Syed Sheraz Mahdi · Rajbir Singh · Bhagyashree Dhekale *Editors*

Adapting to Climate Change in Agriculture-Theories and Practices

Approaches for Adapting to Climate Change in Agriculture in India

Springer

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Editors
Syed Sheraz Mahdi
Division of Agronomy
Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir (SKUAST-K)
Srinagar, Jammu and Kashmir, India

Bhagyashree Dhekale
Division of Agricultural Statistics
Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir (SKUAST-K)
Srinagar, Jammu and Kashmir, India

Rajbir Singh
Department of Plant Pathology
Gochar Mahavidyalaya
Rampur Maniharan, Saharanpur, Uttar Pradesh, India

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Chapter 1
Conservation of Carnivorous Plants in Odisha: A Key Challenge for the Policy Makers

Prasad Kumar Dash, Subhrakanta Jena, Rakesh Kumar Mohalik, and Hemanta Kumar Sahu

1.1 Introduction

Nature has always been a matter of inquisitiveness to human beings due to its stunning and vibrant life forms. Many of its creations have created wave within the scientific communities and scientists are still trying to know and disclose explanations for several such outstanding life forms. Generally, insects eat upon plants and being preyed by the higher animal in the food web operating in nature. However, when it comes to the role of nature the plants can be serve as predators in the food web. Amongst numerous such unclear mysteries, there lies a group of angiosperms that attract, catch, kill, eat, digest and absorb the body juice of animals are called Carnivorous Plants behaviour we normally associate with the animal kingdom. In these plants, the leaves are modified into trap leaves to catch, kill and digest insects. To the plant world, they are also known as "Insectivorous" or 'Hunter plants'. Even though the studies on these menacing predators have started in fourteenth Century, it was Charles Darwin, who was mesmerized by these plants in 1857 and through his experiments and research proved the carnivorous syndrome in these plants. It is called as the Venus flytrap (*Dionaea muscipula*) as "The most wonderful plant in the world." Apart from the angiosperms, there are about 50 species of carnivorous fungi. In the

P. K. Dash (✉)
Odisha Biodiversity Board, Forest and Environmental Department, Government of Odisha, Regional Plant Research Centre Campus, Nayapalli, Bhubaneswar, Odisha 751015, India
e-mail: prasad.dash2008@gmail.com

S. Jena · H. K. Sahu
P.G. Department of Zoology, North Orissa University, Takatpur, Baripada, Mayurbhanj, Odisha 757003, India

R. K. Mohalik
Keonjhar Wildlife Division, Anandapur, Keonjhar, Odisha 758021, India

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evolution process, the insectivorous plants have evolved from 6 distinct lineages. All these plants arisen with a special type of modified leaves to trap different arthropod species and have potential to digest the captured animal (arthropods) to absorb the nutrients. The technique of trapping and utilizing the prey (all arthropod species) makes these plants unique specialized in the nature besides that these plants are also adopted to persist in the marshy places with poor nutrient soil.

1.2 Significance of Carnivorous Plants

Apart from their peculiar behavior and unique food habit in the plant world, these plants also provide various ecosystem services to human beings. These plants also play significant role in human society by eradicating the diseases transmitted through different dipterans vectors as they preferably feed on the dipteran species like mosquitos, midges, deerflies and horse flies (Jennings & Rohr, 2011). Human schistosomes, a disease caused by flatworms inhabiting in the contaminated water along with other parasites. This disease is wide spread over the earth and past record revels that 207 million people are infected and approximately 700 million are at risk. The death records suggest globally, 20 lakh/year death are occurring due to schistosomiasis. The *Utricularia* belong to the carnivorous plant category usually found in the aquatic bodies feeds on mosquito eggs and larvae and even depredates human schistosome miricidia and cercariae, which indicate these plants, can be a source to control and reduce the protozoans parasite diseases there by reducing their vectors through which they are transmitted (Jennings & Rohr, 2011). The carnivorous plants are fatal to those animal species, which fits in their leave traps. Some arthropods are evolved according with carnivorous plant and adapted to survive against the predation of these plants. An Australian bug called as Cryptopcltis bug, which can walk on the sticky traps of these plants and feeds on the prey species of these plants. Several other species insects like some mosquito larvae are adopted to live in the water bodies where the pitcher plants are present. Similarly, some spider species are able to construct their web over the leave of these plants, which prevents the prey fall into the traps and feeds on them.

All most all Droseras are important medicinally. The traditionally ethnobotanical claims suggests that brulsed leave with salt applied to treat blisters corns have been protected by applying leaf extracts of *D. indica*. The past records suggests that the Ayurvedic traditional healers prepare 'Swarnabhasma' (gold-bhasma/Golden ash) from these plants and used to treat different ailments like bronchial asthma, rheumatoid arthritis, diabetes mellitus and nervous disorders, besides that it was also used for poor memory, eye sight, infertility and physical weakness problems. The leaf juice of *D. indica* is used as the antisyphilitic tonic by the tribal healers. In home textile industry, the yellow crystalline substances are obtained from *D. peltata* to make yellow color silk. It has been observed that the extracts of the *D. peltata* has the antimicrobial activity against human pathogenic microbes (Didry et al., 1998). *D. burmanii* is used by the traditional healer inhabiting in Tripura as a antisipetic for snakebites and also used as effective medicine in thought infection. It is locally famous in Tripura as Bishkatali as it reduces the effect of any oision bite in the body (Majumdar et al., 2011). *Drosera burmannii* possess medicinally active compounds like quinones (plumbagin), hydroplumbagin glucoside, flavonoids (kaempferol, myricetin, quercetin, and hyperoside), rossoliside (7-methylhydrojuglone-4-glucoside), as a result this species could be a source of making effective medicine (Raju & Christina, 2013). Similarly, Bladderworts like *Utricularia aurea* and *U. reticulata* are ornamental, species used in aquaria and rockeries. *U. stellaris* can cure cough; *U. caerulae* has wound healing property; *U. bifida* is mostly useful for urinary infection. Anti-tumor activity has been reported in *Utricularia aurea*. *Utricularia bifida* is used in Indian medicine for urinary disorders (Choosawad et al., 2005).

The changes in the environmental parameters in the habitat influences the diversity and distribution of these plants, as the plant species are easily identified so these species can serve as biological indicator in the assessment of ecosystem for health benefits.

1.3 Morphology, Biology and Ecology of Carnivorous Plants

Except few genera, generally carnivorous plants are annual to perennial herbs with rhizomes, fibrous roots, or tubers with a vertical stolon below ground (*Drosera*) or herbaceous, terrestrial (Drosera and Utricularia), epiphytic and saprophytic (Utricularia) or aquatic (*Utricularia*) or climbing shrubs (*Nepanthes*). The leaves are whorled in rosettes. The inflorescence varies from a scapose raceme in Lentibulariaceae to cymose helicoid or dichasial in Droseraceae and racemes or panicles in *Nepanthes*. Flowers bisexual, actinomorphic with brilliant colors, secrete nectars and other ways to attract their prey.

In the ecosystem the carnivorous plants stablish a peculiar type of prey-predator relationship that instead of being eaten by herbivorous their emerge with dual mode of nutritional method i.e. photo autotrophic and heterotrophic nutrition specifically carnivorous nature of eating insects and other animal species, which allow these plants are adopted in such a way that they can able to grow upon poor soil quality, where most of the plants are unable do so. These plants utilize insect for two main purposes i.e., to get nourishment by capturing them and pollinated to continue sexual reproduction. Some of the adaptive feature make these species more efficient to persist in the poor soil i.e., the capability to capture insect, early growth of flower and seed dispersal. The reproduction in carnivorous plant may be of different type some are entomophiles, some reproduce through self-pollination and show vegetative propagation.

