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Innovative Approaches for Sustainable Development

Theories and Practices in Agriculture

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Chapter 1
The Economics of Climate Change in Agriculture

Philip Kuriachen, Aditya Korekallu Srinivasa, Anu Susan Sam, and Subash Surendran Padmaja

Abstract Climate is changing, and further changes are inevitable. It has been noted by IPCC that the globally averaged combined land and ocean surface temperature, as calculated by a linear trend show a warming of 0.85 [0.65–1.06] °C over the period 1880–2012. The mean temperature in India is projected to increase up to 1.7 °C in kharif (July–October) and up to 3.2 °C during rabi (November–March) season, while the mean rainfall is expected to increase by 10% by 2070, leading to frequent weather extremities. There is a growing evidence that climate change would impact agriculture and food security. The extreme weather events such as drought, floods as a result of climate change impact agricultural production and threatens food and livelihood security. However, systematic and comprehensive studies on assessing impact as well as potential impacts of adaptation and mitigation strategies in minimizing effect of climate change are scarce. Coupled with it, the comprehensive literature introducing different existing methodologies are also difficult to find. The chapter draws from the existing empirical literature to summarize different methodologies used to estimate the impact of climate change. The chapter also discusses the agricultural policies on adaption and mitigation strategies to minimize the adverse impacts of climate change on livelihood and food security.

Keywords Agriculture adaptation · Climate change · Economics · Impact · Policies

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1.1 Introduction

The climate of the earth is changing and the changes are projected to continue over the years to come. It has been noted by IPCC that the globally averaged combined land and ocean surface temperature, as calculated by a linear trend, shows a warming of 0.85 [0.65–1.06] °C over the period 1880–2012 (Pachauri et al., 2014). The predicted future trends indicate higher mean temperatures, hot extremes, droughts and heavy precipitation. The changes are expected to affect day and night temperatures differently; extreme hot days in mid latitudes would be warmer by 3 °C on an average (at global warming of 1.5 °C scenario) and in high latitudes, cold nights will be warmer by 4.5 °C. Correspondingly, the sea levels are expected to rise between 0.26 and 0.77 m by 2100 (IPCC, 2018). The hydrological cycle is also expected to change due to increase in temperature, and the weather extremes will become more frequent, all of which has repercussions on people's lives (Childers, 2015; Smit & Mark, 2002). Most of the observed climate change has roots in anthropogenic causes like emission of green house gasses, intensive agriculture and unsustainable use of natural resources. Understanding the gravity of the problem, United Nations in Goal 13 of Sustainable Development Goals (SDG) calls for countries to take urgent action to combat climate change (United Nations Enviromnment Programme, 2018).

With world population set to grow further in years to come, any adverse effect of climate change on agriculture might threaten food security of millions of people (Mark et al., 2013). Agriculture and poverty linkages also makes it even more important to take steps in minimizing the effect of climate change (Pradeep & Rosenthal, 2014). The actions to combat the effect of climate change on agriculture can be broadly classified into two categories; adaptations to climate change and mitigating the climate change. Adaptive strategies aim at making the system resilient in coping with the effects of climate change while the mitigation measures are aimed to minimize the further anthropogenic led changes in the climate. Formulating policies to minimize the effect of climate change on agriculture needs reliable estimates of possible impact of climate change and the impact pathways.

Agriculture, due to its dependence on nature, is both sensitive and vulnerable to climate change (Smit & Mark, 2002; Pradeep & Rosenthal, 2014). Also, it is unique that agriculture is a cause of climate change and at the same time affected by it. Direct effect of climate change is due to increase in temperature and its impact on the length of growing season. In lower latitudes (tropical countries), where the current temperatures are already near optimum, any increase in temperature will reduce the length of growing season and consequential reduction in the yield of most of the crops (Pradeep & Rosenthal, 2014). In contrary, in higher latitudes, regions like southern Europe, parts of Russia, parts of America and North China, (where the temperatures are below optimum for crops), would benefit from global warming (Gornall et al., 2010; Nelson et al., 2009). Increase in temperature will increase the length of growing period and in addition, a greater number of crops become suitable to the region, or the region may become suitable for growing a particular crop, which in turn is expected to increase the production of agricultural commodities from the region. The impacts are also varied after accounting for CO_2 fertilization for few crops (Nelson et al., 2009).

Climate change is expected to impact the water availability for agriculture in two pathways. First, the precipitation, both in terms of magnitude and frequency will change due to increase in temperature and corresponding increase in evaporation both from land and ocean surface (IPCC, 2018; Pradeep & Rosenthal, 2014). Generally, it is predicted that the mean precipitation over land is going to increase. Frequency of rainfall and seasonality will also undergo changes, which coupled with increase mean annual rainfall could impact 'Internal Renewable Water" available from precipitation. Second, the increased temperature results in higher water requirement of crops (Nelson et al., 2009). The expected impact of these hydrological changes are heterogenous across crops and regions. In addition to the effect of increased temperature and reduced water availability for farming, the climate change might also favor newer insects and pathogens, which can cause damage to crop yields (Smit & Mark, 2002).

However, making predictions about aggregate impact of climate change on agriculture is challenging. The climate change will manifest itself differently across different geographies. Temperature and precipitation changes will vary across locations. Further, the extreme weather events are hard to predict and estimating impact is even harder due to intricate relationship with other crop growth parameters. Even if the changes in climate is accurately predicted, the impact on agriculture sector depends on the resource base of farmers and level of adoption of technologies (Pradeep & Rosenthal, 2014). Similar climatic variability can have more devastating impact on agriculture in a poor and resource constrained agricultural system in a developing country, compared to agriculture in developed countries. Developing a prediction model which can accommodate these heterogeneities is challenging.

Impact of climate change are mostly discussed with respect to current averages in growing season conditions, and possible future normals (Arrived through various predictive models) (Centeno et al., 2004). Conventionally these models focus on change in mean temperature, moisture, effect on hydrological cycle, CO_2 fertilization, length of growing season and pest and diseases (Rosenzweig et al., 2014). Initially assessing the impact of climate change on agriculture relied heavily on agronomic models, laboratory experiments and simulations models. However, these experiments although purged of confounding factors were unrealistic in their assumptions and failed to reflect field level scenarios particularly in developing and under-developed countries. They also failed to account for farm level adaptations to change in climate variables resulting in pessimistic expectations on farm revenues. Although some studies tried to incorporate farmers adaptations, they were either partial in nature (changes in fertilizer dosage or irrigation requirements) or reliant on unrealistic assumptions.

In this chapter, we start with methodological approaches used by economists to measure the impact of climate change. Each of the methodology is discussed with respect to the assumptions, rationale, applicability and limitation. Then we will briefly discuss about the adaptations and mitigation strategies pertaining to climate change.

1.2 Methods for Assessing Impact of Climate Change in Agriculture

Methods used to assess the impact of climate change on agriculture may be broadly classified into general equilibrium approaches and partial equilibrium approaches. Partial equilibrium approaches consider agriculture sector in isolation, ignoring the inter-linkages between agriculture and other sectors of the economy. The commonly employed techniques in partial equilibrium analysis comprises of crop simulation models, agro-ecological zone models, production function estimation and Ricardian Analysis. General equilibrium models on the other hand, look at the economy as a complete interdependent system and thereby encapsulate the links between agriculture and non-agriculture sectors and provide an economy wide prospective analysis. Computable General Equilibrium (CGE) models for climate change are an example for this. In the section to follow, we discuss the conceptual framework, advantages and limitations of the various techniques used to estimate the potential impact of climate change on agriculture.

1.2.1 Partial Equilibrium Models

1.2.1.1 Crop Simulation models

Crop simulation models draw on controlled experiments where in, the crops are raised in controlled field or laboratory settings and exposed to varying temperature and CO_2 levels and the yield responses are estimated (Rozensweig & Iglesias, 1998; de Salvo et al., 2013). These yield responses are specific to varieties and a set of input management strategies. Crop simulation models restrict their analysis to crop physiology and tend to focus on biological and ecological impact of change in climatic variables. One of the major advantages of crop simulation models is that they integrate the potential benefits of carbon dioxide fertilization. They are rooted in a comprehensive understanding of agronomic science, thereby providing a reliable depiction of potential impact at various stages of crop growth and provide insights into micro-management strategies (Kumar, 2016). Crop simulation models have extensively focused on the potential impact of rising temperatures and elevated CO_2 levels on crop yields and a review of major findings from literature are tabulated here (Table 1.1). Most of these studies focused on important staple crops of the world, viz., Rice and Wheat. The expected size of impact in terms of yield reduction ranges from 1% to 50% depending on the locale of the study and climatic variable under consideration and its range.

One major limitation of simulation models is its failure to account for farmers' adaptation strategies. As climate changes, so does the agronomic practices followed by farmers in the form of adaptive response to the climate change, and the estimated

Table 1.1 Impact studies using crop simulation models

Study	Region	Crops	Impact
Smith et al. (1996)	*Africa*	*Maize*	*−14% to − 12%*
Yates and Stepzerek (1998)	Egypt	Rice and Wheat	−51% to −5% −25% to −3%
Anwar et al. (2007)	Australia	Wheat	−29%
Rosenzweig and Iglesias (1994)	U.S.A	*Wheat* *Maize* *Soyabean*	−20% to −2% −30 to −15% +40% to 15%
de Siqueira et al. (1994)	Brazil	*Wheat* *Maize* *Soyabean*	−50 to −15% −25 to −2% −61 to −6%
Brklacich et al. (1994)	Canada	*Wheat*	−40 to +234%
Liverman and O'Brien (1991)	Mexico	*Maize*	−61% to −6%
Aggarwal and Kalra (1994)	India	*Wheat*	−18.3% to −3.9%
	India	*Rice*	16.8–1%

impact tends to be an overestimation of actual impact if the researcher doesn't account for adaptation. Although recent studies (Kassie et al., 2015; Krishnan et al., 2007; Challinor & Wheeler, 2008) have tried to account for farm level adaptations exogenously they tend to be limited in scope. Crop modelling studies assessing potential adaptation benefits have focused only a handful of adaptation measures namely irrigation, fertilizer application, changing crop cultivars and sowing dates. Hence these studies fail to assimilate the wide range of adaptation strategies in real world (Challinor et al., 2018). For instance, simulation models fail to integrate crop switching behavior, a prominent adaptation strategy (Kurukulasuriya and Mendelsohn, 2008a, b; Mendelsohn et al., 1994). Moreover, the site specific and crop specific nature, and the estimation of potential impacts for a few major grain crops (Mendelhsohn & Dinar, 2009) limit their scope in quantifying impact on agriculture systems as a whole. Further, simulation models fail to account for the economic dimensions of the impact of climate change.

1.2.1.2 Agro-Ecological Zone Models

Agro-ecological zone models combine crop simulation models with land management decision analysis to delineate the potential changes in agro-climatic resources and its impact (Darwin et al., 1995; Fischer et al., 2005). Land is classified into different categories based on agro-ecological characteristics primarily climate and length of growing season. In addition to soil characteristics and topography, climate variables like temperature and rainfall are key determinants of length of growing season. The potential impact of climate change is identified by tracking changes in climate and distribution of crop zones. Crop specific limitations are identified using agronomic model and environmental matching for a set of management practices. Maximum attainable agronomic yields under different emission scenarios are estimated and the potential impact of change in climate variables is quantified.

One of the major advantages of agro-ecological models is that, unlike simulation models, it enables accounting for crop-switching strategies. Farm level adaptations can also be explicitly controlled for in these models. Proliferation of literature regarding the distribution of agro-ecological zones in developing countries has greatly enhanced the applicability of this technique on a global scale. Several AEZ models have been developed and the prominent one are DSSAT, WOFOST and GAZEZ. A brief review of some studies using AEZ modelling approach is given in Table 1.2. From these studies it is clear that net effects due to climate change is projected to be negative. However, the magnitude of impact varies greatly across tropics and temperate zones. The AEZ models are effective in highlighting such regional heterogeneity in impacts.

The major drawback of AEZ models is the potential overestimation of the impact of climate change (Cline, 2007). The predicted potential yield levels are often much larger than those observed in field conditions and this tend to overestimate the

Table 1.2 Impact studies using Agro-Ecological Zone Models

Study	Region	Model Used	Findings
Masutomi et al. (2009)	Asia	M-GAEZ	In 2020s near future the negative impacts of climate change outweighed the benefits of CO_2 fertilization. In the 2080s the potential decrease in production as well as its probability was lower.
Teixeira et al. (2013)	Global	GAEZ	High risk of yield damage for wheat rice maize and soya bean at high latitudes. Lands at high latitudes ranged from 6 to 10 mha. Area subjected to heat risk in the long term increased for all crops except wheat.
Shah et al. (2008)	Sub-Saharan Africa	AEZ-BLS	Net balance of projected impacts of climate change in SSA is expected to be negative with yield losses amounting to 12%. Approximately 40% of the SSA countries will be at risk of severe yield declines due to climate change.
Fischer et al. (2005)	Sub-Saharan Africa	AEZ-BLS	Critical impact asymmetries due to both climate and socio-economic structures may deepen current production and consumption gaps between developed and developing world
Tang et al. (2000)	China	GAEZ	Arable land area is projected to increase in a new climate condition. The changing scope of arable land area varies from 2.5 to 16.2% under irrigated and rain-fed condition, and from 2.3 to 18.0% under rain-fed condition.
Seo et al. (2008)	Africa	AEZ based Ricardian Analysis	Currently productive areas such as dry/moist savannah are more vulnerable to climate change while currently less productive agricultural zones such as humid forest or sub-humid AEZs become more productive in the future.

benefits of autonomous adaptation. The crop suitability approach is unable to discern the detrimental impacts for subtle changes in temperature within an ecological zone, however the potential impact of a small shift from one zone to another are amplified. Agro-ecological models do not explore the economic dimensions of potential impact of climate change. However, it is important to note that coupling AEZ models with computational general equilibrium models have helped to discern the potential impact on food supply and its economic consequences (Rosenzweig & Iglesias, 1994; Fischer et al., 2005).

1.2.1.3 Production Function Approach

The production function approach models yield sensitivity as a function of climate and non-climate variables like input usage, land management and technology (de Salvo et al., 2013). Production functions are estimated using historical data (Isik & Davadoss, 2006) on crop yields and input usage, or observations from field experiments (An & Carew, 2015; Carew et al. 2017). Major advantage of the production function approach is that, it can be used to assess the potential impact on both output and output fluctuations or yield variability (Isik & Davadoss, 2006).

Just and Pope (J & P) production functions have been extensively used to assess the impact of climate change on agriculture (Isik & Davos, 2006; Holst et al., 2013; Arshad et al., 2017). J & P production function comprises of two components; one associated with output levels and the other associated with variability in output. The mean yield production function is obtained by regressing yield levels against a set of explanatory variables. The error term obtained in this regression is used to estimate the variance equation that accounts for yield risk. Two estimation procedures are followed, namely the Feasible Generalized Least Square (FGLS) and the Maximum Likelihood Estimation (MLE), of which the latter is more efficient in small samples (Saha et al., 1997). In Table 1.3 the findings of a few studies using production function approach to capture climate change impacts are summarized. Most of the results are presented in terms of marginal effects; change in yield for a unit increase in temperature or precipitation from the mean value.

One of the major disadvantages of the production function approach is that it fails to account for on farm adaptations to climate change, as most of these studies depends on state level/county level aggregate time series data for modelling (Holst et al., 2013; Chen et al., 2004). Production function approaches are crop and site specific and have limited applicability in estimating the impact on agriculture sector as a whole. These approaches also fail to represent adequately the socio-economic dimensions of climate change impact on agriculture (de Salvo et al., 2013).

Table 1.3 Impact studies using production function approach

Study	Region	Production function	Crops	Marginal impact temperature	Marginal impact precipitation
Isik and Devadoss (2006)	*Idaho U.S.A*	Just and Pope: Linear and Quadratic functional forms	Wheat, Barley Potatoes, Sugar beet	−1.11% to** −1.14%	−0.32% to ** −0.01%
You et al. (2009)	China	Cobb-Douglas with state and time fixed effects	Wheat	−3% to 10%	N.A
Holst et al. (2013)	China	Just and Pope: Cobb-Douglas functional form	Grain output	−1.45%	1.31% +
Chen et al. (2004)	U.S.A	Just and Pope: Cobb-Douglas with state fixed effects	Corn, Sorghum, Soyabean, Wheat	−0.37%-2.97% **	+0.34%–1.5%**
Cabas et al. (2010)	Ontario, Canada	Just and Pope: Cobb Douglas functional form	Wheat, corn and soyabean	−0.06% to −0.2%**	+0.7%–1.1%**
Poudel and Kotani	Nepal	Just and Pope: Cobb-Douglas functional form	Rice and Wheat	−1.08% to +0.64%**	N.S

Note: ** is 5% significance and *** is 1% significance

1.2.1.4 Ricardian Analysis

One of the major limitations of impact assessment models highlighted earlier is in its failure to account for on farm adaptations to climate change leading to overestimation of the potential impact on agriculture. The aforementioned models often treat as dumb agents who fail to respond to changes in climate variables over time (Mendelsohn et al., 1994). Ricardian analysis was evolved as a potential solution to the "dumb farmer scenario". It is based on two assumptions, perfect competition in land markets and rational farmers who try to maximize net revenues. Provided that these two assumptions hold, a cross-sectional regression of land values or net farm revenues on long term climate normal (30-year averages) and other control variables that might influence land values can be used to estimate the impact of changes in climatic variables on agriculture sector. The estimated impact comprises of both direct impact on crop yields as well as indirect impacts of input substitution, introduction of new varieties, shifting land to other activities and other potential long term adaptation strategies (Mendelsohn et al., 1994; Sanghi & Mendelsohn, 2008). Some of the major studies using the Ricardian analysis have been reviewed and their findings have been tabulated in Table 1.4. Studies reveal that climate change will adversely affect India, China and Sub-saharan Africa under both mild and severe change scenarios with increase in temperature accounting for detrimental impacts. However, agriculture in western Europe and U.S.A are

Table 1.4 Impact studies using Ricardian analysis

Study	Region	Marginal temperature	Marginal rainfall	Mild change	Severe change
Wang et al. (2009)	China	−0.8%	+1.2%	−12%	+23%
Sanghi and Mendelsohn (2008)	India	−9%	−3%	−12%	−20%
Kurukulasuriya and Mendelsohn (2008a, b)	Africa	−6.1%	+0.6%	−8%	−15%
Seo et al. (2008)	South America	−9%	−1.6%	−12%	−29%
Massetti and Mendelsohn (2011)	United States	−1.7%	+5.5%	+17%	−7%
Mendelsohn and Dinar (2009)	Mexico	−26%	−2.8%	−43%	−53%
Van Passel et al. (2017)	West Europe	+8%	+2%	+5%	−32%

expected to beneficiaries of change under mild scenario. Ricardian analysis has the added advantage of measuring the welfare effects of climate change on agriculture directly. The analysis also provides possibilities of assessing spatial correlations and use panel data sets to obtain more robust estimates of climate change impacts (Masetti & Mendelsohn, 2011; Seo et al., 2008).

The major disadvantage of Ricardian analysis is that the estimated coefficients could be biased due to omission of variables that influence land values (Descheneses & Greenstone, 2007). The Ricardian analysis requires that the regression equation to model land values to include all the possible variables which can influence land prices. Panel data regression of net farm revenues against random fluctuations in weather variables while controlling for location specific fixed effects has been proposed as a potential solution for omitted variable bias (Deschenes & Greenstone, 2007) but they fail to account for long term adaptation strategies like crop –switching behavior. The Ricardian approach also fails to account for transaction costs involved in adapting to climate change (Quiggin & Horowitz, 1999). Ricardian analysis fails to account for changes in price levels of agricultural commodities and provide overly optimistic welfare gains. The Ricardian approach while accounting for increments in producer surplus fails to account for decline in consumer surplus resulting from potential increase in prices (Cline, 2007). The Ricardian analysis cannot explicitly account for benefits of CO_2 fertilization by crops (Mendelsohn et al., 1994).

1.2.2 General Equilibrium Models

One of the criticisms against the partial equilibrium methods discussed earlier is that, they consider the agriculture sector in isolation and ignore the interaction between agriculture and non-agriculture sectors and the subsequent spillover effects.

Computational general equilibrium models are ideally suited to portray the interactions between different sectors of the economy, and disaggregation at regional and sector levels help in identifying spillover effects on region or sector specific shocks (Zhai et al., 2009).

CGE are based on Walrasian general equilibrium theory and a system of equations for the demand for goods by consumers, and supply of goods by producers are solved simultaneously to arrive at equilibrium (Arrow & Debreu, 1954). The impact of climate change on the economy is introduced as monetized damages. Monetized damages are modeled as a quadratic function of change in climate variable, usually temperature. Global mean temperature is in turn modeled using a climate impact function in which CO_2 emissions and lagged mean temperature are the dependent variables. Global mean temperatures have risen by 2.5–3 °C over pre-industrial levels. The benchmark damage for temperature rise of this magnitude could range between 1.3 and 2.5% of world income (Pearce et al., 1996).

Climate impacts interaction with the CGE models arise in the form of impact of non-climatic variables on climate variables, potential adaptation to climate change damages and feedbacks of climate change impacts on other sectors of the economy. The impact of climate on other sectors depends on change in climate variables and the vulnerability of the sectors under consideration which in turn are governed by socio-economic factors (Doll, 2009). These interactions are modeled within a general equilibrium framework to give a holistic view of potential climate change impacts and mitigation options.

GEM's are limited in that they aggregate within a single entity diverse sectors with specific economic and spatial dimensions. For instance, agriculture sector is considered as an aggregate sector, ignoring the heterogeneity arising due to its location specificity. Similarly, inputs are also treated as homogenous in different sectors. GEM's also does not account for dimensions like skills and competencies of farmers, which determines adaptive capacity of farmers to climate change (Mendelsohn & Dinar, 2009). The findings of some GEM models have been depicted in the Table 1.5. All studies concur that developing countries are likely to be the worst affected by climate change. Studies also reveal that potential damages due to climate change could be reduced through aggressive adaptation and benefit of prevented damages would outweigh costs incurred in adapting to climate change.

1.3 Adaptations and Mitigation Policies

1.3.1 Country Level Adaptation Strategies and Polices

Adaptation plays a significant role in reducing the severity of climate change impacts on agriculture and rural livelihood. Adaptation to climate change is defined as an adjustment in ecological, social or economic systems in response to observed or expected changes in climatic stimuli and their effects and impacts in order to alleviate adverse impacts of change or take advantage of new opportunities (IPCC,

Table 1.5 Impact studies using General Equilibrium Models

Study	Model	Functional Form	Region	Impact Parameter	Results
de Bruin et al. (2009)	AD-DICE	Quadratic	13	Global mean temperature	Developing countries most affected. Benefits of prevented damages outweigh costs
Manne et al. (1995)	MERGE	Quadratic	5	Regional mean temperature	Developing countries are worst affected Non market damages outweigh market damages
Hope et al. (1993)	PAGE	Quadratic	8	Regional mean temperature	Developing countries are worst affected Aggressive adaptation recommended
Tol (1997)	FUND	Quadratic	16	Global mean temperature	Developing countries are adversely affected Damages to energy sector are pre-dominant

2001; Chakraborty et al., 2000). In any environment, adaptation is the practice through which people make themselves better able to deal with actual or expected climate change, helping to reduce overall vulnerability (McCarthy et al., 2001). Intergovernmental Panel on Climate Change (IPCC) mentioned two reasons why adaptation is gaining importance in climate change risk management (IPCC, 2012). First, adaptation reduces the climate change risk by modifying the environmental and human contexts that contribute to climate-related risk (Sagar, 2017). Secondly, it promotes adequate preparedness for future risk related to climate change (Lavell et al., 2012).

Climate change adaptation measures can be long-term adaptation or short-term coping. Long-term adaption measures address the projected impacts of climate change and vulnerability reduction (Smit & Wandel, 2006; Adger, 2006; Seekao & Pharino, 2016). Short term coping is defined as the use of available skills, resources, and opportunities to address, manage, and overcome adverse conditions with the aim of achieving basic functioning in the short- to medium-terms (IPCC 2012). Local coping and adaptation measures play a vital role in vulnerability reduction in rural areas.

Several countries have formulated national plans to adapt to climate change and agriculture features prominently in these action plans. Herein, we have reviewed government policies and programmes across the global policy space, aimed at promoting adaptions to climate change and reducing potential impact. Policies in China, India, U.S.A, E.U, Sub-Saharan Africa, Australia and Brazil have been reviewed and the objectives and course of action and climate change adaptation schemes have been enlisted in the Table 1.6.

Table 1.6 Adaptation policies by different countries

Country	Policies or schemes	Objectives
India (NAPCC)	National Water Mission	Optimize water use by increasing water use efficiency by 20% with special focus on Integrated Water Management in agriculture.
	National Mission for Sustainable Agriculture	The plan aims to support climate adaptation by development of climate resilient varieties, improving productivity of rainfed areas and expansion of weather insurance mechanism.
	National Mission on Strategic Knowledge on Climate Change	Envision a new Climate Science research fund to gain better understanding of climate change impacts and challenges and improving climate modeling.
China (NCCP2007)	Agricultural Infrastructure Development	Aims to accelerate construction of support facilities in large scale irrigation projects and focus on restoration of degraded farmland. Promotion of small scale irrigation in rainfed areas. Special emphasis on accelerating water storage and utilization projects in mountainous regions.
	Strengthening R & D	Expanding breeding programs with emphasis on drought, water logging, high temperature and pest resistance.
	Extension facilities	Increasing penetration rate of practical technical adaptive training of rural labor to 70% by 2020.
	Special funding arrangement for climate change adaptation	Cloud seeding in Sichuan and Tibet provinces. Water harvesting in Xinjiang province. Burgeoning crop and livestock insurance coverage (revenues of insurance companies focusing on agriculture and allied industries have grown at an annual rate of 80%).
Sub-Saharan-Africa (NAPA)	Climate forecasts	Building technical and human capabilities of national weather service so as to establish reliable seasonal climate.
	Rainwater harvesting	Focus on expanding irrigated agriculture and efficient water conveyance to ensure food security.
	Soil erosion control	Installing anti-erosion mechanisms and introduction of suitable farming systems in to combat soil erosion.
	Cattle breeding	Program to breed zero grazing cattle with twin objectives of enhancing agro-silvo-pastoral production and protecting the environment.
	Plant breeding	Developing short duration and dryness tolerant varieties to enhance agricultural production and ensure food security.

(continued)

Table 1.6 (continued)

Country	Policies or schemes	Objectives
Australia (NCRA 2015)	Education and extension Drought risk management	Increase awareness of local communities regarding the adverse effects of climate change and deforestation. Provision of accurate more frequent and more local seasonal forecasts. Tax deduction on new water facilities and increasing subsidized coverage of farm insurance and risk grants.
	Risk assessment portal	Tasmanian government is helping inform farmers how five crops (wheat, barley, poppies potato and wine grapes could be cultivated under changing climate scenario based on land suitability classification.
	Climate Change Research Program	Produced localized climate information to assess viability of adaptation strategies. Devised strategies to monitor and manage heat stress in livestock. Improved grape varieties and management practices for climate resilient viticulture.
U.S.A (CCAP of USDA)	USDA Regional Climate hubs	Provisioning regional assessment of risks and vulnerabilities. Education and outreach program on science based risk management.
	National Climate Assessment	Aim is to assemble information from publications and technical reports to assist policy making.
	Feed the future initiative	To ensure food security of partner countries to enhance resilience to climate change.
	Climate Smart Agriculture Alliance	To facilitate public-private partnerships for smart agricultural practices in relation to climate change adaptation.
	National Drought Resilience partnership	Aims to establish a framework for better drought monitoring and enhance capabilities for drought risk management.
E.U (CAP)	Green payment	Decoupled direct payments for implementing three compulsory practices namely crop diversification, permanent grasslands and ecological focus areas.
	Good Agricultural and environment conditions	Cross compliance requirements facilitate establishment of buffer strip along water courses, maintenance of soil organic carbon, protection of groundwater against pollution and ensuring minimum land management and to limit erosion and retention of landscape features
	Farm advisory services	Realizing adaptive capacity through education of risks and impacts, planning of farm business and knowledge transfer of research findings and technology.

(continued)

Table 1.6 (continued)

Country	Policies or schemes	Objectives
	Infrastructure development under EARDF	Support to measures for improving water management such as increasing efficiency in water use for irrigation or the creation of hard defenses or improved drainage against increased risk of flooding.
Brazil	Technology development and adaptation	Developing drought resilient cultivars for tropical agriculture, increasing nitrogen fertilization and pH correction and promotion of irrigation saving technologies and increasing water use efficiency by shifting to pressurized irrigation systems.
	Agricultural Zoning Program	The AZP has been expanded to incorporate climate risks so as to indicate crops suitable to different geographical region on the basis of soils, climate and water requirement.
	Agricultural Financing	Linking federal credit schemes with AZP to reduce farm losses due to adverse climatic conditions

1.3.2 Adaptation Strategies Opted by Farmers

In any society, adaptation is the process through which people make themselves better able to cope with actual or expected climatic variation or drought effects, helping to reduce overall vulnerability (McCarthy et al., 2001). Farmers adopted numerous adaptation strategies against changing climatic factors. These strategies are based on their experience and knowledge. Micro-level adaptations studies help identify the common adaptation practices implemented by the local people of a particular region. Following are some of the common adaptation strategies opted by farmers.

Crop-level and natural resource management are the most common adaptation strategies adopted by Indian farmers. Due to variation in climatic factors, mainly precipitation and heat stress at different crop stages, farmers are changing the planting and harvesting dates/ timings. They also use improved crop varieties, which can perform better under adverse climatic situations. In addition, farmers adopt strategies like crop diversification/ intercropping/ mixed cropping to cope with the climate variability. These agronomic practices help to attain better productivity and profitability, especially in the rainfed/dry land regions (Singh et al., 2014; Khanal & Mishra, 2017). In addition to the various agronomic practices, now farmers are adopting environmentally sustainable adaptation measures that can efficiently utilize the available resources.

Livelihood of the farmer is considered to be important for households to cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets, both now and in the future (Paavola, 2008). Farmers face multiple challenges such as stress on land, water and soil health, lack of knowledge/

information, limited exposure to high productivity practices, weak market linkages, inefficient supply chains with high levels of food wastage, and an acute dependence on rainfall. In addition to these factors, variation in climatic factors has increased the income instability of farmers. The diversification of livelihood helps households to choose more defensive strategies, which in turn help them survive during climate shocks and natural disasters (van den Berg, 2010). In order to minimise the risk, they also engage in dairy livestock, poultry and cattle rearing which are considered as common subsidiary activities of agriculture. Casual/ part-time work or self-employed endeavors are some other non-farm strategies adopted by the farmers to reduce the risk from crop failure. Migration is considered an ex-ante risk management strategy. The remittance sent to households increases their assets, which in turn reduces climate change vulnerability (Nyberg-Sorensen et al., 2002).

The people most vulnerable to climate change are those with inadequate access to economic and social capital (Thomalla et al., 2006). With Indian agriculture dominated by marginal and small holders, resource constraint increases the vulnerability of farmers to climate change. Social institutions like NGOs, savings and credit institutions, play an important role to support farmers to cope with risks and uncertainties arising from climate change. As the access to social networks increase, households find themselves less vulnerable to shocks as their ability to cope with risks increases (Lokshin & Yemtsov, 2001). NGOs play a significant role in natural disaster management and preparedness as they work with poorer and more marginalized groups in a society (Benson et al., 2001).

Yield reduction/loss due to climatic variation or natural hazards is a major issue in the Indian agriculture. A sustainable institutional option to manage agricultural risks is crop insurance. A loss in previous crop season deprives farmers of cash to start the next agricultural season and compensation from insurance helps farmers to meet the urgent cash needs. Crop insurance also reduces the burden of compensation on the Government through risk pooling. When it comes to climate related risks, weather based micro insurance is a powerful solution to weather related risks. The key advantage of weather based index insurance is that it provides insurance against incidence of adverse conditions of rainfall, temperature, frost, humidity that could destroy crops.

1.4 Conclusion

In this chapter we elaborated on different methods of estimating the economic impact of climate change with an objective of quick start guide for researchers working in the area. Partial equilibrium methods like crop simulation models, AEZ modelling, production function approach and Ricardian approach and General Equilibrium Models for estimating climate change impacts are discussed with respect to conceptual premises, assumptions, advantages and disadvantages. Modelling climate change is an ever-evolving field of study, researchers must keep himself abreast about the developments and choose the method which suits to the research question. We also reviewed adaptation strategies followed at macro (country) and micro (farmer) level. The chapter thus provides a holistic view into the methods for impact assessment and potential impacts of adaptation and mitigation strategies in minimizing effect of climate change.

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Chapter 2
Indigenous Technical Knowledge Under a Changing Climate

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Abstract Agriculture is not only affected by climate change but also contributing about 24% towards greenhouse gases. Another stark reality is that the compositions of greenhouse gases have been increasing tremendously after industrial evolution. These changes happened because of human activities and/or over exploitation of natural resources. The nature and magnitude of climate change's impact(s) or risk are contextual that vary from location-to-location. The losses in production and productivity of agriculture due to climate change are also location specific which ultimately affect food security. Among the states of Indo-Gangetic Plain, Bihar is one of the states which is adversely affected by climate change because of farm holdings which are small and scattered. There are about 1.61 crore farm holdings of which 91% is marginal. Therefore, there is a need to develop location-specific sustainable agricultural technologies to cope with impact of climate change. Some of CG institutes are promoting science-based climate smart agriculture practices in the state of Bihar for mitigating the impacts of climate change but scaling out of these technologies are limited to a particular area and sometimes not compatible to resource poor families. Farmers are not only receiver of technologies but most of the times they solve their problems by own and/or members of social system. This chapter fundamentally deals with three major points. First climate change and its impact on agriculture; second how grassroots people cope with shock and risk imposed due to climate change and third point is linking Indigenous Technical Knowledge (ITK) and science-based knowledge for coping with climate change.

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2.1 Introduction

The world agriculture is facing myriad problems. Climate change is the single problem which affects farm production, productivity and ecosystem the most. Due to anthropogenic emissions, the concentrations of greenhouse gases, i.e., carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), water vapor and ozone (O_3) in the atmosphere have been increasing substantially after industrial revolution (Watson et al., 1990). Presently, average temperature is 0.7 °C above pre-industrial levels. Intergovernmental Panel on Climate Change (2007) published a projection report, which predicts temperature rises up to 4.5 °C or higher by 2080, and which again depends on anthropogenic changes and other factors. Agriculture is the one which contributes a lot towards GHGs and also directly gets affected due to climate change. Agriculture is facing a number of challenges viz.; heat stress, drought, other extremes, erratic rainfall, depletion of soil water and flood due to climatic change. These factors greatly affect agriculture sector, non-agriculture sector and natural resources which are directly linked to national economy (CCAFS, 2009; Sehgal et al., 2013). Increasing climatic variability affects most of the biological, physical and chemical processes that drive productivity of agricultural and allied systems (Easterling et al., 2007).

Impact of climatic change is more in those countries whose major population or economy on is based on primary sector i.e. agriculture activities based (Anita et al., 2010). Indian Agriculture is highly susceptible towards hazards and shocks due to climate change because majority 60% of its population directly depends on agriculture and allied areas for their livelihoods. Climate change will be further more problematic for the resource poor families because of their economic and social vulnerability (Godfray et al., 2010). The Indo-Gangetic Plain (IGP) is comprised of the five major states of India viz.; Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal. These states are having major contribution in food production about 51% of total food grain production of the country (Mittal & Mehar, 2013). Among the IGP states, Bihar is highly vulnerable due to its socioeconomic conditions and agro-ecological situations. State Action Plan on Climate Change (SAPCC), Bihar (2015) reported that annual temperature of the state during 2011–2040 with respect to 1961–1990 will rise up to 0.8–1.9 °C and consequently this raised temperature will negatively affect productivity of agriculture sector which ultimately will have damaging effect on livelihood of resource poor families.

Most of the time these resource poor families are also seen as vulnerable families towards effects of climatic change. It would be right direction if we understand their sensitivity to risk and shocks due to climatic change and their adaptive capacity, creative ability and behavioral response to changing climatic conditions (Nakashima et al., 2012). No doubt after inception of Intergovernmental Panel on Climate Change (IPCC) in 1988 a large number of scientific facts and/or reports on climate change have been released but they are not proving sufficient to convince policy makers and world leaders to seriously think about minimizing the emission of greenhouse gases. But ironically, indigenous people's knowledge and creativity which is prevalent among local farm people is still unrecognized for adapting the impact of climate change. This knowledge is more contextual, sustainable, cost effective and based on their culture and local demand (Datt et al., 2013).

2.2 Vulnerability

2.2.1 Framework of Vulnerability

Before proceeding to the indigenous adaptation methods towards climatic change or variability first of all there is a need to understand the vulnerability and its dimensions. It is well proven that impacts of climate change vary from place-to-place due to social and agro-ecological conditions. Vulnerability primarily depends on internal coping mechanism and external exposure (Sehgal et al., 2013). Again internal coping mechanism depends on social-ecological system which reflects the idea of human action and social structures including entitlement of resources (Sen, 1981; Adger, 2006). However, in addition to adaptive capacity, vulnerability also depends on sensitivity of the system towards different climatic exposures (Watson et al., 1990; Moser, 1998). According to IPCC, 2007 "Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. In nutshell, vulnerability is the function of exposure, sensitivity and adaptive capacity. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity". Fundamentally, vulnerability depends on three major components viz.; exposure, sensitivity and adaptation. Exposure is degree to which a system experiences environmental and social stresses whereas sensitivity is the degree to a system is modified or affected due to climatic shocks of perturbation. Adaptation is the capacity of a system to cope with hazards or shocks due to climatic change (Adger, 2006).

2.2.2 Entitlement and Vulnerability

Vulnerability greatly depends on the characteristics of social structure and/or especially ownership of resources and access of common resources available in the community and in addition to the unequal distribution of resources, a handful of elite members are having hold and access on knowledge system of the society. For an outsider the ownership of these resources may seem to be simple but the system of distribution of resources among the members of society is rather a complex process. Particularly land distributed as per inheritance law. Generally we think water resources are available for each member of society but practically those who are resource poor they are not able to use community ponds, rivers, canals and ground water because unavailability of pump set and/or fuel. Due to lack of natural resources and their poor economic conditions most of the time resource poor families are unable to access input and output markets. Ultimately this process makes them more susceptible to cope with adverse impacts of climate change (Sen, 1981; Adger, 2006). But at the same time an interesting fact is that when resource poor families could not access modern knowledge pool then they try to solve their own problem in a different way resulting a unique method or technique.

2.2.3 Gender and Vulnerability

Gender refers to male and female and their associated roles and responsibilities assigned for each sex by society. Even society decides resource entitlement and decision making power. Across India and especially in IGP states land entitlement transfers from generation to generation to male members even after government formed a law for equal entitlement for both son and daughter. For accessing credit from banks women need land or assets for collateral, but due to lack of land entitlement they are unable to access credits from financial institutions.

