Chapter 16
Climate Adaptive Agricultural Interventions for Food, Nutritional, Health and Livelihood Security

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Abstract Managing agroecosystem via innovative agricultural practices and climate adaptive strategies is indeed a much-needed intervention to maximize the food production for feeding an ever-increasing human population. Also, such practises are essential for overcoming macro/micro nutrients deficiencies, hidden hunger and malnutrition. In this backdrop, the present chapter exemplifies various adaptive agricultural interventions that are vital in changing climatic conditions to maximize the food production for global sustainability. For an instance, adaptive practices to enhance major cereal productivity, improve soil quality, efficient use of water in agriculture, sustainable utilization of land, conserving lesser utilized pseudo cereals, green leaf's, vegetables, fruits and tubers, etc. are specifically conferred in this chapter. These interventions are imperative for agricultural sustainability and also to enhance the income and livelihood of smallest- to medium-scale farmers in many developing nations. Overall, large-scale adoption of listed climate adaptive measures herein, would also significantly contribute in meeting various national and global sustainable development goals and their targets set for year 2030.

16.1 Introduction

Agroecosystem is under constant rising threat principally due to overgrowing human population and changing climatic conditions (IPCC 2014). The progressive pace of human natality speculates world population to rise up to ten billion by the end of this century (IPCC 2014). Decline in per capita availability of agricultural land results into expanded pressure on land resource, land degradation and thereby food shortage in many parts of world (Edrisi et al. 2019). 1.5 billion people (expected to reach 3.9 billion by mid of century) are still living under the grind of food poverty in most

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developing nations of south Asia and sub-Saharan Africa (Wheeler and von Braun 2013). Nutritional insecurity, hidden hunger, malnutrition, obesity, premature death of children's, affected physical health, well-being and livelihoods of millions of resource poor farmers are threats too, that remain aligned with agriculture sector (Arora 2014). These are the holistic panniers for global biodiversity, amidst of which the agrobiodiversity and soil biodiversity largely faces radical penalties (Singh et al. 2019). Satisfying food and nutritional security is mandate for good physical and mental health, well-being, and quality of life (Dubey et al. 2016, 2019a). In this backdrop, managing agroecosystem under changing climate for food, nutritional, health and livelihood security for one and all, is therefore a prime concern of twenty-first century, both for farming and scientific communities as well as for national and global agencies (Dubey and Singh 2017). This chapter therefore exemplifies adaptive agricultural interventions such as climate resilient/smart agricultural practices; key resource (soil and water) conservation in agriculture; and sustainable utilization of neglected and underutilized crop species (NUC/NUS) for maximizing food production, offering nutritional and health benefits and decent livelihood for one and all. Agricultural interventions conferred in this chapter merits for their scoping and upscaling, if substantial number of United Nation Sustainable Development Goals (UN-SDGs) and their targets set for year 2030 and also post-2030 transformational change (craving to be imperative for agricultural sustainability) has to be achieved (Abhilash et al. 2016; Dubey et al. 2019a, b, 2020).

16.2 Sustainability Challenges in Agriculture Under Changing Environment

Explicitly, changing climate negatively impacts the agriculture sector through various biotic and abiotic stresses on daily basis. Major biotic stress affecting crop plants are: emerging newer pests and disease incidences; herbivory; weed infestations, etc. Abiotic stresses are direct climatic influences or erratic weather events affecting larger agricultural landscape viz. drought, heat shock/waves, flood, chilling stress, salinity, UV radiations, ozone pollution, storms, heavy rains, cloud bursts, etc. (Dubey et al. 2019a). In addition, depleted critical natural resources due to anthropogenic influences further bud these biotic and abiotic stresses (Fig. 16.1).

UN backed study reveals that farmers and industrial agriculture altogether have largely been able to increase food production up to threefold in past two decades as also evident for worlds major cereals discussed in ensuing section (https://news.un.org; Fig. 16.2). However, this has been possible at expense of intensive and unsustainable agronomic practices (such as heavy tilling, overuse of agrochemicals, pesticides, fertilizers, water for irrigation, multiple harvests, etc.) which extensively degrades/depletes the environment (farmlands, soil, water, groundwater and air). For one example, intensive agriculture has globally degraded ~33% of land resources

