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

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## 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

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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.

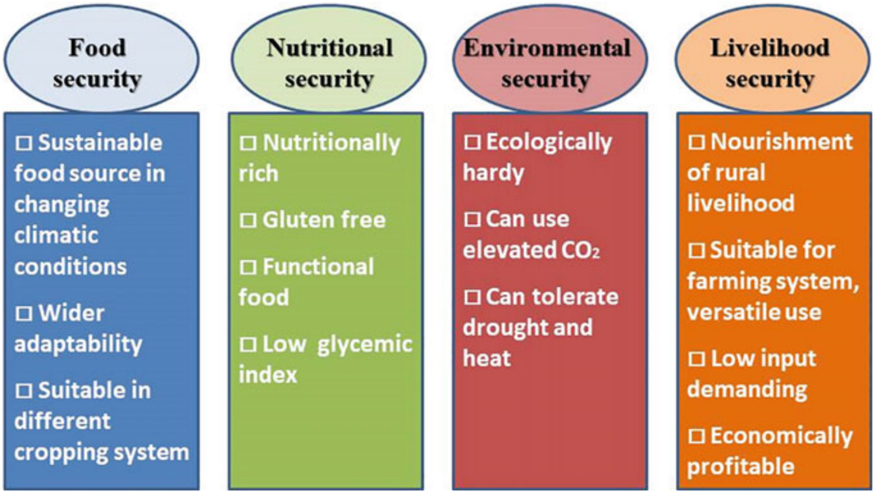

**Fig. 2.1** Versatile role of millets in climate smart and sustainable agriculture

## 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 millets (Appu & Senthilmurugan, 2014). Hydro-priming in pearl millet expressed vigorous growth of finger millet in drylands (Kumar et al., 2002). Earlier Maitra et al. (1997) reported that pre sowing seed 100 ppm $Na_2HPO_4$ and $KH_2PO_4$ registered better yield of finger millet. Similarly, overnight seed soaking with water or 0.25% $CaCl_2$ resulted in increasing yield of finger millet over no treatment (Maitra et al., 1998). In pearl millet, seed priming with NaCl impaired the ill effect of salinity and later showed more growth (Ashraf & Iram, 2002). Pearl millet seed priming with solution of GA (at the rate of 50 mg per litre of water) showed more growth (Vijayaraghavan, 1999). Seeds of pearl millet treated with chlormequat chloride (CCC) or 0.15% succinic acid also recorded higher germination percentage than untreated seeds (Shanmugasundaram & Kannaiyan, 1989). Effect of seed treatment in sorghum was studied by Kadiri and Hussaini (1999) and they noted seed soaking with $CaCl_2$ or $KNO_3$ solution resulted in better germination, growth and chlorophyll content. In barnyard millet (*Echinochloa frumentacea*), seed treatment with 100 ppm IAA or 1% $KH_2$PO4 expressed more germination, plant height, seedling vigour index and drymatter accumulation (Sujatha et al., 2013). Foliar spray of plant growth regulators (PGRs) is also beneficial in millets. Prabha et al. (2016) recommended that foliar spray of nutrients and PGR as consortia could be used for enhancement of growth, productivity and economic return of finger millet and they used brassinosteroids, mepiquat chloride and chlormequat chloride as growth promoters. Growth and yield attributes of finger millet were enhanced by the foliar application of salicylic acid showed enhanced growth and yield attributing characters of finger millet (Sathishkumar et al., 2018). The PGRs are potential to combat abiotic stress in enhancing the growth parameters of pearl millet as reported by Suresh et al. (2018) when NAA application (40 ppm) at 20 and 40 days after sowing was proved beneficial. Earlier, Sivakumar et al. (2002) reported that foliar application of brassinosteroid (0.1 ppm) and triacontanol (10 ppm) expressed more pearl millet grains as well as enhanced grain protein and sugar in pearl millet. The studies clearly indicated that growth promoting substances played a vital role in enhancement of growth and productivity of different millets even under abiotic stress conditions.

