 days), and offering of intense flavours, colours and medicinal values.



Fig 7.37 Micro Greens

Source: Adapted from <http://instagreen.eu>

7.10 Nutri-garden

With the growing population and need to increase food production and buffer stocks, developing countries with more hunger and high food scarcity, various counter strategies are required to meet the growing demand and to avert food and nutritional insecurity. Household nutritional gardens may prove to be an excellent strategy to fight the rural malnutrition. The nutri-gardens not only address the food security and malnutrition but also increases income and livelihood opportunities for resource-poor families. The household nutritional garden is a small-scale production system supplying plant and animal consumption items which are not affordable to poor farmers. These nutri-gardens are located close to home for security, maintenance and care. Generally family labour is involved and locally adapted and plant and animal species are kept which involves very low capital input and simple technology.

In India, food basket is cereal dominated and main cause of malnutrition is non-availability of different ingredients. Vegetables are a major part of nutritional gardens and provide various vitamins, minerals, antioxidants, folic acid and dietary fibres. The diversified household nutritional gardens are affordable and cost effective solution to hidden hunger and malnutrition among the rural resource poor farmers.

7.11 Seed Banks

Seed banks are anticipated to play a bigger role as climate change progresses. Local communities can get climate-resilient seeds of different crops from seed banks to withstand changing local climates. It ensures seed supply and local food security. It is needed to store truthful seeds produced by the farmers and reduce the risk of delaying in onset of monsoon. It also allows local farmers to conserve, and multiply seed of traditional crops and varieties and protects it from extinctions. Providing training to farmers through various capacity building is required to produce truthful labelled seeds of stress tolerant varieties and store them in a community seed bank. The monitoring of the seed production plots by technical persons is a basic requirement to establish that the seed is produced with proper cultivation practices like nutrient, insect pest and disease management, isolation distance, weeding and rouging *etc.* After harvesting, debris, weed seeds are removed from the seed lot and packed with labeling.



Fig. 7.38 Seed Bank

Source: Adapted from <http://www.greenfoundation.in>

7.12 Fodder Banks

Livestock are an integral component of small and medium-scale farms in India for both subsistence purposes and as a means for income. About 55% of the net sown area of the country is under rainfed condition. It is also the home to two third of the livestock. Scarcity of feed and fodder during drought years in rainfed area often pose a serious threat to the livestock population. Establishment of village level community fodder bank can be a climate change adaptation option to meet the fodder demand in lean periods with limited resources available.

Once established, can not only meet the fodder demand in lean periods with limited resource available but also make use of the wasteland and other uncultivable land. Fodder banks can be taken up by a group of farmers to raise and maintain high quality fodder to meet fodder requirement in dry months in the village. Marginal and unproductive land also common land of village can be used for this purpose. A mixture of tree, grass and legume fodder species of both annual and perennial nature suitable for rainfed condition is highly preferable to meet the nutritional demand of livestock and ensure supply of fodder throughout the year.

7.13 Information and Communication Technologies (ICT)

The smallholder resource poor farmers are facing many challenges from climate change in the form of increased frequency of natural disasters, loss of biodiversity, increasing petroleum prices, increasing food prices, inefficient supply chains and others. Farmers require the information for making more decisions on the selection of crop/variety, time of sowing, irrigation, pesticide spray, harvest, choice of markets to sell their products and other decisions that influence the livelihoods of the farm families and society. Certainly, ICT applications make agriculture knowledge-intensive in true sense. Emerging ICTs have provided new opportunities to address the challenges faced by agriculture. Mobile phones for disease surveillance and pest tracking, varietal information, nutrient management are now common practice. ICT tools help to improve access to information and enrich knowledge on production technologies. ICTs facilitate discussion between stakeholders and across levels, and build knowledge networks. ICT enables its users in providing extension and training, and disseminate technology suitable for climate change adaptation.

7.13.1 ICT based dissemination of Agro-met Advisory

Farmers look for a on-demand advisory through ICT route. Follow up for an SMS received by them with close loop in the information advisory and contact mechanism. Farmer's further demand crop specific SMS. Management of crop specific data is a challenge due to change in cropping patterns. Decoding SMS in a regional language is an issue with few farmers. All these can be achieved through digital platform like

- SMS / IVRS to relatively much larger number of farmers.
- Modernize Agrimet website to make it more interactive.
- Multi-platform back end: Web based and front end.
- Multi Linkages among Agri Experts, Knowledge Institutions, Services Providers, etc.
- ICT based agricultural information dissemination models.
- Media Lab Asia: An Interactive Information Dissemination System (IIDS)

Agrimet Domain linked to websites of other Ministries viz., Rural, Panchayati Raj, etc