In Bihar state of India mostly secondary tillage practices, livestock management, fuel and fodder collection, reproductive roles and house management activities mostly performed by the women (FAO, 2012). Climatic change impacts like drought and floods affect women badly compared to men because during flood there is a big challenge of fuel and fodder which is mostly the responsibility of women. Another serious issue during flood is drinking water which is again a responsibly of women. Drought, again causes shortage of these essentials, which becomes a matter of grave concern. All these hassles make women's life more arduous by increasing their work load. Climate stresses not only affect crops where basically men's decisions are involved rather these stresses have more effect on kitchen, energy, drinking water and health where major decisions are being taken by women.

2.3 Indigenous Technical Knowledge (ITK)

2.3.1 What Is ITK?

In ancient times, when there was no formal system of research vis-à-vis documentation even then people used to devise some *modus operandi* in order to develop some technologies and preserve such things, albeit, such people who developed these technologies passed away like, "unsung heroes", but their inventions are still being practiced under the domain of *Indigenous Technical Knowledge* (ITK) (Datt et al., 2013). It could not be possible to develop/shape knowledge of treasurer at grassroots sans scientific temperaments of our ancestors (Levi-Strauss, 1966). The term ITK refers to the knowledge systems developed by a community as opposed to the scientific knowledge that is generally referred to as 'modern' knowledge (Ajibade & Shokemi, 2003). This knowledge is mostly evolved from local community and is unique in its kind which mainly depicts culture and society (Rao et al., 1995). Indigenous Technical Knowledge refers to knowledge and/or know-how accumulated, tested, maintained and transfers across the generations which clearly depicts their wisdom, culture and available materials in their surrounding (Wang, 1988; Warren, 1989; Howes & Chambers, 1979; IFAD, 2016). Fundamentally this knowledge evolves when local people or a community faces problems. Their need helps them to find their own solution (s) through trial and error method. This knowledge is preserved in folk stories, folk proverbs and folk songs. Those who look at this knowledge through scientific glasses, may consider this knowledge unorganized and may skeptical about its validity (Howes & Chambers, 1979). This knowledge is dynamic, ever-changing through available local materials, creativity and interaction with endogenous or exogenous knowledge system (Osunade, 1994; Warrens, 1991). This knowledge may seem simple for outsiders but it represents mechanism to ensure minimal livelihoods for local people. This knowledge is more sustainable, cost effective and having adaptive capacity towards different variations or shocks experienced by the system (Thrupp, 1989).

2.3.2 ITK Vs Modern Technologies

Indigenous knowledge is solely evolved based on farmers' problems and developed by farmers only. Modern technology is developed by the researchers under controlled conditions, with plenty of resources available in the experimental farms, but sometimes these technologies may not be compatible to resource poor families. ITK communicates and modified from generation to generation and from farmers to farmers whereas modern technologies communicated via extension mechanism of the government, private sector or university system to the farmers. ITK is not well documented and so there are greater chances of loss of valuable knowledge. Modern technologies are well documented in research documents and on web in the form of soft copies. ITK is cost effective because it is developed by local materials whereas modern technologies are more expensive because these technologies are developed in sophisticated laboratories. Even as the short term gains from ITK may not be so high as modern techniques, but owing to the other potent benefits of it, this is a high time for policy makers, researchers and change agents could think about complementary use of ITK and modern technologies for combating the impact climatic change (Howes & Chambers, 1979; Rao et al., 1995).

2.3.3 Documentation and Scaling Out of ITK

When our formal system of research came into existence, we shifted from traditional to modern system; consequently, we are also losing our invaluable ITKs gradually, which have been accumulated after huge efforts on the part of several generations of our ancestors. Documentation, screening, validation of ITK is essential before the valuable information is lost forever. There is a myth prevailing among rural communities particularly in case of local medicine's knowledge that if the knowledge is shared with others then medicine will not remain effective. So, these fellows who know about particular knowledge could not able to share it with anyone even up to their death.

There is a serious flaw with our current system of documentation or extracting local knowledge from the society. First- Extension workers, students and researchers do farmers' visits with a large schedule. Farmers mostly feel irritated because some questions are not in logical form or having more scientific language. Second-Most of the time the motives of these survey are extractive by which farmers feel cheated, which also is ethically wrong. Third- Due to lack of empathy or observation part surveyors are unable to understand importance of knowledge and consequently verbally or nonverbally give inferiority signals towards local knowledge (Howes & Chambers, 1979).

Gupta (2016) stated four steps for collecting local knowledge. First stage is development of questionnaire but they should be given questionnaire only after they have visited the field; second stage is sharing schedule with surveyors so they could be able to evaluate with their field experiences; third stage is to learn about contact families and other institutions and about knowledge.; fourth and final stage is to share the entire case or collected knowledge to the family. Particularly in fourth phase, local persons give more comprehensive and personal information as compared to previous visit(s). Across the country a number of studies have been conducted for documentation and validation of ITK particularly by the researchers of Extension Education of agricultural varsities. But this research is limited upto research theses and/or research papers. A pioneer work of documentation was started by *Honey Bee network during 1990s. Indian Council of Agricultural Research (ICAR), New Delhi started documenting ITK under a World Bank funded project National Agricultural Technology (NATP) which was started in 1998.*

> *Honey Bee network is a pioneer network in the world which got started with the philosophy of reciprocal, responsible and mutually respectful knowledge exchange. This network felt the value of available open-source knowledge and started documenting, sharing democratically in local language to them as honey bee do cross pollination. For scouting of local knowledge and grassroots innovations a number of volunteer students, members of civil societies, researchers, farmers joined hands with the network. In 1993 Society for Research and Initiatives for Sustainable Technologies and Institutions (SRISTI), Ahmadabad, India was setup as volunteer organization for technical backstopping of the network. Sharing of local knowledge back to the society was not enough to empower grassroots. Consequently, Grassroots Innovation Augmentation Network (GIAN) got established. Further strengthening of the network National Innovation Foundation (NIF) established in 1999 at Ahmadabad. Now this network is working with the golden triangle linking grassroots innovation/*

traditional knowledge with investment and enterprise and introduced the concept Micro Venture Innovation Fund (MVIF). Honey Bee Network, over the last twenty years has documented more than 1,00,000 ideas, innovations and traditional knowledge practices documented and out of them 730 grassroots technologies have been patented and more than 10000 tradition technologies are in public domain. Presently Honey Bee network is working about 75 countries across the world. Prof. Anil Gupta, IIM-Ahmadabad, India, who is recognized as father of grassroots innovation has been instrumental of in this network (Gupta, 2016).

It is well known that local people abound in creativity. For mitigating the impacts of climate change there is an urgent need of documentation, refinement and scaling out of ITK at field level.

2.3.4 Use of ICT Tools for Documentation and Scaling Out of ITK

It is a herculean task to collect ITK from farmers' field, refine it and make available to the farmers. Since, modern technologies are popularized among the farming communities and resulting, the pace of evolution, use, and transfer from generation to generation of ITK has been downplayed. At the same time youngsters of villages are also not giving much value to indigenous knowledge which is another risk of its loss and maintenance (Ngulube, 2002). It is well proven that our indigenous knowledge is more sustainable and/or could be instrumental in sustainable technology development but this knowledge is in endangered state. In parallel its globally recognized ITK could be used with modern practices in complementary way. Due to lack of human resource it is difficult to reach each and every family to collect ITK and traditional storage system of traditional knowledge is no more responsive. In this case, Information and Communication Technology (ICT) can play a pivotal role in documentation, management and dissemination of ITK (Hunter, 2006). Narrative story is one of the best ways to collect local knowledge because this knowledge is mostly presented in the form of oral tradition. Digital video and/or audio recording is the best way to collect stories which are based on ITK. Social media can also help in connecting with the number of volunteers who are willing to collect and disseminate this knowledge (Panahi et al., 2012). Presently, it is very easy to store indigenous knowledge in digital form.

Traditional Knowledge Digital Library (DKDL) is one of the pioneer initiatives in the field of traditional knowledge management in digital form. This library is basically based in Indian system of medicine which was established in the year of 2001with the collaboration of Council of Scientific and Industrial Research and Ministry of AYUSH. The fundamental objectives of this library are to protect unfair patenting at international level which is already existing in the form of traditional knowledge and to develop knowledge repository (www.tkdl.res.in).

A number of ICT tools like website, portal, social media, and blogs could be harnessed for the dissemination of traditional knowledge to the grassroots, researchers, policy makers and extension workers.

2.4 ITK in Changing Climate

2.4.1 ITK in Weather Forecasting

Accurate information about short-, medium- and long-term weather forecasts are valuable in helping local people with climatic shocks or uncertainties (FAO, 2009) but local people have least access on modern forecast system. In India, the people at grassroots level are having a well established indigenous weather forecasting system on the basis of various factors like air direction, pattern of clouds, temperature, humidity, stars, sun, moon, voice of birds and animals and behaviour of insects predict rainfall, thunderstorm, windstorm, attack of insect pest and even tsunami as well (Anandaraja et al., 2008; Chinlampianga, 2011). Few examples are mentioned in the box:

Traditional Weather Forecasting

Appearance of many dragonflies: when dragonflies fly at a lower heights is an indication of rain (Parneek & Trivedi, 2011; Anandaraja et al., 2008).

Ants with eggs: When ants along with their eggs are climbing up to high places or safe places it indicates raining (Parneek & Trivedi, 2011; Anandaraja et al., 2008; Raj, 2006).

Termites flying: When termites fly during evening hours, this is again indication of raining (Parneek & Trivedi, 2011; Anandaraja et al., 2008).

Frog: when a large number of frogs start croaking it is an indication of raining (Chinlampianga, 2011; Parneek & Trivedi, 2011; Anandaraja et al., 2008)**.** If frog in the well makes continuous sound it is also an indication for raining (Raj, 2006).

Lighting in the sky: If lightning occurs from the east, west, and south, expect rain immediately. If lightning comes in an opposite direction (east to west), expect rain in 1 h (Raj, 2006).

Circles around the moon: If circles are found around the moon, expect less rainfall; if small circles appear, expect less rainfall within 2 days (Raj, 2006).

Location and pattern of clouds: if clouds are thick and black in colour then there is chance of occurrence of rain (Chinlampianga, 2011).

Pattern and movement of stars: Movement of stars from west to east at night under clear sky indicates rainfall within 2–3 days (Rautela & Karki, 2015).

Elderly male farmers, community leaders and/or religious leaders make hypotheses about seasonal and annual weather forecast. Accordingly local people take decisions about farm practices and household activities and cope with adverse effects of climate change. But this practice at village level got downplayed as metrological weather forecast received by the villagers (FAO, 2009). The state of Bihar is facing frequent and extreme weather events, resulting in economic and food insecurity among the farming community. There is need to harness the synergy by science based forecasting with indigenous weather forecasting methods (CGIAR, 2013). This synergic partnership will improve the validity of weather forecast and it will help in documentation of traditional knowledge which is in endangered stage. Indigenous knowledge is mostly available in the communities in the form of proverbs, folk song, rituals and social institutions (Hunter, 2006). One of the famous collections of proverbs across the IGP states is *Ghagh Aur Bhaddari ki Kahawatein* (Proverbs by *Ghagh* and *Bhaddari*).

> *Across the IGP states the proverbs documented by Ghagh Aur Bhaddari are very popular and validity of these proverbs which are based on the package of practices for agriculture and weather predictions have been tested by local people from a number of generations. In fact a number of villagers make farm-level decisions with the help of these proverbs. Both Ghagh and Bhaddari are recognized as "Krishi Pandit" (Master of Agriculture). A very famous saying about Ghagh, is that once he was in the bank of river and saw a daughter of washer man. She was instructing her parents for collecting all dry clothes and was requesting them to return home immediately. Ghagh, was very much inquisitive about her saying. He asked the girl that why you are so hurried then she replied 'very soon there will be heavy rain'. Ghagh was not convinced because it was quite sunny day. After some time, it was raining heavily. Again Ghagh went to her home and asked how she predicted about rain then she replied that she saw a bevy of ants who were climbing very fast on a tree with their eggs. By this event she predicted heavy rain. By this Ghagh was too impressed with the girl and later he married her.*

2.4.2 ITK in Climate Change and Adaptation

Grassroots and traditional people are least users of modern climate smart technologies developed by the research institutes. They not only reside in more fragile areas, prone to climatic uncertainities but also their livelihood is mainly based on natural resources which is more vulnerable to climatic change (Salick & Byg, 2007). Indigenous people are not passive receivers of the technologies rather they perceive the threat of climate change and also develop some solutions to adapt under changing climatic situations in a creative manner. It is well established fact that innovation emerges from multiple sources including grassroots farmers (Salick & Byg, 2007; Biggs, 1990). Therefore, there is a responsibility of policy makers, researchers, international and national institutes to recognize the role of traditional people in contributing towards mitigation and adaptation towards climate change. Across the world there is a number of discussions going on about the importance of indigenous knowledge and participation of local communities on impact mitigation of climate change and coping with adverse condition (Gearheard et al., 2010). Synergistic utilization of ITK into climate change policies that will help in formulating effective policies that are more sustainable, user friendly and cost effective (Robinson & Herbert, 2001; Hunn, 1993). This complementary use will not add any more financial burden but this knowledge will add new dimensions of sustainability (Nyong et al., 2007). Keeping the importance of indigenous technical knowledge, Intergovernmental Panel on Climate Change incorporated a cross-chapter case study on "Indigenous knowledge for adaptation to climate change" published in the Fourth Assessment Report (Parry et al., 2007). After a comprehensive work of documentation, management and dissemination of traditional knowledge and innovation by *Honey bee network,* Ministry of Finance Government of India has provided financial support and technical support rendered by Council of Scientific and Industrial Research (CSIR) for establishing National Innovation Foundation, Ahmadabad (India) for documenting and promoting traditional knowledge and grassroots innovations (Gupta, 2016).

Climate change or extreme events are not new to traditional people. They are coping with climatic shocks and uncertainties like droughts, floods, windstorm and thunderstorms since ancient times. But since these GHGs have been rising, they have envisaged these calamities more frequently and with higher intensity as well. When the people from grassroots have more access on science-based technologies then they do not refer to their self-generated system or they just want an immediate solution for their problems and/or depend on outsider in order to cope with changing climatic conditions. These people are facing different aspects of climate change which depend on site of residence, entitlement of natural resources, access of knowledge system and their gender as well. It is well established fact that scientific climate study can give only overall picture of climate change and its future projection of climate variability for larger area. Now scientific community has started realizing the importance of local people observation about weather and/or climatic changes at local level (Salick & Byg, 2007).

> Certain traditional people/communities are reporting very visible indications like the rise in temperature; late onset and erratic rain fall; shift in rainfall and temperature; variation in day and night temperature; intense sunstroke, frequent droughts and floods; migration of birds; decreasing population of wild animals; disappearance of many flora species; changes in flowering; fruiting and harvesting of crops; attack of insect-pest and diseases; and drying of wells, ponds, rivers and other water bodies in the summer seasons (Banerjee, 2015; Vardan & Kumar, 2014; Tripathi & Singh, 2013; Dhaka et al., 2010; Kelkar et al., 2008; Dash & Hunt, 2007).

Adaptation is the coping mechanism of a system in order to accommodate in response to expected and/or actual environmental hazards (Banerjee, 2015; Banerjee et al., 2013; Parry et al., 2007; Adger, 2006). Traditional knowledge is an outcome of problems faced by individual and/or community as a whole. ITK have proven to be an invaluable for adaptation to environmental hazards (IFAD, 2016). For instance, biodiversity is the main base for indigenous people to adapt with changing climate and secure their livelihood. Around the world about 370 million traditional people are living who are occupying 22% of the global land area, which is home to 80% of the world's biological diversity (UNDP, 2011; IFAD, 2016). It is well proven fact that traditional people are using different alternatives of diverse biodiversity at different climatic conditions and variations from them. But, anthropogenic change is the single pressing threat towards loss of biodiversity (Salick & Byg, 2007; Hannah et al., 2002). The resilience and adaptation to climate change directly depends on *their* local wisdom and biodiversity present in their system (IFAD, 2016). For example Bihar state is one of the most flood and drought affected states of India. There are a number of traditional varieties of rice were preserved by the farming communities flood and drought like situation.

*The major kharif crop of Bihar is rice. In many low lying areas of the state farmers lose their crop due to flood. Besariya is a traditional rice variety of Bihar that can survive in rising flood water by growing up to 24 cm a day. Chakia is an anotherb indigenous variety which is grown under flood like situation. By this variety Chakia-59 was released as selection. This variety is recommended for eastern Uttar Pradesh and Bihar. The Goda variety is popular in Jharkhand and few parts of Bihar. This variety is suitable for drought-like situations. It grows on highlands where the water run-off is high but matures in barely 60 days, compared to the usual varities that take 90 days (*Srivastava, 2010*).*

This unique system of diversity existing at grassroots level, whose complex interaction between floral and faunal species and the physical and social structure shows the resilience strength of that particular system. Across the world traditional people secure their livelihood and cope with environmental shocks. Conservation of this diversity will increase the capacity of a system to respond to climatic variability (IFAD, 2016).

In addition to ITK, collective action, social capital and local institutions of social group play a central role in adaptation process and development of resilience capacity of a system (Adger, 2003; Agrawal, 2008; Banerjee et al., 2013). Adaptations have been undertaken at households' level and at societal level in response to climatic shocks faced by them. At households' level management of climatic risk is a function of education, wealth, natural resources, social organization, local knowledge, and institutional relationships among the factors (Adopted from Mortimore, 1989 in Agrawal, 2008). Adaptive capacity varies from household-to-household and it depends on resource entitlements, local institutional support, social network, market linkage, means of communication and personal characteristics. Collective work and decisions are also the central point for common resource conservation, management and its use. Ways of allocation of these scare resources for securing their livelihoods under uncertain climatic situation shows the adaptive capacity of the system. Second efforts are being taken by government, civil society and private organization to adapt with impact of climate change (Agrawal, 2008).

Indigenous communication methods are also critical for observation, experience, decision, dissemination of climate change related information among other members of the society and adaption towards environmental hazards at society level. Among the indigenous methods village *Choupal* is very popular communication method among the grassroots.

The Village Choupal is a traditional heritage of the past in which villagers sit and discuss their problems, celebrate their happy moments, share the pains of an individual, family or a *particular group and sort out their disputes* (IOM, 2008). *Choupal is a community building or space in the rural areas of North India. It is the hub of community life in villages, especially for male inhabitants. In smaller villages, a Choupal can be a simple raised platform that is shaded by a large tree, typically a Neem, Banyan and Pipal tree* (Chandhoke, 1990). *Bihar Agricultural University has realized the importance of Village Choupal. The varsity started Kisan Choupal on April 28, 2012 in collaboration with 20 Krishi Vigyan Kendras (KVKs) and nine colleges of the varsity. Since then the Choupal is organized every Saturday with the theme Bihar Krishi Vishwa Vidyalaya Kisano Ke Dwar: Kisan Choupal (Bihar Agricultural University at the doorstep of farmers: Kisan Choupal). It is helping the farmers to solve their problems along with the dissemination of scientific know-how of the university at their doorsteps. In addition to dissemination of scientific information, this programme is promoting farmers-to-farmers communication* (Singh et al., 2016)

2.4.3 Traditional Climate Resilient Practices

Farming community of Bihar, India is coping with consequences of climate change. Majority of farmers of the state are resource poor and living in the marginalized conditions, which gets aggravated in situations like flood and droughts. To cope with climatic variability they have developed and/or practicing inherited diverse farming systems that have potential to adapt with shocks and uncertainties due to climatic change. Especially, traditional farming communities and resource poor families manage their farm and livelihoods in way to meet their basic needs sans getting much affected by climatic variability. They are least users of modern climate resilient technologies due to comparatively higher cost, complexity and mostly being skeptical about performance of modern technologies. Risk taking ability of small and marginal farmers is one of the prime factors which limits the adoption of modern technologies. There are some common traditional practices popular among the farming community for particular climatic situation those are mentioned as below in form of case studies.

Case Study-I
Bhoka method of Maize Sowing

The All India Coordinated Research Project (AICRP) on *diara* land Improvement reported that about 40 m.ha. area in India is flood prone and out of which 2.64 m. ha. area is estimated to be *diara* land (Anonymous, 1991). Total area under diara is about 8.76 lakh hectors in the state of Bihar. Basically, diara word is derived from Hindi word '*diya*' meaning earthen lamp. The surface of *diara* land is like bowl in which flood water gets accumulated after rains, creating temporary waterlogged condition. Major crop of this area is rabi maize and suitable time for sowing is last week of October to first week of November. But due to the wet soil of diara in time sowing of maize crop is not possible then; local people started using their own wisdom and evolved a unique method of sowing called "*Bhoka* method". This method is very much popular for sowing of maize crop in *Diara* land of Bihar. Especially, in this method bamboo sticks are used making its one side sharp enough.

With the help of the sharper side of these sticks individual hole is made in order to put maize seed even under wet soil. Interestingly, the sowing method is performed by under aged boys and girls because their weight is supposed to be less than adults. If this method is used by adults then their feet gets immersed in the soil, which hampers proper germination. Through this method there is minimum disturbance of soil which is kind of zero tillage method evolved by traditional people. It is widely recognized that zero tillage is climate resilient technology. Logically, Bhoka method causes less soil disturbance in comparison to zero tillage method. But this method is no longer easy to practice due to lack of farm labour. Undoubtedly like other methods this method is also having weaknesses like more labour requirement and heavy weed infestation due to less tillage. However, this method has proven to be of great importance for sowing of maize crop in diara under wet soil.

Case Study-II
Bamboo Planting in the Rivers' Banks

Bihar state of India is one of the most flood-prone states, with approximately 76% of its population especially north Bihar being more vulnerable to threat of flood. Kale (1997) reported that the plains of north Bihar have recorded the highest number of floods during the last 30 years. Major rivers of the state are Ganga, Gandak, Koshi, Baghmati, Mahananda and Sone. Among the rivers, Koshi is known as "sorrow of Bihar. This river covers basically Nepal, Tibet and India. The total catchment area of Koshi is 74,030 Sq. Km and out of the total catchment area 11410SqKm lies in India (FMIS, Govt of Bihar). This river frequently changes its course of flow due to its unstable nature and causes huge silting and erosion during the flood. Most of the time farmers lose their lands due to erosion and consequently local people started thinking about potential solutions in order to control soil erosion. Local people started using traditional method which is well proven by generation for preventing soil erosion. Planting bamboo helps in preventing erosion and/or protect lands as bunds in areas of rapid run off. The water overflow and current of Koshi River is very high especially during flood or rainy season. Moreover, planting of bamboo is very common in the bunds of plots for managing the soil erosion. Bamboo roots run in the surface near the top soil about 2.5 to 3 feet and in deeper soil to up to 5 feet. If you carefully see their culture you will find bamboo to be of great use, from house making to bed (*Machan*) making. Now bamboo tree has become an integral part of Koshi region's culture.

Case Study-III
Traditional Direct Seeded Rice

Most of the fields of Jharkhand and drought regions of Bihar state are having mono-cropping usually upland rice. Usually 3–4 ploughings are done at long intervals from month of January to May. First broadcast the rice seed and then spread cow dung powder and do ploughing and leveling of field. This practice increases the process of mineralization of nitrogen from supplied organic manure and ensures easy availability of nitrogen to the young plants. This process also increases water holding capacity of soil. Due to less plant population and uneven distribution of plants in fields, farmers are getting less yields. Recently, Government of Bihar has started promoting Direct Seeded Rice (DSR) for solving the problems of labour, drudgery of women and ultimately climate. This DSR technology could be viable complement of their traditional method of sowing but there is a need of ensuring access of zero tillage machines to them. Bihar Agricultural University, Sabour, Bhagalpur, India started promotion of DSR in Banka district which is drought affected district of Bihar. (Source: Dey & Sarkar, 2011).

Case Study-IV
Traditional irrigation method

South Bihar frequently experiences scantly rainfall and drought like situations. The soil of south Bihar is mostly sandy and also marks an average slope of 1.13 to 0.76 metre per km across the region. As a consequence, farmers of this region were unable to grow rice crop due to scarcity of water. *Ahar-pyne is an indigenous water harvesting system of this region and it made it possible to grow rice in kharif season. There is a good network of rivers in south Bihar and during the rainy season there is flood also. In order to prevent wastage of flood water long narrow channels were developed towards villages from south to west side and these channels were locally called pyne. These pynes led off from river to temporary storage called ahar. The pyne may be of various sizes. It is also reported that length of some pynes are* 16 to 32 kms. *Some of pynes are having ten branches called* dasian pynes (pynes with 10 branches) and use for irrigating a large acreage of land. *Ahars are reservoirs with embankments on three sides and fourth side is open for natural drainage. These ahars are different from tanks as neither their beds are dugout nor* do the regular tanks have elevated embankments as do ahars. The water in ahars come either from rainfall (natural drainage) or through pynes. Ahar water is used for irrigation purpose from one field to another field by *dhonga (pipe).* These ahars bed could be used as bed for rabi crops. There is another interesting group dynamism being observed with this indigenous irrigation system for digging of pynes. There is no external agency involved in digging of pynes or maintenance of this irrigation method. There is a public announcement for digging of pynes and locally this process called *gomami*. Especially, people take '*gomani*'as a novel and religious cause and that's why they rarely deny for contribution. It is also being observed that the acreage of ahar-pyne is declining. Pant (1998) reported that there are three basic reasons of declining, first-abolishing of Zamidari system in south Bihar because they had capital and spent for maintaining this because they had more earning if land was irrigated. Second reason is after independence farmers are having a number of alternatives for irrigation. Third reason for declining is new diversion schemes undertaken by the irrigation department of Bihar. For reviving this system Krishi Vigyan Kendra (KVK), Aurangabad, Bihar of BAU, Sabour started maintaining ahar-pyne system in Aurangabad district of Bihar under *National Innovations in Climate Resilient Agriculture* (*NICRA*) project.

(Source: Pant, 1998)

Case Study-V
Traditional Bamboo Irrigation System

After many efforts of government, still many farmers are unable to access the facilities of canals and tubewells for irrigation. In the late 1960s government started promoting shallow tube well under minor irrigation programme. Few creative farmers reinvented shallow tube well as indigenous tube well is called as "*Bamboo boring (Bamboo tube well)*". They made it very cost effective and sunk it in several scattered plots. Pumpset mounted on bullock cart to use for several bamboo tubewells. Now these bamboo borings are very common across the Koshi region of Bihar (Biggs, 2005; Dommen, 1975). Krishi Vigyan Kendra (KVK), Supaul of BAU, Sabour has refined bamboo boring by using MS flatring, bamboo stripe, nylonnet, nylon rope, GI steel or PVC pipe. Generally, life span of ordinary bamboo boring is not more than 5 years but this improved methods life may go up to 10 years. This method is popularized among cucurbits growers. During summer when weather is too hot under that situation cucurbits require more number of frequent irrigation because of weather and less water holding of sandy soil (Sohane & Aditya, 2014). By using this cost effective, modified, indigenous method farmers can cope with high temperature especially during summer season.

2.5 Integrating ITK and Traditional People with Scientific Knowledge for Mitigation and Adaptation Under a Changing Climate

Despite of ITK's potential, it still remains untapped for impact mitigation and adaptation to climate change. ITK solely could not help climate change adaptation and mitigation but it could mainly add value to scientific research (Nyong et al., 2007). There are many ways to harness ITK's potential for climate change-.

– *Participatory Technology Development:* During 1980s and 1990s it was time when scientific world started acknowledging the creativity of local people for location-specific technologies development (Collinson & Lightfoot, 2000; Chambers et al., 1989). When technology is developed at field level in collaboration with scientists and traditional people, certain steps must be followed as advocated by Nyong (2007) the first step is to acknowledge the value of traditional knowledge which provides resilience capacity to the system. Second, there must be active participation of local people in decision making as well as in each step of technology development and encouragement of skill development in the community for combating the impact of climate change. Third step requires local people to be treated as equal partners. Fourth, there must be focus on best technology development for a particular situation instead of replacement of indigenous technologies with scientific ones. After development of these technologies there must be integrated mechanism of modern communication and scientific communication for scaling out of these technologies.

– *Integration of traditional and scientific weather forecast methods:*

  Ironically, both indigenous and scientific weather forecasting methods are having their own strengths and weaknesses. It is truly a herculean task to bring both the stakeholders at a common platform. This is only possible through policy intervention (s). Again there is a need of realizing importance of traditional weather forecasting methods to policy makers and convince them for framing policy about complementary use of these methods in scientific weather forecast (Chagonda et al., 2010). Traditional forecasting method is more location specific and for radius of one to 2 km^2 and this prediction is done by local people with the use of local biological, metrological and astrological indicators. Another side, scientific forecasting mostly use wind speed & direction and temperature and it measures through sophisticated instruments. This scientific weather forecast is basically available for larger area. After a number of studies and experience about prediction of weather forecast and climatic hazards both the systems have proven their importance. Therefore, there is a need of integration of scientific and traditional forecast system.

– *Scientific validation and refinement of traditional knowledge:*

  Scientific validation is one of the crucial elements to promote ITK for adaption and impact mitigation of climate change and integration with scientific knowledge system because local knowledge is an outcome of observation, experience and belief. This process will further enhance the rationality of ITK. Widdowson & Howard, 2008 cited in Matsui (2015) reported that scientific validation of ITK is difficult because foundation of both scientific and local knowledge systems are different. In the literature it is quite visible that now people are using scientific validation of ITK but this process is very less in magnitude and limited only to research studies. There are some widely use methods for scientific validation of ITK i.e. experts method, laboratory method and QuIK method. Among the validation methods, laboratory method is more reliable but not possible with all the ITK. Expert system is a judgmental method in which experts decide the validity of a particular ITK with the help of their past experiences and personal observations. Anne K. de Villiers (1996) designed a method "Quantifying Indigenous Knowledge (QuIK)" which is widely used for validation of medicine based ITK. For further scaling out of ITK, there are need of scientific validation and develop rationality of ITK for other users.

It is appropriate time for complementary use of ITK and scientific technologies under changing climatic conditions. However it is important to note that ITK and Grassroots people could help in sustainable and resilient social development. No doubt the scope and scale of suitability is for limited area and all the ITK may not be effective for given problem. Therefore, before going for integration and scaling out there is a need of validation and suitability of ITK for given the location.

2.6 Conclusion

In nutshell, ITK is a systematic body of knowledge which is generated by generations to generations by their experience, wisdom and by locally available materials. It is unique in its kind and reflects tradition and culture of that particular society. It is also well admitted that local people are not only recipients but they tend to develop some kind of solution to minimize the hassles of their day-to-day life. Certain local communities are realizing the impact of climate change and adapting to changed climate. Now this has been also well taken that climate changes are not affected and/or depended on bio-physical system but also on social system. But the adaptive capacity of a system and/or an individual varies from one another. This adaptive capacity depends on resource endowment, social capital, local institution, knowledge system, gender and governmental policy. Complementary use of traditional and scientific weather forecast could further strengthen the weather prediction system. ITK could be valuable which could be used as exclusive or complementary way for adaptation towards climate. There is an urgent need of documentation, management and dissemination of ITK before this knowledge is lost forever. Grassroots creative people could play remarkable role in technology development and dissemination vis-à-vis climate change. From ancient tradition, society has accumulated a treasurer of knowledge which helps them in adaptation and mitigation to climate change. But, there is an urgent need of integration of traditional knowledge with scientific knowledge for confronting the menace of climate change.

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Chapter 3
Greenhouse Gas (GHG) Emission Mitigation Options: An Approach Towards Climate Smart Agriculture

Namita Das Saha, B. Chakrabarti, A. Bhatia, N. Jain, Archana Sharma, and D. S. Gurjar

Abstract Agricultural practices are vital to ensure food and overall sustenance of life. Agricultural operations also emit greenhouse gases (GHGs) like methane (CH_4) and nitrous oxide (N_2O). GHGs emission from Indian agriculture sector during a period of 1970–2010, has risen by 75%. This is majorly attributed to input intensive agricultural practices which over emphasizes the use of fertilizers and other inputs. However, GHGs emission mitigation in agriculture sector can be achieved by the use of low carbon technologies which will sequester carbon in soil and also will reduce the emission of GHGs like CH_4 and N_2O. Mitigation techniques range from better land use management techniques, altering water and nutrient management practices, cultivation of varieties having lower emission potential, improved organic matter management, enhancing use efficiency of fertilizers and use of other agro-chemicals. The present chapter aims to discuss different GHG mitigation options in agriculture. The chapter elaborates on GHGs emission from agriculture, ways to mitigate GHGs emission in agriculture sector, and also discusses different case studies to reduce GHGs emission. There are several mitigation options which can be used for achieving a win-win situation towards climate smart agriculture with higher productivity and reduced GHGs emission; making agriculture more resilient to climate change.

Keywords Greenhouse gases · Emissions · Mitigation · Climate smart agriculture

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Abbreviations

ACZ	Agro-climatic zone
AM	2-amino-4-chloro–6-methyl-pyrimidine
BMP	Best management practices
CH_4	Methane
CO_2	Carbon dioxide
CSA	Climate smart agriculture
DCD	Dicyandiamide
DSR	Direct seeded rice
FYM	Farm yard manure
GDP	Gross domestic product
Gg	Giga gram (10^9 gram)
GHG	Greenhouse gas
GWP	Global warming potential
IPCC	Intergovernmental panel on climate change
LCA	Low carbon agriculture
LCC	Leaf colour chart
mV	milivolt
N_2O	Nitrous oxide
SOC	Soil organic carbon
SRI	System of rice intensification
SSNM	Site specific nutrient management
Tg	Tera gram (10^{12} gram)

3.1 Introduction

Different anthropogenic activities emit a significant amount of GHGs. Globally; agriculture is a vital source of GHGs emission. As food is basic need thus agriculture is a must and unavoidable activity throughout the globe. Primarily GHGs like CH_4 and N_2O are released from different stages of agricultural operations. According to one estimate by USEPA (EPA, 2012), Agriculture as a sole sector, is the largest most anthropogenic patron to global non-CO_2 GHGs emission, which amounted approximately 54 percent of total non-CO_2 emission during 2005 (about 5800 $MtCO_2e$). GHGs emission are not only restricted to agriculture and food production but several pre and post-activities also contribute a significant amount like fertilizer production at industries, transportation, postharvest activities and cooking of food and so on (Kehlbacher et al., 2016). Agriculture as a whole sector accounts approximately an amount of 10–12% of total anthropogenic GHGs emission (FAO, 2016). Agriculture contributes highest in anthropogenic N_2O emission (Reay et al. 2012). N_2O has a global warming potential (GWP) of 298; thus it means that N_2O can trap ~300 times more heat than equivalent amount of CO_2. Owing to have high GWP, concerns about N_2O triggers many issues. In Indian context, agriculture contributes approximately 58 percent of total emissions of N_2O, which mostly happens because of application of nitrogenous fertilizers (FAO, 2009a). An estimate of Ministry of Environment and Forests unveiled that N_2O is contributing approximately 13 percent of Indian agricultural GHGs emission. Apart from this, crop residues burning also contribute significantly to GHGs emission. The left over crop residues on the field, contain significant amounts of nitrogen and produce N_2O through the process of decomposition, while the burning of crop residues or vegetation usually releases CO_2; CH_4, N_2O and other ozone precursors and huge amount of aerosols (including black carbon) into the atmosphere (IPCC, 2014). While considering globally, the burning of Savanna and crop residues amounts ~6 percent of total GHGs emission from agriculture, but for India the amount is less than 1 percent (FAO, 2016). India is the world's highest emitter of GHGs from enteric fermentation, the second highest emitter from rice cultivation and use of synthetic fertilizers and the third highest from manure management, manure left on pastures and crop residues (FAO 2016).

The ever-growing global population has forced agricultural production systems as an input intensive production system for securing higher food production. Indian agriculture contributes 20% of national gross domestic product (GDP) and nearly 2/3rd of the population in India relies on agriculture (ICAR, 2015). Thus, in a country like India, the backbone of our economy is agriculture which supports national food security and thus the cultivation system should be sustainable and environment friendly without compromising the gross production capacity. Along with increase in demand for foods and other essential commodities, GHGs emission from agriculture has also increased several folds. Thus, there is no other way but to enhance the productivity from per unit of cultivable land as we have limited amount of cultivable lands.

To address this balance between increasing agricultural productivity and mitigation of emissions from different subsectors of agriculture, a new postulation of climate-smart agriculture (CSA) was introduced for the first time in 2009 (FAO, 2009a, b). Although it is considered as new concept but in reality, this approach altogether comprises of different age-old practices only. There was '1st Global Conference on Agriculture, Food Security and Climate Change' held in Hague, where CSA was defined as "agriculture that sustainably increases productivity and resilience (adaptation), reduces/removes emissions of GHGs, and enhances achievement of national food security and development goals" (FAO, 2010). In recent past, the Climate-Smart Agriculture Sourcebook (FAO, 2013) further enhanced the concept of CSA, with an intention of primarily benefiting marginal and small scale farmers of developing countries. There are immense scopes for using improved technologies which not only will help to reduce the GHGs emission from agricultural soil but also will increase the carbon storage in the soil. In this way agriculture can play a crucial role for alleviating climate change by following two ways: 1. By reducing GHGs emission to the atmosphere, 2. By assimilation and sequestration of atmospheric CO_2 into plant biomass and soil respectively.

3.2 Way Towards CSA

CSA is a holistic approach for transmuting agricultural systems to reinforce sustainable development and securing breads and butter in a climate change scenario. CSA is neither a new agriculture practice nor a system. It is a new approach that contributes to meet the development goals as well to bring about secured food supply in our nation and aims to increase productivity at a sustainable manner and mitigates GHGs emission.

CSA is defined and presented by FAO at the Hague Conference on 'Agriculture, Food Security and Climate Change' in 2010, mainly focused to the attainment of sustainable development goals. Three basic dimensions of sustainable development i.e., economic, social and environmental are addressed in an integrated fashion while also jointly addressing food security and climate challenge aspects as well. Thus, CSA comprises following five basic aims and three important pillars (Fig. 3.1).

1. It aims sustainable increase of productivity and income.
2. It aims to secured food supply in the nation.
3. It aims to strengthen the ability to build resilience and adaptation to climate change.
4. It aims mitigation of GHGs emission.
5. It aims to meet the overall development goals.