The victims of these plants also fall in a broad range comprising of almost 150 species of pray like mosquitoes, housefly, small butterflies and beetles, arachnids including mainly spiders and mites, mollusks like snails and slugs, sometimes earthworms. It has observed that the *D. burmanii* species capture 6 insect orders like Lepidoptera, Isoptera, Diptera, Orthoptera, Hymenoptera, and Coleoptera (Majumdar et al., 2011), whereas *Daphnia*, nematodes, mosquito larvae and tadpoles are the major pray species for Utricularias. Zooplankton like rotifers, cladocerans, copepods, annelids, rhizopodeans, and insects; and the phytoplankton like Bacillariophyta, Chlorophyta, Cyanophyta, and Euglenophyta are other victims of aquatic *U. gibba* and *U. inflata.*

Carnivorous plant can maintain aquatic, semiaquatic and terrestrial mode of life. Most of the carnivorous plant species are seasonal as they are inhabiting in marshy, submerged, muddy and sandy areas, usually the soil of their habitat constitute low concentration of N, P and K. In these type of habitats, usually anaerobic conditions are found due to the partial decomposition of organic matters, which generates other acid forms and some unfavorable conditions for the plant.

1.4 Diversity and Distribution

Carnivorous plants are distributed over the world except Antarctica (Barthlott et al., 2007). About 133, 86 and 65 carnivorous plant species are flourishing in the Malaysia, Australia and Brazil region respectively. They represent members of five orders: Poales, Oxalidales, Caryophyllales, Ericales and Scrophulariales. Seven hundred carnivorous plant species are widespread over the world, described under 15 genera and 9 families of dicotylidonous type (Fleischmann, 2012). Very interestingly in India 44 species under five genera are reported so far viz. *Utricularia* (38 species), *Drosera* (3 species), *Nepenthes* (1 species), *Pinguicula* (1 species), and *Aldrovanda* (1 species) belong mainly to three families: Droseraceae, Nepenthaceae and Lentibulariaceae (Kamble et al., 2012). The comparison of carnivorous plant diversity has given in Table 1.1.

1.5 Carnivorous Plants of Odisha Past and Present

Odisha with its unique phytogeographic location in India having varied topography, frequent climatic change and its presence above 5000 ft MSL biogeographic provinces of India—the Eastern Ghats and Chhotanagpur Plateau makes Odisha a unique habitat flourishing flora and fauna in a better way starting from microbes to mammals.

Initially Dr. Saxena, 1965 reported the presence of *Utricularia pubescens* from Odisha. Latter Saxena and Brahmam (1994) reported the occurrence of 14 species of carnivorous plants under 2 families and 2 genera from different districts of Odisha. This includes 3 species *Drosera* under family of Droseraceae and 11 species of *Utricularia* under family Lentibuleriaceae. The present report which is a result of

Table 1.1 Comparison of carnivorous plant diversity

Order	Family	Genus	Number of species		
			World	India	Odisha
Oxalidales	Cephalotaceae	*Cephalotus*	1		
Nepenthales (Caryophyllales)	Droseraceae	*Drosera*	168	3	3
		Aldrovanda	1	1	
		Dionaea	1		
	Drosophyllaceae	*Drosophyllum*	1		
	Nepenthaceae	*Nepenthes*	127	1	
	Dioncophyllaceae	*Triphyophyllum*	1		
Ericales	Sarraceniaceae	*Darlingtonia*	1		
		Heliamphora	20		
		Sarracenia	8		
	Roridulaceae	*Roridula*	2		
Scrophulariales (Lamiales)	Byblidaceae	*Byblis*	7		
	Lentibulariaceae	*Pinguicula*	94	1	
		Genlisea	27		
		Utricularia	234	38	14
Total: 4 orders	9 families	15 genera	693	44	17

Source http://www.omnisterra.com/bot/cp_home.cgi

the survey made by the authors for the period from 2009 to 2013 has include 2 more species of *Utricularia* i.e. *Utricularia reticulata* and *Utricularia praeterita* from the state enhancing the total no. of species in to 17. However, we could not locate the presence of *Utricularia pubescence* during our survey. However, based on the report of Saxena (1965), we have kept this species in the final list of carnivorous plants of Odisha. Odisha hosts 17 species of Carnivorous Plants including 3 species of *Drosera* under family Droseraceae and 14 species of *Utricularia* under family Lentibulariaceae.

1.5.1 The Sundews of Odisha and Its Distribution

Each species of the Droseraceae family popularly called as Sundew. These species have small deep red colour leave covered with small hairy bristles, these leave produces shiny sticky secretions to encounter insects. Insects are trapped or captured when they encounter this leave and, in the mean, while the hairy out growth bend over the insect, the insect dies with suffocation and digested, out of the 4 genera placed under Droseraceae, 2 of the genera are commonly found in India i.e. *Drosera* and *Aldrovanda.* In Odisha, so far only one genus is reported to occur under Droseraceae, i.e., *Drosera.* It is the largest carnivorous plant having more than 170 species distributed over the world, Indian flora represents 3 species of *Drosera* such as *D. burmannii*, *D. indica* and *D. peltata* and all of them are found in Odisha.

Drosera burmannii occurs in moist or exposed sandy soils, in shaded places, nearby rice fields, lowland (Barren land at foothills of Sikharchandi hill) to mountain areas up to 4000 ft. It is distributed in Barkot block of Deogarh, Krishnamali and Khandualmali hills of Karlapat wildlife sanctuary, above 1000 m on laterite plateau in Kalahandi district, Gandhamardan hills of Bolangir district and Mahendragiri hills of Gajapati district and Hemgiri range of Sundargarh district etc. *Drosera indica* occurs in laterite plateaus of Karlapat wildlife sanctuary, above 3000 ft associated with *Eriocaulon* sp., grasses and other carnivorous plants such as *Drosera burmanii*, *Utricularia scandens*, *Utricularia bifida* and *Utricularia minutissima* of Krishnamali and Khandualmali hills, Kalahandi district. Laterite plateau above 3000 ft in Gandhamardan hills of Bolangir district and above 4000 ft in grasslands of Mahendragiri hills, Gajapati district are other critical habitat for *D. indica.* So far, *Drosera peltata* is reported only from Deomali hills of Koraput district above 5000 ft associated with grasses, *Eriocaulon* sp., and as epiphytes on old tree trunks covered with mosses.

1.5.2 The Bladderworts of Odisha and Its Distribution

The members of the genus *Utricularia* are commonly called as Bladderworts. They are not only the largest, but also the most cosmopolitan plant carnivorous genus, with a distribution ranging from high latitudes and boreal environments to the tropics. Their ecological success is further underscored by the great variety of life forms which include aquatic (lentic and lotic), terrestrial, epilithic, and epiphytic species. Utricularias are remarkable for their traps. Though the species show a wide morphologic and biologic diversity, a single type of trap is observed all over the genus. This family of insectivore's plants have 4 genera and more than 230 species are found worldwide of which 50 species are submerged or amphibious aquatics. Two genera such as *Utricularia* and *Pinguicula,* occurs in India. Only one genus i.e. *Utricularia* occurs in Odisha. Fifteen species of *Utricularia* have so far been reported from Odisha, Out of which 2 species (*U. reticulata* and *U. praeterita*) are new distributional record for the state. Other species of bladderworts found in Odisha are *U. aurea, U. bifida, U. caerula, U. exoleta, U. hirta, U. minutissima, U. polygaloides, U. pubescens, U. scandens, U. stellaris, U. striatula* and *U. uliginosa.* Out of them *U. aurea, U. exoleta, U. stellaris* are aquatic and the rest are terrestrial in habitat. The aquatic Utricularias are found to occur in roadside wetlands and swamps from Cuttack to Paradeep, Bhitarkanika mangrove ecosystems, Kanjia lake and RPRC Lake.