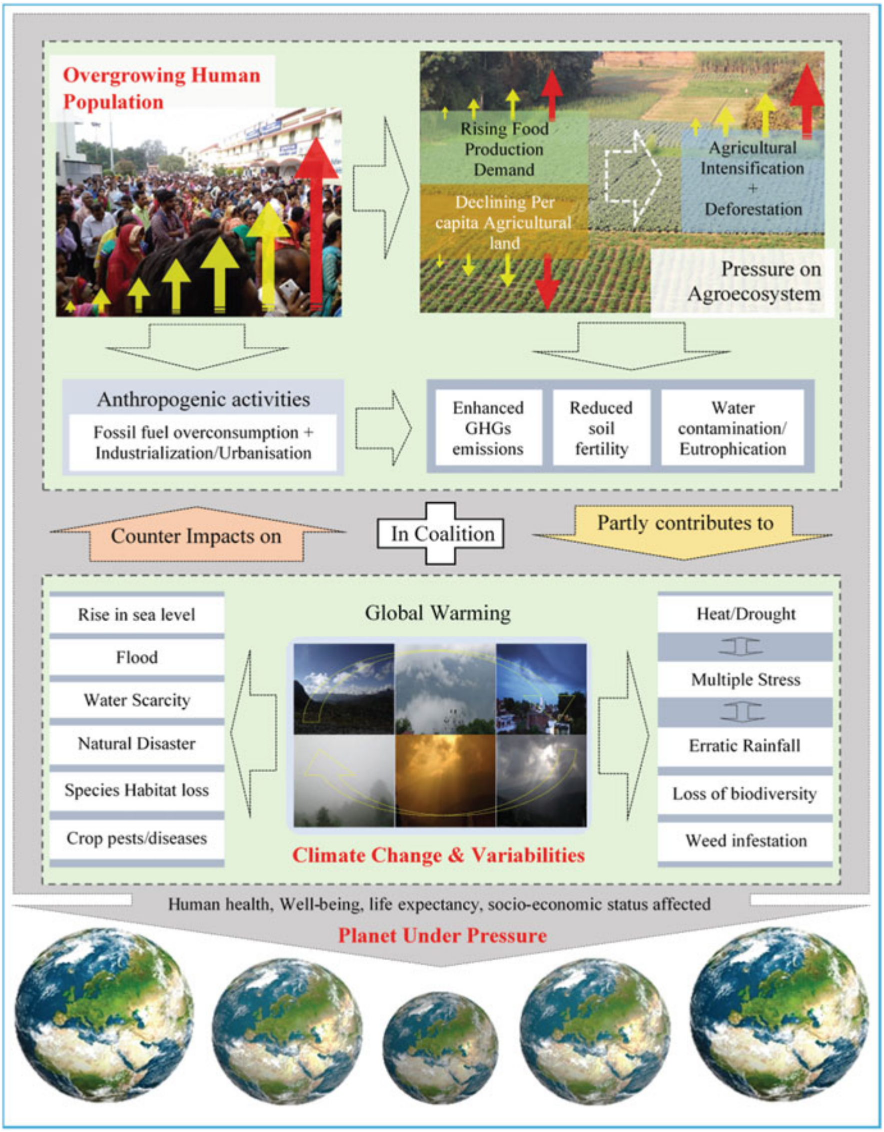

Fig. 16.1 Outline of combined impact of changing climate and overgrowing human population on agricultural system negatively affecting the planet healthy food production (Singh and Abhilash 2018a, b, 2019; Dubey et al. 2020). 'Yellow' and 'red' coloured upright/downward arrows are schematic representation of 'past to present trend' and 'future projections', respectively

and is turning soil infertile at the rate of 2 billion t year^{-1} (Wall and Six 2015). Unsustainable ways of agricultural intensification have already reduced the soil nutrient status (especially organic carbon content) and biodiversity, caused desertification, pollution, etc. Nutritionally deficient soil eventually results in nutrient

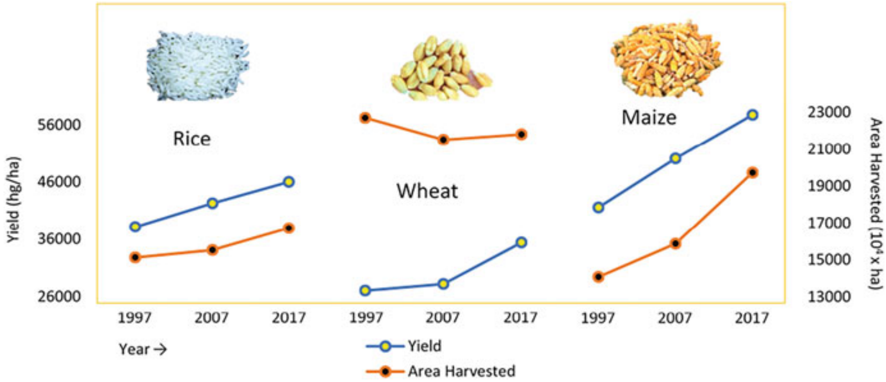

Fig. 16.2 Rise in yield of major cereals (maize, rice and wheat) over past two decades, attained through various adaptive interventions viz. increase/decline in total harvested land area for these crops. This showcase the agricultural adaptability under changing climate, overgrowing human population, land degradation and other factors arising due to climate change. (*Source: FAOSTAT*)

deficiency in humans also (Bhaduri and Purakayastha 2014; Dubey et al. 2019a, b). By middle of the century, ~50% to 70% more production demand of food, fibre, fuel, pharmaceuticals etc. is predicted, which inevitably is forcing for agricultural extensification (requires >60% additional land and ~2.7 to 4.9 M ha year^{-1} arable land by 2050) amid of expanding industrialization and urbanization (Alexandratos and Bruinsma 2012; Abhilash et al. 2016). Agriculture, at such crossroad in second half of the century will face enormous harsh impacts, if no immediate climate adaptive measures are taken in remaining three decades of first half of the century (Challinor et al. 2014).

16.3 Climate Resilient Agronomic Practices for Agricultural Sustainability

Farmers themselves are highly adaptive in nature and keep experimenting new ways at local level to improve their farm productivity (Dubey et al. 2019a; Dhyani and Dhyani 2015). Crop/species/breed/field/farm level emerging agronomic practices are employed by almost all range of farmers (small, medium and large landholding) to bring climate resilience in agriculture either by conserving resources viz. water or building resilience in agricultural soil. However, large-scale utilization of such climate resilient agronomic practice needs industrial and/or government support (Hartoyo et al. 2016). Climate resilient/smart agricultural practices potentially sustain food production in harsh environment thereby ensuring maximum farm generated income, profitability, nutritional and health benefits, reduced GHGs emission and agricultural pollution (Rao et al. 2016).