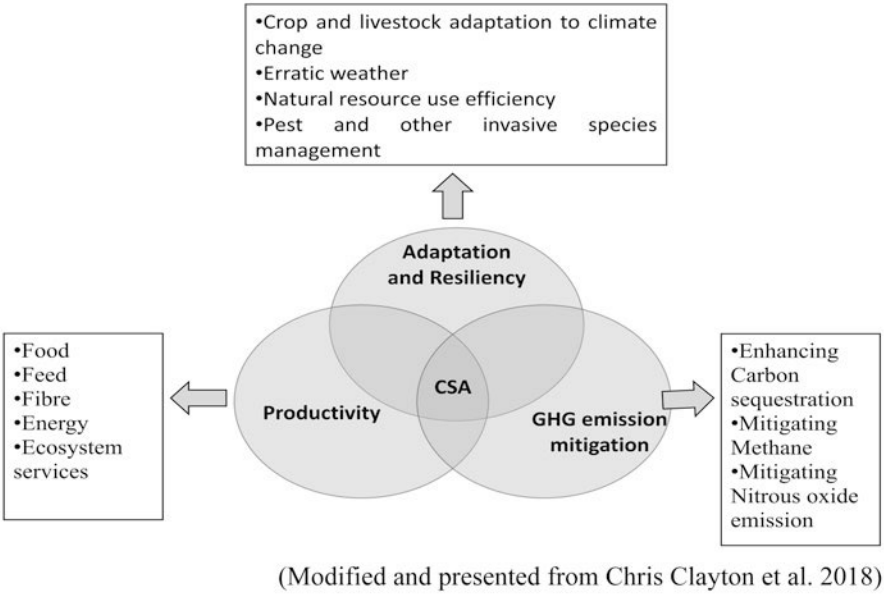

Fig. 3.1 Three basic pillars of CSA. (Modified and presented from Chris Clayton et al., 2018)

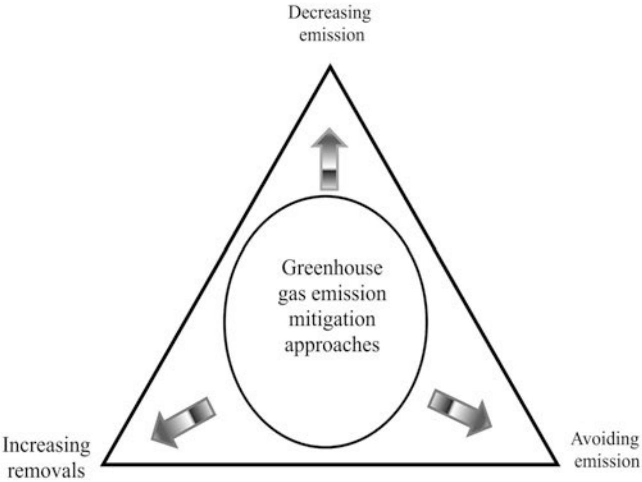

Fig. 3.2 Broad approaches for GHGs emission mitigation from agricultural soil

In CSA, the main focus is on enhancing resource use efficiency, fertilizer use efficiency, crop intensification and mitigating GHGs emission from agricultural practices. Thus, mitigating GHGs emission from agriculture is one of the strongest pillars for CSA. India's National Action Plan highlights sustainable agricultural practices that can help to mitigate GHGs emission. Of the eight missions to combat climate change, the National Action Plan contains one mission fully dedicated to mitigate agricultural emissions. Three broad approaches for GHGs mitigation can be considered (Pathak et al., 2014) and is depicted below (Fig. 3.2).

A) **Reducing emission of GHGs**

This approach refers to the use of different improvised technologies and good management practices that are targeted to lessen emissions of major GHGs. The technologies include improved water management, increasing input use efficiency, using improved crop varieties with less emission potential etc.

B) **Enhancing removals of GHGs**

A large amount of atmospheric carbon dioxide (CO_2) can be removed and trapped as photosynthetically assimilated product in crops. To keep this trapped CO_2 for considerably longer period of time we can follow the residue incorporation into soil instead of burning them at the field. Hence, agricultural soils can serve as a sink of atmospheric CO_2.

C) **Avoiding emissions**

The preliminary production activities like production of agricultural inputs such as fertilisers production at the industry itself, farm machinery generation, soil preparation, management of crop residues and irrigation contributes the major part of emission (Pathak et al., 2010). Hence, the target is to use alternative energy sources from different biofuel producing crops and perennial plants, crop residues in the form of alternative energy sources and other alternative non-conventional energy sources. The net gain from the use of these non-conventional sources is that fossil derived emissions could be replaced. Thus, mean while producing inputs for agriculture, if we use non-conventional sources of energy to produce them, we can avoid huge amount of emission from fossil fuels burning. Apart from this, GHGs emission can also be steer clear off by alteration in different management practices that are employed during different steps of agricultural practices.

3.3 Major GHGs from Agriculture

Agricultural soils majorly release CH_4 and N_2O. Agriculture sector plays the dual role of both emission and consumption of GHGs. Fuels burnt during various agricultural operations, burning of crop residues specially rice straws, decomposition of organic matter altogether causes carbon dioxide (CO_2) emission. CH_4 gets generated by methanogenesis in soil by a specialised group of microbes called methanogens and this process gets initiated at a redox potential–150 mV (Wang et al., 1993) but CH_4 formation is more when the redox potential reaches further low -250 mV to -350 mV. Such low level of redox potential easily develops in submerged rice fields. Therefore, wetland rice cultivation practices are potential source of CH_4. Wetland rice cultivation is the conventional practice for rice cultivation in India wherein puddling and continuous submergence are maintained. Such water regime plays crucial role in methanogenesis and produced CH_4 gets exchanged between soil and atmosphere easily. CH_4 generation is more in the soil containing more SOC content and application of organic manure in soil further accelerates CH_4 emission. On the Global account, irrigated rice contributes maximum CH_4 emission which amounts 70–80% followed by rainfed contributing 15% and deep-water rice contributes 10% of the total CH_4 produced and emitted from rice field (Wassmann et al., 2000). But CH_4 emission from upland rice is non-significant (Neue, 1997).

CH_4 is also emitted via methanogenic bacteria living in rumens of ruminant live-stocks like cattles, sheeps and additionally by termites. Crop residue burning is another area which adds good amount of CH_4 to the global methane budget. According to Yevich and Logan (2003), burning of crop residues resulted in emission of 0.6 Tg $yr.^{-1}$ of CH_4 in India in the year 1985. Although rice cultivation is being blamed always for significantly contributing CH_4 emission but enteric fermentation in ruminant live-stocks is actually the major source of CH_4.

Nitrogenous fertilizer is the main culprit for emitting N_2O from fertilized soils. But for unfertilized soil, N_2O gets emitted from the existent and background nitrogen sources. Both nitrification and denitrification processes is responsible for N_2O production in soil. N_2O is an intermediate product in the sequence of reactions of denitrification and in case of nitrification process, N_2O is again a by product that leaks from microbial cells into the soil and ultimately into the atmosphere. The direct and indirect N_2O emissions from Indian agricultural soils was estimated in the year of 2007 and was found 136.29 Gg (35.3 Tg CO_2 equivalent) and 30.61 Gg (5.8 Tg CO_2 equivalent) respectively (INCCA, 2010). Generally, an increase in N_2O emission is observed following irrigation and precipitation. Crop residues burning also contribute to the global N_2O budget. Congenial amount of soil moisture and carbon further accelerates the production of N_2O if amount of nitrate source is available.

3.4 Possible Mitigation Measures of GHGs Emission from Agriculture

There are many opportunities to mitigate GHGs by employing different improvised agricultural technologies and management options. Mitigating GHGs emission from agriculture can be attained by sequestering more carbon in soil and reducing CH_4 and N_2O emission. Conservation agriculture practises that allow to leave leaf residues/ crop residues, reduce mechanical disturbance in soil specially avoiding deep tillage, encourage the build-up of soil carbon are suitable for mitigating GHGs emission from agricultural soil. Apart from these, incorporation of agro-forestry increases C-stocks in soil (Table 3.1). Scopes for mitigation also include alterations in crop genetics and irrigation management practices, need based application of fertilizers can reduce N_2O and CH_4 emission from agricultural soil. In present chapter our efforts made to focus on all probable mitigation options only in crop cultivation practices, we have excluded the livestock rearing and related aspects for emission and mitigation. While considering natural resource management, the following three major areas can be targeted (Table 3.1).

(i) Following best management options for crops and farming system
(ii) Following best management options for fertilizer, manure and biomass management
(iii) Following best management practices for soil management

3.5 Mitigation of CH_4 Emission

- Actually soil plays dual role both as source and sink for CH_4. But the behaviour of soil is being regulated by moisture content, N level and types of ecosystem. These all factors ultimately decide that a soil will be playing role as source or sink for CH_4. Methanotrophic bacteria which dwells in soil, consume CH_4 (McLain and Martens, 2006) and methanogenic bacteria produce CH_4 by the biochemical process namely methanogenesis (Chan and Parkin, 2001). Since methanogenesis is an anaerobic biochemical process, thus water management during rice production is a vital factor for minimizing CH_4 production from puddled rice field. Short spell of mid season drainage of water allows the soil to become aerobic which

Table 3.1 Overview of mitigation strategies in agriculture and their probable/expected mitigation benefits

Mitigation strategies	Specific mitigation activity	Expected mitigation benefits	References
Best management options for crops and farming system	Use of improved crop varieties for higher productivity	Direct and indirect emissions/kg yield gets ↓ed.	IPCC recommendations Smith et al. (2007)
	Residue management through other alternative options other than biomass burning	↓es direct emissions	
	Inclusion of nitrogen fixing plants to reduce external inputs (fertilizer) loads	↓es both direct and indirect emissions	
	Introduction of short duration legume crops	↓es direct and indirect N_2O emissions	IPCC recommendations Smith et al. (2007)
	Optimization of Rice cultivation practices (e.g. system of rice intensification)	↓es CH_4 but may increase N_2O emissions	USEPA (2010)
Best management options for fertilizer, manure and biomass management	Demand driven fertilizer application, right timing of application for maximum uptake; employing slow release fertilizers and nitrification inhibitors	↓es emissions by 1/3rd to 3/4th amount	Vanotti et al. (2008)
	Avoid biomass burning	↓es emissions of both CH_4 and N_2O	IPCC (2006) vol.4, ch.2
	Use of compost manure	↓es direct emissions of N_2O	IPCC recommendations Smith et al. (2007)
Best management practices for soil management	Introducing legumes; use cover crops; Intercropping; avoid leaving bare soils and fallows	↑es soil organic carbon (SOC), ↓es emissions of direct and indirect N_2O	Smith et al. (2007)
	Reduced tillage No tillage	↑es SOC	Smith et al. (2007)
	Avoid soil compaction	↓es N_2O emissions	Bhandral et al. (2007)
	Adoption of agro-forestry	↑es SOC	Albrecht and Kandji (2003)
	Choosing deep root plantation system	Efficient use of resources and ↓es GHGs emission	Albrecht and Kandji (2003)

oxidize CH_4 and reduces CH_4 emission (US-EPA, 2006). Additionally, manure management, specific fertilizer application like Ammonium Sulphate may further reduce CH_4 production. Also choice of cultivar and biomass (straw) management also potentially reduce CH_4 production (Reicosky et al., 2000). Following are some strategies for CH_4 mitigation from rice field:

- Promoting aerobic degradation/composting of organic matter.
- Use of rice cultivars which are having less numbers of unproductive tillers.
- Use of cultivars which have high root oxidative capacity.
- Low C: N ratio of organic manure is preferably to be used to reduce CH_4 genesis.
- Fermented manure like biogas slurry application is preferable instead of unfermented FYM.
- Using direct seeded rice technique (DSR) instead of conventional puddled submerged rice cultivation technique.
- Sulfur containing fertilizers like Ammonium sulphate reduces CH_4 generation because sulfate reducing bacteria out competes methanogens (Van der Gon et al., 2001).
- Application or augmentation of soil with methanotrophic microorganism for oxidation of methane.

3.6 DSR Technique

Direct seeded Rice (DSR) or aerobic rice cultivation practice is a new alternative to puddled rice cultivation which potentially can reduce CH_4 generation as compared to conventional submerged and puddled rice. As in DSR technique, continuous submergence is not required thus, DSR emits less CH_4. A drastically reduced amount of CH_4 (75%) emission from DSR is estimated and thus DSR potentially reduce GWP (Pathak et al., 2012) but there are controversies in terms of less net grain production from DSR than the conventional practices of rice cultivation.

3.7 Mitigation of N_2O Emission

The management practices which directly or indirectly improve N-use efficiency are the potential options for N_2O emission mitigation. Majorly the practices which retard the microbial processes of denitrification, leading to less N_2O formation will reduce N_2O emission. The available management options to reduce N_2O emission are as follows:

- **Matching N supply with crop demand:** The concept behind this option is that it follows the principle of site-specific nutrient management (SSNM) which employs detailing of crop nutrient requirements, background nitrogen content, and the use efficiency of applied fertilizer (Pathak et al., 2010). Use of urease

Table 3.2 Nitrous oxide mitigation efficiency of different nitrification inhibitors

Nitrification inhibitors	Mitigation efficiency (%)
Neem seed cake	10–21
Neem seed oil	15–21
Nimin (derivative)	25–35
Ca-carbide (coated)	12–29
Dicynamide (DCD)	13–42
Thiosulphate	15–20

Source: Kumar et al. (2000a, b), Pathak et al. (2001), Majumdar et al. (2002), Malla et al. (2005)

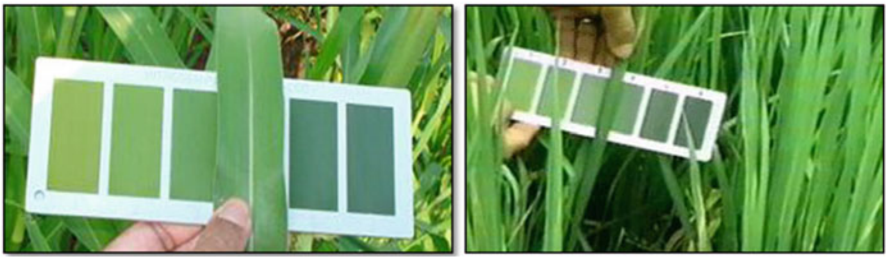

Fig. 3.3 Leaf Colour Chart (LCC) application for demand driven application of Nitrogen-fertilizer

inhibitor and nitrification inhibitors could increase the nitrogen use efficiency by retarding the hydrolysis of urea and by regulating nitrate accumulation in soil. Nitrapyrin, dicyandiamide (DCD), 2-amino-4-chloro–6-methyl-pyrimidine (AM) are some nitrification inhibitors which can reduce N_2O emission (Pathak and Nedwell, 2001). Data in Table 3.2 shows the N_2O mitigation potential of different nitrification inhibitors. Apart from chemically synthesized nitrification inhibitors, many plant-derived derivatives like neem oil, neem cake and karanja seed extracts are equally effective to act as nitrification inhibitors. Nitrification process gets reduced by the action of these inhibitors (natural or synthesized) and thus due to less precursor (NO_3^-) availability, N_2O emission gets reduced. A combination of dicyandiamide (DCD) and hydroquinone have been found to lowering of emissions of both N_2O and CH_4 in rice crop.

- **Demand driven application of fertilizers:** Use of leaf colour chart (LCC) (Fig. 3.3) could reduce N_2O emission, as LCC is a good tool for Nitrogen management in crops (Adhikary 2015). Foliar application of fertilizers also reduces the emission of N_2O. Cyanobacteria are known to fix nitrogen in soil, thus lower the need of fertilizer. One estimation by explained that demand driven N-use by a leaf colour chart (LCC) can potentially reduce N_2O emission and GWP by about 11%.

- **Avoid soil compaction:** Compacted soil contributes to anoxia (lack of oxygen). In wet soil the anoxia problem is compounded causing emission of N_2O. Management in the tillage operations such as adopting zero or minimum tillage, improving drainage of soil, raised bed planting and ultimately reducing compaction will help in reducing the gross N_2O emission from soil.

- **Irrigation management:** Requirement oriented irrigation practices will increase the N-use efficiency and thus indirectly will reduce N_2O emission. Moreover, economic application of irrigation saves both water and energy that is used for pumping. Technologies like drip irrigation, sprinkler irrigation, use of soil moisture meter can also increase N-use efficiencies.
- **Augmentation of soil with N_2O reducing bacteria:** Nature harbours abundant N_2O reducing microbial bacteria and archae who can transform N_2O to nitrogen gas (N_2) by virtue of having *nosZ* gene which is actually responsible for production of N_2O reductase (N_2OR) enzyme and thus the end most step in denitrification takes place and N_2 gas instead of N_2O gets emitted. This is natural N_2O sink in nature.

3.8 Carbon Sequestration in Soil

Globally intensive agricultural practices, deforestation and shifting cultivation has resulted decline in SOC. But better understanding of cropping sequences and adoption of alternative management practices can help in restoring organic matter in the soil (Chakrabarti et al. 2019). Agricultural soil can sequester a significant amount of carbon. Use of improved and best management practices have shown that agricultural practices with scientific approaches at each step, can mitigate the greenhouse effect by increasing carbon storage in soil. Management practices like reduced tillage, use of cover crop, balanced fertilization, manuring, residue incorporation, crop rotation, improving soil biodiversity can enhance sequestration of SOC (Fig. 3.4).

3.9 Conservation Agriculture (CA)

Conservation agricultural practises having three main principles which are as follows:

(i) Least possible disturbances of soil,
(ii) Permanent soil cover and
(iii) Diversified crop rotation

Overall, CA is an approach to attain climate resilient agriculture. It has several benefits including reduced GHGs emission, less use of fossil fuel, reduced soil erosion, improvement in soil structure, more water retention, reduced variation in yield, as well as enrichment of soil carbon and carbon sequestration (Blanco and Lal 2008). A report says that improved fertility management practices can potentially increase the amount of SOC @0.05–0.15 Mg^{-1} ha^{-1} C $yr.^{-1}$ (Lal 2004). Not only that, balanced fertilization can also enrich total carbon and organic carbon content of soil (Majumdar et al., 2008). Apart from these, introduction of sod type legumes and

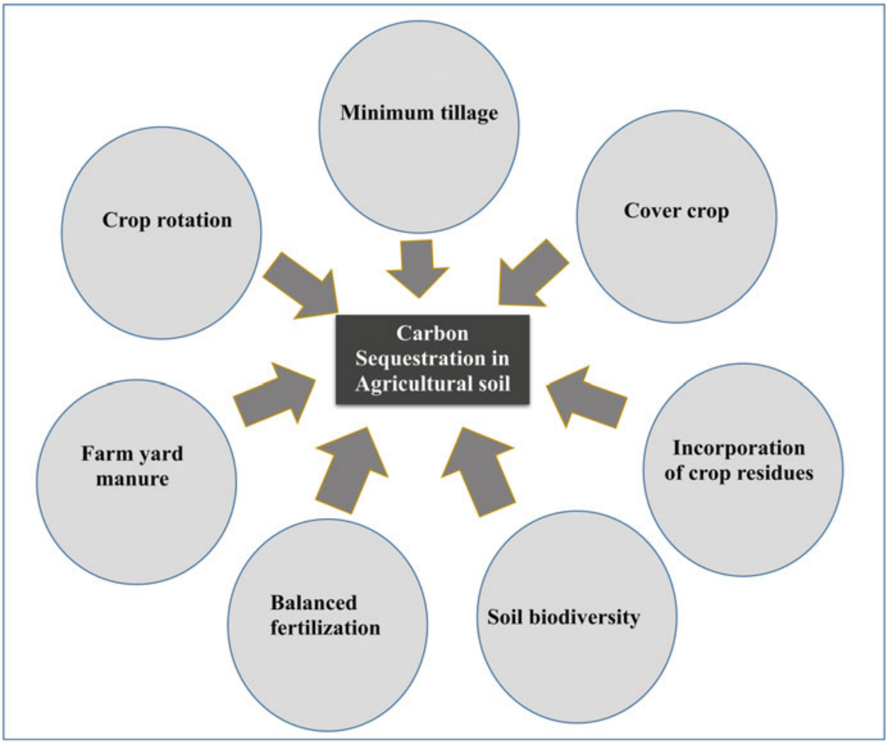

Fig. 3.4 Components of carbon sequestration in agricultural soil

grasses in crop rotation can potentially increase SOC and improve quality of soil. Resource conserving technologies such as zero or minimum tillage, direct seeding, permanent or semi-permanent soil cover with residues of previous crops, crop rotation has high potential to improve use efficiency of natural resources like soil nutrient and water; will enhance soil carbon stock and thus will reduce carbon emission from agricultural soil. Zero tillage practices, crop residue retention on soil and cultivation of leguminous crops are certain strategies which enhance carbon content in agricultural soils (Bhattacharyya et al., 2009; Pathak et al., 2017).

3.10 Low Carbon Agriculture (LCA)

In order to make Indian agriculture more sustainable in future, it is an urgent call to identify and screen management options which will be more climate resilient and less carbon-intensive which can help in enhancement of SOC and reduced GHGs emission (Pathak et al., 2012). The term LCA is given for the set of agricultural practices which target to reduce energy consumptions and GHGs emission from agriculture. It comprises the set of agricultural practices which improves environmental sustainability. There are many options for LCA (Table 3.3), which have been identified and are well proven. But in a large country like India, these innovations only can succeed when they are oriented to focus on specific environmental and socio-economic condition (Garnet et al., 2010, Norse et al., 2012, Uphoff et al., 2006). But, there may be some extra expenditure for implementation of such technologies at the field scale which may reduce farmers' net income. The main hindrance in embracing LCA in India is due to lack of financial incentives from Government. Although the pilot efforts could succeed yet Indian farmers are not readily coming forward to adopt these innovations (Islam et al., 2014, Charnoz et al., 2013, Kumar et al., 2001, Rastogi et al., 2011). Such repelling tendencies can be attributed to some examples like some of the programs seek long gestation period (e.g. agro-forestry) and uncertainties. Thus, complete success of any LCA technology can only be achieved when it addresses socio-cultural and environmental settings of a particular area (Islam et al., 2014).

3.11 Mitigation Technologies for Different Agro-Climatic Zones of India

India is extremely diverse in terms of its climate, socio-cultural and ethical aspect. Due to extremely diverse climate pattern, India is divided into different agro-climatic zones (ACZ). The 15 ACZs have been identified based on predominant climatic conditions which comprise diversified cropping pattern ranging from tropical to temperate crops. Majorly marginal and small farm holdings are operational in India. As earlier also mentioned, the low carbon technologies should be climatic zone and socio-cultural group specific to attain successful implementation and up-scaling of such mitigation technologies. The major low emission technologies (Pathak et al., 2012) which can be used for mitigation of GHG emissions in various agro-climatic zones are presented in below.

- **Western Himalayan region:** This zone comprises of Jammu & Kashmir (J&K), Himachal Pradesh (HP) and Uttarakhand (UK) states. Major cropping systems that are followed in this region are: Rice-Wheat; Maize-wheat; Pulse/Soybean-wheat; sugarcane-wheat. Few identified mitigation technologies for this region are: Zero-tillage**;** Dip irrigation; Nitrification inhibitors.
- **Eastern Himalayan region:** This region comprises of Assam (AS), West Bengal (WB), Sikkim (SK), Mizoram (MZ), Meghalaya (ML), Arunachal Pradesh (AP), Manipur (MN), Nagaland (NL), and Tirpura (TR). This region receives a good amount of rainfall. Thus, have mainly Rice based cropping pattern. Some examples are: Rice-jute-rice; Rice-oilseed; Rice-vegetable; Rice-wheat; Rice-Maize, Rice-Maize; Rice; Rice-Fallow; Potato-tobacco; Rapeseed/mustered; Cotton-jute. Few identified low carbon technologies are: Slow release fertilizers**;** DSR; Intermittent irrigation and mid-season drainage**.**

Table 3.3 Proven LCA technologies in Indian agriculture system

Technology	Pros	Cons	Interventions required
Zero tillage	Saves fuel Saves water Farmer saves money in terms of less expenditure Burning of crop residues issue is also avoided	Paucity of understanding Shortfall of good technology Ancient customs tough to break, especially when constitutively embedded into local cultures Scarcity of zero till drill	Awareness generation Refinement of technologies Skill development
Alternate wetting and drying	Has potential to save water in case of rice cultivation in a range of 25–30% Aerobic decomposition of plant materials allows reduced CH_4 emission (30–35%) Less energy usage Labour cost gets reduced (10–15%) in case of rice crop	Weed problem Weed management enhances cost in term of labour and chemicals Yield penalty (5–10%) in rice Risk of crop failure in dry areas Expected increase of N_2O emission	Accurate weather forecasting Development of cost effective and environment friendly herbicides Provisions for carbon credit for mitigation and incentives for saving water
Drip and sprinkler irrigation	Saves irrigation water Saves energy Reduce nutrient loss and enhance nutrient use efficiency	Initial investment for infrastructures and maintenance is high Requires specific technical expertise	Enhancing public awareness Providing subsidy from government side for initial installation Providing training through Krishi Vigyan Kendra (KVK) at rural level Introduction of carbon credits for mitigation
Slow release nitrogenous fertilizer	Leaching losses gets reduced N-application rate gets reduced and N-use efficiency gets enhanced	Highly technical application process and understanding is required Risk of yield loss	Awareness generation Increase commercial product availability at subsidized price Introduction of carbon credits for mitigation
Nitrification inhibitor/modified urea granules/ neem coated urea (NCU)	Reduce nitrogenous fertilizer applications Less leaching losses and less application of N-fertilizer reduce N_2O emission	Lack of awareness among farmers	Increase awareness among farming community Providing subsidized product
System of Rice intensification (SRI)	Less usage of irrigation water Less pest and diseases	Require special machines and construction structure for precision levelling of fields	High management cost Increase awareness

(continued)

Table 3.3 (continued)

Technology	Pros	Cons	Interventions required
	Less labor costs Increase total income	and water delivery system Shortfall of technical knowledge	
Direct seeded Rice (DSR)	Irrigation water can be saved upto 25–30% 10–15% saving is possible in labour and energy 70–75% reduction in CH_4 emission is expected	Majorly weed problems arise Compromise in terms of yield loss upto 5–10% N_2O emission increases upto 45–50%	Development of environment friendly herbicides which should be of low cost and effective Organization of training for farmers Incentives provision should be there for saving of water Carbon credits provision should be introduced
Residue management	Reduce methane emission Reduce burning generated CO_2 emission Reduce burning generated methane emission	Lack of proper technological knowledge for residue management at a cost-effective way	Training Introduction of carbon credits for mitigation
Site specific nutrient management (SSNM)/use of LCC/ Precision farming	Reduction in nutrient losses Enhance nutrient use efficiency Reduce extra fertilizer input and cost	Application process is highly technical High production cost	Incentives to farmers should be there Carbon credits provision should be introduced
Crop diversification	Reduction in methane emission Saves irrigation water (50–60%) Saves labour and energy cost	Lack of post-harvest facilities Inadequate marketing channels Increase in N_2O emission (45–50%)	Market and post-harvest infrastructure development Awareness generation
Agro-forestry	Increase carbon sequestration Additional income Creates micro habitats Timber and non-timber products as additional gain Benefit from REDD +	Long gestation period REDD+ benefits yet to get functional Implementation of government forest rules	Carbon credits provision should be introduced

Source: Pathak et al. (2012), Wang et al. (2017)

- **Lower Gangetic plains region**: West Bengal (WB) comes under this region. Rice-wheat; Rice-oilseed-rice; Rice-vegetable; Rice are main cropping systems and few identified low carbon technologies are: Nitrification inhibitors; Intercropping; DSR; Low-energy irrigation; Sprinkler; Slow release fertilizers.
- **Middle Gangetic Plains region:** Uttar Pradesh (UP) and Bihar (BR) come under this region. Rice-Wheat; Maize-Wheat; Maize-Pulses; Rice-vegetables; Rice-Pulses; Sugarcane are main cropping system that are followed and Intermittent irrigation; mid-season drainage; SRI; DSR; Nitrification-inhibitors are few examples of well proven low carbon technologies which can be followed in this region.
- **Upper Gangetic Plains region**: Part of Uttar Pradesh (UP) comes under this region. Maize-Wheat; Rice-Wheat; Rice-Pulses; Maize-oilseed; Millet-Pulses; Maize-Pulses; Sugarcane-wheat; Millet-Wheat; Maize-fodder. Low carbon technologies which can be followed here are: Green manuring; Nitrification inhibitors; Slow Release fertilizers; Crop residue incorporation; Alternate wetting and drying.
- **Trans Gangetic Plains region:** Punjab (PB), Haryana (HR) and Rajasthan (RJ) come under this region. Main crops in this region are Rice and Wheat. Few examples of cropping systems which are prevalently followed here are: Maize-wheat; Maize-oilseed; Rice-Wheat; Cotton-Wheat. A few LCA which can be followed here are: Crop residue incorporation; DSR; Low-energy irrigation; SSNM; Nitrification inhibitors; Intermittent irrigation and mid-season drainage; Green manuring.
- **Eastern Plateau and Hills region:** This region comprises of Jharkhand (JH), Chhattisgarh (CG), Madhya Pradesh (MP), Orissa (OR) and Maharashtra (MH) states. This region also follows rice as main crop. Few examples are: Rice-wheat; Rice-oilseed; Rice-pulses; Rice-fodder; Rice-vegetable; Rice-rice. Few examples of well proven low carbon technologies for this region are: mechanization; DSR; Better designs of machinery; Vegetative carbon storage; Carbon capture farming; SRI.
- **Central Plateau and Hills region:** States those come under this region are Madhya Pradesh (MP), Rajasthan (RJ), Uttar Pradesh (UP). Main cropping systems in this region are: Fallow-oilseed; Fallow-pulses; Millet-oilseed; Pulses/Soyabean-wheat; Pulses-oilseed; Maize-fallow; Millet-fallow; Rice-wheat; Rice-fallow; Rice-pulses. Oilseeds and Pulses are main crops in this region. Few well proven LCA are: Zero-tillage, Crop residue incorporation, Green manuring, Biogas slurry application, DSR, intermittent irrigation and mid-season drainage.
- **Western Plateau and Hills region:** Part of Madhya Pradesh (MP) and Maharashtra (MH) comes under this region. Cotton and millets are main crops here. Few cropping systems are: Pulses-oilseed; Cotton-oilseed; Millet-wheat; Sugarcane-wheat; Cotton-wheat; Millet-pulses; Rice-wheat; Millet-oilseed; Rice-pulses; and few mitigation technologies are: Zero-tillage; Intermittent irrigation; Biogas slurry application; SRI; 2–3 mid-season drainage; Crop residue incorporation; Green manuring; Intercropping.

- **Southern Plateau and Hills region:** Andhra Pradesh (AP), Karnataka (KA), Tamil Nadu (TN) come under this climatic region. Main cropping system are Rice-rice; Rice-pulses; Rice-oilseed; Millet-fallow; Sugarcane; Vegetable-vegetable; Millet-oilseed; Maize-wheat; Rice-oilseed-rice; Cotton-wheat. DSR; Intermittent irrigation, mid-season drainage; SRI can be followed here for mitigation of emission of GHGs from agriculture.
- **East Coast Plains and Hills region**: Part of Orissa (OR), Tamil Nadu (TN), Andhra Pradesh (AP), and Pondicherry (PY) come under this region. Mainly rice based cropping system is followed here. Few examples are Rice-rice; Cotton-wheat; Rice-pulses; Rice-Fallow; Rice-oilseed; Rice-vegetable. 1–2 mid-season drainage; DSR; SRI and intermittent irrigation can be followed in this region.
- **West Coast Plains and Ghat region**: Coastal regions of Kerala (KL), Tamil Nadu (TN), Karnataka (KT), Maharashtra (MH), Goa (GA) come in this region. Mostly rice based systems are prevailing here. Rice-rice; Millet-pulses; Rice-oilseed; Rice-pulses; Rice-oilseed-rice; Rice-fallow; Rice-fodder; Rice-vegetable; are few examples of cropping systems. DSR; mid-season drainage and intermittent irrigation are few well proven mitigation technologies which can be practised here.
- **Gujarat Plains and Hills region**: Dadra & Nagar Haveli (DH), Gujarat (GJ), Daman Diu (DD) come under this region. Rice-fodder; Rice-wheat; Cotton-wheat; Fallow-oilseed; Sugarcane; Pulses-oilseed; Millet-wheat; Maize-maize; Millet-pulses; Millet-oilseed; Cotton-oilseed; Fruit-vegetables are few examples of prominent cropping systems. Carbon sequestration; Vegetative carbon storage can be followed as mitigation technologies.
- **Western Dry region:** Rajasthan (RJ) comes under this region. Millet based cropping system is mostly followed. Few examples are: Millet-Fallow; Millet-Oilseed; Fallow-pulse; Millet-wheat; Pulses-oilseed; Millet-pulse; Fallow-oilseed. Technologies for mitigation may be Carbon sequestration.
- **Island region:** Andaman & Nicobar (AN) and Lakshya Deep (LD) islands come under this region. Coconut is most predominant plantation species here. Till date no reports are available for low emission technology for this region. Thus research should focus on this.

3.12 Government Policy for Implementing, Adopting and Scaling up of Low Emission Technology

Prevailing policy structures, identified agro-climatic conditions further define policy formulation and priority setting for a specific area or zone (Norse et al., 2012). Strong policy guidelines along with financial incentives and training of farmers will facilitate rapid deployment of LCA technologies. Although many LCA technologies are available on today's date but they are yet to be embraced by the farmers of India (Smith et al., 2007). The major gap seems to be existing between the development of a policy at national scale and implementation at field itself. Majorly, the identified gaps are as follows: i. The policy developed at national scale is not streamed into specific province and does not get imbibed into local scale plans (because there is always a chance that state governments either can opt or not opt to support such LCA initiatives as agriculture is a decentralized sector); ii. Financial incentives are rarely being offered for adoption of GHG mitigation technologies (As such LCA technologies many a time compromise yield such as SRI, thus farmers are not eager to imbibe these technologies, so provision of incentives may open up hope of adoption of such LCA). For successful adoption and further scaling up of LCA technologies, the technologies must focus on increasing yield and mitigation efficiency as additional benefits. Thus, while developing policies, the policy makers must focus on the following facts: i. Provision of incentives for the farmers who is adopting carbon neutral practices ii. Screening, defining technologies in agriculture that can both mitigate and improve sequestration iii. Development of stringent policy on management of crop residues especially discouraging or banning burning iv. Identifying alternative technologies for handling crop residues wisely v. Identifying some innovative technologies/ industrial applications for crop residues vi. Giving incentives to the farmers for encouraging adoption of alternative and extra income generating technologies for crop residue managements vii. Government should assure the purchase of residues from farmers if not burnt. These policies must then be streamed into state and local plans. As farmers will look for assured benefits from a particular technology, thus carbon credits in agriculture sector must be introduced. There is a voluntary commitment by India to reduce its emissions intensity (emissions per unit GDP) between 20 to 25 percent below 2005 levels by 2020 (Rastogi et al., 2011). As India is an agriculture based country, thus agriculture sector can help India in meeting this target by taking a system approach of "climate smart" agriculture involving application of technologies that would increase productivity and income and at the same time will reduce GHGs emission.

3.13 Conclusions

India is a party to the Paris Agreement. According to the guidelines of this agreement, two key points for each country have been mentioned. They are: i. Each country should start mitigation activities with immediate effect and ii. Each country should plan and functionalise mitigation initiatives for five-years. Food security is the most important aspect for ever-increasing population which we need to increase but presently productivity is almost stagnant. So increasing in productivity will lead to input intensive agricultural practices. Thus, to trade off the agricultural productivity and emissions, we should encourage practices that promote good land governance and ultimately can help in minimizing emissions of GHG. Such practices include (1) zero/ minimum/ reduced tillage, which help in reducing/preventing soil erosion, increase SOC content in soil, and may reduce CH_4 emission but N_2O emission may rise; (2) maintain continuous soil cover with residues from preceeding crops, live cover crops or perennial vegetations, which helps to increase SOC; (3) Precise application of N preferably split application with demand driven approach is expected to reduce N_2O emission; and (4) organic manure management practices to reduce CH_4 and N_2O emission. Thus, immense opportunities exist in all stages of agricultural practices to reduce GHGs emission. Government incentives, policies should support those identified and proven best agricultural land management practices and land governance which has the potential to reduce its environmental footprint and offset GHGs emissions.

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Chapter 4
New Paradigm for Higher Crop Productivity Through Climate Smart Strategies

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Abstract Various, relentless, and site specific impact on farming community are expected with weather alteration. New approaches to climate resilient farming or crop husbandry practices is therefore critical to gaining future foodstuff availability and vagaries of weather goals. Agriculture is a well-known cause as well as a sink of different climate deteriorating factors include greenhouse gases. Therefore it is need of an hour to alter our various farming or allied practices in more climate resilient way to conquer various issues become very challenging. Application of climate smart strategy for higher crop productivity become suitable eco-friendly option to our growers upto certain extent but feasibility become a question mark. This concept leads to different issues mainly reducing level of greenhouse and different harmful gases level in atmosphere, increasing crop productivity in sustainable manner and reinforcement resilience to various weather modification (adaptation). Availability of water and diurnal variation of temperature etc. become critical factor for higher crop growth and production. Various climate-inducted change in soil microbes, insect pest, and weeds variation or shifting in weed taxonomic behaviour in our ecosystem. Unquestionably, various weather or climate induce flux will change the availability of foodstuff and its supply pattern, local competiveness and changing social and economic solidity. Adjustment with the environment is an important aspect that may reorient weather alteration impact on crop productivity. We should reorient our research programme to accurate water supply per unit area, pesticide and nutrient use technology appropriate for marginal to small farmers. Minimum tillage, location specific management option based on modern technique etc. require to be address. Expansion of suitable integrated farming system models for diverse location, keeping in view of farmer' available resources and its feasibility in context of various cropping system is very much pertinent. Control of insect pest through various climate smart practices mainly based on integrated management aspect or precision farming become very much fruitful in present situation.

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4.1 Introduction

Under the threat of population explosion, the need of farming products – fibre, fodder and food – will rise radically. Under the era of climate change, requirement of these thing put more pressure on variable available resources including water and land. Further, foodstuffs cultivation, has to convene significantly rising burden in the future for such huge expansion of population throughout the world. In Asia as well as other continent of world, more food production from limited area of land become a limiting factor (Mukherjee, 2015a, b). Recently molecular biology and other genetic engineering tools has open new avenue for further and faster advance in crop improvement under the resistance or shuttle breeding. Crop variety with suitable adaptability under various abiotic and biotic stress situation becoming a good option for food growers. Moreover, few promising question had to be reply under the resilient agricultural system and these are region based and some time globally influenced as a whole. How production technique of crop were modify for higher yield during coming years under climate change scenario? What kind of character are required for higher crop productivity threat under climate alteration? How can the various molecular or biotechnological approaches becoming suitable under various smart practices? This question become more pertinent under changing climate situation. Global CO_2 levels has been amplified with 31% because of industrialization, which supposed to be accountable for boost of ~0.66 °C in resultant yearly worldwide surface heat; meanwhile it will augment further 1.4–5.8 °C by 2100 with equally increasing atmospheric CO_2 nearby 285–379 ppm in 2005, will pass 550 ppm by 2050 and a value of 770 ppm is expected for 2100 due to fossil fuel use and deforestation (Earl et al., 1996; IPCC, 2007). Such change affect crop productivity and in near future, agriculture as a whole will unavoidably face threat cause by weather transform, this may direct to both worldwide and local alteration. Biotic factor such as disease, pests and insects population etc. decrease the yield of crop only by slight alteration of climate. Shifting of weed flora, decrease crop efficiency and compete for water, light and available nutrients. Likewise, abiotic factors such as rain, temperature, drought etc. influence the net crop yield and problem become severe from temperate to tropical zone. Abiotic factors mainly rain and floods have a huge blow on plants occasionally, destroy the complete crop with rising or decreasing various environmental factors. These can be answer through climate smart agriculture practices (CSA). CSA is an methods, which help to direct action that require to change and reorient agriculture to make sure food availability in a changing environment. Different factor that could manipulate the crop yield in a particular site is presented in Table 4.1. Few factors, which are assigned on left side of table have vital role on crop productivity and yield. However, right side factor of table can be manage to some extent, which could enhance farmer net return either by more crop yield per unit area or by saving input variable cost.