7.13.2 Digital ICT tools to provide solution for farm-related problems

riceXpert

“riceXpert” app an ICT tool developed by ICAR-National Rice Research Institute, Cuttack, Odisha provides information to farmers on nutrients, insects, weeds, nematodes, and disease, rice varieties, farm implements, and

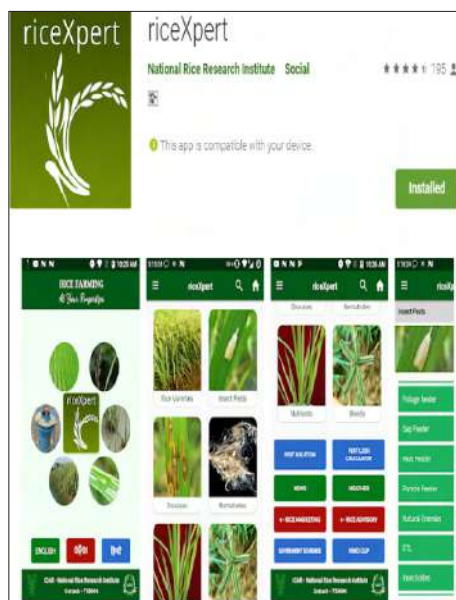
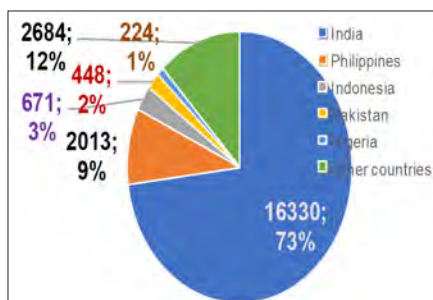


Fig 7.39 (a)Country-wise NRRI ricexpert
Source: Authors' own compilation

(b)Display of riceXpert in google play

post-harvest operations. Other components are news, weather, fertilizer and pesticide calculator, e-rice marketing, announcement, and e-advisory services, frequently asked questions. The app has web-based application systems that enable information flow from experts to the farmers. Farmers can use this app as an analytic tool in their rice fields and ask questions for the prompt answer of their queries by sending text, photo, and voice record. This app is a beneficial tool for all stakeholders working on rice crop. Presently this is available in English, Hindi, Odia, and Assamese. Since release, riceXpert is being used in many countries. More than 70% of users are from India whereas farmers from Philippines, Indonesia, Pakistan, and Nigeria are using riceXpert in significant numbers.

riceNxpert

A smart android based application “riceNxpert” to monitor the leaf N content and determine real-time N fertilizer requirements to synchronize the demand and supply of the rice crops, has been developed by ICAR-National Rice Research Institute, Cuttack, Odisha, India in collaboration Norwegian Institute of Bioeconomy Research, Norway. Using an android based mobile phone, images of ten fully expanded healthy leaves should be taken with white background by placing a white sheet on the back of the leaf from a distance of 15-20 cm during 8-10 AM by the same person using an android smartphone. Then the leaves are cropped and RGB values are extracted. These RGB values are converted into Pantones and then differentiated into four color categories. The N recommendation system is made based on these color categories. The key features of riceNxpert are (i) Nitrogen fertilizer recommendation system based on leaf colour analysis (ii) N fertilizer requirement doses as per the crop requirements at the right time and right dose (iii) Easy to use application. (iv) Direct recommendation in terms of urea. RiceNxpert can be downloaded from google play store or from www.ricenxpert.com or <http://icar-nrri.in/> or www.resilience.org. Application of N fertilizer using riceNxpert resulted at *par* yield with that obtained by using a customized leaf colour chart (CLCC). However, the yield was higher than that obtained by using the recommended dose of fertilizers.



Fig 7.40 Android based nitrogen fertilizer recommendation app developed by ICAR-NRRI

Source: Authors' own collection

ICT tools

ICT tools have been developed for the dissemination of agromet advisory information on rainfall, temperature, wind speed and other services to farmers (Table 7.21).