16.3.1 Climate Resilience Through Water Resource Conservation

Climate resilient agriculture includes shifting the dates of sowing, irrigation, harvesting and also changing planting densities, volume of irrigation water and mode of irrigation viz. drip irrigation or flood irrigation, fertilization rate, and monitoring of straw biomass to be returned into the field etc. (Rao et al. 2016; Dubey et al. 2019a). Water resource conservation is equally crucial for agricultural sustainability and enhanced profitability for all range of farmers. Water harvesting and storage can be done in various ways such as from roads, by small water harvesting pond/fish pond, tube recharge, subsurface dams, sand dams, check dam, valley dam, valley tank, demi-lunes, terraces, grass strips, mulching, agroforestry, etc. (Salman et al. 2016). Countries lying in east (Uganda) and west (Burkina Faso) parts of Africa are employing such methods of surface or ground water storage and soil moisture conservation. These adaptations are beneficial for farmers and local people as it supplements irrigation, and helpful for vegetable production in regions having rainfed agriculture regime. Grass strips on contour lines with gentle slope of 2% having band width of 1 m with grass species such as *Vetiveria nigritana*, *Cymbopogon Schoenateus* and *Andropogon Gayanus* conserve soil moisture significantly. Overall, mode of water conservation and storage could offer scope of irrigation during dry seasons or during dry spells in wet season. Conservation agriculture (CA) has quite substantial scientific evidence to be one of the promising climate adaptive strategy been practiced not just in tropical nations like India and Africa but also in North African (Morocco) and South American (Brazil, Paraguay) countries which are relatively less vulnerable to warming climate (Dubey et al. 2019a). Agronomic practices under CA majorly include crop rotation, crop residue retention, cover crop cultivation, and organic manuring. In Indo-Gangetic Plain region of Asia, CA minimizes nearly one-fourth of production cost, reduces GHG emission to some extent, increases irrigation water productivity by >65%, and reduces canopy temperature by 2.5 °C that allows crop to withstand under warming climate (Sapkota et al. 2015). Example from north African nation (Morocco) could also be cited as 'crop rotation and crop residue retention', increase the crop yield in range of 10–150% over conventional tillage practices (Salman et al. 2016).

16.3.2 Climatic Adaptation by Building Resilience in Soil

Soil resilience in crude sense means soil enriched with organic carbon and microbial diversity. Crop diversification strategies such as intercropping, perenniation, crop rotation, double, mixed and companion cropping are means to increase net system productivity, above and below ground interspecific interactions, soil microbial diversity, and soil health and fertility (Rakshit et al. 2017; Misra et al. 2008a, b, c). Mixed plant canopies offered by crop diversification helps in absorbing more heat and light and tends to increase the uptake of soil macro and micro nutrients by crop plants, thereby enhancing nutritional value in plants edibles parts. Plant growth-promoting microbes/bacteria/rhizobacteria (PGPM/PGPB/PGPR) does multitrophic participation in between plant, soil and microbial communities which offers climate resilience for plant growth and development under stressful environmental conditions (Rana et al. 2012). Alteration in soil microbial community by PGPR agent such as arbuscular mycorrhizal fungi (AMF) has potential to increase soil aggregation and carbon sequestration (Dubey et al. 2017). Beside single inoculation, application in form of consortia may improve both soil C and N storage depending on synthesis of glomalin or glomalin-related proteins (Walley et al. 2014). Under elevated CO_2 condition it has been reported that inoculating *Pseudomonas fluorescens* is able to enhance crop productivity by enhancing C:N ratio in plants (Nie et al. 2015). PGPR also has potential to sequester carbon, reclaim degraded land, promote yield, and improve nutritional make up in plants. For instance, pot study of inoculating consortia (*Pseudomonas aeruginosa* BHUJY16 + *P. putida* BHUJY13 + *P. aeruginosa* BHUJY20 + *P. putida* BHUJY23 + *P. fluorescens* BHUJY29 + *Azospirillum brasilense* + *Azotobacter chroococcum* + 30 kg ha^{-1} P_2O_5) in rice showed significant increase in grain yield by ~9 g pot^{-1} (Yadav et al. 2014). Likewise, in wheat crop inoculation of '*Providencia* sp. PW5 + $N_{60}P_{60}K_{60}$' significantly increases Mn, Cu and Fe content by >36%, 150% and >105%, respectively, while co-inoculation of '*Providencia* sp. PW5 + *Anabaena* sp. + $N_{60}P_{60}K_{60}$' showed rise in yield and grain protein content in range of 11–18% as compared to only $N_{60}P_{60}K_{60}$ application (Rana et al. 2012). Furthermore, enhancement in terms of grain yield, soil quality and economic returns in cereal based cropping is discussed in ensuing section.

16.4 Adaptive Agriculture for World's Three Major Cereals: Maize, Rice and Wheat

Maize, rice and wheat are world's topmost produced cereals with average production of 817, 685, 600 million t during year 2009, 2008 and 2007 respectively (http://www.fao.org/faostat/en/#data). As a result of adoption of climate adaptive strategies and practices by farming communities worldwide, yield of these cereals remained increasing in general and over preceding two decades in particular despite of multiple sustainability challenges in agriculture (Fig. 16.2). Existing scenario urge replication (based on similarity in agroclimatic/agroecological conditions) of resilient agronomic practices at larger agriscape for attaining global food, nutritional, health and livelihood securities (Dubey and Singh 2017). For illustration, some examples of promising practices for cereal cultivation from different regions/nations are discussed herein subsections.