Table 4.1 Factor responsible for crop yield variation

Less manage		Probable management technique		
Texture of soil	:	Structure of soil	pH levels	Micronutrients
Weather	:	Topography	Water availability	Macronutrients
Unseen character	:	Problem soil-reclamation	Water logging	Pest and disease

Therefore, one can identify the variations within a field, quantify, delineate and map and develop strategies to improve the crop productivity with optimization of inputs by utilizing tools and techniques of various climate smart strategies or precision agriculture techniques. There are various approaches practiced by different countries/scientists depending upon the feasibility and availability of resources at their disposal. However, whatever may be the approach to begin with one has to follow the general practical guidelines before shifting to climate smart practices from conventional practice.

4.2 Climate Smart Agriculture (CSA)

CSA appeared as an idea on the policy agenda in 2009 and comes from an increased concern within the global development as a whole, and within the FAO in particular, about the impact of weather transform mainly global foodstuff safety, in combination with a steadily growing population, urbanization and consumption growth trends (FAO, 2016). The definition of CSA, as agreed by many international institutions such as the CGIAR. UN and the World Bank, is that it combine the three aspect of sustainable growth mainly social, economical and ecological, which address foodstuff availability and climate issue, and is as such composed of three major aim:

1. Sustainably increase in farm production to carry reasonable increase in income, foodstuff availability and growth;
2. Adjustment to effect of weather transform from national to farm levels and
3. Reducing greenhouse gases production as much as possible.

This is not a new concept, it mainly encompass combination of three main pillar which may influence crop production under the era of climate shifting throughout the world. Sometime CSA confused with the climate resilient agriculture practices. Climate resilient agriculture main attention is to enhance agricultural output under shifting climate. But climate smart agriculture is this, plus a force to shift farming out of the bag where it is part of the dilemma, and into the bag where it is part of the answer. CSA provide the way to assist stakeholder from confined area to nationwide level, make out farming strategy appropriate to their limited situation (Praharaj et al., 2017). Various organization such as IPCC raised issue of aberrant weather situation along with its effect on future agriculture growth and farm productivity as a whole. No rain or poor water availability likely to increase significantly in dry or arid region by the end of the century. Therefore, there is a dreadful need to start a paradigm move in farming development approach and practice to alleviate the effect of climate change and make crop growing sustainable (www.outlookindia.com). CSA often amalgamates activities geared towards adaptation and mitigation and influenced by various abiotic and biotic factors. This can be easily understood by one case study in West Bengal, India by Ghosh et al., 2017. To represent the agriculture aspect in different district in West Bengal, a combined agricultural scenario index (ASI) was made for all the year from 2001–02 to 2011–12, in view of 11 stricture. More the ASI rate, enhanced the resiliency by a district in a disaster year as compare to erstwhile region suffer the similar incident. Accordingly, agricultural scenario of six north Bengal districts and five south Bengal districts suffered most in 2006–07 and 2007–08, respectively as evident from lowest ASI values for those years when flood occurred. Districts in western region of the state suffer mainly from the drought during 2010–11 as indicated by lowest ASI value. Resilience of agriculture not only depends on sustenance of parameters related to agriculture that is presented through ASI but also on the socio-economic vulnerability and climatic vulnerability; therefore, both socio-economic index (SEI) and climatic vulnerability index (CVI) were worked out. Considering ASI, SEI and CVI together, three districts viz. South 24 Parganas, Cooch Behar and Purulia are found most prone to weather alteration in West Bengal (Ghosh et al., 2017).

4.3 Climate Smart Strategies

Numerous mechanized and developing country have achieve striking rates of farming expansion during recent year. For instance, Asia change its farm income by doubling-up wheat and rice production from 1970 to 2016 by increasing planting areas and using post green revolution new technology (Praharaj et al., 2018). During this phase, per capita incomes nearly double and poverty decline to great extent. However, these gain come with a few harmful effect in our ecosystem. Monetary disparity amplified in country, and so did ecological spoil outcome from wrong use of input mainly irrigation, plant use chemicals etc. As the new century begin, the world face huge challenge to gather the foodstuff, cloth and other basic desires of a rising inhabitants with rising income (Smith et al., 2015). As we know scenario for agricultural land and irrigated areas are narrowed down, augmented food require have to be meet mainly through high output on available usable land area with optimum utilization of available resources in sustainable manner (Mukherjee, 2004). More use of science based agricultural innovation and technology are important to achieve higher growth to farming community. Many crop based cultivation technique such as zero or reduced tillage, diverse methods of crop establishment, irrigation and efficient fertilizer use can increase crop yields. Further efficient water and plant use chemicals reduced greenhouse gas production from various farming activities (Sapkota et al., 2015). Likewise, application of ICTs based regular and timely agro-advisory, proper seed, water conservation and insurance of agricultural produce may help to our growers to decrease the threat of aberrant weather and climate unevenness issues. Adjustment and alleviation be major strategy for tumbling and reducing the threat of typical weather modification. Considerable decrease in green house gases production during coming years may decrease the incidence of climatic unpredictability in the coming decades. Proper use of technology and efficient adaptation plan, decrease the expenditure and challenge of climatic variability in long term in suitable manner (Khatri Chhetri et al., 2016).

4.4 Climate Shifting – A Worldwide Problem

Our ecosystem is extremely complex and our civilization change number of parameter such as soil use, agriculture tools, climate, air quality etc. We must extremely careful regarding any prediction for the actual globe based on our result on lab work in addition to use of various computer models (Mukherjee, 2018a, b). Moreover, science shows trends and directions which we need to understand and plan proper plant protection measures in order to cope up with effects of alteration of environment. Shifting of climate leads to usual penalty for farming and the global food availability. The possible measures has been elaborate via Rosenzweig and Hillel (1995). Mainly they explain liability to weather modification is steadily more in budding country, that mainly confined on lower and warm-humid latitude. In this area, cereal productivity are anticipated to reduced beneath the threat of climate change scenario. Farming community in high to middle latitudes get up, because nationwide availability is predict to increase, and chiefly if food availability are limited and price go up. Therefore, country with the least returns might be the more damage. In European continent, predictable change in weather situation rely on position, with the higher temperature observed for Northeastern and Mediterranean region, less rainfall pattern in southern areas and more rainfall in northern areas particularly in winter (Brooker & Young, 2006). Our world faces many kind of challenges in number of areas, which mainly to increase food production under scare rainfall area and crop improvement programme for rainfed and dry region and more water use competence crop etc. Worldwide, lack of water or poor availability of water resulted in great economic loss and sometime more than various abiotic or biotic factors. Observation revealed that, in United Kingdom less water availability or drought reduced crop yield by 1.2–2.4 t/ha (Foulkes et al., 2013). Various worker raise issue of abiotic stress problem in Europe and USA. Semenov (2008) pointed out the possible threat of future tremendous climate vulnerability to horticultural plant in the United Kingdom by a stochastic weather generator linked with UKCIP02 (Hulme et al., 2002) interpretation of upcoming weather. Key pests, such as diamond-back moth (*Plutella xylostella*) and cutworm (*Agrotis segetun*) might turn into a large risk as per study. Blow of weather alteration on erstwhile microbe or pest because of change in life cycle may be likely all through European continent might leads to a stern danger to yield or manufacturing system. Vary in weather pattern may also leads to change in pathogen life cycle and ultimately host-plant relationship Turner and Annamalai (2012) gave emphasis on modelling work to forecast possible level of infection under aberrant weather during 2081–2090. They observed that wheat disease mainly brown rust (*Puccinia recondita*) will turn into the main intention for infection measures strategy, as it is preferred by heater, drier summers. On the other hand, Septoria leaf blotch (*Mycosphaerella graminicola*), at present the vital problem of wheat in the United Kingdom was predict to reduce. Different practices in agriculture system is potentially sensitive to climate alteration, which lead to raise problem for plant breeders, agronomist, pathologist who are building a long-term outlay. Moreover, proper breeding for various disease resistance may not only good for adjustment to weather change but also it reduce the effect of greenhouse gases emission. Scientist Berry et al. (2008) workout the decrease in emission, that might be achieve in the United Kingdom from infection restirction, with present varieyt and fungicide use, probable to save up to 1.14 Mt. CO_2 eq. in every year. This might be possible by exercise of more infection resistance cultivars, as long as it is not linked with a crop productivity penalty. Lots of work revealed that, weather alteration might leads to more occurrence of different species of weeds, disease and pest problem. In general temperature increase may leads to pathogen-crop association with speed up microbial growth rate, that may enhance reproductive generation in every life cycle of crop, by reducing pathotype death owing to warm the cool season temperatures, and by building the plant for higher susceptibility and ultimately reduced crop productivity.

4.5 Crop Response to Climate Change and Air Quality

Plants, alike to erstwhile flora, are intimately related to the swap of substance among environment and bio-sphere. Sedimentation of different atmospheric compounds to crop canopy, leads to reduced its worth value and also affect in diverse way. In most parts of North America and Europe contact to compounds like NO_2/NO, Sulphur dioxide and various heavy metals is decreased and is now no foremost danger to plant or different species of crops. Moreover, in many parts of world continuously rising level of tropospheric O_3 stay a problem, which leads to an added risk to plant development and strength during the mounting period (Mukherjee, 2014a). In many under developed and developed country the concentration of atmospheric compound such as NH_3, SO_2 and mainly O_3 are speedily rising. Already at present, these pollutant can lead to severe reduction of plant development and ultimately economic value, a situation which might worsen in the future. On a worldwide scale the fast transform in atmospheric sonata by the rising atmospheric CO_2 concentration leads to weather alteration has two main implication.

4.5.1 Direct Effects

Different atmospheric gases are transfer from surrounding to plant canopy system through diffusion, which mainly occurred by micrometeorological situation such as temperature, heat, wind etc. These may enter either thorough stomata or via plant root system. The response of a crop to a known air pollutant rely on the contact proportion, crop behaviour, and outside expansion situation. Short to medium period of contact to comparatively high concentration usually lead in severe visible leaf damage. Slight long period persistent exposure to lower levels can leads to change in physiology of plant system, which lead to premature senescence, chlorosis etc. and ultimately affect economic yield of crops. Under different husbandry practices, severe effects of air pollutants such as O_3 are of particular concern, as they are owing to exposure for few days to whole lifecycle of the plant. As we know, higher O_3 concentration cause a reduction in crop economic yield, for example as rice, maize, blackgram, wheat and cotton (Ashmore, 2005). This yield reduction mainly occurred owing to altered carbon allocation, less photosynthetic rate and more senescence of leaf (Fiscus et al., 2005; Fuhrer, 2009). Work conducted by Mills et al. (2007) on O_3 exposure-response data for 19 farming crops. Revealed that, barley O_3 resistant crop, where as wheat, pulse, water melon, cotton, onion. Turnip etc. as the most ozone-sensitive crops. Worldwide effect of O_3 on plant system or economic production was evaluate by Van Dingenen et al. (2009). They estimate of current worldwide virtual production losses range, 3–5% in maize, 5–15% in soybean, 3–4% in rice and 7–14% for wheat. When translate the yield reduction in the context of global level of four crops, this result in economic loss to the tune of $15–27.1 billion. Nearly 42% of this harm is happening in India and China. Moreover, the ambiguity on these estimate is huge. However, extensive unevenness in O_3 sensitivity among different plant is common (USEPA, 2006). In contrast, a upcoming increase of CO_2 level in atmosphere, will have an encouraging effect on plant development and yield, as CO_2 directly affect crop physiological system and its development by serving as a main substrate for photosynthesis. Usually, more concentration of CO_2 enhance crop yield and biomass considerably in C-3 plants with escalating photosynthesis rate and reducing photo respiration, but with huge difference amongst type in the extent of the yield stimulation (Kimball et al., 2002). Moreover, no noteworthy stimulus of crop economic production was observed in C-4 plants (Long et al., 2005).

4.5.2 Indirect Effects

Various compounds and pollutants from atmosphere and air could act together with other abiotic and biotic factors mainly water, heat, pesticide use, salinity, pathogen and pests, symbiotic relationship etc. in an intricate manner leads to indirect effects on plant activity. Such as, lower viability to ozone stress may create crop more vulnerable to various pathogens, general prediction of ozone effect on effective crop pathotype are not easy, as the accessible data for explicit disease and pests are frequently disputable (Fuhrer, 2009; USEPA, 2006). More vulnerability after O_3 introduction have been report for necro-trophic pathogen, while obligate bio-trophic infection reduced by O_3 (USEPA, 2006). Virus infectivity frequently provide a number of protection damage by O_3; though, the degree and kind of defence rely on the explicit virus and host. Direct effect of high levels of CO_2 on compound symphony of tissue might be an indirect effect on herbivore-crop relations, as host vegetation mounting under enrich carbon dioxide environment generally show example decrease concentration of nitrogen in tissue, better C/N ratio, which might influence foodstuff use by herbivores and related population growth (Stiling & Cornelissen, 2007). Water deliver critically change stomatal conductance and therefore intake of water from the soil system to plant directly influence crop growth (Fuhrer, 2009). Further, observation by climatologist believed that, rising CO_2 concentration often enhance water use efficiency, which alleviate drought stress effects (Manderscheid & Weigel, 2007). Even though the various literature is obviously inadequate to know the significance of exchanges among air pollutants and abiotic or biotic factor, however indirect effect in few condition have direct effect of the gaseous exchange in crop system.

4.6 Climate Smart Practices

4.6.1 Conservation Techniques

Application of various conservation techniques in crop production system is an effective tool for climate smart crop production strategy particularly under changing crop micro-environment. As we know age old practice of agriculture involve vigorous tillage system in soil, which distort the soil profile and texture, which may affect water holding capacity of soil (Mukherjee & Mandal, 2017). Our food growers, realised that in the longer run, extreme or high tillage option essentially reduce soil organic matter availability and expose soil to water and wind erosion, which in time lead to lesser output. As our soil productivity is diminishing day by day due to intensive cropping pattern, to compensate these things now we rely on intensive fertilizer and other chemical input which become harmful to our environment and also uneconomical too. In his work "Plowman Folly" the renowned American author William Faulkner describe the plough as "the villain of the world's agricultural drama (Faulkner, 1943). Thought we know various negative aspect of heavy tillage operation for many decades on weeds etc., use of non-selective and selective, systemic and contact herbicide leads to effective measures to combat these problem (Mukherjee & Singh, 2005). As because of negative effect of tillage worldwide debate raised on this aspect and researcher try to develop pioneering crop growing technology that minimised the requirement of tillage measures. Different option developed to fit different environments and plant no tillage, zero tillage, minimum tillage, ridge tillage, mulch tillage etc. Afterwards, crop rotation and upholding of semi-permanent or stable soil cover (plant residue mulch or live cover crop) are incorporated as an essential part of this methods, now identified as conservation tillage. Different research in worldwide have proven that it's suitability for range of farming pattern from small to large farm area. Conservation tillage protect the higher layer of soil from water, wind erosion etc. in addition to reduce loss of soil water holding capacity. This help to improve beneficial soil microbiological population by provide a suitable environment for fungi, bacteria and insects (Mukherjee, 2017b). More soil microbes help faster decay of mulching materials and enhance its mixing into soil profile as humus and improve of soil productivity. Use of different mulching materials enhance soil organic matter nearby 1 percent in every10 years (Praharaj et al., 2018). In conservation tillage, various kind of weeds are present prior to sowing which can be checked by use of selective or non-selective weedicides (Mukherjee, 2008). Various components of the conservation tillage will vary from location to location, however few key elements may be used in all the situation from tropical to subtropical and temperate situation, these includes:

- Less disturbance of soil and use herbicide etc. if require for cultivation
- Use of mulch as much as possible (live cover crop or dead crop residue)
- Avoid mono-cropping and use crop rotations as much as possible.
- Need based application of recent technology (location based), which enhance soil fertility and crop productivity.

4.6.2 Case Study of South Asia – Indo Gangetic Plains

Approximately fifty percent of 398.54 million ha (gross area) land in Indogangetic plain (IGP) of South Asia's plains mainly India and its neighbouring countries is dedicated to feed 1.8 billion inhabitants (Mukherjee, 2015). Wheat and rice are the main foodstuff and provide nearly eighty percent of the gross grain production comes from Indo-gangetic belt. Appropriate temperature regimes for wheat and rice farming, crop breeding for fertilizer responsive mainly nitrogen and short duration variety, more area under irrigation and more demand for foodstuff, were some of the major factors for higher production Past six decade, more growth rates for foodstuff mainly for paddy 2.4% and wheat 3.1%, have kept tempo with population expansion. Various report at this time confirm, intensive use of various inputs in this region leads to deprivation of the supply base through over-exploitation and salinization of underground water, chemical and physical worsening of the soil, and pest (insect and weeds) problems. More intensive use of various resource conservation technique (RCTs), such as tillage, crop establishment measures etc. for rice cultivation in rice followed by wheat rotation or system are enable food growers to maintain efficiency (Mukherjee, 2016a, b). Various research work showed that these technology get better yields, decrease water demand, and lower down deteriorating impacts of the agro-ecosystem. Vigorous study and growth support by international and national agricultural explore groups, such as CIMMYT,

Table 4.2 Comparison of conservation and conventional techniques under different problem area

Sl. No.	Problem area	Conventional farming	Conservation technologies
1.	Nutrient deficiency	Corrected with inorganic fertilizers	Believe in natural supply of nutrient with livestock and application of plant nutrient in an integrated methods with least use of chemical fertilizers.
2.	Water deficiency	Corrected with irrigation	Efficient use different soil cover plants and various mulch etc. for efficient conservation of precipitation which leads to improve soil moisture holding capacity.
3.	Erosion control	Corrected with physical barriers	Check various erosion by application of minimum or no till practice, in addition to use of different cover crop etc.
4.	Pest management	Application of various pesticide etc. as per need of the crop.	Minimise the pest and disease problem with the use of integrated pest management measures, which are eco-friendly, safe and well accepted by farming community.

World bank progrmme in addition to socio-economic change in the IGP country are foremost to fast acceptance of conservation technique by food growers. Last five year area under zero or reduced tillage for rabi season crops mainly maize, wheat, chickpea, lentil etc. has raised to approximately two million ha, chiefly in Pakistan and India (Makhan et al., 2016). Different RCTs application in these area can keep water, soil and other available resources. Use of zero tillage in presence of mulch etc. with happy seeder sowing methods can saves the cost of production and also enhance grain production under different crop sequence, with reduced weed and other pest management in eco-friendly manner. Application of raised bed and furrow-irrigated bed planting techniques can be used for sustainability of major crop sequence. Recently application of hydrogel (water-adsorbing material) in few crops (mustard, rainfed wheat etc.) enhance crop productivity under rainfed or dryland area by improving the water use efficiency. Application of such kind of new technology become quite effective for implementation of CSA at large scale (Mukherjee, 2015b). Application of laser land levelling can keep enormous quantity of agriculture use water for better productivity similar to conventional level plots. Use of various machinery, which are suitable under different resource conservation techniques and quite costly and heavy, need to be implement through n co-operative basis for the betterment of our farming community (Table 4.2).

4.6.3 Biodiversity Threat

Mounting "a genetically diverse portfolio of improved crop varieties, suited to a range of agro-ecosystems and farming practices, and resilient to climate change" is a validate way for better cultivation systems. As we confront to various biotic turbulence (such as various weed or insect) and abiotic changes (such as heat stress or shifting rainfall distribution) with active biodiversity (response and functional variation) could make the diversity in various agro-ecosystem. In natural world, none of the species either plant or crops grow alone in the field. In a farming system diversity of ecosystem services are compromise (Fuhrer, 2009). Diverse cropping pattern, leads to more variation in plant and living organisms, which is a vital measure for ensure economic stability, farm resilience and profitability. Such kind of variation is quite significant in a climate-smart measures as it contribute to disease and pest management, which has direct role on economic produce and net return and may be quite labour intensive and costly, if exterior input require to be use in farming practices. More on-farm biological diversity and integrating production also provide other milieu, including pollination, that are necessary to food growers and community as a whole. Under good agricultural system, the intensity of biodiversity in the farming system influence the relations of animal, plant and microbes lie on below and above the ground.

4.6.4 Crop Diversification and Intensification

Crop diversification vary place to place or time to time, and it has many forms such as intra-specific or inter-specific diversion. Various multipurpose crop or tree species can be used in an integrate way for various purpose from biofuel, feed, fiber or food etc. which may enhance farm productivity and its functional value being as par to climate smart practice (Mukherjee, 2013a). Transformation or shifting of our farming enterprises from agriculture sector to commodity based farming system (based on local available technology in more efficient way) help to restore natural resources degradation and improve rejuvenation of barren area for farming as a gainful industry (Mukherjee, 2016a, b). Moreover choosing of any cropping sequence under crop intensification must ensure not to harm one another or environment system and not compete for water, nutrient or light etc. Diversified farming practices might be a fruitful agriculture systems, if it consider all the aspect of sustainable ecosystem principle. Diversifications of cropping pattern help food growers against various aberrant climate situation like early rain or mid season drought, frequent dry spell during crop season, heat stress problem etc. Intercropping of pigeonpea + soybean (2:4), pigeonpea + pearlmillet (3:3) and green gram + pigeonpea (2:1) are more remunerative than single crop (Prasad et al., 2014). Because of more urbanization or more intensification of human population, demand for costly food item such as vegetable, dairy, egg, fruits and fish is rising. Further, this demand leads to reduction need or requirement of traditional wheat or rice or any staple food items. Presently we face severe consequences of rice-wheat system (RWS) as of high demand in some area, which enhance income of northern part of India farming community, however it indirectly affect our natural resources such as reduced water table, heavy load of fertilizer or pesticide to our environment etc. (Mukherjee, 2017d). Use of pulse under different crop sequence help to fix atmospheric nitrogen into soil and enrich our soil fertility system via nitrogen fixation. Nitrogen fixing pulses have a lesser water and carbon footprint as compare to erstwhile vegetation. Therefore incorporation of pulse based crop in cropping sequence gave more productive and sustainability to our environment (IYP, 2016). Exploit of climate ready plant or vegetation is an effective option for high productivity (Haefelea et al., 2016). Adding of novel plant cultivars with good economic stability and resistance to numerous stresses (abiotic and biotic) is main component to uphold crop viability under any sequence or system. Under the drought prone area several cultivar of wheat or rice variety released with the help of various SAU and ICAR India. Cultivar Sahbhagi Dhan, which released (notified) in India during 2010, showed a constantly excellent result in transplanted lowland and rain-fed direct seeded upland condition (Singh et al., 2014).

4.6.5 Climate Smart Land Preparation and Site-Specific Nutrient Management

Land or seed bed preparation in an effective way is an important tool for higher crop productivity. Under conservation agriculture, farmers were introduced to laser leveller and today it is the much sought-after machinery both by rainfed farmers and of command areas as of its ability to raise water use efficiency which is of paramount importance. Irrigation and drainage go hand in hand otherwise production will hamper due to water logging and salinity. Uniform water distribution, reduced runoff and erosion are attracting farmers. High potential of cotton mentioned previously in paddy fallows in Kasabe camp is due to laser levelling (Pyati, 2015). This also enabled large plots in case of paddy and thus eliminated mid bunds resulting in overall increased yield and saving of water compared to traditional system where due to uneven land more water was required (Mukherjee, 2014a). Use of new technology such as lesser land levelling or application or light machine for crop cultivation become an effective tools under smart land management system. Allocation of land area under different agriculture system should be based on data availability of various cropping pattern or land variability (zone specific), become very pertinent under good land management system.

Management and recommendation process of nutrient demand for crop in India and other underdeveloped country is soil based crop response data become very useful. Newly emerged concept of site-specific or location base nutrient application measures. This is a need based approach to feed the plant or vegetation under different sequence or crop pattern, while recognizing the inherent spatial variability (Mukherjee & Maji, 2017). It involve observation from all the way crop nutrient supply, and calls for sensible blending of bio fertilizers, organic manures, fertilizers and crop residues to maintain farm productivity. It avoid haphazard use of chemical input into our soil system and enable the food growers to dynamically adjust the fertilizer application to fill the deficit optimally between nutrient wants of the cultivars and nutrient provide from natural resources,, irrigation water, organic sources etc. Various study revealed that use of site specific nutrient management in different location, enhance economic yields to the tune of 12 ton per ha in rice followed by wheat and 13–16 ton per ha in rice after rice cultivation (Anonymous, 2018). Use of the proper nutrient supply (need based), at the right rate (reduced load of chemical to environment), at the right time (appropriate crop stage), in the right place (appropriate place) is necessary to nutrients stewardship. Leaf color chart (LCC), is use to evaluate green color concentration of paddy leaves to measure the nitrogen needs by non-destructive method (Nachimuthu et al., 2007), and is being harmonized with chlorophyll meter. LCC become very effective for proper and right dose of nitrogen application. LCC based urea use can decrease unnecessary utilization of nutrient in a rice-wheat by10.5% in LCC ≤ 4 treatment as compare to blanket use (Bhatia et al., 2012).

4.6.6 Effective Water Management

Farming or various crop husbandry practices are the largest consumer of water through irrigation or any other purpose (mainly freshwater). More than 75% of the accessible freshwater is used by the agricultural sector. In India, food production system become very challenging as because of delicate water resources and malnutrition gap or increasing hunger. Quality of irrigation water and its supply measure to crop field greatly depend on farmer's efficiency and knowhow of modern technology (Mukherjee, 2014a, b, c). As we know, our water resources are very limited we can achieve sustainable agricultural productivity via conserve soil moisture or site specific use of water via drip or sprinkler irrigation which can exploit plant yields per volume of water use. Utilization of more effective irrigation techniques could decrease evapo-transpiration losses from land and crop area. Achieve higher competence in irrigation need extra energy costs which can be enhance through location-based water harvesting technology (Mukherjee, 2014c). Sometime, the development of water based technology require suitable energy application technique such as solar powered pumps for better crop production under smart climate resilient practice. Work conducted by Mukherjee (2016a, b) revealed that, use of reduced irrigation levels to wheat crop during critical phase of life cycle, significantly enhance yield compare to high irrigation rate under rainfed situation of new alluvial zone. Strategy for altering agricultural irrigation requirement include integration of water budget scrutiny into strategic management methods. Water budgeting mainly include catchment level and field level in addition to repercussion that change in water utilize for farming will have on the hydrological or water cycle. Water use efficiency of plant can be enhanced by suitable cultivars under different crop rotation and it should be based on available water supply and rising seasonal evapo-transpiration (ET). The last one can be achieve by irrigation scheduling selection of irrigation method, mulching fertilization and tillage option.

4.6.7 Cropping Sequence

Long term climate unpredictability such as CO_2 level, amplified temperature, untimely flood and drought could influence the yield potential of plants. However, the impact differed transversely regions and crops. Presently we need to know or chalk out crop cultivation under different niches responsive to climate change/ inconsistency and shuffle them in more appropriate area or zone (Mukherjee, 2010). Crop production instability is abridged by altering sowing time which decrease the effect of heat stress induce sterility of spikelet and also avoid time of flowering to match with the high temperature. Some extent this can be feasible in case of wheat cultivation in northern and eastern part of India, however its need more research with new cultivars. Crop schedule provide the information regarding plant site and crop sequence on the basis of climate model that help the grower for cultivation of plant as per the incidence of climate measures. Various crop pattern might have to be changed to the expansion of appropriate variety, escalating crop intensities by more crop per unit area in every year or cultivation of diversified cropping patterns. Farmers or food growers will encompass to follow to altering situation by varying crops. As per example in drought prone area one can cultivate Sahbhagi Dhan with lentil cultivars such as Mallika and Pusa Vaibhav for more yield and a good contingency planning also (Singh et al., 2017). Our approach for growing crop under changing climate regime should be location specific. This can be possible by use of modern tools of land management practices and long-term weather forecasting etc. Various report and work revealed that, exhaustive cropping system such as rice-wheat (RWCS) in South Asia is suffer a lot of environmental issue and sustainability too, such as labour scarcity during peak period of crop life cycle, variable nutrient (micro or macro) disorder/deficiencies, declining land, rising production cost, deteriorating water productivity and groundwater level along with serious threat of soil health issue. Keeping the important of RWCS in South Asia, we should opt for various climate smart technologies for more water efficiency in rice-wheat. While, our food growers are perplexed about selection of appropriate weather based improved technology such as laser land levelling, unpuddled direct seeded rice, twice zero tillage in wheat follow by rice, soil matric potential based irrigation, short duration variety, proper time of transplantation and raised bed planting for improving their livelihoods by escalating water and land efficiency in one hand and more resilient to climate change or worldwide temperature rising penalty on other. Result of above technology is both location and condition explicit, and concern must be taken in utilize them. Climate smart practices' are very effective in water logged or low land area, through calibrated drainage making, which help to reduced recharging of soil profile and utilized in those region where availability is either less or very poor. As a result, introduction of right type of climate smart technology is vital for getting better crop and water output in the era of weather shifting, which use huge water in various cropping system (Hossain and Bhatt, 2018).

4.6.8 Planting Materials and Quality Seed

Use of quality seed for locally suitable variety become a key tool for climate smart practices, as these are fully acclimatized with local weather condition. However, this needs location specific breeding programme, instead of multiplication research trials. Supply of quality seed and good planting materials of different crop cultivars, are the important factors for full proof climate smart agriculture production system. We cannot received good yield from poor seed materials or bad seed lots (FAO, 2016). Number of new genotype tested in different location at national and international institute for good genotype of different crops through good plant breeding measure (involve multilocation trials) for better plant type. These are suited to weather linked aspect under different situation and more proficient to avail various resources to decrease their negative effect (climate change) on the farming bionetwork and the broad milieu. Resilience to salinity, dearth and flood are the very widespread weather linked character for which crop varieties and new genotype should be evolve (Mukherjee, 2017c). Few specific and location wise issue mainly more frequent frost at the pollination or seedling stage, high temperatures or heat stress problem at the dough stage; high temperature or low rainfed; torrential rains which constrict the land, reduce the seed germination capability and ultimately hamper quality seed production. The expansion, good plant cultivars are the steps taken toward the final aim of fulfilling growers objective to access quality planting materials and disease free seeds. Moreover, achieve these objectives, need a consistent market chain for distributing seeds of the most appropriate genotype to the growers. Mostly food growers get their seed either from informal or formal system through various chain mechanism (Chakraborty & Mukherjee, 2010).

4.6.9 Integrated Farming Systems (IFS)

Growing of one crop continuously in same land area become risky to the farmer's under flood and drought prone area. Reliance on sole enterprise increase the menace of crop letdown, poor yield of gain, benefit: cost ratio and ecological uncertainty particularly in rainfed or dry region of the country. IFS is mainly amalgamation of various interconnected, mutually dependent and interacting farm enterprise that are suitable to various ecological and socio-economic state of the growers. IFS modules help to reduce various natural calamity risk from any kind of abiotic or biotic factor compared to single enterprise used by farmers. Use of different type of enterprises under IFS bring throughout the year to the farming community and quite profitable mono-cropped crop cultivation. This improve rural livelihood and pliability to harsh climate variability. Integrated rice-fish-poultry and fish-duck models have been suited for marginal to small farmers under the lowland to upland situation (Dalgliesh et al., 2016). Mukherjee (2012a) observed that, highest net income of Rs. 1,28,633 was obtained with crop +piggery + poultry + milch cattle in north eastern Himalaya

(Darjeeling). Amongst the six enterprise combinations testing highest employment was provided by the crop + piggery + poultry + milch cattle (116.42 days) followed by crop +piggery + poultry (113.56 days) and crop + poultry + milch cattle (108.46 days). For small holder systems various adaptation and alleviation option exist through crop–livestock systems by proper risk management, variation and sustainable amplification strategy. Despite the possible solutions, small to marginal farmers face more problem under different scales, including small farm holding, mono-cropping practice, lack of knowledge of advance climate resilient technology, poor livestock herd management etc. (Mittal, 2012; Mukherjee, 2016a). More change in weather pattern become threat to small to medium farm and production loss is huge due to earth warming. Rise in temperature in ambient leads to faster decay of natural soil organic matter and increase soil mineralization process which influence productivity of land (Mukherjee, 2012a, b). In arid and dry land situation, plant root growth and rate of decay of organic matter drastically reduced and as soil are less cover, chance of more wind erosion increase and this become sever if winds blow intensify. In some pockets, more convective precipitation threat to high rainfall, which ultimately produce stronger gradients of pressure and temperature and more water vapours in air that result in high precipitation, which can root stern soil movement or erosion and finally influence the agriculture system. Hence, there is a need for an approach which could be suitable and help to mitigate the climate change impacts to our soil-ecosystem in holistic way (Mukherjee, 2013a). These can possible through the following ways:

- Reducing the livelihood dependency on single crop/enterprise with diversified output and enhanced income.
- Close integration at farm and household level can enhance food security and less disaster prone
- Extending the growing season through enhanced diversity at species, varieties and ecosystems levels.
- Builds reserves of water, fodder, fire wood etc.
- Increases system resilience through intra system dependency by integration of perennial, semi perennial, animal, soil aquatic organisms etc.
- Reduces the need for external inputs through multi step resource recycling, biological and other renewable resources.
- Reduce inputs and labour through close integration and evolving energy efficient systems.
- Eliminate the need for biocides through crop rotation, use of resilient indigenous varieties, trap crops, etc.
- Inclusion of multi-purpose and multi-functional elements such as live fences, hedge rows, farm ponds etc. which help availability of more cash in hand.

Growing of suitable kind of vegetable or cereals etc. under different farming system practices become a challenging and it would be varying from farm to farm based on specific climate smart agriculture practices.

4.6.10 Weather Forecasting

Various study revealed that, number of farmer's in underdeveloped and developed countries face numerous challenges under the era of climate change. Majority of them are depend on age old methods to realize climate prediction. Location specific weather data is necessary for farm-based decision such as when to crop sowing or irrigation, suitability of pest and disease control measures etc. are necessary for growers and they can trust and utilize weather data for their day to day field work (Mani & Mukherjee, 2016). Unpredictable and extreme weather condition are one of the major challenge under climate shifting scenario and sometime rise in temperature, or change in rainfall patter decide pest and disease incidence in crop field Good and appropriate farming systems with the low quantity of loss to the economic yield, fruitful technology and other technical support to farmer is become very pertinent under climate change. Climate related measures at diverse temporal and spatial scales could be noteworthy instrument for adaptation in farming beneath upcoming weather transformation situation. Accurate and timely weather forecasting become more effective with the help of advance Information and Communication Technologies, which play crucial role to disseminate the weather to farmer's finger tips through modern technique and tools (Rathore et al., 2016). Weather prediction for short or long term become very effective for decision making regarding irrigation, disease pest management, intercultural operation etc. Forecasting as an premature caution measures would be extremely helpful to minimize risk connected with various contingency measures or unforeseen climatic behavior patterns. This helps administrator and research worker in emergent contingency crop strategy and decrease the threat of abnormal climate. Effective crop assurance scheme should be evolve to assist the food growers in dipping the danger of crop damage due to effective and timely weather forecasting through various agro-advisory services. Under the era or ITKs we have numerous new apps in our android mobile set such as "Meghdoot" or any other application software time to time from government in different country become very effective as climate smart tools for higher crop productivity from small to marginal farm.

4.6.11 Precision Agriculture

This is not a particular technique, but rather a set of numerous mechanism from which farmer can choose to form a system that meet their exclusive needs and operation area. Remote sensing, yield observation or mapping and variable rate technology are the key component of precision agriculture. It is an advanced mechanized farming which came in the form of well advance Geographic Information and Global Positioning System (GIS and GPS), where growers have the aptitude to make management decisions and crop production based on the variability of the soil properties within fields. Role of this kind of smart agriculture tools become more useful where weather prediction become very difficult, duet to variability in topography, soil and rainfall patterns, particularly in the hilly region (Mukherjee, 2018b). The term "precision agriculture" describes the amalgamation of GPS and GIS tools to give a meticulous information on plant development, health status, biomass or economic yield of crop, soil variability, nutrient levels, water absorption, topography or land positioning. Such kind of information helpful to give us different tools to manage areas within fields differently, according to the crop physiology and soil characteristics. Therefore, food growers can have the ability to explain linking between non-productive and productive sections of their land used for agriculture purposes, and manage the variability in soil and mineral distribution. Thus, precision farming look intently at the improved efficiencies that can be realize by knowing and dealing with natural variability found within a field. The objective is to manage and distribute the input on a site-specific basis to enhance long term gain in yield and ultimately farmers cost-benefit. It can be summarized as an application of right input, in right amount, at right position, at right time and by right method.

Following are the potential benefits that can be presumed by adopting the precision agriculture:

- The monetary gain from farming community may be increased by improvement in economic produce and reduce in cost of input variables;
- Threat of ecological effluence by heavy use of agricultural chemicals be abridged;
- More access of exact target and footage of plot application to get better traceability.

On the other hand, as the precision agriculture is a systems approach to the agriculture, there must be a good farm management system in place with sound agronomic practice before shifting to precision agriculture from convention agriculture. Moreover, procurement of all sophisticated tools and equipment, access to GIS/remote sensing data, skilled manpower with prospects of trainings to familiarize with modern techniques are very much acquainted under precision agriculture (Godwin et al., 2003).

4.6.12 Climate Smart Plant Protection Measures

We need to understand that, crop growing is influenced by weather alteration, various farm practices, water and input availability etc. which contribute considerably to greenhouse gas production is the major source for climate change (IPCC, 2014). With the mounting globalization of the traffic and trade of germplasm, cultivars, technology leads to changes in behavioural pattern of insect pest, disease and weeds, which further aggravated new challenges for pest management. Pest management strategy can be modify based on local availability of resources and use of indigenous technology without compromising ecosystem (Mukherjee, 2017a, b, c, d). The principles of Integrated Pest Management become very pertinent under present context under climate smart practices. This mainly comprised of cultivation of healthy crops; knowing sustainability measures in the fields and emphasizing natural pest control measures as much as possible, which uphold ecological balance among density of pests (weeds or insect etc.) and their likely enemy (parasitoids, antagonists, predators) and edifice growers ability and sympathetic of agro-climatic need, so they empower to take good decision for optimum pest management for their cultivated area. Climate smart plant protection measure is suitable in a range of different and developing agricultural situation. Independently of how weather alteration will affect farming ecosystems, growers who know integrated pest management philosophy will be better capable to manage with the effect of weather variability and build up sound and location-specific adaptation measures (Allara et al., 2012). As per current world scenario, all through in the globe, circumstances are generally more encouraging for the explosion of insect pests in warmer hot and humid climates (FAO & INRA, 2016). More crop cultivation period or seasons might be able to more reproductive cycle of different insect pest during winter, spring and summer. Pest control measures could promote in synchronized way to stop problem coupled with trans boundary pests problem and reduced seasonal pest outbreak under climate change. More and scientific linkup achieve by developing new partnership and alliance which should associate with stakeholders and growers from local to nationwide and block levels, and facilitate them to deal with widespread challenge (Allara et al., 2012).