Table 7.21 ICT tools for farmers to provide solution for various farming operations

S. No.	Name of the scheme/ programme	Function
1.	Agrisnet	1. Gives information about availability of the inputs 2. Knowledge sharing of information about various government schemes and fertilizers recommending based on soil testing 3. Disseminate latest technologies to increasing productivity.
2.	Digital green	Engage rural community in participatory approach to improve their livelihood through digital solution
3.	eSagu	Deliver solution to the grower's problems throughout the period of cultivation.
4.	Warana	Provide information and services to farmers to increase crop productivity.
5.	Agricultural Marketing Information Network (AGMARKNET)	Enabling decision-making capability of the farmers regarding selling of their produce.
6.	iKisan	Web portal for communicating information to the farmers about crop cultivation, weather forecast, agricultural inputs availability, agriculture related financing institutions, soil quality and market updates.
7.	Digital Mandi	Enabling farmers and agricultural traders to procure and sell agro produce anywhere through electronic platform.
8.	eArik	Disseminate information about CSA practices to achieve food security especially in north-eastern India.
9.	Kisan Call Centers (KCCs)	Provide solution to farmer's queries 24 x 7 in the local languages.
10.	Village Knowledge Centers (VKCs)	Disseminate information related to agricultural inputs, cost and price of both inputs and outputs, information about the use of fertilizers and pesticides. Two VKCs have been established by ICAR-NRRI in collaboration with MSSRF. One in KVK santhapur for Tangi block and one in Ganjam District.
11.	AGRONXT	Multitasking platform provide information about agro input availability in various nearby shop, , agriculture advice, weather advisory etc.

7.14 Developing climate-smart villages

Enhancing the resilience of small and marginal farmers is essential through research and extension efforts bringing convergence of village-level institutions, extension functionaries under one umbrella for making a climate-smart village (CSV) that has capacity to adapt to climate change. The activities under CSV includes the village level vulnerability assessment, resource characterization, and baseline assessment, prioritization, and demonstration of climate-smart agricultural technologies, the establishment of village knowledge centres focusing on the farmer to farmer knowledge exchange, the formation of self-help groups, awareness training, and field-level demonstrations of CSA technologies, use of traditional knowledge, creating alternate income generating avenues for marginal and landless farmers, value chain analysis and development. Model climate-smart villages have been developed by Central Research Institute for Dryland Agriculture (CRIDA) under NICRA project, by National Rice Research Institute under NIBIO and DST project, by International Maize and Wheat Improvement Centre (CIMMYT) under CGIAR Research Program on Climate Change, Food Security and Agriculture (CCAFS). Such models need to be replicated throughout the state under National Adaptation Fund for Climate Change (NAFCC)

7.14.1 Establishment of village knowledge centres (VKC)

Village Knowledge Centre (VKC) is a place to provide distant services from a single window to rural people in remote areas through the use of modern ICT. The knowledge centre will be connected to farmers using various information and communication technologies. The VKC plays a pivotal role and develops training modules, audio, video, and text content for the identified technologies and conduct capacity building programmes to address the challenges of climate variability and climate change in agriculture. The VKC provides scientific and site-specific information and knowledge related to climate-smart agriculture, animal husbandry, health and nutrition, employment, education, and Government entitlements, *etc.*, and to address the requirements of men and women farmers and agricultural labourers. VKC uses a multi-pronged communication strategy through its specialized services such as mobile based audio advisories, farmers' helpline services, audio-video conferences, phone-in programmes, social media, video including multimedia-based learning, plant clinics, *etc.* to disseminate dynamic and static information and knowledge. In Odisha, two VKCs are established by ICAR-NRRI, Cuttack and OUAT, Bhubaneswar in collaboration with M. S. Swaminathan Research Foundation (MSSRF), Chennai. One VKC is established in Ganjam (Chikarada KVK)

whereas the other at KVK, Santhapur in Cuttack. The VKCs are disseminating weather-based agro-advisory given by District Agro Meteorological Unit (DAMU). Village Knowledge Centres are also being established by Odisha Government under National Adaptation Fund for Climate Change (NAFCC) Project in Nuapada district. So far, 547 male and 44 female farmers are registered in VKC at Cuttack for these audio advisories and getting benefits. The financial viability of such centers needs to be ensured by initially establishing VKC in bigger villages making it single-window points for delivery of public services, health-care schemes, social welfare schemes, financial schemes, education, and agriculture services to citizens in those villages in the line of Common Service Center, a great initiative by the Government to allow and offer access to the various government schemes and services.

7.15 Gender mainstreaming for climate-smart agriculture

Agriculture involves both men and women and in order to achieve agricultural productivity improvement, the needs and challenges have to be addressed. The women and men farmers have different challenges and access to the resources and services for preparing and responding to climate change. In India generally, the women have less access to productive resources, financial issues, employment opportunities, and advisory services. Women are generally taking care of the food security of the household but at the same time, are a victim of food insecurity and malnourishment. In India, 79% of rural women are engaged in farming against 63% of men. If the gender gap in agriculture is minimized, it may produce significant gains for women as well as for society as a whole, by enhancing agricultural productivity and promoting economic growth. In the context of climate change, women form a part of the most vulnerable groups and hence it is required to integrate their specific needs, access to resources, and adaptive capacity in the policy formulation to support them. Women are excluded from decision making and may not be the actual beneficiary of the technologies and practices for adapting to climate change. Men and women have different adoption levels for climate-smart technologies and practices. Therefore, it is highly essential to keep gender-specific differences in the forefront while designing and implementing climate change response technologies and strategies. Specific capabilities of men and women should be recognized by gender mainstreaming while formulating a gender-responsive approach for climate-smart agriculture for jointly addressing climate change and food security. Gender-sensitive and responsive climate-smart agricultural technologies help in reducing gender inequalities for ensuring equally beneficial to men, women, boys, and girls in achieving