### *2.8.7 Terminal Drought and Agronomic Manipulation*

In arid and semi-arid conditions, erratic rainfall is a very common during monsson season and rainfed crops may face the consequences of drought. In dryland regions of Africa and Asia, millets are grown mostly as rainfed crop in low fertile soils and occurrence of terminal drought stress results in yield loss. Terminal drought appears in the end season that is in the later part of the reproductive stage. Though millets are drought tolerant and hardy crops, terminal drought creates yield loss drastically in some millet. Finger millet, suffers a lot because of terminal drought and little millet (80.1%), prosomillit (34.6%) and pearl millet (60.1%) also show yield reduction (Bidinger et al., 1987; Goron & Raizada, 2015; Tadele, 2016). However, foxtail millet does not exhibit terminal drought stress. Cultivation of drought tolerant and short duration cultivars is one of the suitable options to overcome such stress (Vadez et al., 2012). Further, taking advantage of pre-rainy season shower millets can be sown early to avoid terminal drought stress.

### 2.8.8 Integrated Weed Management (IWM)

The crop weed competition may cause insufficient share by the crops for resources, namely, soil moisture, light and nutrient which ultimately results in reduction of yield and quality of millets (Mishra et al., 2018). The weed management can be done through integrated manner by using physical, chemical and mechanical methods to manage weed infestation in millets. The millets mainly belong to the grass family, but during the early growth stages weeds can do harm. The growth period from seeding to45 days after sowing is considered as the critical period when crop-weed competition can reduce an average yield between 20 and 60% in different millets. The yield losses due to various weed species in different millets such as sorghum (15–83%), pearl millet (16–94%) and finger millet (55–61%) are more compared to other millets. Striga (*Striga hermonthica*) is a prominent parasitic weed mainly for sorghum and pearl milletthat may cause 50% of yield loss (Oduori, 2007; Wanyera, 2007). Use of pre- and post-emergence herbicides such as oxyfluorfen, atrazine and 2,4-D are effective (Mishra et al., 2018). The different millets affected by various weeds are grass, broad-leaved and sedges. Common weeds of different millets are *Ageratum conyzoides*, *Commelina benghalensis*, *Cynodon dactylon*, *Cyperus rotundus*, *Dactyloctenium aegyptium*, *Echinochloa colona*, *Eleusine indica*, *Euphorbia hirta*, *Solanum nigrum*, *Sorghum halepense*, *Striga litura* and *Trianthema portulacastrum*. In gerenal, cultural management and mechanical practices like off-season tillage, deep summer ploughing and hand weeding are very common among smallholders of drylands. But chemically weeds can be managed by application of herbicides (Table 2.4) (Mishra et al., 2018). However, integrated weed management (IWM) is considered as the best option for weed management as well as sustaining crop productivity.

### 2.8.9 Integrated Pest and Disease Management

Though millets are ecologically hardy crops, pest disease incidence is found in millets also (Table 2.5). Different insects cause damage to millets and loss due to insect pest attack was ranged between 10 and 20% in India and about 50% in Ghana (Bekoye & Dadie, 2015; Gahukar & Jotwani, 1980; Kumar & Channaveerswami, 2015; Tanzubil & Yakubu, 1997). Similarly, under favourable conditions diseases may also cause yield loss.

To protect the crops from pests and diseases integrated pest management (IPM) should be adopted. The choice of pest-disease tolerant cultivars, use of quality and

**Table 2.4** Herbicide recommendation for millets

| Millets | Herbicide | Dose (kg or litre per ha) | Time of application (PE = pre-emergence; PoE = post-emergence | Target weeds | Remarks |
|---|---|---|---|---|---|
| Sorghum | Atrazine | 0.75 | PE and PoE | *Trianthema pottulacastrum* and *Echinochloacolona* | Effective under sole cropping |
| | 2,4-D | 0.50–0.75 | PoE | Broad-leaved weeds | Applied between 4 and 6 weeks after planting |
| | 2,4-D | 1.0 | PoE | Parasitic weeds | Sole cropping |
| | Metolachlor | 1.0–1.5 | PE | Grasses | Suitable for intercropping also |
| | Atrazine + pendimethalin | 0.75 + 0.75 | PE | Broad spectrum weeds | Suitable for intercropping |
| | Atrazine + pendimethalin | 0.75 + 0.50 | PE | Broad spectrum weeds | Suitable for intercropping |
| Pearl millet | Atrazine | 0.50 | PE and PoE | Grassy weeds | Effective under sole cropping |
| Finger millet | Isoproturon | 0.50 | PE | Grassy weeds | Rainfed areas |
| | Oxyflurofen | 0.1 | PoE | Grassy weeds | Irrigated areas |
| | 2, 4-D sodium salt | 0.75 | PoE | Broad leaved weeds | Sprayed after three weeks of sowing |
| Foxtail/ Little/ Proso/ Kodo/ Barnyard millet | Isoproturon | 0.50 | PE | | Rainfed areas |
| | 2, 4-D sodium salt | 0.75 | PoE | Broad leaved weeds | Sprayed after three weeks of sowing |