A steady, regular increase in CO_2 in atmosphere will influence different pest population indirectly and directly. Different plant pest species response to rising carbon dioxide concentration levels vary. In general high concentration of CO_2, Consumption rates of herbivores insect frequently boost up. A number of new study with rising CO_2 have recommended that aphids might turn into new stern pests, although erstwhile study has discern no noteworthy effect on sap feeding hemipterans. Various crop-pathogen based models showed that weather variability might change the rates and stages of growth of specific patho-types, change the host mechanism, and leads to modify in the physiological system of host – pathogen relations. More than specific plant protection measures to the crop, more generalised way with respect to weather alteration need to be devised to manage the possible adverse weather alteration effects from all directions (Katrien et al., 2016). Below given are certain climate smart plant protection practices which need to be followed to minimise these above said effects.

4.7 Various Crop Protection Measures Suitable for Climate Smart Practices

4.7.1 Observation at Field Levels

- Not every insect is your enemy: Know which is friend or a foe.
- Know about changes in pest infestation and keep updated ourselves on regular basis.
- More emphasis on farm school programme either through various government agency or through different KVK etc. where one can know more about various pest there at issue in our crop or cropping system.
- Practical knowhow of crop-pest life cycle and their ecological behaviour and control them bay natural way as much as possible (Pimentel, 2009).

4.7.2 Biodiversity and Tolerance

- Pest control through natural enemy become very challenging but quite friendly in nature. A varied fauna of foe species could fruitfully repress various pathogens and pests (Khan et al., 2008).
- Growing of two crop in same field by changing the row spacing, provide good option to attract many repel pests (push) and natural enemies (pull).
- Less intercultural operation, mulching, minimum tillage (increases spider abundance) reduced harmful pest in eco-friendly manner (Mall et al., 2006).
- Try to avoid irrational use of various pesticide or herbicide in field as its reduced beneficial soil microbial population.
- Combine and alter your cultivars with a broad genetic variability which serve as a base for good crop.

4.7.3 Crop Rotation

- Rotation on crop in such a way, as host plants and pests relation broken up with variation in cropping patterns and check pest problem in eco-friendly manner.
- Residues of various crop in field are mostly host of diverse pathogens and diseases, variation in cropping pattern will stop the spread of disease or pest problem from residue to the crop host (Table 4.3).

Table 4.3 Different cropping systems which could reduce pest incidence

Cropping system	Major pests
Rice mono-cropping	LF, YSB, GM. BHP
Rice – wheat	PSB, YSB
Rice – corn	PSB, YSB, Armyworm.
Rice – pulse	LF, LM, YSB and BHP
Rice – ground nut, Rice – rice – fallow	LF, YSB, WBPH, BPH

Note: Yellow stem borer (YSB), Brown plant hopper (BPH), Leaf folder (LF), Gall midge (GM); Pink stem borer (PSB), Leaf miner (LM); White backed plant hopper (WBPH)

4.8 Practical Aspect of Climate Smart Practices Are as Follows

- Mitigation of the Greenhouse gases (GHGs) emission through different cropping systems.
- Zero tillage/Conservation Agriculture: to increase carbon sequestration.
- Direct seeded rice to reduce methane emissions from paddy fields.
- Maximize crop diversity, change of sowing dates, maintain soil cover, minimize soil tillage and breeding new resistant genotypes.
- Cropland design that favours plant diversity and soil fertility management should be encouraged. For example, through the inclusion of cover crops or perennials.
- Optimize the crop sowing time to avoid moisture stress problem in crop life cycle.
- Prevent pest outbreaks by utilizing site specific management option based on length of the growing season.
- Changes in farming practices such as reduced or no tillage (pest control), soil cover or mulching for more retention of water in different crops. Such as infestation of aphid decrease by mulching in cereal field due to better parasitoids and bio-control of predator (Schnee et al., 2006).
- Drought mitigation strategies which include mainly (a) ecological change of farming practice; (b) Rainfall based weather proofing techniques; (c) creation irrigation system in well-organized manner.
- In the area of outbreak of monsoon, regular hoeing of soil to prevent soil moisture loss (enhance soil water holding capacity) and in long dry spell region, agronomic correction measures such as mulching, cover crop, relay cropping system etc. should be follow.
- Soil management method that decrease emissions of greenhouse gases required to be encouraged. In developing country such method include rising the carbon content of the soil, for example by green manuring, inter-and relay cropping or increasing perennial crops and forage grasses.

4.9 Conclusion

Use of various climate smart strategies based on location and adaptive measures like choice of appropriate variety, suitable IFS models, location specific nutrient and residue management, crop rotation with leguminous crop on regular basis, conservation agriculture based various resource utilization techniques, crop diversification and amplification could reduce negative impact to great level and reinforce food growers by more yield per unit area and net return. Short to medium range weather forecasting could crucial function in design of various farming techniques during high rainfall, frost, hailstorms, drought etc. Various water harvestings measures in addition to water saving techniques help to enhance more water accessibility in rainfed and dry area during lean period. This also helpful to supply quality irrigation water during critical period of crop life cycle and enhance crop productivity as a whole. In general, the various climate smart practices integrate innovative and traditional ideas that are pertinent for particular zone or area in an effective way.

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Chapter 5
Bio-fertilizers a Future Prospect Towards Sustainable Agricultural Development

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Abstract A tremendous increase in the human population year after year has raised a threat to fresh fruits, vegetables, food grains and nutritional security all over the world. As the agricultural land is limited and is even reducing drastically due to the expansion of industrialization and urbanization over the time. Therefore, it is need of the time that agricultural production and quality should be improved considerably in the next few years to meet the ever-increasing demand leading to nutritional food security. Dependency on chemicals like pesticides, weedicides and chemical fertilizers in past years, for more crop production have certainly damaged both human health and the ecosystem to great severity. Nature has its plan for sustainable growth and development and so are the biofertilizers, which are ultimate gift of nature to our agriculture as a replacement for pesticides, weedicides, and synthetic fertilizers. Biofertilizers contain microbes in a living form which encourages the sufficient supply of nutrients and growth promoters to the plants and ensures their good growth, development, and regulation of physiological activities. Living microbes used for the preparation of bio-fertilizers have specific function; they augment plant growth, development, and reproduction. In the above view, bio-fertilizers being important constituents of sustainable agricultural development can play a vital role in conserving long-term soil fertility, soil health, and sustainability in crop production in India as well as internationally.

Keywords Bio-fertilizers · Sustainability · Mycorrhiza · Azospirillum · Soil health · Organic agriculture

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5.1 Introduction

World population is near to 7.6 Billion and the Indian sub-continent alone contains nearly 1.35 Billion, with a day by day increase in it. Population increase imparts immense pressure on agricultural land as well as other resources. Our Agriculture has to fulfill the need of food, feed, and biofuels for a projected population of nine billion by 2050, and agricultural production has to increase by 70%. Farmer's dependency on the use of insecticides, pesticides, weedicides, and inorganic fertilizers for the sake of increased productivity, with the increased demand of growing population from conventional agriculture to meet out its need of food grains (Santos et al., 2012). However pesticides, weedicides, and chemical fertilizers are anthropogenic in origin, they are essential for optimum growth and development of plants, but their indiscriminate use left with harmful effects and may results in to bad soil health, (Chun-li et al., 2014) such as soil acidification, deteriorating of roots, enhance in disease incidence, eutrophication of water bodies and groundwater (Youssef & Eissa, 2014). Leach down of nutrients (nitrates) from upper soil layers to groundwater causing serious health problems i.e. Blue Baby disorder also called methemoglobinemia' (Knobeloch et al., 2000). Future generations will face great impact of such chemicals, as well. In this regard, with a view of the bio-safety and a healthy ecosystem, eco-friendly approaches are gaining popularity. Therefore, bio-fertilizers become important and can play a key role in sustainable agricultural development. The worldwide market share of bio-fertilizers has exceeded market cap of USD 10.2 billion till 2018 and European and Latin American countries emerged as the leading consumers and manufacturers of biofertilizers. In developed countries strict regulations are imposed on distribution and use of inorganic chemical fertilizers, ultimately, substituted chemical fertilizers by biofertilizers (Raja, 2013).

Biofertilizers may be defined as solid/semi-solid/ liquid formulations that have latent microbial cells which colonize the roots of host plant and encourage growth by increasing the availability and supply of essential nutrients to the target crop (Mazid et al., 2011). These are liquid/solid/semi-solid preparations containing latent cells of microorganisms that function as phosphorus solubilizers, nitrogen fixers, sulfur oxidizers, organic matter decomposers and hence are; "eco-friendly" agro-inputs and through their routine metabolic activities convert unavailable essential elements to available form. (Vessey, 2003). 60–90% of applied nutrients are lost by immobilization, leaching, volatilization, etc. and only 10% to 40% are utilized by crops, biofertilizers mobilizes slow and continuous release of essential plant nutrients by their metabolic activities and thus, forms an important part of Integrated Nutrient Management (INM) System to sustain agricultural production (Adesemoye & Kloepper, 2009) (Table 5.1).

Table 5.1 Different groups of bioinoculants

S. No.	Groups	Examples
Nitrogen (N_2) fixer		
i	Associative-symbiotic	*Azospirillum*
ii	Symbiotic	*Rhizobium*, *Anabaena azollae, Frankia*,
iii	Free living	*Azotobacter*, *Clostridium*, *Nostoc, Anabaena*,
Phosphorus solubilizer		
i	Fungi	*Aspergillusawamori, Penicillium*sp
ii	Bacteria	*Pseudomonas striata, Bacillus subtilis*
Phosphorus mobilizer		
i	Arbuscular Mycorrhizae	*Gigaspora* sp., *glomus* sp
ii	Ericoid Mycorrhizae	*Pezizellaericae*
iii	Ectomycorrhiza	*Pisolithus species, Laccarai species Boletus species, Amanita species*
Potassium solubilizer		
i	Bacteria	*Frateuria aurantia*
Micronutrient solubilizer (Zinc and Silicate)		
i	Bacteria	*Bacillus* species
Plant Growth Promoting Rhizobacteria		
I	Bacteria	*Pseudomonas fluorescens*

Source: Barman et al. (2017)

Table 5.2 Bioinoculants for different crops

Bioinoculants	Crops
Azospirillum spp.	Cereals and monocots
Rhizobium spp.	Leguminous crops
Blue Green Algae	Submerged rice
Azotobacter spp.	Cereals crops
Phosphate solubilizers	All crops
Azolla	Submerged rice

Source: FAI (2006–2007)

5.2 Role of Biofertilizers

Biofertilizers increase the biomass and yield of plants by various plant growth-promoting activities and various mechanisms in the plant rhizosphere soil such as, Phosphorus mobilization, nitrogen fixation, Phosphorus, potassium, micronutrient solubilization, prevents depletion of soil organic matter, plant growth promotion, and maintains natural soil habitat (Jeyabal & Kupuswamy, 2001) (Table 5.2).

5.2.1 Biological Nitrogen Fixation

The process of conversion of atmospheric nitrogen into nitrate and nitrite by the action of microbes, like bacteria, fungi, algae etc. is described as biological fixation (Gothwal et al., 2007) and this mechanism of conversion of available atmospheric nitrogen can be exploited by using microbes as potential bio-fertilizers acting as alternate of inorganic chemical fertilizers. They help in maintaining the rhizospheric nitrogen reserve and gives healthy crops with quality yield (Peoples & Craswell, 1992). These microorganisms are grouped into different categories, such as free-living: *Azotobacter*, associative: *Azospirillium, cyanobacteria*, and symbiotic nitrogen fixers: *Rhizobium, Frankia* and *Azolla* (Gupta, 2004). In natural habitat symbiotic associations (Fig. 5.1) contributes maximum for Biological Nitrogen Fixation and apart from *Azotobacter*, other genera also fix atmospheric nitrogen. Six free-living nitrogen-fixing bacteria belonging to the genera *Alcaligenes, Azotobacter* and *Azomonas* were isolated and identified (Latt et al., 2018) using 16 s rRNA sequencing. Different nitrogen fixing genera are summarized as under:

5.2.1.1 Azotobacter

Azotobacter is free-living, gram-negative, aerobic, heterotrophic, biological nitrogen fixer. This bacterium is having the ability of independent biological nitrogen fixation (BNF), some species of *Azotobacter* are also found in association with cereals

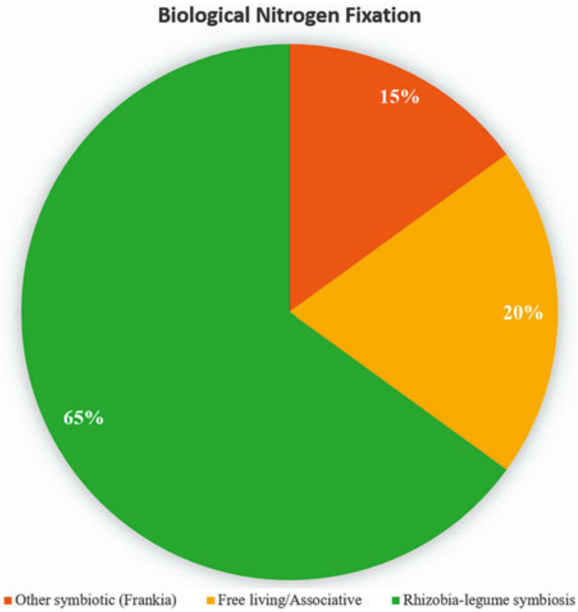

Fig. 5.1 Biological nitrogen fixation by Bouizgarne et al., 2015. (Modified)

Table 5.3 Effect on crop yield using *Azotobacter* bio-fertilizer

Crops	Increase in yield (%)	Crops	Increase in yield over chemical fertilizers (%)
Wheat	Approx. 8–10	Potato	16
Rice	Approx. 5	Carrot	40
Maize	Approx. 15–20	Cauliflower	2–24
Sorghum	Approx. 15–20	Tomato	7–27
Other	Approx. 13	Cotton	9–24

Source: Dudeja et al. (1981)

(Martyniuk & Martyniuk, 2003). These are commonly present in alkaline and natural and arable soils. The genus *Azotobacter* comprise of different species such as A. armeniacus, A. beijerinckii, A. chroococcum, A. nigricans A. paspali, A. salinestri and A. vinelandii, (Gothandapani et al., 2017). Azotobacter species are mesophilic and motile with the ability to fix atmospheric nitrogen (Rawi et al., 2009) on an average of 20 kg nitrogen/ha/per year. *Azotobacter* as a biofertilizer also play different role i.e. production of growth hormones, antibiotic synthesis, pigments, vitamins, exo-polysaccharides and plant defence i.e. antifungal activity (Pandey & Kumar, 1989; Jimenez et al., 2011; Sudhir et al., 1983) (Table 5.3).

5.2.1.2 Azospirillum

Azospirillum is an aerobic, gram-negative, nitrogen-fixing, non-nodule-forming, bacterium belongs to the family Spirillaceae. Generally, found in association with roots of C4 plants having Hatch-Slack pathway (dicarboxylic pathway) of photosynthesis they grow and fix atmospheric nitrogen on the organic salts of aspartic and malic acid (Mishra & Dash, 2014). Root development and exudation are greatly affected by *Azospirillum* (Trabelsi & Mhamdi, 2013). Under micro-aerobic conditions, it can fix 20–40 kg nitrogen/ha/per year. *A. amazonense, A. brasilense, A. halopreferans, A. lipoferum,* and *A. trakense* are some of the important species of *Azospirillum*. Steen houdt and Vanderleyden (2000) reported that production of different phytohormones, by *A. brasilense* sp. increased growth and yield of maize crop. *Azospirillum* is used in seed treatment of different crops few minutes before sowing without application of other seed treating agents i.e. fungicides, pesticides, insecticides, micronutrients, polymers, etc. Apart from biological nitrogen fixation (BNF), it performs many other important functions in the soil i.e. production of siderophore and/or phytohormones, phosphate solubilization biocontrol activity and protection against stress conditions caused due to toxic compounds or soil salinity (Bashan and Bashan, 2010, Creus et al., 1997; Puente et al., 2004).

5.2.1.3 Rhizobium

Rhizobium is found in symbiotic association with leguminous crops, plants provide the photosynthetic product as a source of energy and bacteria fix atmospheric nitrogen from the air for their host plant. It colonizes the roots of legume plants by forming nodules and fixes the atmospheric nitrogen in the form of nitrate and nitrites. In free-living condition physiology and morphology of Rhizobium is different from bacteroids in root nodules. *Rhizobium* is used as an effective bio-fertilizer for legume crops as far as the quantity of biological nitrogen fixation is concerned (Jehangir et al., 2017). Cross-inoculation plays an important role in the host specificity of *Rhizobium* (Table 5.4). The nodulation and nitrogen fixing activity of the bacterium is controlled by *nod, nif* and *fix* genes.

5.2.1.4 Cyanobacteria

Cyanobacteria are also known as blue-green algae (BGA). They are prokaryotes, form water blooms in standing water bodies, and are also present in hot springs and snow. They are photosynthetic in nature and actively fix nitrogen in submerged rice fields, they can fix around 20–30 kg nitrogen/ha and also produces plant growth hormones such as: - auxins (indole acetic acid), gibberellic acid which promotes plant growth. Application of Azospirillum + BGA found advantageous in improving LAI and yield attributes in low land rice conditions (Mishra et al., 2013). *Anabaena, Aphanotheca, Aulosira, Cylindro spermum, Gloetrichia, Nostoc,* and *Tolypothrix*, are some common examples of blue-green algae (BGA). Rice productivity is enhanced from 15% to 38% with the application of BGA. The beneficial effects of cyanobacterial (BGA) inoculation are reported on a variety of crops such as chilly, tomato, radish, lettuce, barley, oats, cotton, sugarcane, and maize (Thajuddin & Subramanian, 2005).

Table 5.4 Major inoculation groups with inoculant and host plants

Cross Inoculation Group	*Rhizobium* species	Host Legumes
Alfalfa	*Rhizobium meliloti*	Sweet clover
Bean	*Rhizobium phaseoli*	All beans
Clover	*Rhizobium trifoli*	Clover / berseem
Cowpea	*Rhizobium* species.	Groundnut, moong, urd, arhar and cowpea
Pea	*Rhizobium leguminosarum*	Pea, sweet pea
Soybean	*Bradyrhizobium japonicum*	Lupins

Source: Ponmurugan and Gopi (2006)

5.2.1.5 Azolla

Azolla is an example of a floating symbiotic nitrogen fixer; pteridophytes sheltering an aquatic fern a cyanobacterium. Aound 80,000 symbiotic cyanobacteria (endosymbiont) are present on its leaves, extensively used as biofertilizer in rice cultivation. When *Azolla* as biofertilizer, partially substituted with synthetic nitrogen fertilizer reduces loss and enhance uptake, the association (*Anabaena azollae*) also improves soil health and soil fertility. *Azolla* is an important nitrogen fixer; its potential varies between 30–50 kg nitrogen/ ha/crop and works as a good source for agro-industry (Yao et al., 2018). Application of *Azolla* in rice crop brought a (Gupta, 2004) significantly increased the yield by 0.5 to 2 t/ha. Sundaravarathan and Kannaiyan (2002) found that grain yield increased by 29.2% when *Azolla microphylla* was applied @ 15 t/ha.

5.2.1.6 Gluconacetobacter Diazotrophicus

Gluconacetobacter diazotrophicus is an active nitrogen fixer, generally found in monocot plant sugarcane, where the bacterium provides significant amount of nitrogen to plants by fixing atmospheric nitrogen. This bacterium does not form the complex root organ i.e. nodules, it generally forms a colony within the intercellular space of the root and stem of the plant. *G. diazotrophicus* is also found in a variety of plant species as the bacterium does not have host plant/crop specificity. Notably, as the bacteria were retrieved from monocot plants, so there exists an opportunity that the biological nitrogen fixing ability of the bacterium can also be utilized in other monocot plants/crops.

5.2.2 Phosphorus Solubilization

Phosphorus is an important plant macronutrient that promotes growth and development, mostly present in insoluble form in the soil and hence remains unavailable to plants. In soil unavailable phosphorus is present in the form of organic matter such as apatite, phosphodiesters, inositol phosphate; plants can absorb phosphorus in two soluble, monobasic and dibasic forms for their growth and development. Sometimes soluble inorganic phosphorus fertilizers become unavailable to the plants due to immobilization. In soil phosphorus solubilizing bacteria (*Bacillus megaterium* and *Pseudomonas putida*), fungi (*Penicillium* and *Aspergillus*) solubilizes bound phosphate and fix phosphorus so that it becomes available to the plants. PSB and PSF meet out 20–25% of the phosphorus requirement of crops/plants. Hence, its use as biofertilizers in crop production not only reduces manufacturing cost of phosphatic fertilizers but also mobilize insoluble form to soluble forms in soil (Chang & Yang, 2009). Among possible phosphorus solubilizers' in soil, bacterial population (PSB) constitutes 1 to 50%, while fungal population (PSF) constitutes only 0.1 to 0.5% in soil (Chen et al., 2006). Certain actinomycetes can also solubilize phosphorus, produce antibiotics and phytohormones; these days they are gaining popularity due to their added advantage of surviving in extreme environmental conditions i.e. drought (Hamdali et al., 2008) studied that about 20% of actinomycetes present in soil have the capacity of phosphorus solubilization, counting those present in the common genera *Streptomyces* and *Micromono spora*. Some common phosphorus solubilizing microbes are discussed as under:

5.2.2.1 Bacteria

Bacillus megaterium, also known as "Phosphobacterium" are rod-shaped, Gram +ve bacteria, enhance solubilization of mineral phosphorus (Lach et al., 1990). The mechanism of phosphorus solubilization takes place by the secretion of inorganic and organic acids; proton excretion that supplement NH_4+ assimilation and by the release of enzyme phosphatase, mineralization of organic P compound takes place in the soil (Stevenson, 1986). Phosphobacterium also has the potential of solubilizing Mn, Zn, Fe, and K (Amalraj et al., 2012). The release of growth-promoting hormones enhances root proliferation of plants and supplies phosphorus to the plants at an average of 10 to 15 kg/ha and saving up to 50% over the cost of inorganic chemical fertilizers. This biofertilizer can be applied through soil application, seed treatment, root dipping before transplanting, and drip irrigation method. *Pseudomonas chlororaphis* and *Pseudomonas erwinia* having the capability of solubilizing phosphorus and HPCL studies showed release of several organic acids (Diriba et al., 2013).

5.2.2.2 Fungi

Fungi are also potential phosphorus solubilizing agents present in natural soil habitats. *Aspergillus* and *Penicillium* fungi are found dominantly (Vassilev et al., 2007; Oliveira et al., 2009). *Aspergillus* species, *Mucor* and *Penicillium* species are generally found in arable soils and have augmented plant growth by 5 to 20% (Gunes et al., 2009). Numerous species of *Penicillium* and *Aspergillus* were recognized that can solubilize insoluble phosphate reported by Kucey and Paul (1982). Chickpea plants when inoculated with *Aspergillus niger*, dry biomass is increased by 22 to 33% over non-inoculated control, (Kapri & Tewari, 2010). Phosphate solubilizing fungi (PSF) increased solubility of unavailable phosphorus present in soil and gave considerably higher grain yield over control alone by 12.6%. PSF (*Penicillium bilaii*) when used as a bio-inoculant along with 50% dose of recommended phosphatic fertilizer produced wheat yield comparable to 100% phosphorus dose, without inoculation of PSF (Ram et al., 2015) (Fig. 5.2).

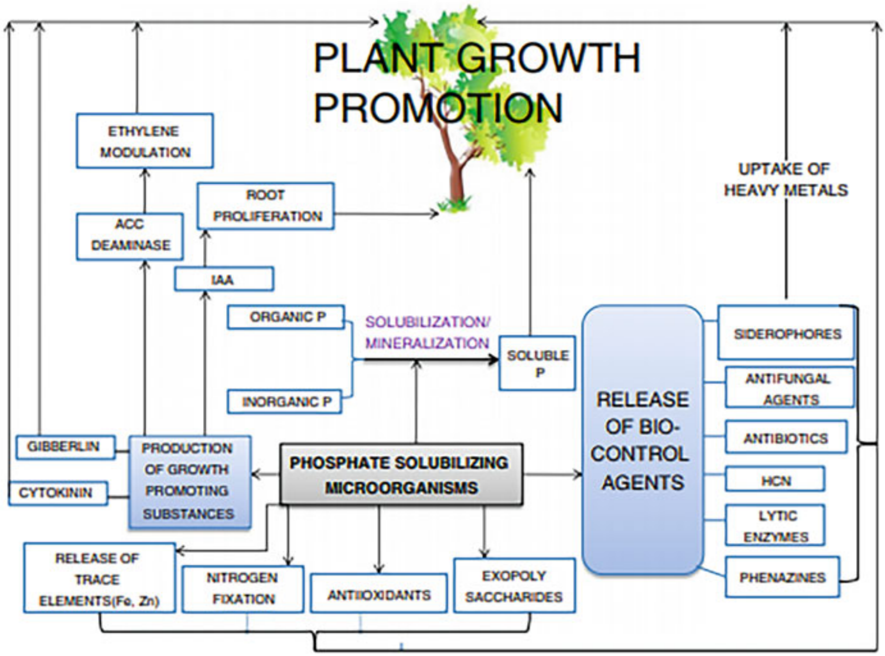

Fig. 5.2 Mechanisms involved in plant growth promotion by PSM (Sharma et al., 2013)

5.2.3 Phosphorus Mobilizers

Several microbes are involved in phosphorus mobilization, instead of solubilizing, it from a phosphorus-rich environment, and increases its uptake by the plants. Microorganisms involved in this mechanism are called phosphorus mobilizers. *Arbuscular mycorrhizal* fungi play vital role in increasing mobility of phosphate of phosphatic fertilizers by reducing fixation, these fungi are having the capacity of increasing phosphorus availability in soils low in phosphorus (Ghorbanian et al., 2012). Mobilization of phosphorus increased the growth of young apple trees when inoculated with *Pseudomonas letiola* grown in pots, showed a significant increase in total shoot length, and solubilization of insoluble phosphorus compounds took place present in the soil (Ewak et al., 2013).

5.2.3.1 Mycorrhiza

Mycorrhiza a group of fungi found in symbiotic relationship with plant roots in the rhizospheric zone and greatly improves the uptake of phosphorus and comparatively immobile plant nutrients present in the soil, by plant root systems, belongs to phylum *Glomeromycota* (Bolan, 1991). They increased phosphorus uptake by exploiting a larger soil volume with the help of hyphal structures deep inside the soil. Jakobsen et al. (1992) reported that different amounts of phosphorus were supplied to the host plant by different amounts of external mycelium produced by *Arbuscular mycorrhizae* Fungi. Yao et al. (2001) conducted a study, and the results proved that under conditions of low phosphorus availability, the AMF provided better contact with phosphates present in the soil through mobilizing phosphates and solubilizing phosphorus with the production of organic acids. The smaller diameter of fungal hyphae 2 to 20 m helps in easier phosphorus acquisition in comparison with the new roots formed in plants. The Arbuscule interface is the principal site of nutrient transfer from fungus to plant, also occurs at the site of the hyphal coils (Karandashov et al., 2004). The mycorrhizal associations help in alleviating aluminum toxicity, increasing phosphorus, nitrogen, and micronutrient uptake, maintaining soil structure by the production-specific protein called "Glomulin".

5.2.4 Potassium Solubilizing Bacteria

Potassium (K) is generally considered as an essential macronutrient for plants. Obviously, potassium is present in larger quantity in soils than any other nutrient but in unavailable form and can't be utilized by plants only 1to 2% is available to the plants (Sparks & Huang, 1985). Diverse group of microbes can solubilize potassium present in soil i.e. fungi, bacteria, and actinomycetes. Bacteria solubilize potassium by producing organic and inorganic acids, chelation, acidolysis, complexlysis, exchange reactions, and polysaccharides (Archana et al., 2013; Meena et al., 2015). *Pseudomonas azotoformans* and *Bacillus licheniformis* show higher potassium solubilizing ability over other rhizobacterial isolates when isolated from rice fields (Saha et al., 2016). *Enterobacter hormoechei* bacteria having the ability of potassium solubilization and remarkably enhanced chlorophyll and potassium content in cucumber Prajapati and Modi (2016). *Frateuria aurantia* a bacterial strain mobilizes potassium when inoculated with soluble form in tobacco crop improved leaf quality, nutrient content, plant biomass and potassium content in leaf increased by 39% Subhashini (2015). Many bacterial species are having the ability to solubilize potassium such as *Acidithiobacillus ferrooxidans, Bacillus edaphicus, Bacillus mucilaginosus, Bacillus circulans, Burkholderia, Paenibacillus*, and *Pseudomona* spp.

5.3 Plant Growth Promoting Rhizobacteria (PGPR)

Plant growth-promoting rhizobacteria are groups of bacterial strains that are having the ability to colonize plant roots or rhizospheric soil and have a beneficial effect on the crop. *Pseudomonas fluorescence* and *Bacillus* species have the potential to act as microbial pesticides. PGPR inoculants promote plant growth through several mechanisms i.e. Bio-fertilizers: - improves nutrient availability and uptake to plants/ crops, Bio-protectants: - suppression of several plant/crop diseases, Bio-stimulants or phytohormones production, which makes their commercial utilization. *Pseudomonas* and *Bacillus* Species can produce growth regulators or phytohormones which include indole-acetic acid, cytokinins, gibberellins and inhibitors of ethylene that can increase the absorptive surface area of roots for the uptake of nutrients. Rhizobacteria induce their antagonistic effect by producing jasmonic acid, salicylic acid-dependent SAR pathway, and ethylene perception from the plant for ISR. They can be used for bio-control strategies by formulating new bio inoculants with combination of different mechanism of action i.e. antagonism and inducing resistance in plants.

5.4 Zinc Solubilizers

Several microorganisms can solubilize zinc added or present in the soil viz., *Thiobacillus thioxidans, Bacillus subtilis,* and *Saccharomyces* species. The solubilizing ability of these microbes can be utilized for manufacturing bio-fertilizer for solubilizing micronutrients fixed in the soil. The bacterial species *Bacillus* has the ability of Zn solubilization; this can be exploited for the production of bio-fertilizer for zinc. The Zn solubilizing bio-fertilizer application is better than costly zinc sulfate gives better results when applied in soils where natural zinc is higher and in combination with insoluble cheaper source of zinc compounds i.e. zinc sulfide (ZnS), zinc oxide (ZnO), and zinc carbonate (ZnCO3) (Mahdi et al., 2010).

5.5 Strategies for Development of Bio-fertilizers for Sustainable Agricultural Development

The following are some strategies for development of Bio-fertilizers for Sustainable Agricultural Development:

(i) Use of biotechnological techniques for strain improvement.
(ii) Exchange of biological cultures between countries having similar agro climates and evaluating their performance for a better strain for particular crop and checking their activity during storage to avoid natural mutations.
(iii) Developing suitable alternate formulations like granular formulations or liquid inoculants for all bioinoculants and also standardizing the media, method of inoculation, to carrier-based inoculants, etc., for new formulations.
(iv) Production units should be under regulation and monitoring of microbiologists.
(v) Developing cold storage facilities in production units.

(vi) Manufacturers should be given technical training of production, quality control, rendering technical advice and projects to them.
(vii) Disseminating information through social media, newspapers, publications, bulletins etc.

5.6 Conclusion and Future Perspective

Producing healthy crops with the quality yield for the ever-increasing demand of growing population totally depends upon the type of fertilizers used to provide all the essential nutrients to the plants. But more dependency on inorganic chemical fertilizers is deteriorating the environmental ecological balance and cause negative effects on the health of human beings. Microorganisms used as bio-fertilizers are the essential component of sustainable farming and can play a vital role in improving nutrient status, their accessibility to plants, sustainability, and maintaining long-term soil fertility. In sustainable agriculture, plant nutrients are the most vital components. Hence, using microorganisms as bio-fertilizers is believed to be the best substitute for inorganic chemical fertilizers, because of their eco-friendly behavior for plant growth and soil fertility. Microorganisms as bio-fertilizers provide significant benefits to crops for sustainable agricultural development. The plant roots are colonized by endophytic, epiphytic, and rhizospheric microorganisms, play an important role in nutrient uptake from the surrounding ecosystem and also promote plant growth under natural as well as extreme environments. These plant growth-promoting microorganisms (PGPM) augment the plant growth by a variety of direct and indirect mechanisms by producing various plant growth hormones, hydrolytic enzymes, HCN, siderophores, biological nitrogen fixation, and solubilization of phosphorus, potassium, and zinc. In the long-run impact of chemical fertilizers on the environment and cost of production will not be a practical approach both in domestic assets and foreign exchange. Bio-fertilizers are natural products that are expected to be commercially encouraging in the long run once sufficient information becomes available to producers and farmers. The use of bio-fertilizers in India will not only have an impression on ecological agriculture's financial development but will also contribute to a viable ecosystem and the complete well-being of the country.

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Chapter 6
On-Farm Water Harvesting: Promising Intervention Towards Crop Diversification and Doubling Farmers Income in Drought Prone Central Province of India

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Abstract On farm water harvesting and reuse of rain water will be a critical intervention in rainfed farming will remain the main stay for the livelihood support of millions of small and marginal farmers across the country even after realizing the complete irrigation potential. Rainwater management is the most critical component of rainfed farming. The successful production of rainfed crops largely depends on how efficiently soil moisture is conserved in situ or the surplus runoff is harvested, stored and recycled for supplemental irrigation. Diversification of crops from the existing cropping system and adoption of related enterprise fetches more income to the farmer. System productivity can be made more then four times by increasing the cropping intensity of any farm. Despite these experiences, the adoption of farm ponds at the individual farm level has been very low, particularly for drought proofing through life saving irrigation of kharif crops. A number of technological and socio-economic constraints are cited for this poor adoption and up-scaling. With climate change posing a major challenge for rainfed agriculture and the constraints in further expansion of irrigated area in the country, rainwater harvesting and efficient water use are inevitable options to sustain rainfed agriculture in future.

Keywords Crop diversification · Water harvesting · Rainfed farming

6.1 Introduction

Indian economy is largely agriculture driven with nearly 55% of the population depending on it and allied sectors for their livelihoods while it contributes only 15% to the nation's GVA. Marginal and small land holdings (under 2 ha) comprise 85%

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of the total operational land holdings both in terms of number and area. Of 193.7 million ha, around 45% (87.7 million ha) is irrigated while the rest is rain fed. Groundwater and surface water sources irrigate about 31% and 68% of the irrigated area respectively. In addition to water scarcity and increasing land degradation, Indian farmers are vulnerable to impacts of climate change as their livelihood largely depends on monsoon, markets and intermediaries who are integral part of their lives but are unpredictable and play havoc on rural livelihoods. With the agricultural growth rate stagnant around 3–3.5% annually, farmers are in economic distress despite huge subsidies being pumped to farm sector. The brighter side of the economy is that, Indian agriculture has many advantages, which includes robust demand (domestic and international), largest agricultural land (> 157 million ha) with 15 agro-ecologies and 46 different global soil types uniquely positions India to design, develop and deliver solutions for smallholder farmers in India.

Popularizing innovative technologies and achieving larger impacts on the ground requires the involvement of various stake holders. Further, Mechanism and models of delivery will require focused funding, institutional incentives, behavioral change, and rethinking on the role of public extension systems. For strengthening the technology delivery system, 700 plus KVKs across the country have played a larger role in skill development and participatory technology demonstration to address location-specific constraints. These solutions can then be scaled through targeted dissemination that will empower farmers to act on ecologically sound and marketable options to increase their incomes. Besides, Agricultural Technology Management Agency (ATMA) has given an institutional identity to extension, strengthen linkages with other line departments and *Krishi Vigyan Kendras* (KVKs).

6.2 Water Harvesting

Water is one of the most critical input in agriculture having a determining effect on the eventual yield. Good seeds and fertilizers or any other innovative technology fail to achieve their full potential if plants are not optimally watered. India accounts for about 17% of the world's population but only 4% of the world fresh water resources. Distribution of these water resources across the vast expanse of the country is also uneven. Indian agriculture is a gamble of monsoon rains received during the 4 months of the year i.e., from June to September. Since more than 54% of the arable land is dependent on rains, hence water harvesting is the only viable option to carry out the agricultural activities so as to feed the ever-burgeoning population on one hand and on the other owing to fast industrialization and urbanization there is a huge pressure on arable land as more and more area is being put into non-agricultural work, thus demanding more production per unit area and more crop per drop of water. For scientific and meaningful water harvesting the total annual precipitation received plays a crucial role particularly when climate change and global warming has made its presence felt more consistently over the last few decades.

6.3 Distribution of Annual Rainfall in India

Distribution of rainfall in the Indian Sub-continent is mostly influenced by the relief features on the surface of the Earth and the direction of the rain-bearing winds in that region. Apart from the above factor, the path followed by the cyclonic depressions decide the amount of rain at any place. The region located on the windward side of mountains, hills or plateaus receives comparatively more rainfall than the leeward side, Majumdar (2002).The normal annual rainfall precipitation in the country is estimated to be 400 million hectare-metres (Mha-m) of water. India's water budget has been estimated and reported by Gupta and Deshpande (2004), Kumar et al. (2005), and Garg and Hassan (2007). These analyses are based on estimates of water budget components presented in a report by the National Commission for Integrated Water Resources Development Plan (Table 6.1).

6.4 Importance of Rainwater Harvesting

Rainwater harvesting is defined as a method for inducing, collecting, storing and conserving local surface runoff for agriculture in arid and semi-arid regions. Rainfall has four facets. Rainfall induces surface flow on the runoff area. At the lower end of the slope, runoff collects in the basin area, where a major portion infiltrates and is stored in the root zone. After infiltration has ceased, then follows the conservation of the stored soil water. Verma et al. (2008) indicate that decentralized small water harvesting structures are very good alternative to the conventional river basin irrigation infrastructures which requires high initial investment and hence not affordable by individual farmer. Several studies have reflected that a clear relationship between the size of catchment and amount of run-off that can be captured exists. Increasing the size of the catchment from 1 hectare (ha) to about 2 ha reduces the water collection per hectare by as much as 20–25%. Thus, in a drought prone area where water is scarce, tiny dams with a catchment of 1 ha each will collect more water than one larger dam with huge catchment. Similar inference has been drawn by Moench and Kumar 1993, Khurana 2003, and Rockstrom et al. 2009. Shah and Raju (2001) studied the socio-ecology of tanks and water harvesting in Rajasthan reported that there are multiple benefits from tanks. Tanks lead to substantial rainwater harvesting at the local level, and the associated distribution system leads to water

Table 6.1 Principal annual components of India's water budget1

Component	Volume (km^3)	Precipitation (%)
Precipitation	3838	100
Potential flow in rivers	1869	48.7
Natural recharge	432	11.3
Available water	1869 + 432 = 2301	60
Evapotranspiration	3838 − (1869 + 432) = 1537	100 − (48.7 + 11.3) = 40.0

Source: Gupta and Deshpande (2004), Planning Commission (2007) availability in large areas and to larger numbers of farmers. Most significant effect of percolation of rainwater is groundwater recharge along with higher water table in the area. Other benefits include low-cost flow irrigation, reduction in intensity of flash floods, concentration of silt and minerals to fertilize the soil in the command area, and reduction in soil erosion.