sustainable and equitable results. In gender mainstreaming, the implications of any planned action, including legislation, plans, and programmes are assessed for men and women. It involves the strategy for making the experiences of women and men an integral part of the design, monitoring, and evaluation of plans and programs for achieving gender equality.

7.16 Knowledge-smart technologies for mitigation, adaptation and higher productivity

Among knowledge-smart technologies, technologies that fulfill the criteria of all the three pillars (e.g. hydroponics, vertical farming, IFS) are considered as highly preferred. However, a few technologies (*e.g.* IPM, IWM and IDM) satisfy only two pillars are known as moderately preferred technologies.

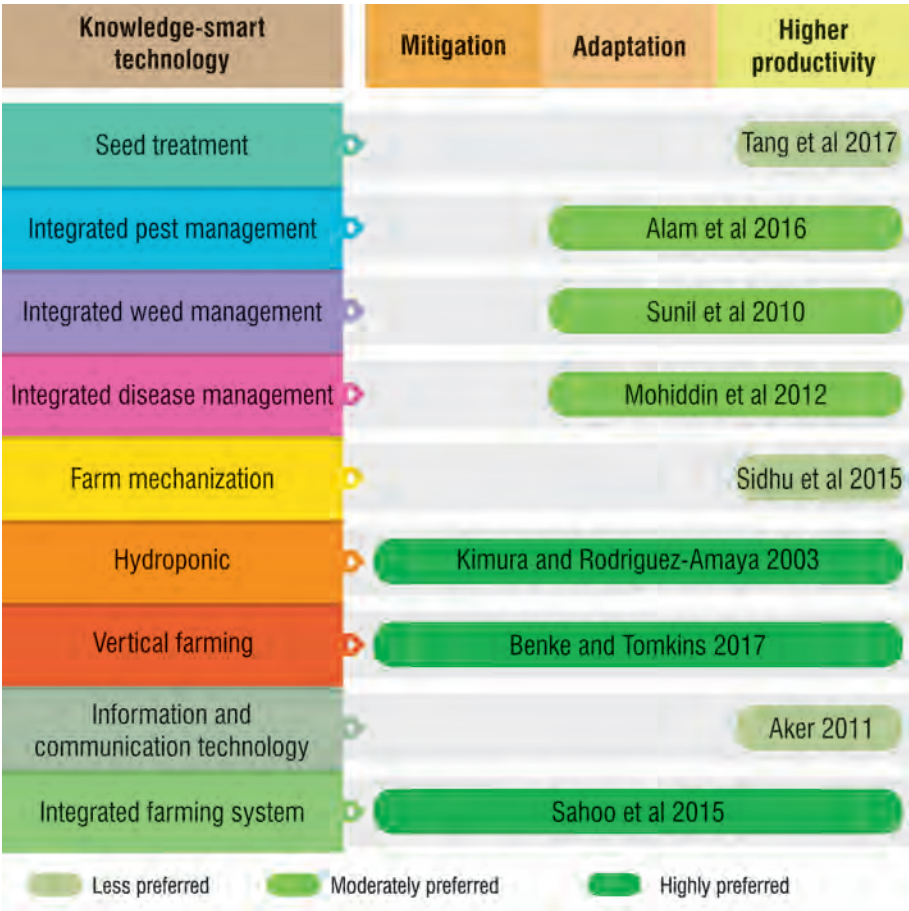


Fig. 7.41 Knowledge-smart technologies for mitigation, adaptation and crop productivity
 Source: Author’s own analysis.

Technologies like seed treatment and farm mechanisation are known for their increase in crop productivity, are known as preferred. Interestingly, all the knowledge-smart technologies are increasing crop productivity. IPM, IWM and IDM of various crops are used for increasing the adaptation to climate change as it helps to control crop damage by decreasing intensity in the infestation of crop diseases, weeds, and insect pest, help to sustain crop productivity by keeping the infestation below the economic threshold level. Knowledge-smart technologies for mitigation, adaptation, and crop productivity is shown in Fig 7.41.