16.4.1 Climate Adaptive Agronomic Practices in Rice-Wheat System

Decision-making for adoption of climate and site-specific agronomic practices are being done through simulation-based studies via climate and crop models (Dubey et al. 2019a). For one example, CERES model for rice and wheat crops and DSSAT cropping models estimated 'alternate wet and dry irrigation practices + dry seeded rice with deep placing of urea in soil + crop residue retention' for drylands of central Asia to be far more beneficial and resource conserving as compared to 'water seeded rice with flood irrigation and no crop residue utilization for soil health recuperations'. Adoption of such climate smart agronomic practices can save ~60% irrigation water and increase crop yield nearly by 0.5 t ha^{-1} (Devkota et al. 2015a). Simulations studies revealed rice yield increases 13 years after adoption of practice, while wheat yield increased since inception of the practice (Devkota et al. 2015a). Likewise, various adaptation in agronomic practices is employed time and again by farmers for more farm-derived benefits such as enhanced yield, resource conservation and improved soil quality etc. For example, 'dry seeded rice + surface seeded wheat + crop residue retention' saves >65% volume of irrigation water in comparison to conventional (dry tillage + flooded irrigation in rice + surface seeded wheat) farming practice as witnessed in North-West Uzbekistan (Devkota et al. 2015b). This practice can overcome excessive salinity loss at deeper soil depth (which otherwise may have long-term disadvantages in cereal cultivation), and when done in established bed field 15% more volume of irrigation water could be saved. Study done in Faisalabad, Pakistan revealed 'zero tillage in wheat + aerobic rice culture' over 'deep tillage + flooded irrigation/alternate wet and dry irrigation' conserve relatively more resources and has higher monetary benefit: cost ratio (Farooq and Nawaz 2014). Although, zero tillage in wheat leads in occurrence of narrow leave weeds such as little seed canary grass but mentioned agronomic practice minimizes the emergence of other major weeds such as toothed dock (Rumex dentatus L.). For Indo-Gangetic plain (IGP) region, in addition to zero tillage practice, timely sowing of wheat after rice harvest offers multitude of advantages. For example, it can conserve water, control weed (Phalaris minor), increase yield (by 5–7%) and save input cost (by and US$ 52 ha^{-1}) (Erenstein and Laxmi 2008). For improving soil health and system productivity using cover crops, wheat crop residue retention in field prior to rice cultivation, direct seeded rice, zero/reduced tillage in wheat and green manure viz. *Sesbania* cultivation during fallow periods are promising practices for tropical climate as in IGP plains (Rao et al. 2016). Bhattacharyya et al. (2015) also investigated in Indian tropics Shift from rice-wheat to rice-wheat-green gram cropping system following dry seeded rice cultivation as well as no tillage (for rice and mung bean) and residue retention (40% of rice residue and entire mung bean residue) increases above ground biomass by 2.9 Mg ha^{-1} year^{-1}, grain yield by 10–15%, soil organic carbon by 150 kg C ha^{-1} year^{-1} in 5–15 cm top soil layer. Labile carbon pool increases by ~25% subsequently projecting 125% increase in soil carbon content in next 3 years. This will reduce soil bulk density, increase surface soil nutrient holding capacity thereby enhancing overall system productivity.

16.4.2 Encouraging Maize Cropping as an Emerging Adaptation

Owing to relatively high system yield and less water intensive, maize cultivation in rotation with rice or wheat crop is gaining more attention and is replacing the existing typical rice-rice or rice-wheat cropping pattern that predominated in many south Asian nations (Gathala et al. 2015; Singh et al. 2016). Farmers adopting maize-based cropping are getting additional income benefits, as maize production provides feedstocks for poultry and fish industries which are expanding their brim owing to overgrowing global food and dietary demands. Therefore, global rise in 'area harvested' and 'yield' of maize is relatively higher than rice and wheat in past two decades as shown in Fig. 16.2. In eastern gangetic plains of Bangladesh and in West Bengal, India where three seasons (boro/rabi; aus/premonsoon kharif; aman/monsoon kharif) of intensively irrigated/rainfed rice cultivation with wet tillage leaving rice stubble of 5–10 cm in the field, was once (decades ago) largely practiced, has now shifted to just two seasons rice cropping (Boro and Aman) due to declining critical natural resources in agriculture. In compensation to system yield losses caused by such transformation and restore/enhance system productivity, Alam et al. (2015) in Bangladesh validated two adaptive strategies. One is integration of maize/mung bean during fallow period (aus season) and second is replacement of Boro rice cultivation by potato-relay maize-mung bean cultivation. Both practices showed significant rise in yield, water and energy use efficiency and net economic benefit in range of two- to threefold. In addition to this, intervention of resilient agronomic practices specifically for maize cropping is need of an hour for better water resource conservation and many associated farm benefits. For an instance, rice-maize cultivation with conventional tillage and puddled rice transplantation degrades the soil structure, hamper yield potential due to delay in maize plantation, require intense cost, energy and labour inputs (Gathala et al. 2015; Singh et al. 2016). However, interestingly practices such as zero/strip/reduce tillage on established raised bed, dry seeded rice cultivation and crop residue retention can potentially increase grain and system yield and be a cost-effective strategy for resource poor farmers (Bhattacharyya et al. 2015). 'Flat-bed crop establishment mode replaced with raised bed + zero tillage' practices in maize-wheat-green gram cropping system along with residue retention of wheat and maize crops in the field can increase system energy use efficiency by 9% over conventional farming practices as observed in North-West IGP in India. Despite relatively more energy is invested in mentioned adaptive practice during the process of land preparation, seed sowing and irrigation, but residue retention on other hand significantly increases the energy output by 17% (Saad et al. 2016). Intensively irrigated maize systems in North India majorly includes maize–wheat–mung bean, maize–mustard–mung bean, maize–maize–Sesbania and maize chickpea–Sesbania (green manure) etc. Parihar et al. (2016) enumerated how 'permanent bed preparation + zero-tillage' agronomic practices can be beneficial over 'conventional tillage' practices in these maize based cropping systems in terms of maize and glucose equivalent yield, water use efficiency and net economic gain over period of 6 years. Rise in maize and glucose equivalent yield ranges between 1.3 and 1.9 Mg ha^{-1} and 0.5–1.0 Mg ha^{-1} respectively, while irrigation water volume required decreased by 50–81 ha mm. System water productivity and net profit raised by 20% as the cost input for zero tillage minimizes at rate greater than 70$ ha^{-1} (Parihar et al. 2016).