6.5 Why Double Farmers' Income?

The major dilemma of more than 138 million Indian farmer's is that they are facing a decline in their farm income on one hand and the increasing cost of inputs on the other, both of which are parallel in nature and have no chances to intersect at a common point. A recent study by the National Institute of Agricultural Economics and Policy Research (NIAP) has shown that around 70% farmers in the country have annual per capita income less than Rs.15, 000. NIAP have further analyzed the situation geographically and finds that, the problem is precarious in Uttar Pradesh (27.4%), Bihar (11.4%), West Bengal (9.9%), Odisha (6.3%), Rajasthan (5.8%), Madhya Pradesh (5.3%), Maharashtra (4.9%), Assam (3.9%) and Jharkhand (3.2%) as, these states lack the required infrastructure for agricultural income growth. NITI *Ayog* (Formerly Planning Commission of India) concluded that, the post Independence strategy for the development of agriculture was dependent on the following factors.

(a) Increase in productivity through the drivers of Green Revolution.
(b) Incentive structures I the form of remunerative prices for some crops or subsidies for the other.
(c) Public investment in the sector and
(d) Facilitating the Institutions.

The above strategy fell short in realizing the increase in farmers' income. Under actual production scenario, increase in production should have also led to increase in farmers' income. But the real fact is that instead of increase in income, there was a steep down fall so much so that the income of farmers was below the poverty line leading to mass suicide in some states of the country between 1994 and 2004. Situation in states like Jharkhand was so precarious that more than 45% farmers were below the poverty line. There was also a disparity between the income of different sectors of economy. Those engaged in farm related activities, the income was far less than the non-agriculture sector by more than four times. The low and fluctuating farm income led to loss of interest in agriculture and particularly the youth started leaving this profession and migrating to urban areas for search of bread and butter. All the above factors forced the Government to pay special attention to the farming community of the country and hence the year 2015–16 was selected as base year and the target was fixed that the income of farmers' would be doubled by 2022 based on the economic parameters prevailing during the base year. This means that Indian agriculture needs to grow by more than 14.86% annually to meet the target, Gulati 2016.

6.6 Case Study

Rapid expansion of groundwater use in *Malwa* plateau of Madhya Pradesh in the last three decades has resulted in a steep decline in the groundwater table. This has led to drying up of a huge number of wells, low well productivity, and rapid rise in well and pumping depths, deteriorating groundwater quality, and also salinity/alkalinity problem in many areas. Rain-fed agriculture is practiced on 80% of the world's agricultural land area, and generates 65–70% of the world's staple foods, but it also produces most of the food for the poor communities in developing countries and least favored areas. Rain-fed areas in India are highly diverse, ranging from resource-rich areas with good agricultural potential to resource-constrained areas with much more constrained potential. It is in the rain-fed regions where cultivation of nutritious (coarse) cereals (91%), pulses (91%), oilseeds (80%) and cotton (65%) predominate. Rainfall is a truly random factor in the rain-fed production system, and its variation and uncertainty is high in areas of low rainfall. Supplemental irrigation is a key strategy, so far underutilized, to unlock rain-fed yield potentials. Since time immemorial, water conservation and harvesting have been practiced in India and other parts of world. The production process depends on the timely water conservation in Talab, pokhar, johad, khet talab, and bandhan which will provide the supplemental or lifesaving irrigation. The objective of supplemental irrigation is not to provide stress-free conditions through the crop growth for maximum yields, but to provide just enough water to tide over moisture scarcity at critical growth stages to produce optimal yields per unit of water. In this precarious situation integration of different agriculturally related enterprises with crop activity as base, provide ways to recycle the products and by-products of one component as input to another serves to realize the best use of available natural and manmade resources.

Ujjain district of Malwa Agro-climatic zone in central India is a drought prone area with unsustainable production systems. Krishi Vigyan Kendra working here as a developmental agency for the transfer of technology to the farmers conducted On-Farm trials from 2014 to 2017 in five different agro-ecological situations by emphasizing on the harvesting of run-off water in suitable storage structures. Water harvesting tanks with a capacity of 6000–7500 cubic meter constructed at the lower end of the catchment in five different villages, served as the base for increasing the cropping intensity, change in the cropping sequences, incorporation of market driven cash crops and increase in the overall system productivity.

6.7 Intervention

To assess the impact of rain water harvesting structures at the farm level, On Farm trial was planned based upon the Participatory Research Appraisal with the help of the beneficiaries of the village and the most critical problem i.e. the shortage of irrigation water was taken up. This problem was the basic hindrance in diversification of crops and in adoption of new technologies or cropping system. For this, five independent sites under two different agro-ecological situations were selected and the interventions were implemented in three different phases as described below.

I. At the first instance water harvesting tanks measuring 70*60*4 m^3 was dug out at the lowest elevation having not less than 2.0 ha of catchment area. Thus, a pond of size 16,800 m^3 was available to the farmer for rainfall storage. The entire expenditure was subsidized by the state government @ Rs 80,000 per tank to promote the farmers. After the rainy season the tanks were loaded with full capacity and then the plan for the diversification was given to farmers providing new varieties and complete package of practice.
II. The plan was executed continuously for three consecutive years and the emphasis was paid in increasing the grossed cropped area with the help of supplemental irrigation from the tamk. Simultaneously, high yielding crop varieties and inclusion of cash crop like potato was also introduced. A separate unit to recycle the farm waste was prepared and vermin-compost was prepared and used in the fields to maintain the soil physical conditions and to increase the water use efficiency.
III. At the end of fourth year the farm produce was subjected to Seed Certification process so that the entire production received could be sold out as seed and a higher remunerative could be fetched by the farmer. The yearly progress on diversification, sequential change in various economic parameters, change in family income and finally the change in enterprise reflected is presented below through different tables and figures. The events of intervention are shown as pictorial graphics below.

6.8 Result and Discussion

The results of 4 years study revealed that during the base year the cropping intensity of all the farmers ranged between 135 and 143% under the conventional soybean based cropping system, in which soybean was followed by wheat and or chickpea and the total system productivity was 6.4 kg/ha /day. After full storage of water tanks the total water stored was 2–3 irrigation was made possible at critical stages and the farmers shifted from the conventional cropping sequences to soybean-potato-wheat, soybean-potato-onion, and soybean –green peas-wheat-fodder. Crops were also substituted with additional enterprise taking 5–6 milch animals for better utilization of farm wastes and the by-products of the animals was utilized to prepare sight specific nutrient options to take care of decreasing soil health mainly due to loss of organic carbon. The cropping intensity increased to more than 262 and the system productivity in terms of soybean equivalent yield increased to 64.8 kg/ha/day. This was reflected in terms of increase in yield per unit area due to higher water use efficiency, increased nutrient use efficiency, increase in milk yield due availability of green fodder, etc. This was a quantum leap in the net income from mere Rs 4224 per month to Rs 38,400 per month per family through the system approach, which is far more than doubling of income of farm families. The increase in family income led to change in the life style particularly in the field of food, hygiene, children education and affording the luxurious amenities Thus the results are clear indicative of the facts that the above model of integration of resources is capable to combat the vagaries associated with the changing climatic scenario and the above model is resilient to climatic aberrations (Tables 6.2 and 6.3, 6.4, 6.5 and Fig. 6.1).

Data in Table 6.6 pertain to a new intervention when the farm families were asked to change the enterprise and sell their entire agriculture produce as seed after due certification process. As a result of that the total produce of 1670 qt was certified as

Table 6.2 Productivity and economics of crop production in the base year

Year	Season	Crops	Area	Production	Gross income	Cost of cultivation	Net income
2014–15	Kharif	Soybean	16.5	206.25	371,250	156,750	214,500
	Rabi	Wheat	4	128	147,200	30,000	117,200
		Gram	5.5	52.25	104,500	52,250	52,250
		Gross area	26	386.5	622,950	239,000	383,950
		Cropping intensity	159.4	System productivity = 4.07 kg/ha/day			
		Prod./day (kg/day)	106				
		Gross income./ day (Rs/day)	1707				
		Net income./day (Rs/day)	1052				
		B:C ratio	2.61				

Table 6.3 Productivity and economics of crop production in the second year as affected by crop diversification

Year	Season	Crops	Area	Production	Gross income	Cost of cultivation	Net income
2015–16	Kharif	Soybean	20	270	486,000	190,000	296,000
	Rabi	Wheat	8	280	322,000	60,000	262,000
		Gram	4	44	88,000	38,000	50,000
		Potato	3	525	262,500	135,000	127,500
		Onion	2	500	250,000	96,000	154,000
		Gross area	37	1619	1,408,500	519,000	889,500
		Cropping intensity	185	System productivity = 11.98 kg/ha/day			
		Prod./day (kg/day)	444				
		Gross income. / day (Rs/day)	3859				
		Net income. / day (Rs/day)	2437				
		B:C ratio	2.7				

Table 6.4 Productivity and economics of crop production in the third year as affected by crop diversification

Year	Season	Crops	Area ha	Production (Qt)	Gross income Rs	Cost of cultivation	Net income Rs
2016–17	Kharif	Soybean	20	270	486,000	190,000	296,000
	Rabi	Wheat	8	304	349,600	60,000	289,600
		Gram	4	46	92,000	38,000	54,000
		Potato	5	1050	525,000	225,000	300,000
		Green pea	3	150	120,000	25,500	94,500
	Summer	Onion	8	2000	1,000,000	384,000	616,000
		Fodder	2	300	45,000	8000	37,000
		Gross area	50	4120	2,617,600	930,500	1,687,100
		Cropping intensity	250	System productivity = 22.57 kg/ha/day			
		Prod./day (kg/day)	1129				
		Gross income./ day (Rs/day)	7172				
		Net income./ day (Rs/day)	4622				
		B:C ratio	2.8				

Table 6.5 Effect of converting to seed enterprise on farm income

Crops	Area (ha) under seed production	Raw seed produced (qt)	Total cost of production (Rs)	Market value of seed (Rs)	Net income seed (Rs)	Net income/Ha in seeds (Rs)	Net income/Ha in conventional farming (Rs)	ICBR seed
Soybean	20.00	270	325,600	665,280	339,680	16,984	7750	4.49
Wheat	8.00	304	173,120	548,416	375,296	46,912	36,500	4.41
Gram	4.00	46	50,880	129,536	78,656	19,664	27,300	6.11
Potato	5.00	1050	519,000	1,386,000	867,000	173,400	123,000	2.95
Total	37.00	1670	1,068,600	2,729,232	1,660,632	64,240	48,638	4.49

seed and the income rose from Rs 48,638/ha to Rs 64,240/ha. This is a rise in income by 32.1% and the Incremental Cost benefit Ratio was 4.49 i.e. almost the double from the conventional farming. Thus, the case study clearly reflects the possibility, means and measures of doubling the farm income with assured irrigation and diversifying the crops and enterprise.

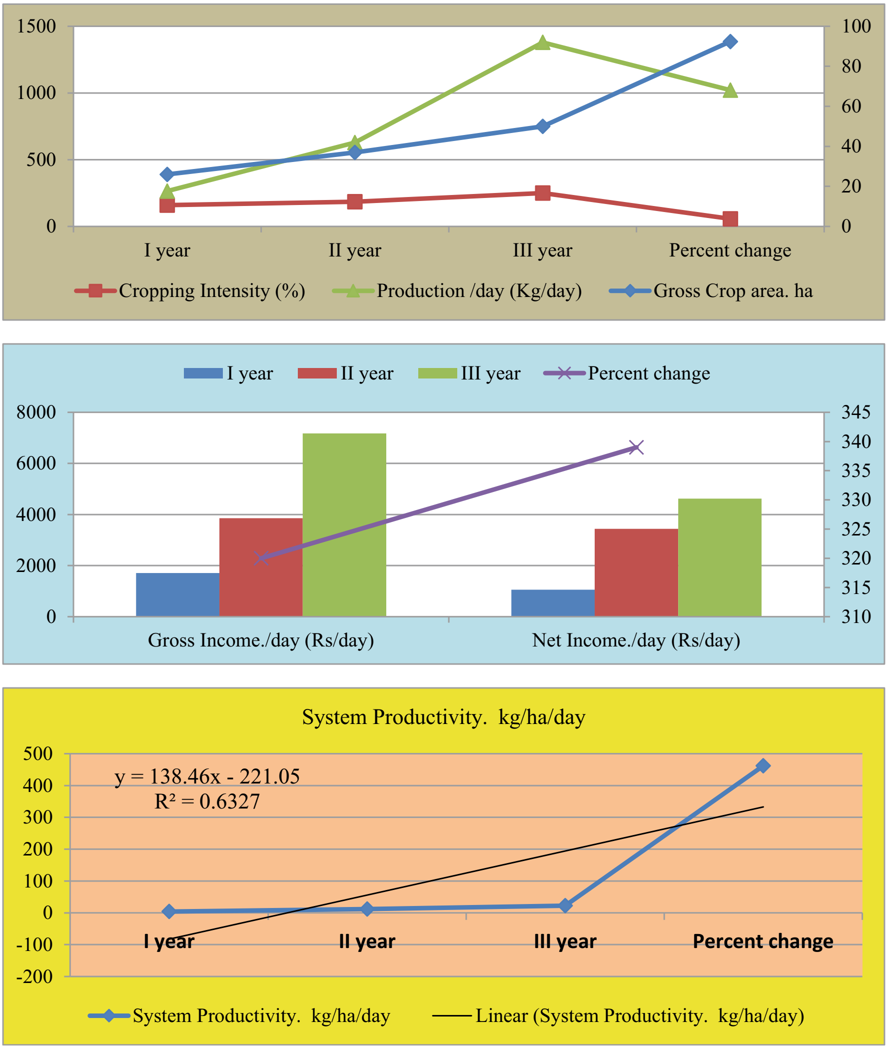
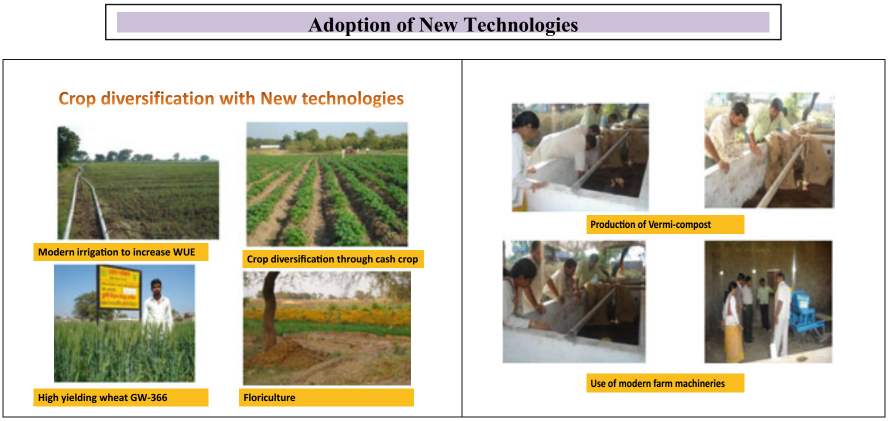


Fig. 6.1 Sequential changes due to interventions and crop diversification



Farm Family Transformed to Seed Producer.

1. Seed Producers Cooperative society was registered with the state government in 2016-17 as per the Seed Act rule 1966.
2. The Society comprising beneficiaries of all the five sites pooled their production and got it certified to be sold as seed with I the district.

Fig. 6.1 (continued)

Table 6.6 Effect of intervention on family income

Year	Gross area (ha)	Total annual production (Quintal)	Annual gross income (Rs)	Cost of cultivation (Rs)	Annual net income (Rs)	Percent change in income
First	26	387	622,950	239,000	383,950	*
Second	37	1619	1,408,500	519,000	889,500	131.7
Third	50	4120	2,617,600	930,500	1,687,100	89.7
Mean	37.7	2042.0	1,549,683	562,833	986,850	110.7

6.9 Conclusion

With assured irrigation in arid and semi-arid tropics the crop intensity can be increased with appropriate diversification of crop and enterprise. Adoption of timely and sequential interventions leads to almost doubling the farm income. By adoption of new enterprise related to agricultural activity the income can be further doubled or can be made four times from the base line or the conventional approach. The system productivity is the key to doubling of farm income. On farm water harvesting is the only option under the changing climatic scenario and hence this study clearly focuses upon the adoption al viable option for the farmers of the tropics.

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Chapter 7
Non-thermal Processing of Food: An Alternative for Traditional Food Processing

Arshi Siddiqui and Khan Chand

Abstract Heating and frying are the conventional thermal processing procedures used in the food business to inactivate harmful and spoilage bacteria. The shelf life of food is extended as a result, and food safety is maintained. However, the high temperature used has an adverse effect on critical food characteristics such as colour, flavour, taste, appearance, and nutrient content. Such impacts reduce consumer approval of thermally processed meals, which has a detrimental impact on food product sales and future industry revenue. As a result, non-thermal food processing/preservative methods have arisen as viable alternatives to the thermal and chemical unit operations in food processing. Non-thermal processing preserves food without diminishing its quality, and it appears to be more cost-effective because these processes take less time and energy. Non-thermal technologies produce goods that are safe, affordable, and consumer-friendly, making them a preferable option for preservation. Ultrasound, ultra-high pressure, pulsed X-ray, ionising radiation, pulsed electric fields, pulsed light, high voltage arc discharge, hurdle technologies and magnetic fields are examples of these processes.

Keywords Thermal processing · Non-thermal processing · Food industry · Preservation method

7.1 Introduction

Traditional thermal processing regulates biological and chemical activities in food, resulting in higher product quality and food safety. The key techniques for providing thermal reactions in food are enzyme and microbial inactivation. However, high

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temperatures have a negative impact on critical aspects such as food colour, nutritional value, sensory qualities, and flavour. As a result, today's manufacturers and customers seek nutritious foods in order to achieve quality parameters with the least amount of variation. As a result, the demand for non-thermal innovative approaches has increased. Nonthermal processing of food and preservation procedures has minimal effect on the nutritional and sensory characteristics of foods, and they help extend the shelf life of food by inhibiting or killing microbes. As a result, food packaging scientists, producers, and consumers are all interested in non-thermal food processing. These processes are more energy efficient and preserve higher quality attributes than typical thermal processing. Nonthermal processes provide the sector with value-added products, new market prospects, and enhanced safety margins. Non-thermal food preservation techniques such as high-pressure processing, various types of ionising radiation, gases, light, and ultrasonication are discussed in this chapter.

Conventional food processing uses heat to eliminate foodborne pathogens (bacteria, viruses, and parasites) and make food protected to eat. Heating is an efficient method to treat many foods. However, there are numerous food varieties for which heat is either undesirable or cannot be used as certain food varieties would have a danger of bacterial or viral foodborne disease. Many customers wanted minimally processed foods, such as pre-cut greens, fruit, and oysters, with a long shelf life and the ability to be processed, cooked, and eaten. The researchers are investigating alternative non-thermal processing methods for inactivating infections and providing foods that are safe to eat while keeping sensory qualities and nutrient content similar to raw or fresh foods. Various alternative processing technologies that have proved their ability to inactivate germs while maintaining desirable food quality have been promoted.

Food varieties treated with non-thermal process require refrigeration to delay spoilage and are safer to eat than untreated products. As a result, a processor is used who must certify that the non-thermal procedures will eradicate the particular, targeted microorganisms in their product, just like any other traditional food preservation method (for example, canning or pasteurization).

7.2 Non-thermal Methods in the Food Industry

Electromagnetic technologies have attracted increased industrial interest in food processing and have the potential to replace, at least partially, the traditional well-established preservation procedures. In contrast to traditional heat processing methods ohmic heating and dielectric heating (radio frequency (RF) and microwave (MW) heating) are intriguing alternatives. These innovative thermal technologies are volumetric heating methods that generate thermal energy within the food. As a result, this typical pattern of heat generation can be used to overcome the long cooking times. As a result, these could have direct ramifications for energy and heating efficiency. Nonthermal techniques for microorganisms' inactivation have also been developed in the last decade with regards to the global demand for more fresh and natural foods.

Ionising radiation (IR), pulsed electric fields (PEF), high pressure processing (HPP), and pulsed light treatment (PLT), among other non-thermal processes, can inactivate microorganisms at temperatures close to ambient, preventing thermal derogation of food components and, as a result, maintaining the sensory and nutritional quality of food products.

7.2.1 Pulsed Electric Field

Pulsed Electric Field (PEF) is a non-thermal technology for preservation of food in which an electric field of high-voltage is applied for a very brief time. It is used at very low temperatures to keep the taste, flavour, and nutritional value of the food. This procedure is intended to kill microorganisms while leaving little or no change in the quality of the product, allowing for a longer shelf life.

Foods put between two electrodes are subjected to high voltage (10–80 kV/cm) at ambient temperature for less than 1 s before being packaged aseptically and distributed cold. The energy is then released through the use of either static foods or foods that are flowing through a treatment chamber. Short bursts of electric current of about sub-microseconds to milliseconds are used in PEF and have little to no effect on the quality of pumpable meals. The rupturing of cell membranes in liquid medium then delivers a 5-log reduction in most microorganisms. It has only little negative effects on the physical and sensory qualities of foods, and hence aids in the preservation of food quality and nutrients. This process is commonly used in the food industry to pasteurise foods such as milk, fruit juice, soups, liquid eggs, and more products that can withstand electric fields of high intensity. Extraction of polysaccharides and peptides can be aided by high electric field pulses. PEF has limited impact on microbiological spores and should not be applied on materials that contain or may contain air bubbles. Foods with a greater or changeable electrical conductivity cannot be used. The logarithmic model, oblong pulse model, declining pulse, sudden recycled beats, and pulsing beats models are the most prevalent PEF technology applications (Fig. 7.1).

Short bursts of electricity are utilised to inactivate germs while producing minimal food quality loss in a nonthermal food preservation technology known as pulsed electric fields (PEF). The goal of PEF technology is to provide consumers with high-quality foods. It's a relatively new method of food preservation. In the processing of liquid and semi-liquid foods, PEFs are extensively used. PEF technology is preferred over normal thermal processing processes because it eliminates or significantly lowers adverse changes in the sensory and physical properties of meals.

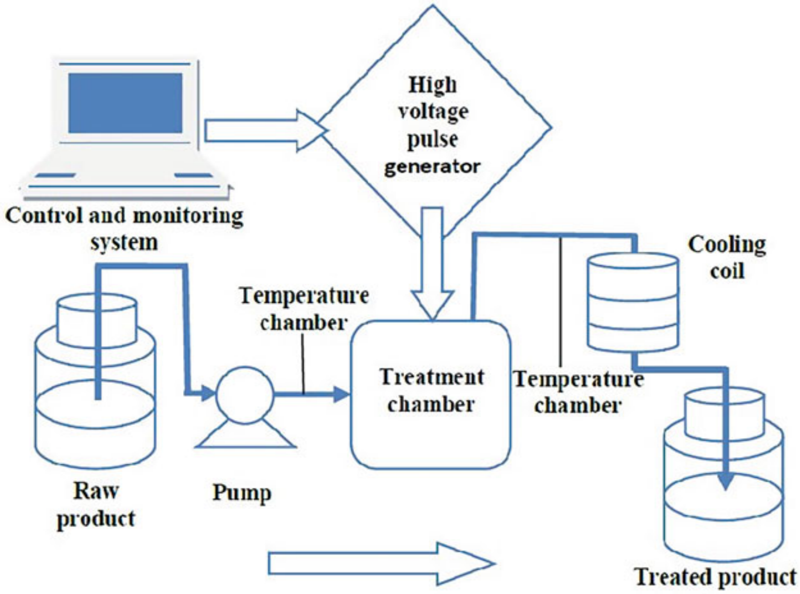

Fig. 7.1 Pulsed electic field system

PEF technology has been deemed superior to others since it eliminates bacteria while preserving the unprocessed food's original colour, flavour, texture, and nutritional content. PEF treatment is particularly successful in inactivating microorganisms, increasing the effectiveness of fruit juice extraction, and accelerating the dehydration and drying of food. Certain obstacles must be solved in order for PEF to be commercialised.

a. For a lucrative output, the system must be scaled up efficiently.
b. The existence of bubbles could result in irregularities in treatment, along with operational and safety risks.
c. Soy sauce suspension therapy.

7.2.2 Pulsed Visible Light

Pulsed visible light processing is a sterilisation or decontamination method for inactivating surface microorganisms on meals, packaging materials, and equipment. This approach employs focused light energy and the intense brief bursts of light (pulses) are exposed to the substrate. 1–20 flashes per second are usually used for food preparation. Pulsed visible light processing is a non-thermal food processing method in which electric pulses of high voltage (up to 70 kV/cm) are discharged into the food product placed between two electrodes for a few seconds. It's one of the newer methods that's being utilised to replace traditional thermal pasteurisation in non-thermal processes. It's a decontamination method that removes pests, spoilage germs, and pathogens from food while preserving its quality. Pulsed ultraviolet light, high intensity broad-spectrum pulsed light, pulsed light, and pulsed white light are all terms used in scientific literature to describe it. Pulsed light is a type of UV radiation that is used to treat meals. This technique uses Xenon lamps that produce multiple-second flashes.

The use of the following units is usually indicative of this technology:

- **Fluence rate:** The energy collected from the lamp per unit area per second by the sample. Watt/meter^2/second (W/m^2/s) is the unit of measurement.
- **Fluence/Dose:** This is the amount of energy received by the sample per unit area from the lamp during the treatment. Joule/meter^2 (J/m^2) is its unit.
- **Pulse width:** This is the length of time that energy is supplied.
- **Exposure time:** This is the amount of time in seconds that a patient is exposed to treatment.
- **Peak power** is calculated by dividing the pulse energy by the pulse duration. Watt is the unit of measurement (W).
- **PRR (pulse repetition rate):** This is the number of pulses per second [Hertz (Hz)] or even commonly expressed as pps (pulses per second).

This non-thermal technique involves gradually building the energy from low to high. The highly concentrated energy is then released in broad-spectrum bursts on the surface of foods and packaging to ensure microbial decontamination. The electromagnetic energy is then stored in the capacitor for a fraction of a second before being released as light in a billionth of a second, resulting in power amplification with very little extra energy consumption. The inactivation efficiency of pulsed light is determined by the intensity (measured in Joule/cm^2) and number of pulses supplied. The following are some examples of how this technology can be used:

- Eggs were given a pulsed light treatment to decontaminate their surfaces.
- Using pulsed light, extend the shelf life of ready-to-eat beef items while also inactivating Listeria monocytogenes.
- Decontamination of chicken with pulsed light to remove food germs.
- Freshly cut mushrooms are given a pulsed light treatment.
- Using a continuous flow pulsed light technology, microorganisms in fruit juices and milk are inactivated.
- Pulsed ultraviolet (UV) light is used to decontaminate food powders.
- Packaging material decontamination.

7.2.3 Ultrasonication

“Vibrations per second with sound waves of frequencies higher than 20 kHz that execute energy development” is how ultrasonication is characterised. Ultrasonication typically employs frequencies between 20 kHz and 10 MHz. The process temperature should be kept low during ultrasonication while introducing unwanted and pathogenic microorganisms to activate corruption-causing enzymes. It is the most significant advantage of ultrasonication over thermal distortion processing. As a result, this procedure helps to preserve the product's taste, smell, texture, and nutrients. There are three ways to express the effect of ultrasonication on microorganisms. The use of low-frequency ultrasound for food processing has cavitational consequences. Within the structure of the cavitation bubbles, there is a tremendous amount of warmth and pressure at the time of the explosion. Microorganisms are rendered inactive as a result of this dual impact. The cytoplasmic membrane is destroyed by ultrasonication, which has a damaging effect on bacteria. The production of radicals is another way for microbial inactivation. The formation of OH-radicals and hydrogen peroxide occurs when ultrasonography is used. Also present chemicals have a potent bactericidal impact. Several studies have looked into changes in the inactivation of dangerous bacteria. Various research, including changes in harmful microbe inactivation, food quality indicators, and products in enzyme activation, were studied, and successful findings were obtained.

Ultrasonic waves (sound waves with frequencies more than 20 kHz) cause gas bubbles to form in liquid mediums. When they explode, they will create a large temperature and pressure increase. As a result of these pressure changes, acoustic cavitation occurs, and gas bubbles form in the medium. During the expansion cycle, these bubbles have a larger surface area, which enhances gas diffusion and leads the bubble to expand. Fast condensation occurs when the quantity of ultrasonic energy available is insufficient to hold the vapour phase in the bubble. When condensed molecules collide violently, shock waves are produced. Extremely high temperatures and pressures are generated by these shock waves, with temperatures and pressures reaching up to 5500 °C and 50,000 kPa. The main bactericidal action of ultrasonography is caused by pressure changes caused by these encounters. Some bacteria can be killed by hot zones, but they are very limited and do not effect a broad enough region. The weakening of cell membranes, localised heating, and generation of free radicals are all part of the microbial death mechanism. Temperature, hydrostatic pressure, dissolved gas, specific heat and tensile strength of the liquid and the gas in the bubble define the cavitation threshold of a medium, or the minimal oscillation of pressure required to create cavitation. Because cavitation does not occur over 2.5 MHz, the ultrasonic frequency employed must be below that.

7.2.4 Ionizing Radiation

Ionising radiation could be a nonthermal food pasteurisation treatment that decreases or eliminates spoilage and hazardous bacteria like Salmonella, E. coli O157:H7, Listeria monocytogenes, and Campylobacter jejuni by fragmenting DNA. Radioactive chemicals continue to emit rays into the environment as they fragment atoms. Ionising radiation creates electrically charged ions when it interacts with a substance. X-rays, gamma rays, and accelerated electron beams are employed to preserve food. A 5 MeV (million electron volt) energy source and low-energy resources are used to

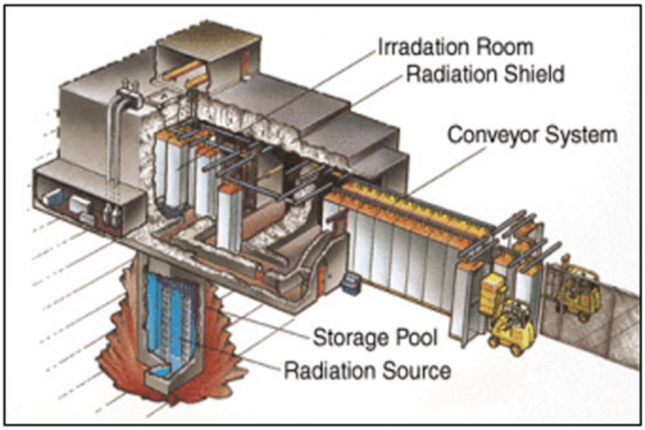

Fig. 7.2 Irradiation system

create X-rays. One example is a T research on fresh strawberries against Norovirusa. The T study on fresh strawberries yielded positive results against Norovirus and Tulane viruses, for example. Extremely high-dose irradiation causes a loss of aroma, especially in meals with a lot of fat (Fig. 7.2).

Food processing by radiation is becoming increasingly important in the shifting global trade landscape. It is frequently used to remove viruses and disease-causing entities from a variety of products, including fruits and vegetables. It is one of the most recent food preservation techniques. This procedure, which is comparable to pasteurisation, makes food safer to ingest by killing microorganisms. The biological mechanisms that lead to degradation and the ability to sprout are disrupted by radiation processing. Because radiation is a cold procedure, it is frequently used to pasteurise and sterilise foods without altering their freshness or texture. In addition, unlike chemical fumigants, radiation leaves no adverse toxic residues in food and is easier to use, thus it may be used to treat packaged goods as well.

Irradiation helps to reduce post-harvest losses. In foods like potatoes, it also decreases perishability and prevents sprouting. Irradiation can be used to disinfect legumes, grains, fruits, vegetables, melons, etc., as well as maintain colour in fresh meats and reduce microbial contamination in eggs, pig, poultry, and beef. Not all foods, however, are suitable for irradiation. Milk and other protein foods may develop an off-flavor, odour, or colour, and some fruits may soften and discolour, especially at large doses. Radiation must be approved by the Food and Drug Administration (FDA), since it is classed as a food additive. This guideline applies to all materials used in packaging. In 1990, the FDA allowed the use of 1.5–3.0 kilogray irradiation of poultry products (kGy). Irradiation of fresh or frozen meats such as lamb, cattle, and pork was permitted by the FDA in 1997. With 1.5 kGy irradiation, reduced oxygen packing, and refrigeration, ground beef can last up to 15 days on the shelf, compared to 4 days with non-irradiated ground beef. However, for ground beef, a dose of 1.0 kGy is recommended to prevent sensory quality degradation. Irradiation of over 100 food items has been permitted in more than 40 nations. Among the non-thermal freshness-enhancing technologies, many people consider that irradiation is the most efficient technique to eradicate viruses and bacteria causing spoilage from the food supply.

7.2.5 High Hydrostatic Pressure

For more than a century, high pressure processing (HPP), also known as "High Hydrostatic Pressure" or "Ultra High Pressure," has been a viable preservation strategy. HPP uses pressures of up to 900 MPa to kill a wide spectrum of bacteria in foods, even at room temperature, while preserving vitamins, flavour, and colour. Food packets submerged in liquid are subjected to high pressures of up to 1000 MPa, which are diffused quickly and uniformly throughout the food. A tenfold reduction in vegetative cells of bacteria, yeasts, or moulds can be achieved by applying a pressure of 350 MPa for 30 min or 400 MPa for 5 min. There are no heating or cooling intervals in high-pressure processes. When compared to thermal processing, there is a rapid pressurisation or depressurization cycle, which reduces processing times. The fundamental idea of high hydrostatic pressure processing is the compression of the fluid force supplied to the fluid that envelops the product. A pressure vessel plus a pressure generating device make up an HPP unit. The vessel is loaded with food packets and the lid is closed. Water is frequently injected into the tank from the bottom as the pressure medium. When the desired pressure is reached, the pumping is turned off, the valves are closed, and the pressure is maintained without the use of additional energy. This method is now widely employed in the food business. Microorganism inactivation, protein denaturation, and enzyme activation are all essential applications. It also preserves sensory characteristics while increasing extraction yield. At room temperature, a high hydrostatic pressure in the range of 100–900 MPa is used to inhibit microbiological growth in vegetables, fruit juice, the beverage industry and meat products, as well as to retain the sensory qualities of these foods. It's also used to remove shellfish meat, thaw frozen meat, remove the bitterness of grapefruit juice, harden chocolate, and gelatinize starch and proteins in vegetable products, vitamin protection in fruit juice. This technique has been demonstrated to preserve the, colour, flavour, freshness and taste of food.

HPP works over a mass of food fast and consistently, regardless of size, shape, or material. Every 100 MPa, compression elevates the temperature of meals by around 3 °C, and it may also change the pH of the food depending on the applied pressure. Pressure pasteurisation, as opposed to heat treatment, can be done at room temperature and saves energy. Water activity and pH are important process parameters in HPP microorganism inactivation. Raising the temperature of the meal beyond room temperature and, to a lesser extent, decreasing it below room temperature can both boost the rate of microorganism inactivation following HPP therapy. At temperatures between 45 and 50 °C, food pathogens and spoilage bacteria appear to be inactivated more quickly. To inactivate spore-forming microorganisms like Clostridium botulinum, temperatures of 90 to 110 degrees Celsius were combined with pressures of 500–700 MPa. Batch and semi-continuous systems are used in today's pressure processes. Pressure has a variety of effects on food components, including protein denaturation or modification, enzyme activation or inactivation, changes in enzyme–substrate interactions, and changes in the properties of polymer carbohydrates and lipids, in addition to microbe annihilation.

7.2.5.1 Effect of HPP on Food Quality

HPP offers the potential to generate high-quality, fresh, microbiologically safe foods with a long shelf life. Foods containing HPP are now classified as new foods. It's a relatively new preservation technology with a short history of use. Consumer perceptions of food quality are influenced by a variety of dietary components, including biochemical and enzymatic responses, as well as structural alterations.

HPP can affect food yield as well as sensory aspects such as colour and texture. Because covalent bonds are not broken in HPP-processed foods, there are little chemical changes. As a result, there are no substantial losses in sensory qualities, nutrients, and especially bioactive substances of various commercially accessible food items. Pressure affects weaker bonds like Van der Waals forces, electrostatic interactions, and hydrogen bridges, and modifications to these explain how HPP treatments preserve them. They alter membrane architecture, causing microbial inactivation, but they can also make it easier for an enzyme to access its substrate, resulting in product deterioration during storage.

Food look and colour have been found to have a major impact on consumer sales. While some protein denaturation may occur with HPP treatment of certain high-protein foods, the consequent changes in physical functionality and/or raw product colour are markedly different from those seen with traditional heat processing approaches.

7.2.6 Plasma Sterilization

Irving Langmuir discovers plasma for the first time in 1928. Plasma is the fourth state of matter, possessing properties that are distinct from solids, liquids, and gases. Gas plasma, according to some physicists, is a gas composed of ions and free electrons. Plasma is a non-charged sterilising medium made up of atoms, molecules, and radicals. When a gas or gases are exposed to a steady (direct) current or trapped between two electrodes, plasma is generated. During plasma creation, electrons and ions are emitted. This has an effect on the cell walls of microorganisms. As a result of the inactivation, sterilisation is made easier. It led to positive microbiological discoveries in a number of foods, including vegetables, fruits, and animal products, according to studies. Plasma can be classified as either hot or cool. Cold plasma has an ion temperature that is close to room temperature, making it ideal for usage in food.

7.2.7 High Voltage Arc Discharge (HVAD)

When a pulse is delivered using the HVAD technique, an arc is produced in the liquid media. It is a pasteurisation procedure that includes rapidly discharging electricity across an electrode gap, resulting in strong waves and electrolysis, which inactivates bacteria. This chemical action is influenced by a variety of factors, including the type of microbe, initial cell concentration, volume of fluid used, dissemination of chemical radicals, and electrode material, among others.

Freshly squeezed grapefruit juice was HVAD-processed, and it was discovered that the treated juice kept its fresh flavour for more than 100 days. To contaminate the surface of food and beverages, a pulsed high-voltage arc discharge was used. HVAD has been discovered to be an extremely effectual microbe-killing method. Through indirect arc discharge, energy from the electric field can be transferred to plasma, then to shock waves, resulting in free radicals and oxidising agents within the product. The nutritional and organoleptic qualities of foods, particularly liquids, could be preserved through non-thermal plasma generation. Food is put between two electrodes in a therapeutic chamber, and charged-reversed electrical pulses are provided. Each electrical pulse with a pulse width of 1 to 5 s raises the voltage to a peak. There is a voltage drop after that, which lasts until the voltage peaks in the opposite polarity. Vertical pulses have field strengths ranging from 15 to 120 kilovolts per centimetres and pulse values ranging from 0.1 to 25 J. HVAD causes enzyme inactivation due to free radicals and oxidation processes. Electrolytic chemical product contamination of the treated food and food particle disintegration by shock waves are the main drawbacks of this electrical approach.