7.17 Knowledge-smart technology supported by Government Schemes

Knowledge-smart technology is needed to achieve better yield, greater income, timely doing of agricultural operations, year-round income generation, better plant protection, better seed treatment and nursery management. The knowledge-smart technologies are supported by various government schemes that are listed in Table 7.22.

Table 7.22 Knowledge-smart technology supported by Government Schemes

Sl. No	Name of Scheme/ Programme	Knowledge-smart technology supported by the scheme	Reference
Central Government scheme			
1.	National Mission For Sustainable Agriculture (NMSA) sub mission Rainfed Area Development (RAD)	Integrated Farming System	https://nmsa.dac.gov.in/frmComponents.aspx
2.	National Mission For Sustainable Agriculture (NMSA) sub mission on Agroforestry (SMAF)	Promotion of Agroforestry	https://nmsa.dac.gov.in/frmComponents.aspx
3.	Bringing Green Revolution to Eastern India (BGREI)	Improved seed varieties, Farm machines & implements, Integrated Pest Management Knowledge-based interventions	https://diragri.assam.gov.in/schemes/detail/bringing-green-revolution-to-eastern-india-bgrei

Sl. No	Name of Scheme/ Programme	Knowledge-smart technology supported by the scheme	Reference
4.	Strengthening & Modernisation of Pest Management Approach (SMPMA) in India	Promotion of Integrated Pest Management (IPM)	http://ppqs.gov.in/divisions/integrated-pest-management/ipm-glance
5.	Technology Mission on Oilseeds, Pulses & Maize	Promotion of Integrated Pest Management (IPM)	http://www.ncap.res.in/upload_files/workshop/wsp11.pdf
6.	Sub-Mission on Agricultural Mechanization (SMAM)	Providing 50 to 80% subsidy on agricultural implements	https://agrimachinery.nic.in/GraphReport/SMAMFmtti/SMAMFmtti.aspx
State Government schemes			
7.	Odisha Free Smartphone Yojana for Women Farmers	Provide smartphones for women farmers to get useful agriculture information	https://www.pradhan-mantriyojana.co.in/free-smart-phone-scheme-women-farmer-odisha/
8.	MukhyamantriKrishi-UdyogYojana	Simplification of loan subsidies to farmers	http://www.apicol.nic.in/
9.	Mobile for Farmers	Provide smartphones for farmers	https://orissadiary.com/odisha-govt-provide-android-smart-phones-farmers/
10.	Odisha Fish Pond Yojana	Create additional water bodies and subsidize fish farming	http://www.far-dodisha.gov.in/?q=node/17%27%3B
11.	Mukhyamantri-AdibandhaYojana	Improve pond embankment	https://sarkariyojana.com/odisha/

8. CSA Implementation and Way Forward

India has adopted the United Nations agenda for 2030 Sustainable Development (Box 1) and announced its Intended Nationally Determined Contribution (INDC) under Paris agreement (Box 2) in the year 2015. In the developing country like India Agriculture is at the centre of Sustainable Developmental goal-2030 (SDG 2030) and key to ending hunger and extreme poverty and addressing climate action targets envisaged in its INDC. Building up Climate Smart Agriculture (CSA) portfolio and guidelines for its step by step implementation compatible with country's/state's effort to achieve the SDGs and INDC targets are essential component of both national and state authorities. Climate Smart Agriculture (Box 3) can transform the agriculture to support the sustainable developmental goal under climate change. Climate Smart Agriculture offers possibility to help the states to achieve its SDGs and INDC objectives. Prioritization of sustainable development and meeting SDGs is consistent with climate change actions. Sustainable development has the potential to significantly reduce system vulnerability, enhance adaptive capability and promote livelihood security for poor and disadvantaged population.

BOX 1 – SDGs India

In 2015, India adopted Agenda 2030 and its 17 SDGs along with 169 targets to be achieved by 2030. NITI Aayog is mandated with the task of coordinating work on the SDGs to achieve the country's target.

Individual adaptation and mitigation options are associated with both positive and negative interaction with the SDGs. If carefully selected together with enabling condition will have benefits for sustainable development and poverty reduction although trade-offs are possible. However appropriate choices across the adaptation and mitigation portfolios can help to maximize synergy while minimizing trade-offs. Social justice and equality are the core aspects of climate resilient development pathway for transformational social change. Identifying and implementing CSA compatible with low carbon and climate resilient pathways needs to be done without making the poor and disadvantage worse off.

BOX 2 – India's INDC-The Paris Agreement

As per the Paris Agreement under United Nation Frame Work of Climate Change (UNFCCC), India announced its INDC on 2015 pledging to reduce 33-35% emission intensity in its GDP by 2030 below 2005 level.