16.4.3 Balanced Fertilizer Application for Reduced Environmental Externalities

Optimum fertilizer dosage and limiting the leaching of soil nutrients in cereal based cropping, is mandate to limit agriculture based GHGs emissions and thereby global warming. For example, shallow flooding with suitable nitrogen management in rice can reduce N loss in soil by 2.8%, limit GHG emissions by $>34\%$ and increase rice yield by 1.7% (Chen et al. 2016). In summer maize cropping, optimum dosage of N fertilizer could reduce N losses by 44–65 kg N ha^{-1} and increases N efficiency and partial factor productivity by 16% and 36 kg kg^{-1} respectively (Cui et al. 2008). Guo et al. (2015) in parts of China where average rice grain yield is 7.67-t ha^{-1}, advised 200–250 kg N ha^{-1} to be optimum field nitrogen fertilizer dosage for appropriate plant nutrient uptake, nitrogen use efficiency and grain yield. Cao et al. (2014) proposed increment in fertilization frequency and decrement in rate of N fertilizer field input with dense planting of seedlings in rice-wheat cropping system. This practice enhances rice grain yield by ~7%, reduces nitrogen leaching by 21% (in particular reduction in nitrate leaching by 14%). Study done in Haryana, India for rice-wheat cropping system convince 'no tillage + split nitrogen fertilizer application with site specificity (amount and time of fertilizer broadcasted is based on nutrient expert, Green Seeker TM)' to be much more climate adaptive and resilient over 'conventional tillage + fertilizer inputs as per state recommendation'. Significant decline in global warming potential of wheat production was noticed with 3% and 5% rise in plant biomass and yield (Sapkota et al. 2014). Specifically, basal N fertilization as per nutrient expert optical sensor for wheat cultivation can limit N_2O emission to a large extent. Moreover, suitable NPK nutrient management strategy (depending on yield targets, crop nutrient demand and field nutrient application) for wheat cultivation at landscape level in IGP region of India have showed rise in grain yield by 1.55-t ha^{-1} and provides remarkable net economic return of US$ 585 ha^{-1} (Singh et al. 2014).

16.5 Neglected and Underutilized Crops (NUC) for Nutritional and Health Security

Food and agriculture organization of united nations (UN-FAO) have recently projected Neglected and underutilized crops/species (NUC/NUS) and its wild varieties to be future climate smart crops (www.unfao.org). Such wild crops are genetic resource and a treasure trove of special climate resilient traits for breeding and future crop improvement program (Dubey et al. 2016; Nair 2019). These crops can be grown anywhere (marginal/degraded land, rail/road ways), demands minimal agronomic care, are stress (drought, heat shocks, salinity etc.) tolerant, less resource intensive, and are nutritionally and medicinally enriched (Nair 2019; Singh et al. 2018a, b, 2019; Fig. 16.3). NUC have tendency to eradicate poverty, hunger, hidden hunger by generating local markets of locally grown wild edibles and providing balanced diet through dietary diversification. It can profoundly help in meeting various UN-SDGs (No poverty, zero hunger, good health and wellbeing) by providing healthy and nutritive food to one and all (Singh et al. 2018a,b; Singh and Abhilash 2019; Dubey et al. 2019a).

Wild crops such as Indian spinach, wild amaranth, pseudo cereal, pearl millet, winged bean, word bean, ground cherry, etc. are rich in Vitamins, Calcium, Iron,

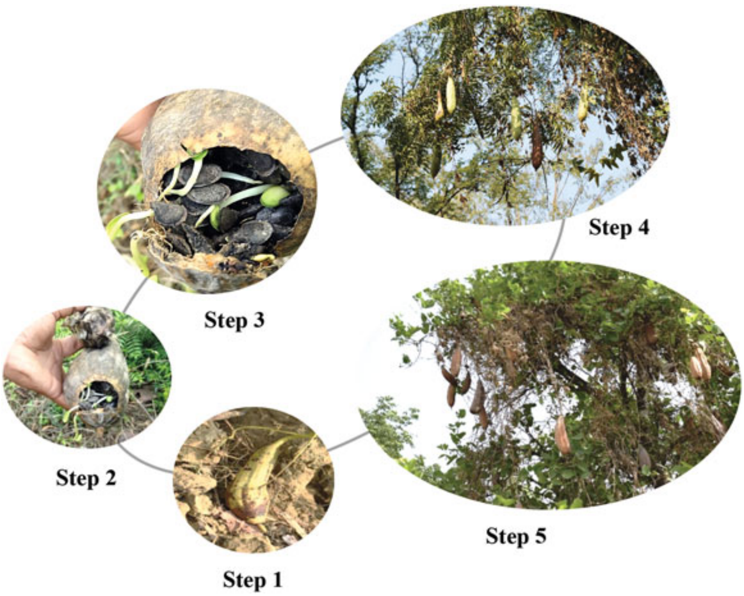

Fig. 16.3 The cycle (steps 1–5) shows minimal/no care required for NUS and wild crops, as they are highly drought, salinity, temperature and pest tolerant. Step 1: Ripened fruit fall on its own on ground at maturity; Step 2: In rainy season seed germination starts by available soil moisture; Step 3: Germinated seed emerge out; Step 4: Plant connected to surrounding shrubs or tree start luxurious growth; Step 5: Ripened fruit again falls on ground and cycle continues likewise

Magnesium, Phosphorus, Potassium, Zinc, and other essential amino acids (Singh et al. 2018a). Many NUC crops in general have vitamins and other nutrients in relatively much higher proportion in comparison with many modern crops (Dhyani et al. 2010; Misra et al. 2008a, b, c). For one example, the protein content in winged bean is 5 and 10 times more than in yam/taro and cassava/sweet potato respectively (Karikari 1978). Similarly, Vitamin A, Vitamin C, Ca, K, Fe and protein content in Moringa is 10, 7, 17, 15, 25 and 9 times more as compared to carrot, orange, milk, banana, spinach, yoghurt, respectively (Rockwood et al. 2013). Reports states Amaranthus contains Vitamin C, Ca, Niacin 3 times more than spinach; and Vitamin A, Vitamin C, Ca, Fe more than 18, 13, 20, 7 times as compared to Lettuce (Guillet 2004). Interestingly, the habit and habitat of Amaranthus or Indian Spinach (Basella Sp.) lies at areas where human influences are extremely common (Fig. 16.4).