*Source* Chapke et al. (2018), Mishra et al. (2018)

certified seeds, adoption of summer and deep tillage, soil solarization, management of nutrients and establishment of optimum plant stand are some cultural methods which can be adopted for a healthy crop. Mechanical measures like collection and destruction of pests and disease infected plants, use of different traps and erection of bird perches should be taken into consideration. Use of biopesticidesand organic formulations like *Trichoderma* spp. and *Pseudonomas* sp. for disease management and application of *Bacillus thuringiensis* and neem-based products are beneficial to

**Table 2.5** Common pests and diseases of different millets

| Crop | Insect | Disease |
|---|---|---|
| Sorghum | Shoot fly (*Atherigonasoccata*), stem borer (*Chilopartellus*), aphids (*Melanaphissacchari*) | Grain mould (*Fusariumsemitectum*, *F. moniliforme*, *Curvularialunata*), downy mildew (*Peronosclerosporasorghi*), charcoal rot (*Macrophominaphaseolina*) |
| Pearl millet | White grub (*Holotrichiaconsanguinea*), shoot fly (*Atherigona approximate*, *A. hyalinipennis*), grass hoppers (*Aiolopussavignyi, Aiolopussimulatrix, Oedaleus senegalensis, Kraussariaangulifera*), stem borer (*Acigonaignefusalis*, *Sesamiainferens*) | Downy mildew (*Sclerosporagraminicola*), rust (*Puccinia substriata*), smut (*Pennisetum glaucum*), blast (*Pyricularia grisea*) |
| Finger millet | Cut worm (*Spodoptera exigua*), leaf aphid (*Rhopalosiphummaidis*), stem borer (*Chilozonellus*, *Saluriainficita*), earhead caterpillars (*Cryptoblabesangustipennella*, *C. gnidiella*) | Blast (*Pyricularia grisea*), leaf spot (*Cercosporaeleusine*), brown spot (*Drechsleranodulosum*), Smut (*Melanopsichiumeleusinis*), rust (*Uromyces eragrostidis*) |
| Foxtail millet | Shoot fly (*Atherigonaatripalpis*) | Downy mildew (*Sclerophthoramacrospora*) |
| Little millet | Shoot fly (*Atherigonaatripalpis*), stem borer (*Acigonaignefusalis*), termites (*Microtemes* spp., *Odontotermes* spp.) | Blast (*Pyricularia grisea*) |
| Proso millet | Shoot fly (*Atherigonaatripalpis*) | Smut (*Melanopsichiumeleusinis*) |
| Kodo millet | Shoot fly (*Atherigonaatripalpis*), termites (*Microtemes* spp., *Odontotermes* spp.), stem borer (*Atherigonaatripalpis*) | Head smut (*Ustilagotrichophora*) |
| Brown-top millet | Armyworms (*Syrphisunipuncta*, *Mythimnaunipuncta*), Grasshopper (*Oedaleus senegalensis*, *Aiolopussimulatrix*) | Greengram yellow mosaic virus |
| Barnyard millet | Pink borer (*Sesamiainferens*) | Head smut (*Ustilagotrichophora*) |

*Source* Chapke et al. (2018), El-Shafie (2020), Gahukar and Reddy (2019), ICRISAT (1989), Kaurav et al. (2018), Reddy (1991), Tetreault et al. (2019)

manage pest population. Further, need based chemicals can be applied when the pest-disease population dynamics will exceed the economic threshold level. Ultimately, good crop management (GAP) practices should be adopted for ensuring sustainability in millets cultivation.