The terrestrial Utricularias are common in marshy places, along grasses in rice fields associated with *Eriocaulon* sp., such as *Utricularia hirta*, *Utricularia polygaloides*, *Utricularia scandens* and *Utricularia bifida* occurs in ditches and banks of small perennial water holes in Kamakhyanagar, Dhenkanal district, Paniganda wetlands in Ganjam, Similipal, Talcher, Sambalpur, Sunabedha wl sanctuary etc. Species like *Utricularia minutissima, Utricularia caerula, Utricularia praeterita, Utricularia uliginosa, Utricularia reticulata and Utricularia striatula* occurs in associated with grasses, in low land areas and swamps of Ranpur, Nayagarh district, Swamps of Bhitarkanika, Kendrapada district, small water wholes of Kamakhya Nagar, Dhenkanal district to high altitudinal plateaus of mahendragiri hills of Gajapati district, Deomali hills of Koraput district, Krishnamali and Khandualmali hills of Karlapat wildlife sanctuary in Kalahandi district, Laterite plateau above 3000 ft in Gandhamardan hills of Bolangir district and above 4000 ft, above 2500 ft in 2400 ft, Malayagiri hills of Angul district and in Phulbani forest divisions of Kandhamal district.

1.6 Carnivorous Plants in Biotechnology

The carnivorous plants are rich source of a number phytochemicals. The *Drosero* genus contains phytochemicals like Plumbaginin, 7-methyljuglone and flavonoids, quercetins and quinines. These phytochemicals have immunomodulatory, antispasmodics, cytotoxic activity against cancer cell, antibacterial, antifungal and antiviral, anti-inflammatory and antioxidant activities. It has observed that this phytochemical also promotes the phagocytic activities of WBC (granulocytes) and boost the immune response against different pathogens of human body. *D. indica* extracts have potential bioactivities like antioxidant and anticancer activity. The phytochemicals present in the *D. indica* also have nutritional and have property to prevent free radicals to reduce toxic level in the body. These plants do have organic acids and enzyme, which can help in curdling the milk. *Drosera burmannii* contains quinones, hydroplumbagin glucoside, flavonoids (kaempferol, myricetin, quercetin, and hyperoside), rossoliside (7-methyl-hydrojuglone-4-glucoside), and useful for several disorders.

The genus *Utricularia* is also very interesting at the molecular level. Some species are known to have minute genomes: *U. gibba* has the smallest known plant genome, which has 80 mega bases, comprises the half of *Arabidopsis*. The molecular genomic studies also focused on the evolution rate of chloroplast, mitochondria and nuclear ribosomal sequence (Greilhuber et al., 2006).

1.7 Threats to Carnivorous Plants of Odisha

All most 50% of the carnivorous plant species have assessed through IUCN with respect to the threaten level but still not all the species have not been quantified systematically and not been placed in any IUCN threat level. Few records published in last few years suggests that IUCN listed 102 species of 7 genera have been placed under critically endangered 11 species under endangered category and 39 species are in vulnerable rank. Consequently, of these IUCN-evaluated species, 56% are considered to be threatened, which is lower than the whole angiosperm present in the earth i.e., 70%. IUCN, records suggest that diversity is depleted due to sampling of wild plants for search, pollution, and natural modifications. Some species are at the verge of extinction over the world. In India 3 species of carnivorous plants are categorized under red data book as endangered plants.

The species *D. indica* and *D. burmanii* are commercially imported from Asia to European countries for the production of "Herba dorserae" a Ayurvedic herbal cosmetic products instead of focusing their own localized carnivorous plant i.e., *D. rotundifilia*. The exporter are frequently exploiting these plants in a huge quantity annoyingly about the abundance of these plant species in their own locality (Jayaram & Prasad, 2006). In our neighboring state like Andhra Pradesh, *D. indica* and *D. burmanii* have categorized under vulnerable category by IUCN. All these threatened species are in the vulnerable category now they are going to enlist under the endangered category if the Govt. will not take any initiative conservation strategy. These plants are declined accordingly due to their popularity of being used medicinal herbs and their commercial values in local as well as in the abroad market. These species are used for making cosmetic herbal products in foreign countries. The problem of conversion of land into either agricultural or residential areas is threatening the natural habitat of these carnivorous plants. In addition, mining and pollution of water bodies highly affects the growth of these plants. Currently the anthropogenic activities as urban development and industrialization are putting impact on the carnivorous plants diversity as a result their number is declining in the wetland habitats. Now days due to the continuous exposure of influents or pollutants, the wetland is declining day by day and putting on the impact on the diversity and distribution of the carnivorous plant. As they are adopted to poor nutrient environment, so they also could not grow up on the high nutrient, containing soils. Currently the contaminated water bodies are populated with weeds, which indirectly wipe out carnivorous plants from their niche.

1.8 Conservation Strategies

Public awareness is essential for the conservation of these plants and should be circulated among the student communities, researchers, scientists, foresters, policy makers. The biodiversity assessment should be periodically conducted regarding the diversity, distribution and other ecological parameters in relation to these plants. The early botanical survey regarding these represents that besides the natural causes the anthropogenic activities are vulnerable to this carnivorous plant diversity. All the facts and problem should be recorded through documentation and store in cataloged format so that more research will be conducted in a better way to conserve these plant species in their own natural habitat. The research should be carried out in a sustainable manner as these plant species are not only a good medicinal source but also play vital role in the ecosystem and serving as an indicator species in the nature.

The state legislation should establish some conservation strategy special meant for carnivorous plants, which should be operated by the forest department. It is imperative to locate areas such as plateaus, bordering areas of rice fields, wetlands etc. that have a high probability of *Drosera* and associated occurrence of terrestrial *Utricularia* species and aquatic Utricularias, so in the natural areas in-situ conservation strategy should be build up in a better way. The above mention suggestions not only helpful to conserve the carnivorous plants but also brings ecological integrity among the co-existence species in their habitats. Several other methods like field transfer of these plants from hazardous region to the conservation territory, seedbed preparation in the in-vivo condition, seed preservation and their maintenance through standardize methods. The molecular genomic information should be encoded and kept in the research database of different institutes to make the future these plants in safe side. The first step towards preserving these plants is to preserve at least some parts of their natural habitats. Along with it, it is also necessary to develop horticultural techniques for the species and promote ex-situ conservation. Otherwise, we may end up having only photographic evidence proving that the plant predators existed in Odisha.

1.9 Future Prospects in Research on Carnivorous Plants

The Carnivorous Plants are these days coming into limelight of modern research because of their characteristic enzyme complexes, absent in other plants. Unfortunately, these plants are on the decline when they have the potential to open up new vistas in the field of medicine. Given such a significant body of phytochemical research to date, future research prospects for the genus Drosera appear promising. Apart from micro propagation, It is hypothesize that three particularly novel lines may include the discovery of medicinal agents against multi-drug resistant (MDR) TB, applications in green chemistry, and anthocyanin-mediated nitrogen transport in these plants.