A careful assessment and mapping of CSA-SDG and inter-linkage based on their synergy and trade-offs will help to identify and prioritize the CSA portfolios and can contribute in achieving the SDGs and INDC objectives (FAO 2019). The potential of CSA differs between and within the country and among its states due to developmental contest and system vulnerability. Assessing the linkage between SDGs & CSA activities highlighting the potential synergy and trade-offs will help the national and state authority to provide the instruments of implementation of CSA activities (Table 8.1, 8.2, 8.3, 8.4, 8.5 & 8.6). Wherever trade-offs are possible, implementation plan is carefully devised so that the trade-offs are avoided or minimized. The synergy and trade-offs analysis presented in the tables (Table 8.1 to 8.6) was done by extensive literature survey and expert judgment. Sometimes these synergies and trade-offs presented in this book may not be universally valid however it provides a frame work for prioritization of CSA portfolios for investment.

BOX 3 – Climate Smart Agriculture (CSA)

Climate-smart agriculture (CSA) involves sustainable increase in agricultural productivity and incomes, adapting and building resilience to climate change and wherever possible, reducing and/or removing GHG emissions (FAO, 2013)

State Action Plan on Climate Change (SAPCC) of Govt. of Odisha has internalized some of 2030 Agenda for sustainable development and INDC targets committed by India under the Paris Agreement. This needs to be further strengthened by set of appropriate implementation steps mentioned below that further supports SAPCC.

- Building and expanding the evidence base for CSA impact through research and demonstration results from NICRA, RESILIENCE, DST and other similar projects implemented in the state is required for integrating CSA into state's effort to achieve SDGs and INDC targets.
- Assessing impact of climate change (current and future) on agricultural sector particularly rice-based system is required so as to pin point targeted mitigation policy and CSA implementation.
- Prioritization of CSA options by identifying the potential synergy and trade-offs between pillars of CSA (adaptation, mitigation and sustainable production enhancement), CSA and SDGs will help in identifying CSA activities for investment.
- Analysis of drivers and challenges to adoption of CSA needs to be done in a specific context for its implementation at the field level.

- Identify national and state policies and strategies having actual contribution to CSA objectives for leveraging them during implementation.
- The barriers such as lack of awareness, training, access to financial services, credits and market needs to be removed for a positive feedback loop in the adoption of CSA.
- Enable equal opportunity for marginalized sectors such as women and poor to the productive resources such as land, extension services, ICT and seed stock.
- Strengthening the capabilities for climate action of state authorities, institutions, NGOs, private sectors, indigenous people and local communities that support the implementation.
- Stakeholders' engagement is crucial for CSA adoption at field level in bottom up approach, the interventions can be tailored and refined in a participatory mode in a farmer school approach (FSA) as per the agro ecological, socio-economic condition of the target population.
- Increasing investment in physical and societal infrastructure in the key enabling condition to enhance the resilience and the adaptive capacity of the society.
- Monitoring and evaluation system put in place as per the developmental context and vulnerabilities of the area may lead to mid-term modification of program and implementation plan.

Table 8.1. Synergy and trade-offs between CSA- weather-smart technology and SDGs

	Weather forecasting	Agromet services	Climate resilient crop and varieties	Changing planting time	Agroecological crop intensification	Contingency plan against extreme event	Crop Insurance	Non farm employment
SDG1 No Poverty	●	●	●	●	●	●	●	●
SDG2 Zero Hunger	●	●	●	●	●	●	●	●
SDG 3 Good Health and Well-being	●	●	●	●	●	●	●	●
SDG 4 Quality Education	●							●
SDG 5 Gender Equality	●	●						●
SDG 6 Clean Water and Sanitation	●		●	●	● ●			
SDG 7 Affordable and Clean Energy								
SDG 8 Decent Work and Economic Growth							●	●

[illegible]

Table 8 2. Synergy and trade-offs between CSA -water-smart activities and SDGs

	DSR	Laser land leveling	Field bund raising	Mulching	Contour farming	SRI	AWD	Micro irrigation	Improved drainage	Community nursery	Participatory irrigation management	Rain water harvesting	Farm ponds	Check dams	Roof top harvesting
SDG1 No Poverty	●	●	●	●	●	●	●	●	●	●	●	●	●	●●	●
SDG2 Zero Hunger	●	●	●	●	●	●	●	●	●	●	●	●	●	●●	●
SDG 3 Good Health and Well-being									●						
SDG 4 Quality Education															
SDG 5 Gender Equality	●	●							●		●	●	●	●	●
SDG 6 Clean Water and Sanitation	●	●	●	●	●	●	●	●	●	●	●	●	●	●●	●
SDG 7 Affordable and Clean Energy															
SDG 8 Decent Work and Economic Growth		●				●	●	●							