Arora (2014) reported total 992 NUC species of world, region wise distribution of which across globe is shown in Fig. 16.5. Few examples of highly nutritive, neglected and underutilized millets species suitable for Indian climatic conditions are listed and displayed in Table 16.1 and Fig. 16.6. Moreover, validation of suitable agronomic practices for growing different NUC crop species in any agroclimatic conditions is also highly imperative. In addition, recently four steps have been proposed for sustainable utilization of such wild, neglected and underutilized crops as: (1) exploring the unexplored; (2) refining the unrefined traits; (3) cultivating the uncultivated; (4) popularizing the unpopular (Singh et al. 2019). For attaining food and nutritional security in different geographies of the world different set of agronomic practices those are validated for different NUC species are listed in Table 16.2 for illustration.

16.6 Integrated Farming Practices for Enhancing Farmers Livelihoods

16.6.1 Organic Farming Practices

Integration of animals viz. cow, buffalo, sheep, goat, poultry, fish, etc. in farmlands, use of green manure, biofertilizers, bioinoculants, replacement of chemical fertilizers and pesticides with organic agroinputs, etc. are all one or other form of organic farming been practiced by farmers (Misra et al. 2008a, b, c; Rao et al. 2016; Dubey et al. 2019a). Organic farming can be best coupled with mixed crop-livestock farming practices as crop residues (straw) generated can be used for feeding domestic animals, while animal waste/cattle dung generated is used as source of organic agroinputs for optimum soil and crop nutrient management (Abhilash et al. 2016; Rakshit et al. 2017). Small to large farmlands in African region viz. Murehwa, Ruaca, and Gorongosa generates 0.2–2.2 t ha^{-1} of crop residue which is less in quantity ($<30\%$) for utilizing it as cover crop, however since it serves as straw for

Fig. 16.4 Two NUS i.e. *Amaranthus viridis* (A–F) and *Basella alba* (1–6) shows ubiquitous distribution: backyard garden (A, 4); kitchen garden (2); agricultural field/boundaries (3, 5); on boundary walls (B, C); vegetables field (D); road side (E, 1); railway track (F); Boundary walls (6)

cattle feeding therefore it can sustain livestock population as well as soil fertility by addition of dung and urine excreted by livestock (Rusinamhodzi et al. 2016). In rice-wheat cropping system addition of farm yard manure + domestic sewage sludge can compensate 25% requirement of N fertilizers, impart soil fertility, and results in less water intensive rice cultivation (Bhaduri and Purakayastha 2014). Green manure is more beneficial than cattle manure in terms of reducing risk of nitrogen loss (as nitrate in soil and as NH_3, N_2O, N_2 in atmosphere), replacing amount of chemical fertilizer and high crop yield (Ti et al. 2012). For instance, green manure input in maize field reduces requirement for chemical fertilizer input by 30% (Shun et al. 2015). Use of biofertilizers is also a unique alternative as an organic agroinputs as it

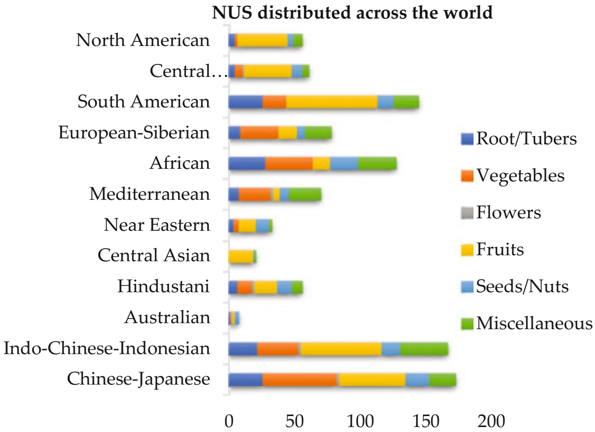

Fig. 16.5 Worldwide distribution of Neglected and Underutilized Species (NUS) Arora (2014)

Table 16.1 Neglected and underutilized millets of India with per 100 g nutritional content (Gopalan et al. 1989)

Nutrients	Pearl millet	Sorghum	Finger millet	Foxtail millet	Proso millet	Barnyard millet	Kodo millet
Energy (kcal)	361	349	328	331	341	397	309
Protein (g)	11.6	10.4	7.3	12.3	7.7	6.2	8.3
Fat (g)	5.0	1.9	1.3	4.3	4.7	2.2	1.4
Calcium (mg)	42.0	25.0	344	31.0	17.0	20.0	27.0
Iron (mg)	8.0	4.1	3.9	2.8	9.3	5.0	0.5
Zink (mg)	3.1	1.6	2.3	2.4	3.7	3.0	0.7
Thiamine (mg)	0.33	0.37	0.42	0.59	0.21	0.33	0.33
Riboflavin (mg)	0.25	0.13	0.19	0.11	0.01	0.10	0.09
Folic acid (mg)	45.5	20	18.3	15.0	9.0	–	23.1
Fibre (g)	1.2	1.6	3.6	8.0	7.6	9.8	9.0

can significantly raise the phosphorous use efficiency and reduce the requisite for phosphatic fertilizer (costliest for small farmers) to large extent phosphate solubilizing micro-organisms (PSM) and vesicular arbuscular mycorrhizal (VAM) are commonly used biofertilizers. For soybean-wheat cropping system in inceptisol soil of Indo Gangetic Plains, use of these two biofertilizers can minimize P fertilizer application by half the amount as used in normal practice while increasing yield of both crops nearly by 4–5% (Mahanta et al. 2014). Biofertilizers specifically alters the root morphology and phosphorous inflow rate and enhance crop yield. Sustainable utilization of cattle integrated farming, green manure, biofertilizers at larger