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Chapter 2
Climate-Smart Millets Production in Future for Food and Nutritional Security

Sagar Maitra, Tanmoy Shankar, Akbar Hossain, Masina Sairam, Lalichetti Sagar, Upasana Sahoo, Dinkar Jagannath Gaikwad, Biswajit Pramanick, Tanuj Kumar Mandal, Sukamal Sarkar, Harun I. Gitari, and Esmaeil Rezaei-Chiyaneh

2.1 Introduction

The millet crops belong to the family of grasses which show tolerance to soil moisture stress and different adverse weather conditions. They are mostly annuals with small grains and warm weather coarse cereals which are often used as food and

S. Maitra (✉) · T. Shankar · M. Sairam · L. Sagar · U. Sahoo · D. J. Gaikwad
M.S. Swaminathan School of Agriculture, Centurion University of Technology and Management, Paralakhemundi, India
e-mail: sagar.maitra@cutm.ac.in

A. Hossain
Bangladesh Wheat and Maize Research Institute, Dinajpur, Bangladesh

B. Pramanick
Department of Agronomy, Dr. Rajendra Prasad Central Agricultural University, Samastipur, Bihar, India

T. K. Mandal
School of Agriculture and Allied Sciences, The Neotia University, Jhinga, Sarisha, West Bengal, India

S. Sarkar
School of Agriculture and Rural Development, Ramakrishna Mission Vivekananda Educational and Research Institute, Narendrapur, West Bengal, India

H. I. Gitari
School of Agriculture and Enterprise Development, Kenyatta University, Nairobi, Kenya

E. Rezaei-Chiyaneh
Department of Plant Production and Genetics, Faculty of Agriculture, Urmia University, Urmia, Iran

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fooder (Fahad et al., 2017; Maitra et al., 2023a, b). During last few decades when major emphasis was given to fine cereals, namely, rice, wheat and maize, millets were neglected and treated as ‘orphan cereals.’ But over time millets have been re-evaluated and considering their nutritional value these are further treated as ‘nutri-cereal’. Still millets are grown by the tribal and small farmers under the drought and rainfed conditions of mainly in arid and semi-arid regions (Saxena et al., 2018). Millets cultivation is predominantly confined in Africa, Asia and few regions of Europe. Worldwide, millets are grown in 33.56 million ha with an output of 31 million t of grains (FAOSTAT, 2020). Generally, millets are grouped into two categories, such as major and small millets. Pearl millet (*Pennisetum glaucum* L.) and sorghum (*Sorghum bicolor* L.) and fit into major millets, whereas, minor millets are barnyard millet (*Echinochloa frumentacea* L.), brown-top millet (*Brachiaria ramose* L. Stapf; *Panicum ramosum* L.) finger millet (*Eleusine coracana* L. Gaertn), foxtail millet (*Setaria italica* L.), kodomillet (*Paspalum scrobiculatum* L.), proso millet (*Panicum miliaceum* L.), little millet (*Panicum sumatrens* L.) and so on (Maitra, 2020a).

Presently, climatic aberration is appeared as a menace to agriculture and the modification of normal climate is very common. The anthropogenic intervention leading to climate change resulted production of greenhouse gases (GHGs) and aerosol which adversely impacted primarily on rainfall and temperature. As per the estimation of the Intergovernmental Panel on Climate Change (IPCC, 2007), if the anthropogenic activities go on in the same manner there will be a possibility of enhancement of earth’s temperature by 1.1 to 5.4 °C by 2100. Moreover, global warming may trigger the occurrence of natural calamities such as excess rain, inundation and floods, scanty rain, soil moisture stress and drought, and cyclonic storms as resultant of increase of temperature and improper distribution of rain. The cumulative effect of climatic aberrations change in rainfall, temperature and elevated CO_2 ultimately causes hindrances to normal farming activities. Climate change hampers crop productivity with qualitative changes (Aryal et al., 2020). Mitigation of the adverse impacts of climatic abnormalities and global warming on farming and quality agricultural output are tremendous jobs (Ergon et al., 2018; Nuttall et al., 2017). However, to combat with the situation, adaptation options have already been taken into consideration in different regions of the world. There are several thermo-tolerant cultivars which have been developed and already are under cultivation (Ishimaru et al., 2016; Morita et al., 2016). The adverse influence of climate change has already been reflected in the performance of major food crops (Gaikwad et al., 2022), namely, rice (Bhatt et al., 2019; Rahman et al., 2017; Soora et al., 2012), wheat (Chakraborty et al., 2019; Hossain et al., 2021; Mukherjee et al., 2019; Xiao et al., 2018) and maize (Ureta et al., 2020). In the present consequence of climatic abnormalities, millets can be considered as climate-smart crops as they are drought and thermo-tolerant, rich in nutrients, can ensure bio-diversity, check soil erosion in marginal lands, as C_4 plants enable to use elevated atmospheric CO_2 and suitable to grown in wider ecological conditions (Banerjee & Maitra, 2020; Brahmachari et al., 2018; Srinivasarao et al., 2014). However, millets can be stored better than other food grains under normal condition for the quality of resistance from damage of insect attack (Adekunle, 2012; Li & Brutnell, 2011; Sage & Zhu, 2011; Sage et al., 2011).

In the present world, the country leaders and policy makers including leading international organizations implemented various initiatives to eradicate hunger towards achieving sustainable development goal (SDG), but hunger is still prevailing particularly in some corners of the developing countries (Rimas & Fraser, 2010).

The prime issues faced by the all concerned are population growth, urbanization and change in food demand and enough need for agricultural produces with dwindling and degrading natural resources (Gladek et al., 2016). Further, climate change imposed an interruption in achieving the targetted food security. The food security emphasizes availability, accessibility and proper use of food (with nutrition security) (Gross et al., 2000). A large portion of small and marginal farmers of dryland areas aground the world grows millets in the subsistence farming. Millets consumption can fulfill the food as well as nutritional security to the undernourished populace residing in the under-developped countries. In the chapter, effects of climate change on agricultural productivity, suitability of millets under the circumstances and climate-smart technologies for millets cultivation have been discussed thoroughly.

2.2 Climate Change Impact on Agriculture

During recent years, disasters occurring very frequently and climate change is responsible for occurrence of disasters like flood, drought, and cyclonic storms and so on. The developing countries are mostly affected by the climatic aberration (Maitra & Shankar, 2019). The production of important cereals such as rice, wheat and maize has declined drastically by ill effects of temperature rise and erratic rainfall (Lesk et al., 2016). The projected prediction has indicated that population growth in the developing countries; especially, the Sub-Saharan Africa and South Asia will be nourishing added population of 2.4 billion by the middle of the present century. The population living in the above-mentioned geographical locality lives on farming and allied activities and about one-fifth of the human population residing in the developing part of the world are suffering from starvation and malnutrition (Saxena et al., 2018). In future food crisis may be more crucial to the under changed climatic conditions. A general recommendation mentioned that there will be need for further enhancement of agricultural production by 60% in 2050 to fulfill the foodneeds of the future population. The present context demands for enhanced agricultural productivity and revenue in the developing countries (Lipper et al., 2014).