To extract key components like polyphenols from plant material, novel technologies such as high-voltage electrical discharges (HVED) are being applied. HVED technology's electrical and mechanical effects (0–400 kJ/kg) promote degeneration by damaging cell membranes and tissues. A study on pressed rapeseed was undertaken. As a result, high-voltage electrical discharges and a solid-liquid ratio of 1:5 to 1:20 (w/w) were used with positive results to reduce high-component loss. One of the most recent food conservation strategies is Cayman arc discharge (CAD). It's a technique that involves the utilisation of an electric arc discharge.

7.2.8 Magnetic Field Heating and Moderate Magnetic Field Heating

Researchers looked at the effects of a static magnetic field (SMF) and a mobile magnetic field (MMF) on food microbe inactivation. In SMF, the magnetic field intensity varies in sinusoidal waves. The magnetic field's DNA production, as well as ionic transport across the plasma membrane, creates changes in the sequence of biomolecules or biomembranes. Cell growth rates are affected as a result. It is used in the manufacture of solid, liquid, and packaged foodsBoth the Pressured Electric

Field (PEF) and the Static Magnetic Field (SMF) are employed in food freezing, and both produce good results. The Moderate Magnetic Field (MMF) is defined as the completion of an electrical circuit based on the concept of food by transmitting electrical current through it. It is usually used to break down cell membranes in order to make fruit crushing less efficient. When paired with other processes, a voltage gradient of less than 100 Volts per centimetres is used for microbial component extraction, fermentation yield, and shelf life extension.

Microbial inactivation strategies include static magnetic fields (SMF) and oscillating magnetic fields (OMF). SMF uses constant amplitude or decaying amplitude sinusoidal waves, whereas OMF uses constant amplitude or decaying amplitude sinusoidal waves. Magnetic fields can be homogeneous (uniform magnetic field intensity) or heterogeneous (variable magnetic field intensity) (magnetic field intensity is inversely proportional to distance from coil). The charge for each pulse is reversed when OMF is used in the form of pulses, and the intensity of each pulse declines over time to roughly 10% of its initial intensity. Food is preserved using OMF by sealing it in a bag and exposing it to 1–100 pulses in an OMF with a frequency of 5–500 kHz at temperatures ranging from 0 to 500 °C for a total exposure period of 25–100 ms. Microbial inactivation is less effective at frequencies above 500 kHz, and these frequencies have a tendency to heat the food. Inactivation processes for microorganisms and harmful cells placed in SMF or OMF have been explained by two theories. According to the first theory, OMF causes ions and proteins to lose their links. Many proteins that are important for cell metabolism include ions that are destroyed by OMF, such as enzymes and hormone precursors. A second idea focuses on the effect of SMF and OMF on calcium ions bound in calcium-binding proteins like calmodulin. When the magnetic field is changed to calmodulin, cyclotron resonance occurs, causing the calcium ion and calmodulin link to loosen. This eventually leads to metabolic disturbances and cell death.

7.2.9 Microfiltration

Microfiltration separates microns from bigger particles in a liquid solution. Microfiltration membrane holes range from 0.05 to 5 mm in diameter. Membranes are operated under low pressure when their resistance is low, and they can operate up to 2.0 bar. Microfiltration allows particles with molecular weights more than 200 kDa to be distributed selectively. It’s a pressure-based approach that ranges from 0.1 to 0.5 bar. The membrane’s pore diameter ranges from 0.1 to 10 micrometres. To separate particles, spores and bacteria from milk or whey, fat globules, somatic cells, and big compounds like phospholipids are all used. According to different studies, milk that has gone through the microfiltration process can be preserved for much longer than pasteurised milk.

7.2.10 Hurdle Technologies

Hurdle technology is a method for removing or controlling microorganisms from food. In this strategy, various methodologies are merged. These tactics could be thought of as "barriers" that the virus must overcome in order to stay active in the diet. The many ways fall under the category of hurdle technologies, and some called them may incorporate the use of mild heat in conjunction with other methods to protect foods. In addition to the aforementioned and other technologies, this technique makes use of MAP, cryogenic freezing, antioxidants, active packaging, ozonation, and enzymes. Because MAP raises the CO_2 level inside the container, it has a longer shelf life than standard packaging. Other gases may be added, and the O_2 level may be reduced. CO_2 has antibacterial characteristics. When utilising MAP, packaged foods should be maintained at temperatures below 5 °C. To avoid product degradation or microbiological growth, active packaging contains absorbing or emitting compounds that control oxygen, moisture, carbon dioxide, and smells. To cool a product fast and extend its shelf life, cryogenic cooling and freezing can be used.

Hurdle technologies can also have a synergistic impact by combining high temperatures (55 °C), antimicrobials, and Pulsed electric field processing, and they're currently being researched to kill microbes in products like apple cider, mango juice, grape juice, and tomato juice. When utilised as a barrier, antioxidants have been proven to help reduce and delay lipid oxidation. It has been proven that combining antioxidants derived from plant extracts with irradiation reduces oxidation and warm-over flavour in chicken. In addition to utilising enzymes to inactivate or limit the operations of other enzymes due to their antibacterial and antioxidant capabilities, other non-thermal food preservation tactics include using enzymes to inactivate or limit the actions of other enzymes. As an alternative to heat preservation, packaging can be used. It can help keep food fresher for longer by extending its shelf life. As a result, hurdle technologies appear to be the most efficient means of achieving things that non-thermal technologies alone have failed to attain.

7.3 Conclusion

Thermal approaches have been shown to have negative effects on food items, leading manufacturers to avoid using them. As a result, non-thermal techniques have grown more common in order to provide a high-quality sensory and nutritious product. Non-thermal techniques can prevent nutrient loss and sensory alterations caused by high temperatures in the food structure. Without the use of preservatives or chemicals, non-thermal approaches preserve colour, flavour, texture, and nutritional and functional characteristics while increasing shelf life. Ultrasonication, high-pressure processing, the pulsed light method, and hurdle technologies are examples of non-thermal techniques. Due to their numerous advantages over traditional thermal processes, these approaches are now widely employed in the food processing industry. Non-thermal technology may currently be utilised to process and package acidic foods like fruit juice, but further research is needed for shelf-stable low acid meals. Various food scientists are researching in this approach, with the goal of using non-thermal ways to ensure the safety of low acid meals. Although several novel non-thermal processes have lately been deployed in industrial-scale systems for commercial and scientific purposes, the majority of non-thermal technologies are still in their infancy. Combining non-thermal treatments, according to scientific studies, has a lot of potential for improving food safety and quality while also retaining freshness.

Chapter 8
Enhancement of Shelf Life of Food Using Active Packaging Technologies

Arshi Siddiqui and Khan Chand

Abstract The food processing business relies heavily on packaging. It's a low-cost means of ensuring the safe delivery of good-condition products to customers. With the increasing increase of chilled, MAP/CAP, and minimally processed foods, a number of packaging innovations have been investigated, which can be categorised as "active packaging." Active packaging is an effective solution for a variety of food sector applications. This method of packaging involves interaction between the package, the product, and the environment. The most significant benefit of active packaging is the reduction in food product loss due to increased shelf life. Oxygen scavengers, ethylene scavengers, carbon dioxide scavengers or emitters, taste and odour absorber/releasers, antibacterial, and antioxidant packaging technologies are examples of active packaging systems. Active systems are the future courses of action for food packaging development and increased customer acceptance; in the approaching years, economic prosperity should be predicted.

Keywords Active packaging · Food industry · Shelf life

8.1 Introduction

The technology designed to protect food from physical, chemical, and biological contamination is known as packaging. This method entails the creation of a container or pack to hold the food. Because of packaging, foods can be securely transported to large distances from their point of origin, while yet remaining healthy when consumed. Food packaging's major purpose is to protect food from contaminants such as air, water vapour, UV light, as well as chemical and microbiological

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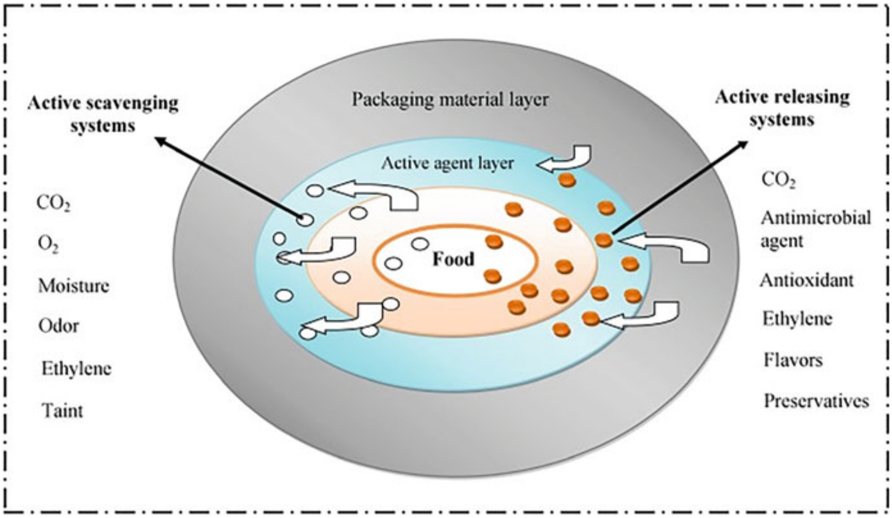

Fig. 8.1 Examples of active packaging applications

contamination. Due to changes in contemporary consumer needs and industrial advances, the field of Active Packaging is becoming increasingly important (Anna and Svensson, 2004). Active Packaging is a solution that includes:

- scavenging of oxygen
- production of CO_2
- release of preservatives (e.g. ethanol production)
- antimicrobial action
- release of aroma
- removal of moisture
- removal of odours, off-flavors, or ethylene
- time-temperature indicators
- gas indicators
- edible coatings and films

Active Packaging is a cutting-edge concept defined as a packaging approach involving interaction between package, product, and environment. It actively alters the packed food's conditions to extend shelf life, increase microbiological safety, and/or sensory qualities, all while retaining the food's quality. The correct conditions within the packaging are managed to increase the shelf life and maintain the quality of the packaged food. These scenarios include physiological processes like fresh fruit and vegetable respiration, physical processes like bread ageing, chemical activities like lipid oxidation and dehydration, and microbiological aspects like microorganism spoiling (Fig. 8.1).

8.2 Methods of Active Packaging

8.2.1 Oxygen Scavengers

Oxygen can have a lot of negative consequences on food. Foods containing lipids, such as bread, biscuits, pizzas, cured or smoked meat and fish, cheese, almonds, chocolate, and beverages such as coffee and tea, are easily spoiled by oxygen in food packaging. As a result, scavenging of oxygen is beneficial for items that are susceptive to both light and oxygen. Oxygen scavengers, also known as oxygen absorbers, can be used to remove oxygen from food, lowering food spoilage reactions, limiting undesired oxidation of pigments and vitamins, reducing oxidative rancidity, controlling enzymatic browning, and suppressing aerobic microorganism development. Antioxidants, absorbers, and scavengers are employed to eliminate oxygen or prevent it from entering the package's inside. The amount of O_2 in packaged food is frequently a determining aspect in a product's shelf life. The flavour, colour, and odour of a food item can all be changed by oxidation. It also depletes nutrients while promoting the development of aerobic bacteria, moulds, and insects. As a result, food-packaging scientists have long sought to remove O_2 from the headspace of package and from the solution in liquid foods and beverages. The use of O_2 scavengers, which remove leftover O_2 after packing, can reduce the quality degradation of O_2-sensitive items. Vacuum sealing or utilising inert gases like N_2 and CO_2 in the packaging, or both, can remove oxygen from the headspace of food packaging. These procedures can remove 90–95% of the oxygen present in the air from the packed food before or during packing. Oxygen scavenging devices are employed in the packaging of orange juice and beer, as well as in modified-atmosphere food packaging. The availability of oxygen in fresh meat allows myoglobin to be oxygenated, giving it its characteristic red hue. This attribute of meat is necessary since people rate meat by its appearance, texture, and flavour. High quantities of oxygen, on the other hand, accelerate the oxidation of muscle lipids that has a negative impact on the colour of fresh meat. Meat's shelf life is extended by lowering oxygen levels, which inhibits the growth of fungus and aerobic bacteria.

Oxygen scavengers actively control and reduce residual oxygen levels inside the package below 0.01% oxygen in some cases, which is unattainable with other packaging technologies. Oxygen scavengers, which are embedded into the package structure or in sachets and remove oxygen through chemical reactions, are the immensely economically crucial active packaging system for food products. Ferrous compounds or iron-based compounds are the most commonly utilised oxygen scavengers. The oxygen scavengers generally react with the water in the food to form a reactive hydrated metallic reducing agent that scavenges oxygen within the food package and converts it to a stable oxide in an irreversible manner. As an oxygen scavenger, a tiny, extremely oxygen permeable sachet containing iron powder is utilised. The sachet is labelled 'Do not consume,' and it comes with a diagram to illustrate the warning. The fundamental benefit of adopting such oxygen scavengers is that they may reduce oxygen levels to less than 0.01%, which is far

Fig. 8.2 Oxygen absorber sachet

lower than the average residual oxygen levels of 0.3–3.0% achieved through modified atmosphere packaging (MAP). Ascorbic acid, catechol and oxidative enzymes like glucose oxidase, as well as unsaturated hydrocarbons and polyamides, are all oxygen scavengers (Brian, 2008) (Fig. 8.2).

Scavengers of oxygen can be employed alone or in conjunction with MAP. The use of oxygen scavengers alone can reduce packing times and obviate the requirement for MAP machinery. However, MAP is most typically used commercially to eliminate the majority of ambient oxygen before mopping up the remaining oxygen within the food packing with a small and affordable scavenger. The much lower capital expenditure required for Active Packaging than Modified Atmosphere Packaging (MAP) is a significant advantage. Because the equipment for packaging is often the extremely expensive component, this is advantageous and profitable for small and medium-sized food businesses. As a substitute to sachets, the scavengers of oxygen can be built into the container structure itself. This reduces unfavourable customer reactions while also providing a potential economic benefit through greater production. It also prevents the chance of the sachets accidentally bursting and the contents being consumed inadvertently. Oxygen absorbers physically trap oxygen rather than relying on chemical reactions to do so. However, only a few oxygen absorbers are capable to physically removing oxygen.

Antioxidants are also used in food packaging to keep oxygen out. Antioxidants are oxidised in the presence of light by radicals formed by lipids or peroxides, or by single oxygen, resulting in oxygen consumption. Rather than being integrated into the packaging, these antioxidants are usually blended with the meal. Antioxidants include butylated hydroxyl anisole (BHA), butylated hydroxyl toluene (BHT), propyl gallate, vitamin A, carotene, tocopherol (vitamin E), and ascorbic acid. Chemicals like BHA/BHT are widely used in plastic films to keep the components from oxidising. Antioxidants are integrated into packaging materials for diffusion into the package interior and transmission to the food product (Prasad and Kochhar, 2014).

Oxygen scavengers have opened up new perspectives and possibilities in terms of protecting food quality and prolonging shelf life. Before ideal, secure, and cost-effective packages can be produced, further knowledge on the behaviour of O_2 scavengers in various situations is required. This is especially critical for oxygen scavenging films, sheets, labels and trays, which were only recently released.

8.2.2 Carbon Dioxide Scavengers/Emitters

Microbial activity is halted by carbon dioxide. On the surface of various goods, such as meat and chicken, the high amounts of carbon dioxide in the packaging have antibacterial properties. As a result, the shelf life of these packaged meals will be extended. As a result, adding a CO_2 producing device to a package, or including one in the form of a sachet, is a complementary method to O_2 scavenging. Because carbon dioxide has a permeability 3 to 5 times that of oxygen in most plastic films, it may be necessary to create CO_2 in the packaging in some cases to maintain the required gas composition. A carbon dioxide generator is only practical in a few applications, such as poultry, fresh meat, fish, and cheese packing, because excessive carbon dioxide levels may harm the taste of food (Fig. 8.3).

CO_2 adsorption is also used to hinder pressure build-up, swelling, and even rupture of respiring food containers, which shortens the product's shelf life. Number of commercial sachets and label devices have been developed that can scavenge or emit carbon dioxide. CO_2 scavenger sachets are placed in the containers of freshly

Fig. 8.3 CO_2 scavengers and O_2 absorbers in packages of coffee

roasted or ground coffees that emit a lot of CO_2. Moisture and oxygen will cause freshly roasted or ground coffees to lose their ideal volatile aromas and flavours if they are left unpackaged. The Strecker degradation reaction between sugars and amino acids produces a lot of carbon dioxide in roasted coffee. Both oxygen and carbon dioxide levels are reduced using a scavenger consisting of iron powder and calcium hydroxide. The reduced oxygen content avoids oxidative flavour changes, whereas the lower carbon dioxide content keeps the package from exploding. As a result, the product's shelf life will be extended.

If food products are packed with an oxygen scavenger, collapsing of pack or the formation of a partial vacuum may occur. To solve this issue, sachets and labels having dual-action of oxygen scavenging or carbon dioxide emission have been developed. They catch oxygen while also creating equal amounts of carbon dioxide. There are also non-ferrous options, such as ascorbate and sodium hydrogen carbonate. Ferrous carbonate and a metal halide catalyst are frequently used in these sachets and labels, but non ferrous choices like ascorbate and sodium hydrogen carbonate are also available. Snack items (such as almonds) and sponge cakes are the most usual places to discover these sachets and labels having dual-action of oxygen scavenging or carbon dioxide emission. CO_2 absorbers and emitters are a modest but developing market area in active packaging.

8.2.3 Ethylene Scavengers

Ethylene management under storage conditions is critical for extending the post-harvest life of different types of fresh vegetables. Ethylene is emitted after most fruits and vegetables are harvested. Ethylene is a plant hormone that causes ripening to start and speed up, as well as softening and chlorophyll breakdown, causing fresh or hardly handled fruits and vegetables to deteriorate. Bananas, apples, mangoes, onions, tomatoes, and carrots are all ethylene-sensitive fruits and vegetables that can benefit from ethylene scavengers. Although ethylene has some beneficial effects, such as increasing blooming in pineapples and development of colour in bananas, tomatoes, and citrus fruits, it is preferable to remove or restrict its effects in most horticultural conditions. As a result, ethylene scavengers are used in the packing and storage of fresh fruit. However, the use of ethylene scavengers in research has not yielded commercial success. Ethylene can also be removed with a number of metal catalysts and activated carbon-based scavengers. They've been utilised to scavenge ethylene from produce warehouses, packaging it in sachets for use in produce packing, and embedding it in paper bags or corrugated board boxes for product storage. A dual-action scavenger of ethylene and moisture absorber has been marketed in Japan by Sekisui Jushi Limited. NeupalonTM sachets are constructed of activated carbon, metal catalyst, and silica gel, and can absorb moisture while also scavenging ethylene. By removing ethylene from the surrounding environment of the fruit or vegetable, the respiration rate of the fruit or vegetable is delayed, resulting in slower ripening and thus a longer shelf life. The reaction of ethylene with potassium permanganate is the most popular method of removing it ($KMnO_4$). The colour of potassium permanganate changes from purple to brown as ethylene is converted to ethylene glycol. In individual boxes of fruits and vegetables, $KMnO_4$ sachets are put, however, blankets and tubes infused with $KMnO_4$ are employed in transport trucks.

Other ethylene removers include bentonite, activated charcoal and alumino silicates like zeolites. The ethylene scavenger namely 'Orega' was developed in Korea and is made out of fine porous films that have minerals such as zeolite, cristobalite, active carbon, and clinoptilolite. In addition, the ethylene absorber namely 'ProFresh,' which contains an unidentified mineral-based scavenger, was developed in Austria and is now available commercially in a number of countries. It has also been shown that this substance can absorb odours. The 'Frisspack' paper was developed by Dunapak in Hungary, and it contains a silica gel that adsorbs ethylene and $KMnO_4$-particles that oxidise it. However, significant volumes of silica gel are necessary to absorb ethylene effectively.

8.2.4 Flavor and Odor Absorber/Releaser

Essences and scents are added to food products to make them more appealing to consumers, increase the fresh product's aroma, or enhance the flavour of food once it has been opened. These flavours and odours are released during the course of the shelf life of packaged product, and they can be timed to coincide with package opening or food preparation. In long-lasting products, the gradual release of aromas can help to compensate for the natural loss of taste and smell. Commercial usage of taste or odour absorbers and releasers is controversial, as there are worries that they may hide natural spoilage reactions, misinforming consumers about the product's state. Packaging's impact on food flavours and scents has long been acknowledged, particularly in the case of unwanted flavour stripping of desirable food components. After the two weeks storage of orange juice in aseptic containers, a significant amount of essential limonene was scalped, for example. Despite the fact that there are few commercially accessible active packaging options for removing undesirable tastes and taints, there are various possibilities. The debittering of pasteurised orange juices is a notable illustration of this. Limonin-induced bitterness, which is released into the juice during pressing and pasteurisation, is more susceptible to some orange cultivars, such as Navel. By passing such juices through cellulose triacetate or nylon beads columns, processes for debittering them have been created. Include limonin absorbers (such as cellulose triacetate or acetylated paper) in orange juice packaging mats as a viable active packaging solution.

Active packaging can eliminate amines and aldehydes, which are two types of taints. When fish muscle proteins are broken down, amines are produced, whereas when lipids and oils are autooxidized, aldehydes are produced. A range of acidic substances can neutralise trimethylamine and other alkaline amines implicated in fish protein breakdown, such as trimethylamine. Anico Co. Ltd. sells AnicoTM bags in Japan, which are made of film and contain a ferrous salt and an organic acid such as citrate or ascorbate. Because the polymer layer absorbs amines, these bags are designed to oxidise them.

Many foods produce disagreeable scents, including protein-rich fresh poultry and fat-rich grains. Sulphurous chemicals like hydrogen sulphide are commonly formed during protein breakdown, and off-odors created during lipid oxidation of fats and oils include aldehydes and ketones. During anaerobic glycolysis, aldehydes and ketones are also generated. Some scents can be detected at very low concentrations. Even if the food product is still safe to eat, odours held in gas-barrier containers emit an unpleasant odour when they are opened.

Another reason to utilise odour scavengers is that odours can form in packing materials, particularly during plastic processes such as extrusion and moulding. Antioxidants are frequently used as a processing addition to help reduce the amount of off-odors produced. DuPont, for example, has inserted molecular sieves into polyethylene to eliminate oxidation odours caused by the plastic resin's manufacturing.

8.2.5 Preservative Releasers

When the integrity of a package is compromised by a burst seal, puncture, dents, or poor glass finishes, pathogenic or spoilage microorganisms can cause microbiological contamination. Heat treatment, freezing, drying, refrigeration, modified-atmosphere packaging, irradiation, and the addition of salts or antimicrobial chemicals are all traditional methods for protecting food against the damaging effects of microbial development. Antimicrobial packaging can take the shape of a sachet, bio-active agents dispersed in the packaging, bio-active agents coated on the packaging material's surface, antimicrobial macromolecules with film-forming capabilities, or edible matrices. Antimicrobial chemicals (such as CO_2, ethanol, silver ions, antibiotics, chlorine dioxide, organic acids, spices, essential oils and others) are used to stop bacteria from growing and spoiling food. Bacteria can also wreak havoc on food packaging, causing it to lose its function and quality. As a result, antimicrobial and antibacterial compounds are used to prevent food from rotting.

In recent years, there has been a lot of buzz about the possibility of using antimicrobial and antioxidant packaging films with preservation qualities to increase the shelf life of a variety of foods. Antimicrobials have been used in food for a long time, but antimicrobial interactive packaging is a new way to controlling microbial surface contamination of meals. Antimicrobial systems can be migrating or non-migrating. The principal uses have been vacuum or skin-packed items, as both demand significant interaction between the food product and the packaging material.

Plant extracts, chlorine dioxide, sulphur dioxide, carbon dioxide, essential oils, and allyl isothiocyanate release systems are examples of packaging systems that release volatile antimicrobials. According to theory, volatile antimicrobials have the benefit of penetrating much of the food matrix and polymer without coming into immediate contact with the food. This sort of active packaging is appropriate for foods that do not come into contact with the package, such as ground beef. One of the most fundamental mechanisms that contributes to food deterioration and microbial development is lipid oxidation. Lipid oxidation shortens the shelf life of food by changing its flavour and/or odour, reducing the texture and utility of muscle meals, and lowering nutritional quality. The oxygen scavengers and antioxidant compounds used in food packaging can help to avoid oxidation. The purpose of active packaging is to hinder or slow down oxidation reactions that degrade food quality. When oxygen is present, however, radicals such as oxo, hydroxyl, and superoxide are generated, and they are the principal initiators of oxidation. By removing radicals as soon as they develop, oxidation can be avoided.

A varnish containing rosemary extract, a natural antioxidant that functions as a radical scavenger in the vapour phase or by immediate contact, can be applied to food packaging to prevent or delay oxidation. As a result, antioxidants do not need to be added to the packaging or food. Using an antioxidant active film in the preservation process can help fresh meat resist oxidation. The migration of -tocopherol from a multilayer active packaging (made up of high-density polyethylene, ethylene vinyl alcohol, and a layer of low-density polyethylene containing the antioxidant -tocopherol) delays lipid oxidation in whole milk powder. The antioxidant level drops during storage due to antioxidant diffusion through the coating and evaporation following at the surface. To prevent the loss of antioxidant capacity, an extra layer of film can be added. Antioxidants can be found in oil, almonds, butter, fresh meat, meat derivatives, bread products, fruits and vegetables. Antioxidant packaging films are becoming increasingly popular due to two considerations. The first is a customer demand for meals with fewer antioxidants and other additives. The desire of plastics makers to use natural and recommended food antioxidants (such as vitamin E) for stability of polymer rather than synthetic antioxidants produced expressly for plastics is the second factor. Antioxidant evaporation from packing sheets into meals has been extensively examined and, in some cases, commercialised. The cereal business in the United States has employed this method to release the antioxidants butylated hydroxytoluene (BHT) and butylatedhydroxyanisole (BHA) from waxed paper liners into breakfast cereal and snack food products. Since there have been concerns about the safety of BHT and BHA, vitamin E has been suggested as a suitable replacement for BHT/BHA-impregnated packaging sheets. As a result, both filmmakers and the food industry can benefit from the usage of vitamin E-containing packaging films. According to a study, vitamin E appears to be a more effective antioxidant in preventing packaging film deterioration during extrusion or blow moulding than BHT, BHA, or other synthetic polymer antioxidants. Vitamin E is a secure and effectual antioxidant for cereal and snack foods with low to medium water activity (aw), which are susceptible to rancid smells and flavours as a shelf-life-limiting breakdown mechanism.

8.2.6 Moisture Absorbers

Food deterioration is frequently caused by excessive moisture. Different absorbers or desiccants are used to absorb the moisture. These moisture absorbers are particularly efficacious at protecting quality of food and increasing shelf life by suppressing microbial proliferation and moisture-related texture and flavour degradation. Moisture absorbers come in a variety of forms, including sachets, pads, sheets, and blankets. Desiccants like silica gel, calcium oxide, activated clays, and minerals are commonly used in TyvekTM (Dupont Chemicals, Wilmington, Delaware, USA) tear-resistant permeable plastic sachets for packed dried food applications. These sachets have activated carbon for adsorption of odour or iron powder for scavenging of oxygen for a dual action. Moisture absorber sachets are commonly used in Japan to prevent a variety of dry items from moisture and humidity damage in the food packaging. MultisorbTechnologies, Inc. (Buffalo, New York), United Desiccants (Louisville, Kentucky), and Baltimore Chemicals are among the largest suppliers of moisture absorber sachets in the United States (Baltimore, Maryland). These sachets are used for a variety of pharmaceutical, electrical, and electronic products in addition to dried snack foods and cereals. Marks&SpencerPlc. in the United Kingdom has employed silica gel-based moisture absorbers sachets to keep loaded ciabatta bread rolls crisp. Water is produced during the metabolism of lipids and carbohydrates in respiring foods, and wet food produces a high water vapour pressure. As a result, condensation is frequent in many packaged goods, particularly fruits and vegetables. Water droplets occur on the packing walls or cover the food surface when the temperature inside or outside the package differs. Water droplets on the packing surface degrade the aesthetic of the product and reduce consumption. While a moistened food surface promotes surface mould growth and so shortens the shelf life of the product (Suppakul, 2003). Using a desiccating film or sachet can prevent this.

To absorb water, propylene glycol or cellulose fibre pads are commonly used in proximity with meat and fish within containers. Silica gels that can absorb up to 35% of their own weight in water, are the most often used desiccants in dry foods. Salts like sodium chloride, glucose solutions encased in water vapour permeable (but not water permeable) sheets, water adsorptive polymers like sodium polyacrylate, and zeolites are all examples of desiccants. The hunt for a more efficient method of incorporating the desiccant into the package has begun.

8.3 Conclusion

Food packaging has existed since the dawn of time and continues to play an important role in current civilization. It has progressed from being merely a container for holding food to becoming something that meets the needs of both customers and the food business. As a result of recent advancements in packaging, material science, biotechnology, and new client needs, active packaging is earning new trust. It's a relatively new field that has the potential to improve food preservation in general. The goal of this technology is to keep food's sensory quality while extending its shelf life. It also guarantees that food is free of bacteria and that nutritional quality is maintained. O_2 scavengers and moisture absorbers are the most cost-effective active packaging sub-categories. Other active packaging methods include ethylene scavengers, moisture absorbers, CO_2 scavengers and emitters, and temperature control packaging. Aside from the aforementioned quality, safety, and distribution concerns, active packaging provides a diverse range of marketing opportunities. Food will have a longer shelf life and be safer if various types of active or intelligent packaging are used properly. The acceptance and cost-effectiveness of this type of packaging for businesses and customers, on the other hand, will decide its growth and development.

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Chapter 9
Nutrient Adequacy, Dietary Diversification, Food Processing Practices to Ensure Household Food Security Among Rural Women

Virginia Paul and Ajit Paul

Abstract Health of women and their status in the society are found to be linked. The consequence of this is the lower level of literacy among women as compared to men, lower sex ratio and lower level of employment in non-agricultural sectors. The nutritional status of women at the household level is found to be determined by the cultural norms, practices and the socio-economic factors. In this present investigation, data on diet and nutritional status of women population, were collected from villages of Jasara and Chaka blocks of Allahabad District. The data shows that the food consumption pattern and daily intake of nutrient is not sufficient according to RDA which ultimately leads to the poor nutritional status of respondents and further to the frequent infections, reduce physical capability and micronutrient deficiency disorders like iron deficiency-anaemia which are very common deficiency disorder among rural women.

The role of indigenous food processing knowledge in enhancing the food security of rural population households of Allahabad District and factors that limit the use of such knowledge was examined and documented. It was found that out of 600 respondents, 78% practiced indigenous food processing whereas 22% of them didn't. One of the major reasons cited for not practicing indigenous food processing practices was economic crisis (72%). The other reasons were lack of equipment (18%) and of raw materials (10%). Sun drying (96%) was one of the most widely practiced indigenous food processing practices. Other types of processing include salting and sugaring (82%), fermentation (48%) while 16% of respondents practiced dairy processing. There is a felt need for creating mass awareness programme, through

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extension education agents, on practicing indigenous food processing practices to enhance food security in resource scarce rural areas.

Keywords Indigenous food processing knowledge · Women · Food security

9.1 Introduction

Whereas several efforts are being made by the Government of India in developing health and population policies, the implementation of appropriate interventions are affected due to poverty, gender discrimination, and illiteracy in the population (Buckshee, 1997). The repercussions of poor health of women are felt not only by women themselves but also by the families. Poor nutrition and health of women lead to the birth of infants with low weight and an inability to provide proper food and care to their children. It also affects the economic wellbeing of the household as women with poor health are more likely to be less productive. The health and nutrition of women in India are adversely affected by the prevailing cultural and traditional practices. As observed by Chatterjee (1990) and Desai (1994), while malnutrition is prevalent among all segments of the population, poor nutrition among women begins in infancy and continues throughout their lifetime. This is a cause of concerns as the livelihood of the rural areas depends on agricultural activities and women, who constituted about 70% of the rural population (as per census), are the backbone of such activities. Indigenous knowledge is knowledge that is unique to a given culture or society (Grenier, 1998). Indigenous food processing methods offers a solution to food insecurity in rural areas. These valuable methods, passed on from generations and modified as per the existing knowledge and innovations, are well known to the rural women population. And as managers of the local resources, with good awareness about such resources and environment, women are well placed to ensure sustainable food security for the rural households. Keeping in mind the tremendous potential that such indigenous knowledge has in ensuring food security, this present investigation has been conceptualized. The objective of the investigation is to assess the dietary adequacy of the respondents. The methods and objectives of the present investigation are: Through a 24 h recall method, assess the dietary adequacy of the respondents, through food consumption frequency method, assess the dietary diversification of the respondents, Identify the indigenous food processing practices, Determine the factors limiting the use of indigenous food processing practices.

9.2 Materials and Methods

The investigation adopted a cross-sectional and descriptive study based on the prevalent conditions of the population. For this study, women between the age of 18 years to 25 years were chosen as a unit of study. The sample size of study was

600, selected randomly from the villages of Chaka and Jasara blocks of Allahabad District. The mean age of respondents was 21.5 ± 6.48. Through the 24 h recall method, daily intake of energy, fat, iron, protein and vitamin C was assessed and exchange list was used to convert the intake of food by respondents in to the nutrients intake. The nutrient intake was then compared with ICMR's RDA for the assessment of nutritional adequacy of the respondents. Through the use of Food Frequency Table, information on food habits and food consumption pattern of respondents was collected. Data obtained was subjected to statistical analysis by using Arithmetic Mean technique.

Villages of Semara, Kanjasa, and Dalbabari of Jasara block and villages of Dandupur, Dhanuha and Sarangapur of Chaka blocks of Allahabad District were selected as area of study. 100 respondents were selected from each village for the study. Data was collected through semi-structured questionnaires, group discussions, and personal interviews and through informal observation regarding the identification of indigenous food processing practices, the extent of its use and the factors limiting the use of such knowledge in combating food insecurity of the household.

9.3 Results and Discussion

9.3.1 Demographic Profile of the Respondents

The demographic characteristics are the result of the health and nutritional status of the population. The demographic condition of the selected respondents revealed that out of 600 samples, 34% subjects were between 18 and 20 years, 66% were between 21 and 25 years. As far as caste is concerned, out of 600 respondents, there were 24% general, 44% OBC and 32% SC/ST caste. 60% subjects were married while 40% were unmarried. The religious profile of respondents showed that there were 80% Hindu and 20% Muslims. Joint family system is being replaced today by the nuclear family system. The percentage of nuclear family stands at 78% while the joint family stands at only 22%. In similar studies it was also found that 45.71% population is joint families and 55.28% populations are nuclear families (Akhter, 2003). It was also established in the same study that nuclear families are becoming more common and the joint families are breaking up. One of the reasons for such trend could be due to migration from rural areas to urban areas. With limited income the size of the family affects both the quality and quantity of food availability. The family income of majority of the respondents (56%) was between 5000 and 10,000 per month and are in the low or lower middle class group. Limited resources and less income leads to deficiency disorders and females are more prone to nutritional deficiency like anaemia. Similar study also found that the degree of anaemia is linked with the income of the family (Alaofe et al., 1996). Parent's educational status and especially that of the mother plays a vital role in the health and nutritional condition of adolescents. As compared to the health and nutritional status of less educated

Table 9.1 Demographic profile of the respondents

Categories	Particulars	Frequency	Percentage
Age	18–20 years	204	34
	21–25 years	396	66
Category	General	144	24
	OBC	264	44
	SC/ST	192	32
Religion	Hindu	480	80
	Muslim	120	20
	Christian	0	0
	Other	0	0
Type of family	Joint	132	22
	Nuclear	468	78
Family income/month	<5000Rs.	0	0
	5000–10,000Rs.	336	56
	10,000–15,000Rs.	228	38
	>15,000Rs.	36	6
Literacy	Illiterate	312	52
	Literate	288	48
Educational qualification (n = 288)	Primary	72	25
	Secondary	144	50
	High school	34	12
	Intermediate	24	8
	Graduation	14	5
	Post-graduation	0	0

parents, improved condition was found for educated parents. In the current study it was found that the highest percentage of literacy was secondary level (24%). Maximum respondents belonged to less education level which is a primary cause of their adverse health and nutritional status which may leads to deficiency disorders like anaemia, as depicted in Table 9.1.

9.3.2 *Dietary Pattern of Respondents*

The present study found that majority of the women are vegetarian (56%) and hand pump is the main source of drinking water. Also all respondents (100%) consumed green leafy vegetables. It was also found that for majority of the respondents, the main staple crops are wheat and rice (70%). For about 54% of the respondents, green leafy vegetables was found in their diet, with the frequency of two to three times in a week (54%). It was found that less consumption of protective foods like GLVs and fruits are the main causes of frequent occurrence of deficiency disorders. The data revealed that majority of the females consumed less green leafy vegetables in their

Table 9.2 Dietary pattern of respondents

Categories	Particulars	Frequency	Percentage
Dietary habits	Vegetarian	336	56
	Non-vegetarian	216	36
	Eggitarian	48	8
Appetite	Normal	444	74
	More	36	6
	Less	120	20
Meal pattern	2 meals	516	86
	3–4 meals	84	14
	>Meals	0	0
Staple crop	Rice	156	26
	Wheat	324	54
	Rice-wheat	120	20
	Others	0	0
Source of drinking water	Well	156	26
	Hand pump	444	74
	Running water	0	0
	Pipe water	0	0
Inclusion of GLV's	Yes	324	54
	No	276	46
Frequency of consumption of GLV's (n = 324)	Daily	149	46
	2–3 times a week	174	54
	Never	0	0

diet and their diet are based mainly on the staple crops which leads to the micronutrient deficiency like anaemia, as shown in Table 9.2.