SDG 9 Industry, Innovation and Infrastructure	●			●	●	●	●	
SDG 10 Reduced nequalities	●			●	●	●	●	
SDG 11 Sustainable Cities and Communities	●	●		●	●	●		
SDG 12 Responsible Consumption and Production	●		●	●	●	●		
SDG 13 Climate Action	●			●	●	●		
SDG 14 Life Below Water	●			●	●	●		
SDG 15 Life on Land	●			●	●	●		
SDG 16 Peace, Justice and Strong Institutions	●			●	●	●		
SDG 17 Partnerships for the Goals	●			●	●	●		

● Synergy

● Trade-offs

[illegible]

- Synergy
- Trade-offs;

SSNNM: Site specific nutrient management; INM: Integrated nutrient management; PSM: Phosphate solubilizing microbes; AWD: Alternate wetting and drying; DSR: Direct seeded rice; SRI: System of rice intensification

Table 8.4. Synergy and trade-off between CSA- Carbon-smart technology and SDGs

	Conservation agriculture	Rice residue management	Bioethanol production from rice straw	Organic farming	Agroforestry
SDG1 No Poverty	●	●	●	●	● ●
SDG2 Zero Hunger	●	●	●	●	● ●
SDG 3 Good Health and Well-being	●	●	●	●	●
SDG 4 Quality Education					
SDG 5 Gender Equality	●	●	●	●	●
SDG 6 Clean Water and Sanitation	●	●	●	●	●
SDG 7 Affordable and Clean Energy	●				
SDG 8 Decent Work and Economic Growth	●		●	●	●
SDG 9 Industry, Innovation and Infrastructure					
SDG 10 Reduced Inequalities	●	●	●	●	● ●

SDG 11 Sustainable Cities and Communities	●	●	●	●	●	
SDG 12 Responsible Consumption and Production	●	●	●	●	●	●
SDG 13 Climate Action	●	●	●	●	●	●
SDG 14 Life Below Water	●	●	●	●	●	
SDG 15 Life on Land	●	●	●	●	●	●
SDG 16 Peace, Justice and Strong Institutions						
SDG 17 Partnerships for the Goals						

● Synergy ● Trade-offs

Table 8.5. Synergy and tradeoffs between CSA - energy-smart technology and SDGs

	Energy efficient management	Conservation Tillage	Permanent Raised Beds	Residue Management	Energy Plantation	Solar Energy based Equipments
SDG1 No Poverty	●	●●●	●	●	●●●	●
SDG2 Zero Hunger	●	●	●	●	●	●
SDG 3 Good Health and Well-being				●		●
SDG 4 Quality Education						
SDG 5 Gender Equality	●	●	●	●		●
SDG 6 Clean Water and Sanitation						
SDG 7 Affordable and Clean Energy	●	●	●	●	●	●
SDG 8 Decent Work and Economic Growth	●	●	●	●		
SDG 9 Industry, Innovation and Infrastructure	●	●		●	●	●

SDG 10 Reduced Inequalities	●	●	●	●	●	●	●
SDG 11 Sustainable Cities and Communities							●
SDG 12 Responsible Consumption and Production							
SDG 13 Climate Action	●	●	●	●	●	●	●
SDG 14 Life Below Water		●			●		
SDG 15 Life on Land		●			●	●	●
SDG 16 Peace, Justice and Strong Institutions							
SDG 17 Partnerships for the Goals							

● Synergy ● Trade-offs

[illegible]

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Abbreviation

AG	Anaerobic germination
AMF	Arbuscular mycorrhizal fungi
AMFUs	Agro-Met Field Units
AWD	Alternate wetting and drying
BGA	Blue-green algae
BKVY	Biju Krushak Vikash Yojana
BPH	Brown plant hopper
CA	Conservation agriculture
CC	Chak Committees
CCIS	Comprehensive Crop Insurance Scheme
CGIAR	Consultative group on international agriculture research
CLCC	Customized Leaf Color Chart
CRs	Crop residues
CSA	Climate-smart agriculture
CT	Conventional tillage
DAE	Days after emergence
DAMUs	District Agromet Units
DAS	Days after seeding
DC	Distributary Committee
D-DSR	Dry direct-seeded rice
DIP	Drainage Improvement Programme
DPAP	Drought Prone Area Programme
DSR	Direct seeded rice
EAS	Employment Assurance Scheme
EEF	Enhanced efficiency fertilizer
ETL	Economic threshold level
FIRB	Furrow irrigated raised bed planting
FPR	Flood Prone River
FYM	Farm yard manure
GFCS	Global Framework for Climate Services
GHGs	Greenhouse gases
GLH	Green leafhopper
GPS	global positioning systems
GW	Groundwater
IAAS	Integrated Agro-Met Advisory Services
ICAR	Indian Council of Agricultural Research
ICT	Information and communication technology
IDM	Integrated disease management
IFS	Integrated farming system
IIDS	Interactive information dissemination system
IITM	Indian Institute for Tropical Meteorology
IMD	India Meteorological Department