### 2.8.10 System of Millet Intensification (SMI)

System of crop intensification (SCI) is a new approach of sustainable intensification (Adhikari et al., 2018). During last two decades, System of Rice Intensification (SRI) was adopted by rice farmers of different countries. The main aspects of SRI are transplanting of early aged seedlings, square planting width wide spacing, incorporation of organic manures and judicious water use. Research evidences and farmers experiences revealed that SRI crop yielded more (Adhikari et al., 2018; Kassam et al., 2009; Pradan/SDTT, 2012; Uphoff, 2017). In the present context of gradual shrinkage of frees water availability, SRI has become more relevant because stagnation of water in rice field as per the conventional system causes low water use efficiency. In arid and semi-arid conditions, adverse impact of climate change is more prominent and sustainable agricultural production is a great challenge. The situation warrants adoption of more innovative and environment-friendly approaches in drylands (Gurjeet et al., 2011). In millets cultivation also SCI technologies adopted and research conducted on system of finger millet intensification (SFMI) showed that finger millet yielded more with transplanting seedlings of less than two weeds and planting with row x hill spacing of 25 cm × 25 cm compared to conventional practices with closer spacing and planting of aged seedlings (Bhatta et al., 2017). There is urgent need of resource conservation with production enhancement and SCI focuses to that direction; thus, system of millets intensification (SMI) may be a boon for drylands, if the technologies for different millets are standardized. However, SCI is typically suitable for transplanted crops and the scope of direct seeded crops has not been demonstrated.

### 2.8.11 Adoption of Smart Technologies in Millet Cultivation in the Future

Under the present scenario of climatic aberrations, agriculture should be smart enough to combat the situation and accordingly climate smart technologies should be adopted. Millets-based intercropping systems can be considered as a climate-smart technology as it can provide a natural insurance against failure of a component crop (Maitra, 2020b; Maitra et al., 2000). There is enough advancement of science and technologies which has been reflected in human civilization. But in agriculture, there is very limited reflectance of latest innovation of science and that too in neglected crops cultivation like millets. Precision agriculture (PA) is a new concept in the developing world where smart technologies are adopted to take appropriate decision and make farming operations easier. The effiecient use of inputs in agriculture can be increased by adoption of PA and thus more agricultural production can be obtained with the precise quantity of inputs. PA is information and technology (IT) based crop production technology which identifies, analyzs and manages the onfarm variability for a target yield and it ensures profit in crop production and efficient management of resources and thus, makes agriculture economically viable and sustainable (Saiz-Rubio & Rovira-Más, 2020). In this regard, remote sensing, different sensors and internet of things (IoT) for irrigation and water management (Maitra & Pine, 2020), artificial intelligence (AI) and machine learning (ML), easily applicable decision support tools like different apps will be in practice in the future. Further, hyperspectral imagery and image processing and use of drones and unmanned air vehicles (UAV) are important tools for decision making and crop health and soil monitoring and crop management. Site specific nutrient management (SSNM) can be an ideal option for nutrient management in millets. Presently, millets are still neglected crops and raising of millets is confined among the smallholders in drylands with less investment in farming. The nutritional importance of millets has been re-evaluated recently which created optimism that such climate resilient crops will be the future foods under the threat of climate change. But the situation warrants research needs for flourish of millets in daily food basket and PA can play a great role in the direction. All the new technologies are future of farming and can make application of valuable inputs more precisely for a target yield. Moreover, with the pace of technological innovation, it may be stated that in the future smart farms will be equipped with sensing technology, applications with IoT-based crop and precision water management, data analytics, technology enabled input delivery as well as smart crop management. In the dawn of technological embellishment, it may be anticipated that the conventional millets cultivation may be switched over into the direction of fast-growing concept of Agriculture 5.0 that infers precise management with automation in which robots, UAVs and application of AI and ML will be more prominent (Saiz-Rubio & Rovira-Más, 2020) for a target productivity on sustainable basis.

## 2.9 Conclusion

Millets fulfill some desired qualities in terms of health and nutrition benefits and ecological soundness which are very much important in present context. These are ancient grains, but remained neglected due to more instutional focus on fine cereals. Recently under climate change scenario, millets regained their old pride and became a suitable option amongst policymakers and health-conscious consumers recognized the nutritional composition. As millets remained neglected for last few decades, sufficient research works have not been conducted. There is enough scope for enhancement of productivity eco-friendly millets by intensifying research on climate-smart technologies as well as good agricultural practices. The focus areas for research are nutrients management options like INM, SSNM and STCR, RCT and organic agriculture as well as CA, other climate-smart agronomic manipulations inclusive of change of sowing time and planting geometry and water management. Further, PA technologies can further refine the hurdles of millets farming and thus can ensure food and nutritional security along with agricultural sustainability in the future.

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