The collective effect of climatic abnormalities results in disturbance in normal agricultural activities. Agriculture is an anthropogenic activity and dependent on climatic parameters, namely, humidity, temperature, rainfall and so on (Gornall et al., 2010; Yohannes, 2016). Climatic aberration affects qualitative and quantitative fluctuation on agricultural productivity. Alteration in agro-ecosystem may also decline intensity of cropping and drought or water stagnation led to degradation of natural resources and biodiversity. Agriculture has enough importance in the economy and livelihood in the developing countries (Ackerman & Stanton, 2013). A projection has indicated that there will be the need for around 14,886 million tonnes of cereal equivalent food in the world in 2050 (Islam & Karim, 2019) to feed 9.7 billion people. As per present concept, food security is synonymous to food and nutritional security. To meet the target, latest and proven technologies are adopted considering the cropping as well as farming systems of various agro-ecological regions. As the productivity of fine cereals are adversely affected by climate change, millets can be chosen targeting uninterrupted production of food grains, because millets are hardy crops with wider adaptability to diverse agro-climatic conditions and cropping systems (Arendt & Dal Bello, 2011; Upadhyaya et al., 2008). Further, millets can easily be stored under normal storage conditions and so can be treated as famine food under contingency situations (Michaelraj & Shanmugam, 2013).

2.3 Adaptation Options Against Climate Change

Climate change denotes aberrations in the normal system and adaptation options are essential (Iizumi, 2019). To combat with the adverse impacts of climatic aberration, crop management options are considered which include changes in crop cultivation methods, cultivation of existing crops and cultivars with modified agronomic management, giving preference to the varieties of the same crop with abiotic stress tolerance, substitution to the crops with abiotic stress tolerance, availing crop insurance facilities, providing more emphasis to weather forecast and agrometeorological advisories, and crop insurance. Further, manipulation of sowing date, nutrient management, irrigation, drainage and water management, conservation agriculture inclusive of tillage, mulching and cover cropping are common agronomic management practices generally adopted against climate change (Fujibe et al., 2006). During present times, prediction of climate variability has become easier and considering the climate extremes suitable agronomic measures are adopted (IPCC, 2013; Vrieling et al., 2016). In this regard, different agro-meteorological tools are useful in weather related decision support system as farmers can adopt suitable measures (Hayashi et al., 2018). Further, there is the need for more precise information (Iizumi, 2019) with proper communication network to the farmers, particularly, smallholders in their local vernacular. Crop insurance is another adaptive measure to safeguard the smallholders from crop failure due to climatic issues. During present time, elimination of hunger and food security can be achieved by combined application biotechnology and information technology with ecofriendly adoption of agronomic management (Swaminathan & Kesavan, 2012). Development of climatic stress tolerant cultivar is genetic and biotechnological approaches suitable as adaptation measure. Recent advancement in the front of science and technology provided sophisticated tools for precision agriculture.

2.4 Millets: The Climate-Smart Crops

The climate change for agriculture is becoming a major challenge. The different factors which act as important issues like scanty rainfall and temperature raise directly increase the rate of evapotranspiration and reduction of water table in poor and marginal soil. Further, increased level of CO_2 and other GHGs are major issues influence crop production. So, to combat with the environmental issues, smart crops such as millets cultivation may be considered because millets come under C_4 plants category which are acquiescent with climate change. The C_4 mechanism can fight against drought and some other environmental stresses and these are of short to medium in duration with requirement of less number of inputs like labour, irrigation and nutrients. Generally, C_4 plants (millets) show greater nitrogen use efficiency than C_3 plants. As millets are C_4 plants, produce more phosynthate with enhanced temperature iclusive of increased level of flexible distribution arrays of dry matter and reduced hydraulic conductivity per unit leaf area (Sage & Zhu, 2011). Moreover, millets register more water use efficiency (WUE) than prime cereal crops. To produce 1 g dry matter foxtail millet uses 257 g water, whereas maize and wheat requires 470 g and 510 g of water respectively to yield the same dry matter (Bandyopadhyay et al., 2017). In future, when water scarcity will be more crucial, millets will be preferred to fine cerals to manage the food grain production target. Millets are hardy in nature and the crops show less susceptibility against pest and disease attack. Millets are C_4 plants which can use more of CO_2 and register less carbon footprint in agriculture (Aubry et al., 2011; Bandyopadhyay et al., 2017; Li & Brutnell, 2011). Agronomic measures are important in contribution of GHGs emission. Production of maize, wheat and rice contributes carbon equivalent emission of 935, 1000 and 956 kg C ha^{-1}, respectively (Jain et al., 2016). However, millets register less compared to above fine cereals and cultivation of millets is known to minimize C footprint in agriculture (Saxena et al., 2018). Further, chemical fertilizers are generally applied to crop field to supply the nutrients need of the crops and chemical N fertilizer is a very common input in agriculture. The production process of chemical N fertilizer produces CO_2. An estimate mentioned that the quantity of chemical N fertilizers produced worldwide generates 300 Tg of CO_2 to the atmosphere (Jensen et al., 2012).

Millets need a smaller amount nutrirnts than other fine cereals and hence, application chemical inputs are less which is environment friendly. In developing conutries, over-dependence on major cerals caused erosion of genetic diversity during last five decades. In contrast, diversified millets have enough potential to create diversity in agroecosystem ensuring superior ecosystem services. Moreover, millets play multifaceted role in food production system and sustainability of rural livelihood (Fig. 2.1) by providing food as well as nutritional and environmental security.

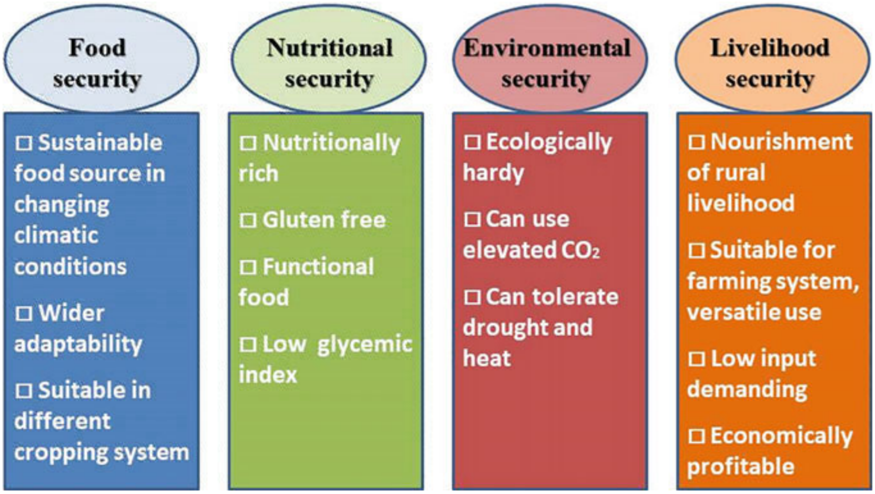

Fig. 2.1 Versatile role of millets in climate smart and sustainable agriculture

2.5 Nutritional Importance of Millets

The millets are also known as 'nutri-cereals' as they contain protein, fats, carbohydrates, vitamins, minerals and some micronutrients and phytochemicals (Table 2.1) (Banerjee & Maitra, 2020; Saleh et al., 2013). Further, millets are treated as functional food. During recent years, health-conscious people started consuming millets in their diet.