Fig. 16.6 Neglected and underutilized millets of India (for popularizing the unpopular crops) having more Vitamin and mineral as compared to most of modern grains viz. rice, wheat, etc.

landscape can be significant, cost effective and upgrade the livelihood of millions of farmers.

16.6.2 Agroforestry

Tree-based farming is largely practiced by aware farmers today as it is high income giving, increases farm productivity and profitability and has many ecosystem benefits (Mbow et al. 2014). Integration of horticultural trees, crops, livestock, woody plants, bamboo, shrubs, etc. were cultural practices in many parts of world such as in East Kalimantan, Indonesia and its small cultivation areas like Simpung munaan, Lembo, Kampung merabu and kampung birang since long time back (Hartoyo et al. 2016). Similarly, bamboo-based agroforestry was traditionally practiced by local and indigenous people in Barak valley of North East India (Nath et al. 2015). These agroforestry practices were source of soil carbon sequestration and have been reported to sequester carbon at rate of 0.44 Mg C ha^{-1} year^{-1} thereby gathering 30.5 Mg C ha^{-1}. Modern agroforestry practices are extension to such traditional practices in which new crop and tree species (rubber/cocoa etc.) are grown in same land and serves commercial purpose. Agroforestry practices done over from past 15 years have been seen to increase overall biomass and soil carbon sequestration by 70% and 30% respectively (Kim et al. 2016). Since it sequesters carbon at appreciating rate i.e. upto 10-t C ha^{-1} year^{-1} therefore can potentially mitigate GHG (methane and N_2O) emission with rate of 13–41 t CO_2-eq ha^{-1} year^{-1}. Not just this promoting agroforestry practices in pasture land or land where monoculture cropping predominated could increase biodiversity and livelihood of local and indigenous people. For one example, by introducing coffee-based agroforestry in

Table 16.2 List of reported agronomic practices with neglected and underutilized crops and their output for enhancing food and nutrient security

Neglected and Underutilized crop species (NUC/NUS)	Nutritional and health benefits/source of income	Climate adaptability and agronomic remarks	Country (References)
Talinum fruticosum (L.) Juss	Young foliage leaves are the source of income for rural people	Planting with 3 × 5 cm with 10 t ha^{-1} poultry manure provide highest fresh and dry matter yields	Nigeria (Uko et al. 2013)
Basella alba L.	Leaves are rich in Vit A, B, C and minerals such as Fe and Ca	Combined application of poultry manure at 3 t ha^{-1} and weekly harvesting can positively increase the crop growth, yield and fresh foliage (177.40 g $plant^{-1}$)	Nigeria (Salami and babajide 2017)
Cleome gynandra L.	Rich source of protein, Vit A and C, minerals viz. Ca and Fe	Application of farm yard manure at 11.5 t ha^{-1} gives highest fresh yield up to 12.3 t ha^{-1}	Kenya (Ng'etich et al. 2012)
Amorphophallus paeoniifolius	Used for making culinary dishes, pickles and used in remedy for patients suffering from dysentery, piles, asthma and abdominal pain	Integrated application of N-P_2O_5-K_2O (100-60-100 kg ha^{-1}) + FYM at 10 t ha^{-1} under irrigated condition is recommended for increasing corn productivity	India (Sahoo et al. 2015)
Corchorus olitorius L.	Rich in Fe and folate	Chicken manure input at 20 t ha^{-1} substantially increases the growth under semi-arid environment.	Sudan (Naim et al. 2015)
Trigonella foenum-graecum L.	Rich in Fe, Ca, vitamins and essential amino acids (e.g. lysine, leucine and phenylanaline)	Application of vermicompost at 4 t ha^{-1} and Sulphur at 40 kg ha^{-1} is recommended for higher growth attributes, root nodules, leghaemoglobin content, seeds and straw yields	India (Verma et al. 2014)
Crotalaria juncea L.	Important source of natural fibre and highly useful green manure that can grow robustly in entire India	Showing sunnhemp at spacing 30 × 10 cm coupled with topping at 30 days after sowing is effective in increasing the seed yield of sunnhemp.	India (Tripathi et al. 2013)
Colocosia esculentus L.	High energy food enriched with protein, vitamins and minerals. Small farmer cultivates as cash crop	Poultry manure at 10 t ha^{-1} and NPK at 150 kg ha^{-1} increases cocoyam plant height, number of leaves per plant and yield.	Nigeria (Hamma et al. 2014)

(continued)

Table 16.2 (continued)

Neglected and Underutilized crop species (NUC/NUS)	Nutritional and health benefits/source of income	Climate adaptability and agronomic remarks	Country (References)
Physalis peruviana L.	High income giving crop with significant medicinal applications	Application of vermicompost at 5 t ha^{-1}, Azotobacter at 10 kg ha^{-1}, and PSB at 10 kg ha^{-1} produces maximum number of fruits per plant, fruit weight, fruit volume, fruit yield per plant.	India (Nagar 2018)
Ipomoea batatas (L.) Lam. (Sweet potato)	Cash crop with high tolerance for abiotic stress. Rich in protein, carbohydrate, Fe, vitamins A, C and fibre.	Planting on ridges and harvesting vines after 65% growth completed (105 days after planting) produces herbage for fodder in sufficient amount without compensating yield (in form of tuberous roots)	Ethiopia (Ahmed et al. 2012)