INDC	Intended Nationally Determined Contribution
INM	Integrated nutrient management
IPM	Integrated pest management
IPNI	International Plant Nutrition Institute
ISOPOM	Integrated Scheme of Oilseeds, Pulses, Oil Palm and Maize
IWDP	Integrated Wasteland Development Programme
IWDP	Integrated Wasteland Development Programme
IWM	Integrated weed management
IWRM	Integrated Water Resources Management
KVK	Krishi vigyan kendra
LCC	Leaf color chart
LEWA	Low energy water application
MATY	Mukshyamantri adibandhatiariyोजना
MGNREGA	Mahatma gandhi national rural employment guarantee act
MIDH	Mission for Integrated Development of Horticulture
MNAIS	Modified national agricultural insurance scheme
MT	Minimum tillage
MUS	Multiple-use water services
NABARD	National Bank for Agriculture & Rural Development
NAIS	National agricultural insurance scheme
NAPCC	National Action Plan for Climate Change
NBS	Nutrient based subsidy
NCMRWF	National Centre for Medium-Range Weather forecasting
NCOF	National Centre of Organic Farming
NFSM	National food security mission
NGO	Non-governmental organizations
NICRA	National Innovations on Climate Resilient Agriculture
NMAET	National Mission on Agricultural Extension and Technology
NMH	National Mission for Horticulture
NMSA	National Mission for Sustainable Agriculture
NMSHE	National Mission for Sustaining the Himalayan Ecosystem
NMSKCC	National Mission on Strategic Knowledge for Climate Change
NPK	Nitrogen, phosphorus and potassium
NPOF	National Project on Organic Farming
NPOP	National Programme for Organic Production
NSKE	Neem Seed Kernal Extract
NSSO	National sample survey office
NWDPRRA	National Watershed Development Project for Rainfed Areas
NWM	National water mission
NWP	Numerical weather prediction
OAEs	Own-account enterprises
OIIAWMIP	Odisha integrated irrigated agriculture water management investment programme

OIIPCRA	Odisha Integrated Irrigation Project for Climate Resilient Agriculture
OLM	Odisha livelihood mission
OSDMA	Odisha state disaster management authority
OSOCA	Odisha state organic certification agency
OWRCP	Water resources consolidation project
PC	Project committee
PEG	Polyethylene glycol
PGS-India	Participatory Guarantee System of certification for India
PIM	Participatory irrigation management
PKVY	Paramparagat Krishi vikasyojana
PMFBY	Pradhan mantri fasal bima yojana
PMKSY	Pradhan mantri krishi sinchayee yojana
PP	Pani panchayats
QTLs	Quantitative trait locus
RCM	Rice crop manager
RDF	Recommended dose of fertilizers
RKVY	Rashtriya krishi vikas yojana
RSB	Raised and sunken bed
SAPCC	State Action Plan on Climate Change
SDGs	Sustainable development goals
SHG	Self help group
SHM	Soil health management
SMAF	Sub-Mission on Agroforestry
SOC	Soil organic carbon
SPAD	Plant analysis development
SRI	System of rice intensification
SSB	Silicate solubilizing bacteria
SSC	Saturated soil culture
SSNM	Site-specific nutrient management
STRVs	Stress-tolerant rice varieties
SWC	Soil and water conservation
VKC	Village knowledge centers
VKC	Village knowledge centers
WBCIS	Weather based Crop Insurance Scheme
W-DSR	Wet direct-seeded rice
WORLP	Western odisha rural livelihoods project
WP	Wettable Powder
WSIDP	Water sector infrastructure development programme
WSM	Watershed management
WUA	Water users associations
ZSB	Zinc solubilizing bacteria
ZT	Zero tillage
ZT-DSR	Zero tillage direct-seeded rice



ICAR-National Rice Research Institute

Cuttack – 753006, Odisha, India

Phone: +91-671-2367757/67

EPBX: +91-671-2367768-783; Fax: +91-671-2367663

Email: director.nrri@icar.gov.in; <https://icar-nrri.in>



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