The richness in the nutritional quality has elevated millets as healthy foods for proper nutritional requirements. Millets are primarily used as food, however, they are also used as animal feed. Millets are generally gluten free and so preferred by

Table 2.1 Nutritional quality of millets (per 100 g of edible portion)

Crops	Crude fibre (g)	Protein (g)	Fat (g)	Mineral (g)	Carbohydrate (g)
Barnyard millet	14.7	11.6	5.8	4.7	74.3
Brown-top millet	–	9.0	1.9	3.9	71.3
Finger millet	3.6	7.3	1.3	2.7	72.0
Foxtail millet	8.0	12.3	4.3	3.3	60.0
Kodo millet	9.0	8.3	1.4	2.6	65.9
Little millet	8.6	8.7	5.3	1.7	75.7
Pearl millet	1.2	11.6	5.0	2.3	67.5
Proso millet	2.2	12.5	1.1	1.9	70.4
Sorghum	1.6	10.4	1.9	1.6	72.6

Source GOI (2020), Maitra et al. (2022), Banerjee and Maitra (2020) the people suffering from gluten allergy and celiac disease. Besides, millets are comprised of enough of fibre content, vitamins and essential mineral matters which are vital to fulfill the nutritional security of undernourished people.

Millets are comprised of healthy phytochemicals like polyphenols, lignans, phytosterols, phyto-oestrogens andphytocyanins. The millets are treated as functional food because of presence of antioxidants, detoxifying agents and immune modulators that can potentially benefit against hyperglycemia, cardiovascular diseases, tumour, respiratory diseases, Parkinson's diseases and so on (Chandrasekara et al., 2012; Rao et al., 2011, 2012). The antioxidants present in millets can protect the DNA, proteins molecules and lipids membranes (Banerjee & Maitra, 2020).

2.6 Demand of Foods in Future and Role of Millets

For achieving the security of food and nutrition, it is very important to acquire the yield enhancement for the increasing population and to manage the distribution of the food grains. There is limitation in the world to provide healthy and nutritious food to all. In the developing countries of Africa and Asia, the problem is more crucial. Due to climate change the available resource and their limited utilization is raising the problem for food and nutritional security (Committee on World Food Security, 2012). About 815 million people of Africa and Asia are facing malnutrition (El Bilali, 2018; El Bilali et al., 2019). The potential of millets with rich nutritive and healthy benefit which is consumed as staple food and due to the high nutritional value of these crops is called as nutri-cereals. Further, consumption of millets crops is better in comparison to fine cereals because it contents more fibre content and easy digestive food (Banerjee & Maitra, 2020). The estimated population in the world will be 9.7 and 11.2 billion by 2050 and 2100 (FAO, 2017). There are already shrinkage and decline of land and water resources. On the other hand, urbanization is taking place rapidly with change food habits. In urban areas, demand for value added and animal source foods are more which need more energy to produce. The change in food demand is combined effect of increased population and income growth (Valina et al., 2014). Now there is the urgent need for sustainable intensification of farm productivity (Garnett, 2014). Earlier, farm output in the developing countries has been enhanced by adoption input driven technologies and over a period of few decades environmental degradation has been noticed. In the present context, the agricultural productivity has to be increased by about 50 per cent to meet the demand in 2050 (World Bank Group, 2016). Mueller et al. (2012) estimated that the enhancement of crop production should be 45 to 70% more than the present level. In 2050, the cereal equivalent food demand will be around 14,886 million tonnes (Islam & Karim, 2019). Food waste is another important factor to be considered while addressing the food requirement for the future and wastage of food is observed in several corners of the world. The climate change impacts created an additional burden in this regard. All these factors clearly indicate the requirement of more food production targeting food and nutritional security (FAO, 2018). Considering above constraints, targets and the huge potential of millets in terms of ecological soundness and nutritional value, it can be mentioned that millets will be one of the suitable options to ensure food and nutritional security of a considerable number of world population.

2.7 Value Added Food from Millets

Millets are multipurpose grains used as food and feed because of nutritional composition (Devi et al., 2014). The straw of millet crops is valuable as livestock feed and livestock is an essential component for smallholders in their integrated farming system. Sorghum is used as pet feed preparation (Aruna & Visarada, 2019). In northern India, different traditional festival this crop used from ancient time during fasting period for making sweet dishes. Finger millet grains are used for traditional food preparation in different countries including alcoholic and non-alcoholic beverages (Ramashia et al., 2019). Different products like *rawa*, flour, sweet, cake, pasta, biscuits, cookies, chocolates are made by using millets as ingredients. Value added products developed from sorghum in India are nutritional enriched (Table 2.2).

Use of sorghum mill feed and pellets are very common as fish and shrimp feed. Different value-added food products and health drinks are prepared from millets and the course cereals are of high demand in food and health industry. The phenolic

Table 2.2 Nutritional composition of sorghum based valued added products (per 100 g)

Parameters	Grain	Flour	Fine rawa	Medium rawa	Flakes	Vermicelli	Pasta	Pops	Biscuits
Moisture (%)	11.9	13.8	10.2	9.0	13.8	8.4	11.5	5.9	5.7
Ash (%)	1.6	1.6	0.7	2.0	0.6	0.8	0.8	0.6	2.0
Protein (%)	10.4	6.2	6.7	7.2	5.1	8.4	8.4	5.0	4.6
Fat (%)	1.9	2.8	1.7	1.2	2.4	1.4	1.4	2.6	24.5
Carbohydrate (%)	72.6	76.2	77.8	77.7	75.0	76.2	76.2	83.1	60.3
Iron (mg)	4.1	8.4	10.6	5.1	87.8	64.5	64.5	2.4	2.3
Calcium (mg)	25.0	10.0	7.6	5.8	93.2	54.5	64.5	10.3	68.8
Chromium (mg)	0.0	0.0	1.3	1.5	0.9	0.2	0.2	1.4	0.2
Zinc (mg)	1.6	1.3	1.2	1.4	8.8	7.5	5.7	4.5	BDL
Magnesium (mg)	171.0	171.0	76.5	86.0	80.5	67.5	67.5	86.8	56.1
Riboflavin (mg)	0.1	0.4	0.1	1.1	0.0	1.3	1.3	0.2	2.3
Energy (Kcal/100 g)	349.0	355.0	350.0	350.0	342.0	355.0	355.0	376.0	481.0

Source Dayakar et al. (2017), Kumar and Maitra (2020), Abah et al. (2020)

compounds present in sorghum (Dykes & Rooney, 2006; Dykes et al., 2013) are beneficial against non-communicable diseases and widely used for pasta making by substituting wheat (Khan et al., 2015). The gluten free millet-based products ultimately lower blood sugar and energy intake and increase antioxidant status (Cardoso et al., 2017). Further, sorghum is known in treatment of sickle cell disease and orthopedic treatment (Aruna & Visarada, 2019) and tablet preparation (Alebiowu & Itiola, 2002; Zhu, 2014). The edible cutlery and syrup are also produced from millets. Bioindustrial products like ethanol (Corredor et al., 2006), biodegradable and edible films for packaging (Kaur et al., 2014), food colourants (Clifford, 2000) are other industrial products derived from millets. In paper and construction industries also stover of sorghum, pearl millets and other millets is used (House et al., 2000; Saeed et al., 2017).