Chiapas, Mexico the Inga tree species diversity which was 34% of all tree species raised to 45% (Valencia et al. 2014). Rubber-based agroforestry was also seen to reduce soil erosion by 50–70% in comparison to when no rubber plantation or rubber monoculture was established (Liu et al. 2016). Cocoa–coconut-based agroforestry in Indonesia was found to increase microbial (Pseudomonas and Trichoderma) population in soil, soil organic carbon and yield of both plants (Utomo et al. 2016). This agroforestry practices are good for environmental sustainability also as producing 1 t of cocoa pod requires only 2.25 E−05 kg PO_4-eq, 3.67 E+01 kg CO_2-eq and 4.31 E−02 kg SO_2-eq which are known causes for eutrophication, global warming and acidification, respectively. Besides this, agroforestry practices with integration of livestock can be even more income giving and sustainable practice. For an instance, poultry + olive orchard system can enhance fertilization in olive orchards, reduce weed infestation, and reduce harmful land use impact by 18% and 12% that was caused due to chickens and olive production respectively (Paolotti et al. 2016). Overall, agroforestry practices are promising source for enhancing livelihoods of millions of poor peoples by alleviating poverty (Mbow et al. 2014).

16.7 Concluding Remarks and Way Forward

Small- to medium-scale farmers (owing less than a hectare of agricultural land) in particular of tropical nations such as Africa and India are sturdily predicted to be hit hardest by the climate change and its harsh impacts (Abhilash et al. 2016; Dubey et al. 2019a). Hundreds of millions of such farmers are responsibly feeding and nourishing the world by the quantitative and qualitative food they produce (Arora

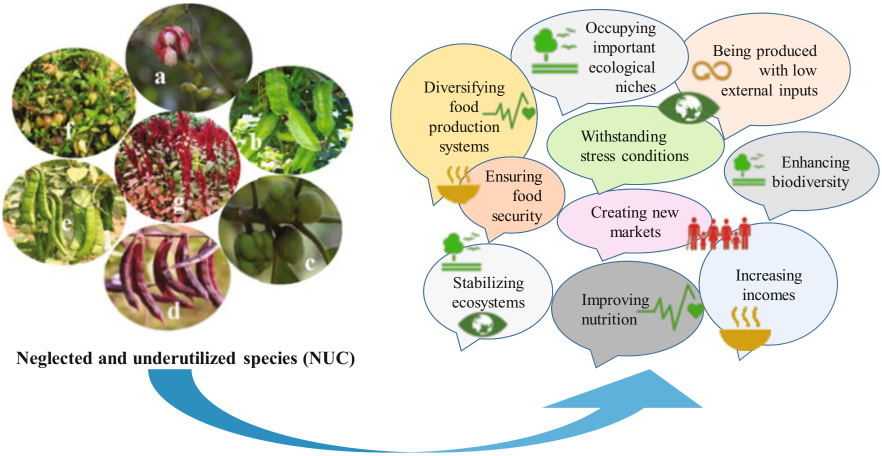

Fig. 16.7 Interrelation between NUS and some of UN-SDGs (represented with symbols) such as goal 1 (No Poverty), goal 2 (zero hunger), goal 3 (good health and well-being), goal 12 (responsible consumption and production), goal 13 (climate action), goal 15 (life on land). NUS shown here are: (**a**) Madras Thorn (*Pithecellobium dulce* (Roxb.) Benth.), (**b**) Winged bean (*Psophocarpus tetragonolobus* (L.) DC.) (**c**) Cluster fig (*Ficus racemosa* L.) (**d**) Lablab (*Lablab purpureus* (L.) Sweet) (**e**) Sword Bean (*Canavalia gladiata* (Jacq.) DC.) (**f**) gooseberry (*Physalis angulata* L.) (**g**) red amaranth (*Amaranthus cruentus* L.)

2014; Singh et al. 2019). However, unfortunately possibly tens of millions among these farmers themselves are barely nourished and are unable to afford three meals a day for their families and themselves. Many such small-scale farmers are devoid of direct access to extension services provided by government due to unawareness and also lack of access to markets as well as affordability in purchasing expensive external agroinputs from the markets (Challinor et al. 2014). This conclusively push farmers to either lease out their agricultural land for industrial/urbanization interests or make them shift from their traditional trade of farming to searching job opportunities and employment in urban sector (Dubey et al. 2019a). This will essentially end up in largely creating climate refugees and thereby economic disturbances in future. To avoid inevitable cusp that may arise on planet due to climate refugees and economic slowdown, the agriculture sector therefore needs urgent climate actions in form of large-scale adoption of sustainable, climate adaptive, resilient, resource conserving, innovative and profitable agronomic practices.

In conclusion, this chapter eloquently highlights certain promising farming practices (such as crop diversification, residue retention, agroforestry, balanced use of chemical fertilizers, organic farming, livestock mixed farming) along with suitable intervention of science (climate and crop models for climate smart agriculture, use of biofertilizers/bioinoculants, breeding technologies, precision agriculture) and innovations (integrated farming, conserving agrobiodiversity, utilizing neglected and underutilized crops). Overall, adoption of these climate adaptive measures in large agriscape, would significantly contribute in meeting various global and national SDGs and their targets set for year 2030 (Fig. 16.7). Explicitly UN-SDGs goal

1 (No poverty), goal 2 (Zero Hunger), goal 3 (Good health and well-being), goal 12 (responsible consumption and production), goal 13 (climate action), and goal 15 (life on land) are directly linked to enhanced farm productivity and agricultural sustainability.

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