2.8 Climate-Smart Technologies in Millets Cultivation

The climate change impacts imposed a question mark before the enhancement of production and yield of major cereals and automatically millets could be considered as climate-smart crops because of their resilience against climatic aberrations. To fulfill the present requirement as well as sustainable production of food grains, millets production should be directed in a climate-smart way where all suitable technologies of Good Agricultural Practice (GAP) should be adopted. Moreover, technology enabled precision crop management should also be taken into consideration for maximization of input use efficiency. Following are the climate-smart technologies for sustainable millets cultivation.

2.8.1 Integrated Nutrient Management

Integrated nutrient management (INM) shows the positive impact on yield by applying with integration of different nutrient sources such as organic manures, biofertilizers and inorganic fertilizers which enhance the soil health (Kumara et al., 2007). The nonjudicious supply of chemical nutrients inputs is not properly utilized by the plants. As a result, applied chemical fertilizers register very poor nutrient use efficiency (NUE) for different crops (Parkinson, 2013; Zhang et al., 2012) as well as in millets. In the world, sustaining agricultural productivity is a hugetask under the present threat of climaticfactors. Production of chemical fertilizers consumes energy and causes emission of GHGs. By substituting chemical nutrients with biofertilizers and organic manures in crop production, atmospheric pollution can be checked. The INM targets sustainability in crop production along with enhancement of productivity and economically viability (Chen et al., 2011; Jagathjothi et al., 2010, 2011; Pallavi et al., 2017; Wu & Ma, 2015;). Generally, organic manures are having low analytical value and huge quantity of bulky organic manures is required to fulfill the demand of the crops. But millets are less nutrient demanding crops. Hence, a portion of chemical nutrients can easily be substituted by organic sources and biofertilizers. Research evidences indicated better performance of INM practices in different millets (Table 2.3).

Moreover, nano materials are presently in use as nutrients. A study revealed that foliar application of nano-urea supplement along with the recommended dose of nitrogen increased growth and yield of finger millet (Samanta et al., 2022).

2.8.2 Nutrient Management Based on Soil Test Crop Response (STCR)

The soil test crop response (STCR) is an approach of nutrient management that aims for precision supply of fertilizers based on the nutrient status of the soil and its response for a target yield. Among different nutrient management practices adopted in crop production, the STCR method quantifies nutrients from applied inputs and soil for a target yield (Maitra et al., 2020a; Regar & Singh, 2014). The focus of the STCR approach is to ensure fertilization application in a balanced manner considering the role of soil and nutrients provided (Choudhary et al., 2019). As per STCR method fertilizers can be recommended based on regression analysis of certain percent of maximum yield. The STCR considers the three factors, namely, nutrient requirement of the crop, percentage contribution from soil available nutrients and percentage contribution from added fertilizers. For achieving a target yield of crop in a given location, the STCR approach may be considered as aprecision decision making tool where the right amount of nutrient application in the soil is prescribed depending upon soil value to maintain soil fertility. The STCR approach enhances profitability with more yield in an environmentally friendly way (Das et al., 2015) and it further increases the NUE (Jemila et al., 2017; Lal, 2015; Sekaran et al., 2018a; Santhi et al., 2011a, b). As per the STCR, finger millet responded well to the application of 200% N, 100% P, 100% K, 25% Zn, 25% S, 25% B and 5 t ha^{-1} FYM (for a target productivity of 4 t ha^{-1}) against RDF (Sandhya Rani et al., 2017). Shetty and Kumar (2018) also mentioned that STCR-based NPK along with compost 10 t ha^{-1} performed better compared to other nutrient doses in alfisols of Karnataka, India. The STCR method clearly indicated that it was the suitable method to maintain nutrient balance and soil health. A long-termtrial conducted at Indian Agricultural Research Institute, India on pearl millet–wheat cropping system clearly revealed that STCR based nutrient arrangement was better for a target yield of cereals (Sharma et al., 2016). Researches carried out on STCR based integrated plant nutrition system (STCR-IPNS) for nutrient recommendation in pearl millet under Inceptisol of Tamilnadu, India and revealed that for a yield target of 4 t ha^{-1}, STCR-IPNS expressed its superiority over other practices. Further, STCR recorded more grain yield of pearl millet than blanket application of nutrients, blanket supply of chemical fertilizers along with FYM and farmer's practice of the locality (Sekaran et al., 2018a, b).

Table 2.3 Studies on INM in different millets

Crop	Study area	Salient feature of the research	Reference
Sorghum	India	In Sorghum—wheat cropping system, INM enhanced grain and fodder productivity of sorghum by 18.5 and 9.4%	Patidar and Mali (2001)
	India	Application of 75% recommended dose of fertilizer (RDF) + 3 t ha^{-1} of farmyard manure (FYM) along with either *Azospirillum* or phosphate solubilizing bacteria (PSB) yielded at par with RDF (chemicals) in winter sorghum	Srinivas et al. (2008)
Pearl millet	India	In pearl millet—wheat cropping system, pearl millet with 50% RDF + 50% N FYM yielded at par with 100% RDF	Kumar et al. (2005)
	Niger	In the Sahelian zone, combined application 0.9 t ha^{-1} millet stover and 2.7 t ha^{-1} organic manure along with 15 kg N and 4 kg P ha^{-1} through chemicals resulted in 132% grain productivity	Akponikpe et al. (2008)
	India	INM with chemical ferilizers, FYM and biofertilizer combination enhanced growth, yield attributes and yield ofpearlmillet during rainy season	Rajput (2008a, b)
	Zimbabwe	Cattle manure with a combination of either biomass transfer and/or ammonium nitrate showed increases of soil fertility parameters, panicle length and grain yields	Kokerai et al. (2019)
	India	The RDF (120 kg N + 45 kg P + 45 kg K + 20 kg $ZnSO_4$ ha^{-1}) produced more grain and fodder yield of pearl millet and the treatment remained at par with 50% RDF + 5 t ha^{-1} FYM + bio-fertilizer	Kadam et al. (2019)
Finger millet	Nepal	Organi manures with chemical fertilizers produced more grain yield over chemical nutrients	Pilbeam et al. (2002)
	India	Phosphorus-enriched FYM and recommended dose of N (RDN) increased grain yield over application of RDF	Jagathjothi et al. (2011)
	India	A combination of 10 t ha^{-1} FYM + 100% NPK and 5 t ha^{-1} maize residue incorporation + 100% NPK yielded more grains in semi-arid tropical Alfisol	Sankar et al. (2011)
	India	Combined application of 10 t ha^{-1} FYM + biofertilizer consortia (*Azospirillum brasilense* + *Bacillus* spp. + *Psuedomonasflurosence* @ 20 g kg^{-1} seed each) + $ZnSO_4$ (12.5 kg ha^{-1}) + Borax (kg ha^{-1}) + 100% RDF (50:30:25) yielded more than RDF in sandy loam soil	Roy et al. (2018)

(continued)

Table 2.3 (continued)

Crop	Study area	Salient feature of the research	Reference
Foxtail millet	India	Application of 50% RDF (through chemicals) + 25% N (through neem cake) + microbial fertilizer registered more yield than only RDF	Monisha et al. (2019)
	India	Integrated application of FYM + RDF + 3% *Panchagavya* produced more grains than RDF	Kumaran and Parasuraman (2019)
	India	Application of 75% RDN (chemical) + 25% N (poultry manure) + seed inoculation with *Azospirillum* increased grain yield	Selectstar Marwein et al. (2019)
Little millet	India	Application of 7.5 t ha^{-1} of FYM, NPK (40:20:10 kg ha^{-1}) calcium carbonate, zinc sulphate, and borax produced higher grain yield than RDF	Parihar et al. (2010)
	India	A combination of 100% RDF + 1 t ha^{-1} neem ensured higher yield than RDF	Sandhya Rani et al. (2017)
		Combined application of 75% RDN (chemical) + 25% RDN (vermicompost) yielded more than RDF	Thesiya et al. (2019)
Kodo millet	India	Integrated application of of 125% RDF + soil *Azospirillum* @ 2 kg ha^{-1} (soil) + vermicompost @ 2 t ha^{-1} + foliar application of 1% nutrient supplement increased grain yield of kodo millet	Prabudoss et al. (2014)

2.8.3 Site Specific Nutrient Management (SSNM)

The different nutrients which are deficient worldwide in the soil are mainly six elements, namely, N, P, K, S, Zn and B. Presently, precision management of essential nutrients can be adopted as different tools and decision support systems are available for the purpose. These tools fine tune the fertilizer application to the crop fields. The identification and management of variability and site-specific management is one of the best ways of crop nutrients management. During last six decades, enough of chemical inputs have been applied to crop field and unbalanced application of chemical fertilizers in intensive agriculture caused wastage, pollution and deficiency of some specific nutrients. In this regard site specific nutrient management (SSNM) can be adopted for judicious use of fertilizers. The SSNM works in such condition where deficient nutrients can be reclaimed by this methodology. The primary thing needs to be done under SSNM is initial soil test and based on the soil test results, a yield target can be fixed and nutrients are applied accordingly to the soil (Rathod et al., 2012). The research on SSNM for major cereals has been carried out, but limited research has been carried out on millets. Ramachandrappa et al. (2015) noted that the impact of SSNM on finger millet under intercropping with red gram performed well in Bangalore, India for a target productivity of 4 t ha^{-1} and SSNM resulted in higher yield of finger millet and profitability with soil health improvement. Singh and Bharadwaj (2017) studied on multi-locational trial and mentioned that SSNM practice gave more grain yield of pearl millet than the recommended practice and farmer's practice. The result of an experiment conducted in Uttar Pradesh, India clearly indicated that the effect of SSNM on pearl millet—wheat cropping system yielded more than farmer's practice and state recommendation (Kumar & Singh, 2019). In soybean–sorghum cropping system, the SSNM practice resulted in better productivity for both the crops at Raichur, Karnataka, India (Ravi et al., 2020).

2.8.4 Resource Conservation Technology (RCT)

Resource conservation technologies (RCTs) are important as mitigation and adaptation options to combat climate change because of numerous benefits. RCTs focus on conservation agriculture (CA) practices that include soil cover, minimum tillage, crop diversification and application of organic inputs (FAO, 2020). CA is a farming system approach which promotes minimum use of high energy inputs in agriculture with a goal of resource conservation, enhancement of nutrient and water use efficiency leading to agricultural sustainability. As regard of soil health and its management, minimum or zero tillage is a wonder technique for the different millet crops which expressed better results on growth and productivity under resource poor conditions (Verma et al., 2017, 2018; Wilson et al., 2008). Besides, zero tillage or conservation tillage is economically beneficial because of less energy involvement in farming compared to conventional tillage. Further in conventional tillage, farm machineries are operated by fossil fuel burning which causes emission of more GHGs (Martin-Gorriza et al., 2020). Reduced tillage also save labour input in agriculture compared to conventional tillage (Choudhary et al., 2018; Malviya et al., 2019). Millets are diversified grains of various nature and thus millets cultivation creates on-farm biodiversity suitable to drylands facilitation a new green revolution (Goron & Raizada, 2015; Michaelraj & Shanmugam, 2013). In erosion prone areas, residue incorporation and mulching are beneficial for soil conservation (Mgolozeli et al., 2020). In drylands, soil moisture and fertility are two major contraints for a good harvest (Choudhary et al., 2018; Schlegel et al., 2017) and CA has enough potential to overcome these issues because cover cropping and mulching can enable higher soil moisture content and residue incorporation in soil can ensure higher organic C and other nutrients (Chehade et al., 2019; Prasad et al., 2016; Srinivasarao et al., 2013). Intensive tillage causes loss of soil organic carbon (SOC) and global loss of SOC in this operation has been quantified as 60–90 Pg (Lal, 1999). Not only loss of SOC, but also conventional tillage impacts negatively on soil physical, chemical and biological properties (Lal, 2004). In contrast, CA facilitates gain in SOC inclusive of improvement of soil properties. Studies conducted at different locations clearly indicated positive impacts of RCTs on soil health improvement. In pearl millet—wheat cropping system, zero tillage resulted in a greater SOC and available nutrients than conventional tillage (Kaushik et al., 2018). Inclusion of crop residue was advantageous in pearl millet and sorghum cultivation in West Africa as it decreased top-soil temperature, increased water availability and improved soil physico-chemical properties (Buerkert et al., 2000). Sankar et al. (2011) observed from multi-locational trials carried out in Inceptisol, Vertisol and Aridisol of India and mentioned that reduced tillage was more productive and economic for production of pearl millet under arid and semi-arid conditions. Finger millet yield was increased by substituting 50% of the RDN with organic manures in Alfisol. Further, a conservation tillage enhanced SOC (Prasad et al., 2016). Malviya et al. (2019) concluded that farmers should adopt reduced tillage as well as inclusion of residue of previous crop as mulch material for kodo millet cultivation in Rewa, Madhya Pradesh of India.

2.8.5 Inoculation of Growth Promoting Microorganisms

Under the present context of climate change, plants are supposed to fetch weather abnormalities and stress due biotic and abiotic factors. Different plant growth promoting microorganisms are capable to provide support to the plants to overcome these abnormalities (Ojuederie et al., 2019). Research conducted on microbes mediated abiotic stress tolerance revealed that plant growth promoting rhizobacteria (PGPR), namely, *Bacillus atrophaeus*, *B. sphaericus*, *B. subtilis*, *Pseudomonas* spp. and *Staphylococcus kloosii* are capable to reduce stress in finger millet by enhancing root and shoot growth (Chandra et al., 2018; Shultana et al., 2020). The endophytic bacteria *Bacillus amyloliquefaciens* EPP90 played versatile role in stress tolerance in pearl millet (Kushwaha et al., 2019). Niu et al. (2018) showed that the isolates of bacterial strains of *Pseudomonas fluorescens, Entero bacterhormaechei*, and *Pseudomonas migulae* enhanced seed germination and seedling vigour of foxtail millet under drought conditions because of ability to produced exopolysaccharide and 1-aminocyclopropane-1-carboxylic acid (ACC) deaminase. Abiotic factors are responsible for different biotic stress also and PGPR can be used for recovery of abiotic stress. The study indicated that the rhizobacterial strain of *Pseudomonas* sp. MSSRFD41 was effective against blast disease of finger millet (*Pyriculariagrisea*) and growth enhancement (Sekar et al., 2018). Further, biopriming of finger millet seeds with *Pseudomonas* sp. MSSRFD41 was beneficial in terms of increase in germination and plant growth. The strains of *Pseudomonas* spp., UOM ISR 17 and UOM ISR 23 were able to check the spread of downy mildew (*Sclerospora graminicola* (Sacc.) Schroet) effectively in pearl millet (Jogaiah et al., 2010).

2.8.6 Application of Growth Promoters

The phytohormones and growth promoting substances play vital role in plant growth and stress mitigation. Seed treatment and foliar application of hormones and growth promoters resulted in better growth and development of different crops including