9.3.3 Food Consumption Pattern of the Respondents

Based on the items listed on the food frequency questionnaire, the frequency of specific foods consumed by the study group was evaluated. All the respondents (100%) reported eating rice and wheat daily. It was also found that majority of the respondents (37%) eat washed pulses (legumes) while 22% reported eating citrus fruit and only 6% eat other fruits on daily basis. It was also found that vegetables are consumed frequently. Green leafy vegetables are consumed daily by half of the respondents while 46% of the respondents consumed potatoes daily. But it was reported that only 6% of the subjects consumed low fat milk daily. The respondents use less butter and ghee i.e., 12% and 16% respectively. 14% participants reported consuming fish monthly whereas only 4% reported to consume weekly. Mutton consumption was reported among 1/3rd of the participants, while 20% and 4% are

Table 9.3 Food consumption pattern of the respondents

Categories	Particulars	Never		Once a month		Once a week		2–3 times a week		Daily	
		N	%	N	%	N	%	N	%	N	%
Cereals	Rice	0	0	0	0	0	0	0	0	600	100
	Wheat	0	0	0	0	0	0	0	0	600	100
	Semolina	96	16	132	22	204	34	96	16	72	12
	Millets	48	8	132	22	156	26	168	28	96	16
	Puffed rice	24	4	72	12	120	20	264	44	120	20
	Rice flakes	72	12	156	26	288	48	60	10	24	4
Pulses	Whole	24	4	84	14	336	56	120	20	36	6
	Washed	150	25	36	6	48	8	144	24	222	37
	Sprouted	444	74	48	8	48	8	36	6	24	4
	Soyabean	348	58	108	18	72	12	72	12	0	0
	Ground nut	252	42	228	38	84	14	36	6	0	0
Fruits	Citrus	252	42	84	14	72	12	60	10	132	22
	Other	468	78	48	8	24	4	24	4	36	6
	Seasonal	96	16	156	26	252	42	72	12	24	4
Vegetables	GLV	60	10	0	0	0	0	240	40	300	50
	Cruciferous	24	4	84	14	156	26	216	36	120	20
	Roots	0	0	48	8	60	10	216	36	276	46
Dairy	Low fat	396	66	24	4	72	12	72	12	36	6
Fats and oil	Butter	516	86	72	12	12	2	0	0	0	0
	Ghee	492	82	96	16	12	2	0	0	0	0
	Refined oil	564	94	36	6	0	0	0	0	0	0
	Ground nut	600	100	0	0	0	0	0	0	0	0
	Mustard oil	0	0	0	0	0	0	0	0	600	100
Sweets	Sugar	60	10	36	6	24	4	48	8	432	72
	Jaggery	156	26	72	12	96	16	216	36	60	10
Non-veg (n = 216)	Eggs	36	6	48	8	72	12	36	6	24	4
	Fish	108	18	84	14	24	4	0	0	0	0
	Poultry and mutton	0	0	36	6	120	20	36	6	24	4
	Pork and beef	180	30	24	4	12	2	0	0	0	0

consumed on weekly and daily basis (Sultana et al., 2014). This data is given in Table 9.3.

9.3.4 Average Daily Nutrient Intake of the Respondents

The average intake of energy and macro nutrients is presented in Table 9.4. It is seen that the average energy and protein intake in all age groups was lower than the

Table 9.4 Average daily nutrient intake of the respondents

Group	Nutrient	Energy (kcal)	Protein (g)	Fat (g)	Iron (mg)	Vit. C (mg)
Women aged between 18 and 25 years (N = 600)	Intake	1181.14	31.42	15.67	19	21
	RDA	1875	50	25	30	40
	Difference	−694	−18.58	−9.33	−11	−10
	t-value	27.71	23.83	28.31	10.09	10.00

recommended dietary intake. Iron and vitamin C intake was also less than the RDA as prescribed by Indian Council of Medical Research. In this study the t- value for energy was 27.71 followed by 23.83 for protein, 28.31 for fat, 10.09 for iron and 10 for vitamin C. So there is significant difference between the different nutrients intake and the RDA among the respondents and the daily nutrient intake of the respondents differ significantly with the RDA. Similar studies have been reported by Sultana et al. (2014) in which data shows that the nutrient intake was less than the RDA in the community which results in poor nutritional status of the population. Thus, this data given in Table 9.4 also reveals that the food consumption pattern and daily intake of nutrient is not sufficient according to the RDA which ultimately leads to the poor nutritional status of the respondents and further to the frequent infections, reduce physical capability and micronutrient deficiency disorders like iron deficiency (anaemia) which is a very common deficiency disorder among rural women.

9.3.5 *Knowledge and Practices of Traditional Food Processing Practices*

Results have revealed that 32% of the respondents have extra amount of cereals grown in their fields, whereas 26%, 22% and 20% respondents have extra amount of grown pulses, vegetables plus cereals and vegetables plus pulses respectively. Out of 600 respondents, 38% respondents processed the extra grown crops whereas 22% respondents adopted storage along with food processing. 88% respondents have knowledge of food processing whereas 12% respondents do not have any knowledge of food processing. 78% of the respondents were found practicing food processing methods. The reasons for non-practicing food processing include economic difficulty (72%), lack of equipment (18%) and lack of raw materials (10%). The various types of food processing methods adopted by the respondents are sun drying (96%), powder making (74%), salting plus sugaring (82%), dairy products making (16%) and fermentation (48%). According to another study, food processing is the best way to combat nutritional deficiency disorders as with the help of food processing we can consume protective food like vegetables and fruits in an efficient way as it is available in all the season (Kapil et al., 1999). The data as shown in Table 9.5 revealed that the selected respondents have less application of food processing methods due to various reasons which may results in adverse health outcomes.

Table 9.5 Knowledge and practices of traditional food processing practices

Categories	Particulars	Frequency	Percentage
Extra amount of grown crops	Cereals	192	32
	Pulses	156	26
	Vegetable + cereals	132	22
	Vegetables + pulses	120	20
Mode of utilization of extra amount	Processing	228	38
	Storing	132	22
	Processing + storing	156	26
	Processing + distribution	84	14
Knowledge of processing	Yes	528	88
	No	72	12
Application of processing	Yes	468	78
	No	132	22
Reason for absence of processing (n = 132)	Economic crisis	95	72
	Lack of equipment	24	18
	Lack of raw material	13	10
Type of processing (n = 600)	Sun drying	576	96
	Powder making	444	74
	Salting + sugaring	492	82
	Dairy products	96	16
	Soaking	108	18
	Fermentation	288	48

9.3.6 Indigenous Food Product Preparation by Different Processing Methods

Various products were prepared using traditional processing practices by the respondents, as given in Table 9.6. Out of 576 respondents who practiced sun drying, 54% respondents make aloo *papad,* 19% respondents make sago *papad,* 23% respondents prepared rice *papad* and 4% women make semolina *papad*. Out of 576 respondents who practiced sun drying, 49% respondents make *uradbadi*, 39% respondents make moong badi and 12% women make mixed badi. Turmeric powder, coriander powder, chilli powder, mango powder and ginger powder were prepared by 18%, 32%, 22%, 22% and 6% respondents respectively. Out of 492 respondents who do salting, 51% respondents make mango pickle, 9% Jackfruit pickle, 22% chilli pickle and 18% respondents make *amla* pickle. 89% respondents make *Murabba*, 5% ladoo whereas 6% respondents make sweets. As far as coarse grain utilization is concerned 56% respondents prepared *Laiyyaladdoo*, 28% *Tilladoo* and 16% respondents make *Ramdanaladdoo.* In dairy products maximum respondents (50%) prepared butter milk followed by butter (25%) and ghee (25%). In a separate study it was stated that the various indigenous techniques from fermentation to sun-drying are viewed as unique techniques to preserve foods for years and it is seen as meaningful, socially as

Table 9.6 Indigenous food product preparation by different processing methods

Categories	Particulars	Frequency	Percentage
Papad (n = 576)	Aloo	311	54
	Sago	109	19
	Rice	132	23
	Smolina	24	4
Badi (n = 576)	Urad	282	49
	Moong	224	39
	Mixed with vegetable	70	12
Spices powder (n = 444)	Turmeric	78	18
	Coriander	142	32
	Chilli	99	22
	Mango	99	22
	Ginger	26	6
Fermentation (n = 288)	Curd	193	67
	Vinegar	95	33
Salting (n = 492)	Mango	252	51
	Jackfruit	44	9
	Chilli	108	22
	Carrot	0	0
	Amla	88	18
Sugaring (n = 492)	Murabba	438	89
	Ladoo	24	5
	Sweets	30	6
Dairy products (N = 96)	Ghee	24	25
	Butter Milk	48	50
	Paneer	24	25
Coarse gain utilization (n = 600)	Laiyya ladoo	336	56
	Til ladoo	168	28
	Ramdana ladoo	96	16

well as technically, to improve the indigenous knowledge for achieving rural food security (Ibnouf, 2012).

9.4 Conclusion

The present study revealed the inadequate dietary intake among rural Indian women. Women's health varies from state to state due to various factors like culture, religion, and levels of development and education among different Indian States. The study highlighted the need for more community participation in various developmental programmes, improve literacy rate among females to remove poverty and improve the nutritional health of women. Health and nutrition education has to be strengthened through the Department of health and ICDS, in order to create awareness and behavioral changes amongst public for better health and nutrition practices, to improve the nutritional status of mother and child. Women in rural areas of Allahabad district tend to use locally available resources effectively in achieving household food security, based on indigenous knowledge in processing and preserving, thus relieving the stress of seasonal food scarcity particularly during shortage of rainfall or drought.

9.5 Recommendations

Cultivating and developing indigenous knowledge as a way of building the capacity of rural women by giving them larger role to utilize their potential is important, since using their indigenous knowledge in food processing and preserving is a practical way to ensure food and nutritional security. Therefore, instead of blindly adopting alien approaches and methods, it would be more meaningful, socially as well as technically, to develop the indigenous knowledge for achieving rural food security.

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Chapter 10
Sustainability Science Perspective in Integrated and Sustainable Agriculture Development: Case Study of Indonesia

Helmi

Abstract Aspects related to agriculture and the environments are among the cores agenda in sustainable development goals (SDGs), newly adopted as UN Declaration. SDGs, basically, reflected the sustainable development problems in all the goals (17 goals) intended to deliver which is complex in nature. Failure in addressing sustainable development problems in the last 20 years (Halle et al., The future of sustainable development: rethinking sustainable development after Rio+20 and implications for UNEP. The International Institute for Sustainable Development (IISD), Winnipeg, 2013, p. 1) has implication on the scientific basis upon which innovative solutions for the problems are formulated. It has intensified debates whether solutions to sustainable development problems (including in agriculture) can be provided solely by natural sciences or social sciences independently since there is interface between natural and social aspects of life system. Given the complexities of delivery of SDGs which are inter/trans-disciplinary in nature, a new strand of science, the so-called the sustainability science (SS) has developed which bridged eco- and social system in order to create impact on society. This chapter intended to contribute to the framing of application and advancement of SS in the context of integrated and sustainable agriculture and environment to support delivery of SDGS. It is the argument put forward in this paper that delivery of SDGs is about actions at local level and synergy among four major stakeholders of sustainable agriculture development (community, government, universities/research institutes, and private sector) is important in implementing science-based innovative solutions. In addition to that, it is also required a local institutions which function as prime mover for the application of SS and function as platform for synergy among stakeholders.

Keywords Sustainable agriculture · Sustainability science · Inter/trans-disciplinary knowledge generation · Integrated agriculture development · Livelihood improvement

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10.1 Introduction

Attention on the sustainability as paradigm for human progress has evolved since 1972 with the UN Declaration on Human Environment and after that the commitment for sustainable development has reiterated from one period to another. The latest one is the 2015 UN Declaration on SDGs where sustainable agriculture, livelihood improvement, natural resources and environment are among the cores agenda.

Even though the universal agreements already agreed and independent commission set-up, however, the threats of un-sustainability were still exist and tended to get worse. The IISD meeting in 2012 (Halle et al., 2013) noted that, even though advances have been made after 20 years of Earth Summit (in 1992), but the results was not as expected to reform global economy toward a more sustainable direction. The report from IISD meeting specifically mentioned the inadequacy of the progresses made happened in most of development areas such as in terms of equity, social justice, climate change and biodiversity conservation. It is indicated that there are still more efforts and actions, especially at local and community levels needed, beyond meetings and producing documents. In my view, it is not because the summits, the conventions and agreements, and the independent commissions were not useful. The problem lies with failure in translating the global conventions and agreements into actions at locality or bio-region and community levels. The phrase “act locally” in the past, seems not sufficiently got attention and leaved the phrase with mostly with “think globally”.

The World Social Science Report 2013 (ISSC/UNESCO, 2013), further emphasise the need for effective responses to environmental and social changes. It can only be happen if all elements and actors (at different levels) working together to balance actions at the three basic aspects of sustainable development: environment, economy and social in order to achieve well being for all. At this point, attention is needed to devise framework to response to environmental and social changes effectively. Since the eco-system and social system are interrelated each other, then, concerted action both in term of generating sustainability science and improving its application or practices need to be organised in an integrated and inter/trans-disciplinary manner. It this relation the delivery of SDGs in the context of sustainable agriculture, to a large extend, will depend on the framing of SS application at local and community levels.

10.2 Conceptual Basis for Integrated and Inter/Trans-disciplinary Approach in SS Generation and Application

Eco-system and social system are the two sides of human life on earth and the relationship between the two has well explained by Falkenmark (1997, please see Fig. 10.1). Eco-system is the essential basis for social system to operate and improving well-being of human kind. Eco-system provide factors of production

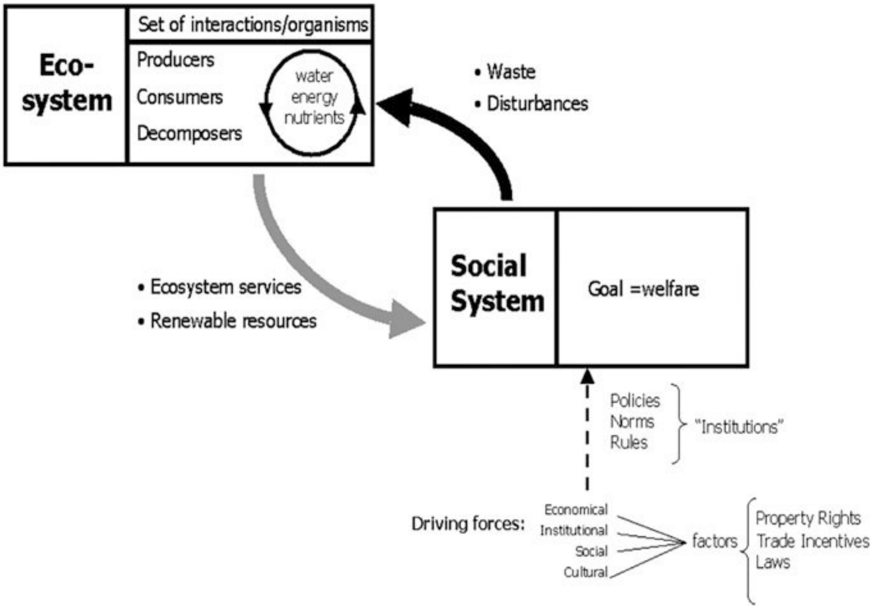

Fig. 10.1 The eco-system and social system: The two sides of life systems on earth. (Source: Falkenmark, 1997)

from the renewable resources and eco-system services. Human activities in the social system are aim at to fulfil the livelihood needs (clean and drinking water, food, energy, fiber, and shelter), solve the problems (poverty, health, and quality of environment, exclusion and powerlessness), and meet the challenges (to improve well-being), and provide support for economic growth (energy, natural materials, non-renewable minerals resources). All human activities would have impact on eco-system (land, water, forest/vegetation). The impacts caused by altering, modifying, and exploiting natural resources in the eco-system and wastes produced from various livelihood and economic development activities.

Based on conceptual framework proposed by Falkenmark (1997), sustainable progress in human life on earth (sustainable development), basically have three dimensions: environmental dimension; social dimension; and economics dimension as a major driving force in the social system (beside socio-cultural and institutional factors). Sustainable development will be achieved if there is a balance between objectives and practices in each dimension and the overlapping sections. A number of authors have indicated the dynamics of interactions among the dimensions and indicated that among the key factors to enable transition to sustainable development are: (1) economic incentives and social entrepreneurship (Vennesland, 2004; Helmi & Rusdi, 2017); (2) social capital (institutions), governance system at different levels, and related government policies (see Uphoff, 2000; Woolcock & Deepa, 2000; Coleman, 2000; Grootaert & van Bastelaer, 2002; Vennesland, 2004;

Alinon & Antoine, 2008; Helmi & Vermillion, 1990; Helmi, 2009); (3) participation and synergy, and roles of private sector; and (4) application of knowledge, technologies, and innovations (Helmi, 2015; Helmi & Khodeli, 2015).

The sustainability in the economics and environmental dimension has been the predominant concern in the past (with the so-called technocratic approach). However, less attention given to the social dimension and intersection between economics and social dimensions (socio-economic) and intersection between social and environmental dimensions (socio-environment). The abandonment on these aspects was one of the important factor affecting sustainability of benefits stream from eco-system and the progress in social system. IISD in its 2012 report pointed out that after 20 years of Earth Summit (in 1992), the objective of sustainable development not yet achieved, partly because narrow and technocratic approach, focused more on environmental aspects which rooted more on natural sciences. However, the approach failed to solve sufficiently more pressing problems in the social system domain such as poverty alleviation, environmental degradation, and social breakdown or social exclusion (Creech & Willard, 2001).

Some of my previous works on this topic at the practical level related to land, water and irrigation, and forest resources indicated the need for and better performance with integrated approach (see among other: Helmi, 1998, 2000, 2005, 2012; Helmi & Ifdal, 2002; Helmi & Rusdi, 2009; Helmi & Yonariza, 2000; Bruns & Helmi, 1996). The realities indicated the need to understand both eco-system and social system equally by applying a more interdisciplinary and integrated approach in knowledge, technologies and innovations generation which oriented toward provide innovative solutions to sustainable development problems.

Given the very close interface between the eco-system and social system, a balance an integrated approach to the eco- and social system is very important for the sustainability of life on earth. The concept of sustainability is related, on the one hand, to the benefits stream from eco-system in the form of ecosystem services and renewable resources required for livelihood and economic development. On the other hand, the concept of sustainability is related to the managing and controlling wastes produced and disturbances occurred from social and economic development activities. Therefore, fulfilling the needs and solve the problems in the social system and maintaining the carrying capacity and conserving the eco-system could not be handled in separate ways. For this purpose there is a need for designing research which is relevant to policy and practices (Korten, 1987). This is the challenge for sustainability of benefits stream from the eco-system as well as controlling the waste and disturbance from the social system for the well-being of human kind.

The Nature, Journal of Science, in earlier 2015 edition, has emphasised the need for a more beneficial knowledge for society, where integrated and inter/trans-disciplinary approach in knowledge generation are the keys. At the Editorial section it is written:

> "Physics, chemistry, biology and the environmental sciences can deliver wonderful solutions to some of the challenges facing individuals and societies, but whether those solutions will gain traction depends on factors beyond their discoverers" ken. ... If social, economic and/or cultural factors are not included in the framing of the questions, a great deal of creativity can

> be wasted. ... All credit, therefore, to those . . . who integrate natural sciences, social sciences and humanities from the outset. If you want science to deliver for society, through commerce, government or philanthropy, you need to support a capacity to understand that society that is as deep as your capacity to understand the science. (Nature, Journal of Science, Vol. 517, 1 January 2015, p. 5).

One of the major point from the quote is that, we cannot let our creativity in doing research, generating knowledge, and developing technologies and innovations to be wasted. It happened when we failed to bridge natural science and social science to produce knowledge-based innovative solutions for sustainable development problems. In addition to that, the knowledge produced were not in line with the aim to develop a descent standard of living, stronger social cohesion, and meaningful participation by society. Transition toward sustainability required identification of problems and challenges and map out the options and associated consequences. Therefore, science and technology generated from research can be both the origins of the sustainability problems as well as instruments to deal with them (Spangenberg, 2002).

Researchers have been working to deepening understanding on SS in the last 15 years. The works indicated that that there is a need to put attention in three aspects. One, is fragmentation and divided domain between social and natural science which made sciences less relevant in formulating solution to complex and interrelated problems of un-sustainability (please see among others Spangenberg, 2002; Komiyama & Kazuhiko, 2006; Bennet, 2013; Swart et al., 2004). Second, is the need for inter/trans disciplinary approach to formulate and implementing innovative solution to un-sustainability problems by bridging natural and social sciences specifically related to: understanding and guiding interaction between nature and society along sustainable trajectories, and applying social learning approach in fostering transition toward sustainability (please see among other Jerneck et al., 2011; Miller et al., 2014); Sedlacko et al., 2013; ISSC/UNESCO, 2013). And, the third, is related to multi actors involvement in the complex problems and solution to un-sustainability problems. In this context there is a need to apply participatory processes involving not only scientist but also society/community affected, practitioners, government institutions, and international organisations concern with the un-sustainability problems. It is meant that SS required innovative approach in setting boundary of analysis, assessing impacts of un-sustainability problems, and in formulating solutions and their implementation, which essentially related to co-production of knowledge, reciprocal learning and applied aspects of science (see among others Jerneck et al., 2011; Spangenberg, 2002; Bennet, 2013).

The framework to operationalise SS in knowledge generation involved the universities/research institutes (with researchers from various disciplines); (part of) society facing sustainability problems; and other sustainable development actors (please see Fig. 10.2). Both knowledge generation and implementation of solutions are done with participatory manner involving each sustainable development actors at appropriate stage(s).

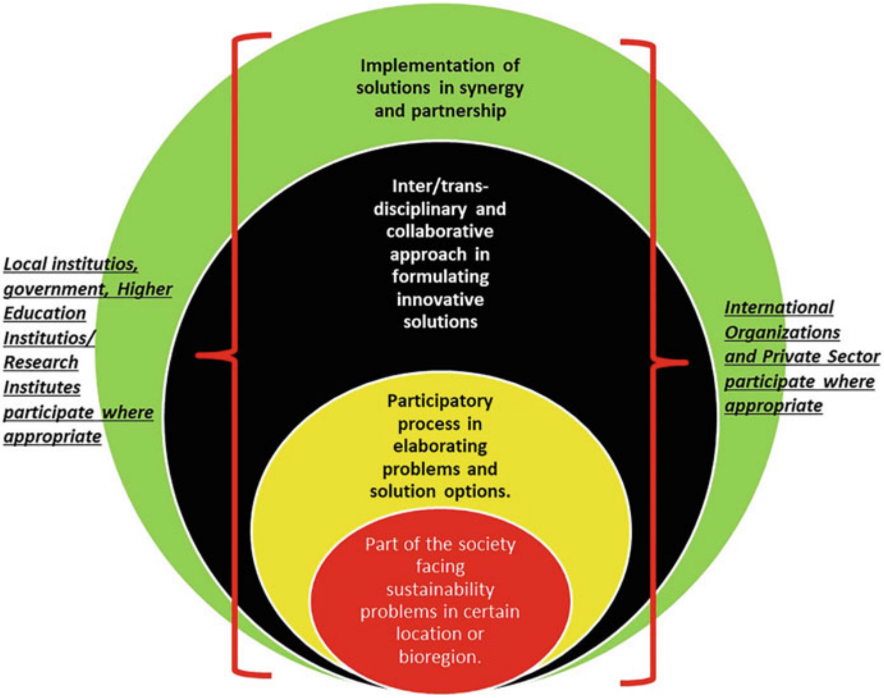

Fig. 10.2 Framework for participatory and society's impact oriented SS generation and its application

Overall the SDGs contained seventeenth goals and agriculture together with environment are among the core goals. It stressed the need to put attention on those problems which insufficiently addressed in the past period in the social system domain which greatly affected the eco-system. Those problems are poverty, hunger, exclusive and un-sustainable economic growth, unemployment and indecent work, social exclusion and social breakdown, ineffective and un-accountable institutions at all levels, and weak partnership in development. To mention among agriculture and environmental related goals are the following: end poverty in all its forms everywhere (Goal #1), including in agriculture sector; food security, nutrition, and sustainable agriculture (Goal #2); sustainable management of water and sanitation (Goal #6); access to affordable, reliable, and sustainable energy (Goal #7); inclusive and sustainable economic growth, full and productive employment and descent work (Goal #8); inclusive and sustainable industrialisation and foster innovation for all (Goal #9); combating climate change and its impacts (Goal #13); conserve, protect, restore, and promote sustainable use of natural resources (Goal #14 and #15); peaceful and inclusive societies for sustainable development, access to justice, effective, accountable, and inclusive institutions (Goal #16); partnership and synergy to achieved sustainable development goals (Goal #17). Formulation of the goals clearly indicated the need for integrated and inter/trans-disciplinary approach in addressing sustainable development problems.

In the context of SDGs delivery, the focus is on impact of science on society, especially in the context of agriculture. The main issue is that how could knowledge, technologies, and innovations generated from research not only end up in publications, but go further to provide basis to solve sustainability problems in the society. One of the concern was the analytical basis on how to link between science and economy toward a sustainable society (Komiyama & Kazuhiko, 2006). It implies that knowledge generation and associated research conducted has to be solutions oriented toward society problems. Therefore, it has to go further than the traditional research and knowledge generation. This is what is meant as SS as the new science discipline. The main difference of SS with traditional science is that in its knowledge generation approach which are integrated and interdisciplinary from the outset (or initial stage). It is oriented toward creating innovative solutions to sustainability problems facing by human kind to improve well-being for all. The obstacles to achieve it are (Komiyama & Kazuhiko, 2006, pp. 3–4): “(1) complexity of the problems and the specialisation of the scholarship that seek to address them; (2) the discipline that examines this complex problems have themselves grown increasingly fragmented in recent years, so much research is conducted from a highly restricted perspective with regard to both phenomena identification and problem solving; and (3) piecemeal approach which constraining the development and application of comprehensive solutions to these problems”. There is a need to address the obstacles. One of the question, then, is how the framework for application and advancement of SS, especially in the context SDGs delivery, will look like? The efforts to deliver SDGs without support from SS will leave the rhetorics of sustainable development without realities.

The orientation toward solutions means that problems definition and direction of the research is formulated in a participatory ways involving (part of) the society concerned and those institutions which will involve in solving the problems, producing goods and services and deliver the SDGs. In this context, delivery of SDGs require synergy and concerted actions by sustainable development actors (society/community concerned, government, the private sector, the universities/research institutions) with the support from international organizations committed to deliver SDGs.

The delivery of SDGs based-on SS consists of three dimensions:

- SDGs and sustainability problems related to SDGs;
- integrated and inter/trans-disciplinary knowledge generation and innovative solutions formulation;
- delivery of SDGs based on innovative solutions developed and strategies to implement them.

In the context of sustainable agriculture, livelihood, natural resources management and environment, the aspects for the integrated and interdisciplinary works can be divided into three area, which are:

- Basic resources (e.g. land-used and vegetation changes, soil conditions and soil fertility, biodiversity loss, water scarcity, climate changes, etc.);

- Production processes, productivity, and efficiency (e.g. seeds, fertilisers, pest and diseases control, feeds, etc.);
- Post-harvest (products processing, packaging, added value creation, and supply chain management, etc.).
- Socio-economic, institutional, and cultural aspects related to (1), (2), and (3) above.

10.3 Framing the Application of SS in the Context of Integrated and Sustainable Agriculture in Indonesia

10.3.1 Overview of the Research

This assessment embarked from observation on the tendency that less attention was given to the agriculture-based community livelihood improvement in the area which has experienced deforestation and land degradation. The aim is to understand the social impact of deforestation and land degradation and the agriculture-based livelihood conditions of local people in the affected area. Included in the assessment were identifications of priority agriculture-based livelihood improvement activities, capacity building needs, supportive local government policy, local institutions, and possible support from university and private sector. The activities in the assessment were conducted in a participatory manners. Based on the understanding attempts have been made to develop a framework for application and advancement of SS in integrated and sustainable agriculture to support delivery of SDGs.

The assessment project has been implemented in three villages experienced forest and land degradation in three different provinces, namely West Sumatra (Solok District), Yogyakarta Special Region (Bantul District), and West Nusa Tenggara (in Lombok Barat District). Overall, the framework for implementation of the applied research summarised in Fig. 10.3. This figure also shown interconnection and synergy among parties in contributing to advancement and application of SS in delivery of SDGs in a Quadruple Helix Approach.

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10.3.2 Research Results

The data collected from the three sites suggested that degradation of forest and land caused drought and declining of soil fertility which lead to the decline of livelihoods (poverty). The intention to integrate agriculture-based livelihood improvement efforts with rehabilitation of forest and land need to take into account the interconnection between the three aspects (drought, soil fertility declined, and livelihood declined). These were the stepping stones to develop a framework which could

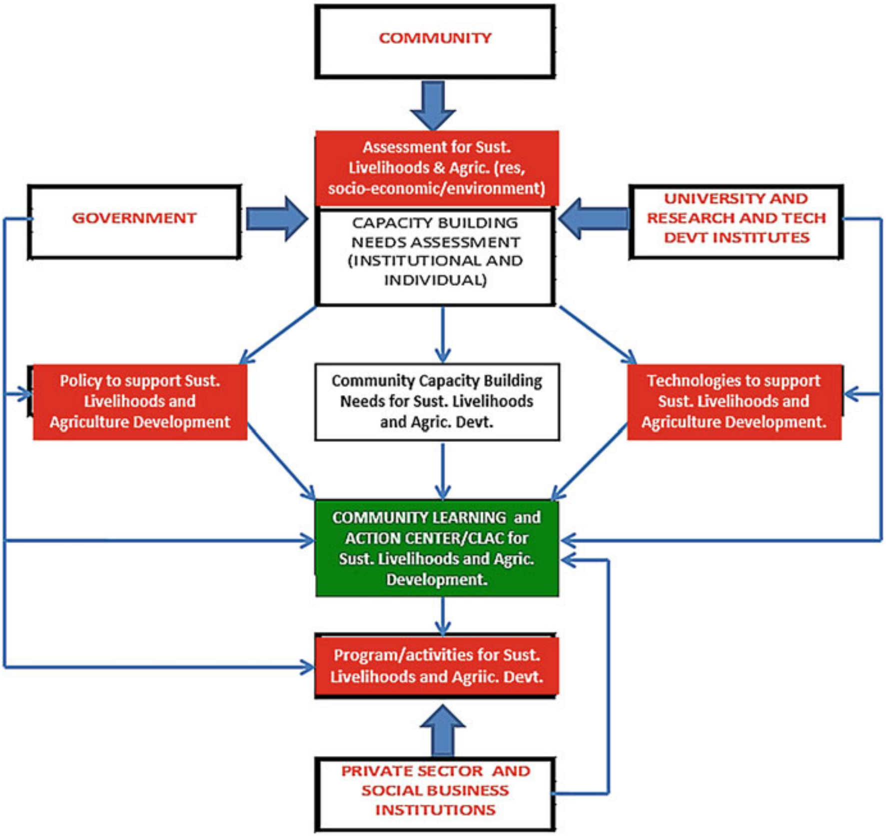

Fig. 10.3 Research framework

integrate the livelihoods improvement and rehabilitation of degraded forest and land. It means that the choice of agriculture-based livelihood improvement activities has to be something which could foster the rehabilitation of degraded forest and land.

The data showed that there are two types of major activities which have this kind of nature. The first one is re-greening the degraded land and provision of water supply (for drinking, sanitation, and irrigation). The re-greening efforts are tailored with the income generation objectives such as choosing the types of tree which can produce flowers to provide feeds for honey bees, or tree which can function as shedding of coffee crop, and/or arranging trees planting such that seasonal crops for cash income can be planted between and/or under the trees (strip cropping). The choice of tree can also consider it as the raw material for biomass-based electricity power generation (such as bamboo). The other type of livelihood improvement activity is livestock development which can function both for income generation

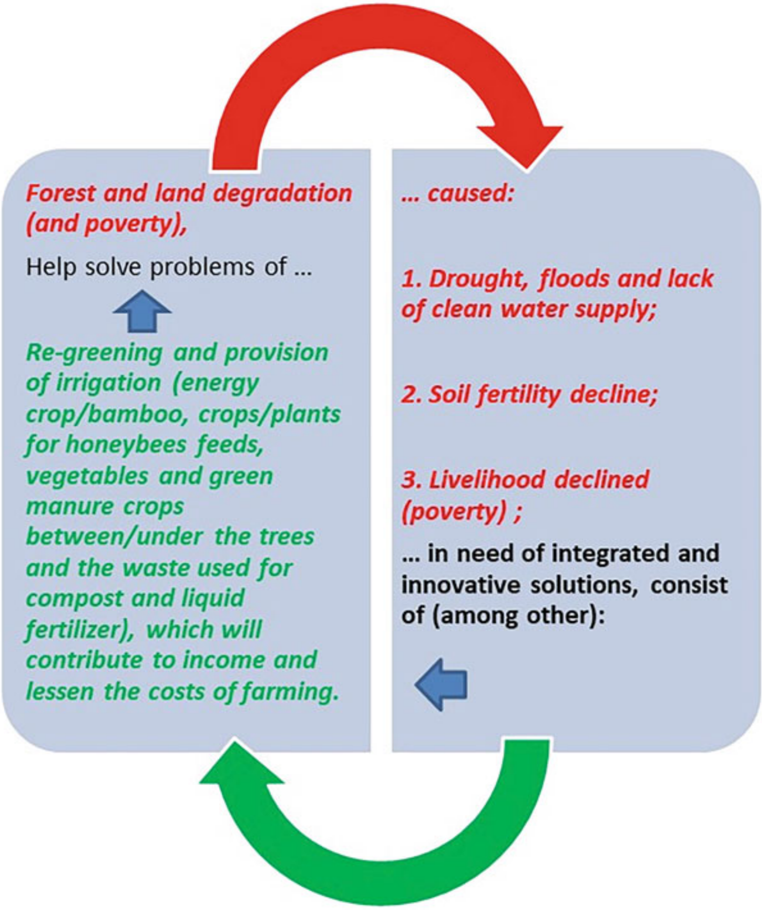

Fig. 10.4 A model to integrate efforts for livelihoods improvement and rehabilitation of degraded forest and land

as well as rehabilitation of soil fertility and physical condition. A model for integrating livelihoods improvement efforts and rehabilitation of degraded forest and land can be seen in Fig. 10.4.

The integration of livelihoods improvement and rehabilitation of degraded forest and land need to consider the area development (small region or cluster) approach. It is to make the various activities can be implemented efficiently and has an economic of scale sufficient for the growth of the community and the area to achieve prosperity. In addition to the area development approach, a local institution need to be developed and/or strengthened as prime mover (or "engine") for social and environmental changes toward sustainability. The local institutions function as community learning and action centre (CLAC) and facilitating synergy and partnership among sustainable development actors.

Fig. 10.5 Framework for practicing SS at community level, advancing its development, and contributing to delivery of SDGs

The development of framework for application and advancement of SS and delivery of SDGs is done based on the learning process approach to develop capacity, experiences, scaling-up coverage, and generating SS. Learning process approach starts from "learning to be effective" where the focus is building technical capacity. It is then followed by the "learning to be efficient", where the activities can be carried out efficiently. When the effective and efficiency aspects have been developed, learning to expand (scaling-up) can be done. The proven solution, at a later stage, can be integrated into government policy and or implementation of corporate social responsibility (CSR) of private sector. The scaling-up can be implemented with the support from other sustainable development actors (private sector, universities, and international organisations). Please see Fig. 10.5 for the role of CLAC in creating innovative solution, contributing to the achievement of sustainable development agenda, and the generation and advancement of SS.

10.4 Conclusions

This chapter have reviewed the development of SS and issues related to its application to help formulate science-based innovative solutions to integrated and sustainable agriculture development problems. There are two related important points to take into account: (1) the need for integrated approach between ecosystem and social system in dealing with sustainability problems; and (2) the need for co-production in generating, applying, and advancing scientific knowledge for sustainable development through inter/trans-disciplinary approach and synergy among stakeholders. These two points were used as the basis to conduct the assessment of socio-economic impact of deforestation and land degradation on agriculture-based livelihood. The results of the assessment, then, used to develop specific framework for application and advancement of SS in integrated and sustainable agriculture, livelihood improvement, and environment.

The important components of the framework in applying SS in this contexts consist of the following elements: (a) participatory formulation of the problems; (b) inter/trans-disciplinary scientific knowledge co-production and formulation of innovative solutions; (c) piloting the implementation of the innovative solutions at community and local levels; and (d) scaling-up the implementation in synergy and partnership among sustainable agriculture development actors. The successful implementation would added-up to the best practices in application and advancement of SS to support delivery of SDGs in integrated and sustainable agriculture.

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Chapter 11
Horticulture: A Key for Sustainable Development

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Abstract The ecofriendly practices applied in the sustainable agriculture aims to maintain or enhance the health of the natural resource within the constraints of the market-based production system. Usually, sustainability in agriculture is defined within the periphery of local environmental effects only as it involves the effects of the system on the people, economy, as well as on the environment. The ultimate definition of a sustainable system is one that serves people, sustains or improves the environment, and enhances the economy on the scale of the entire planet and over the next hundred or several hundred years. In India, economic backwardness and fragility of the hilly terrain demands more attention towards the sustainable development and restoration of environment. Field crops solely cannot fulfill the food demand of huge population and also are not so much economically viable. Thus, by keeping the food insecurity in mind, the people living in hilly terrains of India are forced to migrate towards foothills and plain area of its nearby surrounding there by imparting the more pressure on the people already living in the plains to meet out their nutritional demands. Horticulture sector is best suited for empowerment of women, contribute to the protection and enrichment of biodiversity as well as enhancing the economic and environmental restoration. Facing the combined challenges of an increasing world population, environmental degradation, climate change and civil unrest of world in general and India in particular needs new responses to sustainable development of horticulture. India is one of the leading producers of horticultural crops, because of having congenial climatic conditions for almost all type of horticultural crops whether these are fruits, vegetables or flowers and even in spices and condiments. But in recent years due to increment in population dynamics, rapid changes in climate have announced an alarming sign in the development of the horticulture in the country. Consequently, the productivity of horticultural crops has declined in the recent decades. Therefore, the sustainability of

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horticultural activities in the country is highly demanded for fulfilling the qualitative nutritional demands of the population.

Keywords Horticulture · Sustainable · Environmental · Organic farming · Climate change

11.1 Introduction

Sustainable development term was coined within the paper Our Common Future, released by the Brundtland Commission. Sustainable development is the one that meets the requirements of present without compromising the ability of future generations to satisfy their own needs. The two key concepts of sustainable development are the concept of "needs" especially the essential needs of the world's poorest people, to which they ought to tend overriding priority and the idea of limitations which is imposed by the state of technology and social organization on the environment's ability to satisfy needs of present and future generation (Francis et al., 2017). The three main pillars of sustainable development include economic process, environmental protection and social equality. While many folks agree that each of these three ideas contribute to the overall idea of sustainability, it's difficult to hunt out evidence of equal levels of initiatives for the three pillars in countries policies worldwide. With the overwhelming number of countries that put process on the forefront of sustainable development, it's evident that the other two pillars are suffering, especially with the general well-being of the environment during a dangerously unhealthy state (DSD Resources, 2012). The concept of sustainable development is intuitively understandable, but remains difficult to be expressed in a concrete practical definition as it is interpreted differently from different field (Briassoulis, 2001). It is a pattern of resource use that aims to meet human needs while preserving the environment so that these needs can be met not only in the present, but also for generations to come (Smith & Rees, 1998).

Sustainability is the capability to use those, necessary the paper to create goods and services, while having the least possible impact on the environment. The cultivation of fruits, vegetables and flowers is known as Horticulture. Horticultural activities help to cover waste land and to improve the environmental conditions and the socio-economic status of the people. Sustainable horticulture means focusing on optimizing plant health without reliance on fungicides and insecticides, as well as practices that promote abundant life in our plant collections, gardens and other ecosystems. Ecologist define the carrying capacity of the ecosystem as the population of humans and animals that can be sustained, based on the primary productivity of plants, with the available resources and services without damaging the resource base soil, water and environment (Daily & Ehrlich, 1992). Horticulture significantly contributes an important share to the Indian economy. The income elasticity for fruits and vegetables is reported to be 0.42% and 0.35%, respectively against only 0.05% for rice and −0.06% for wheat. The annual growth rate in domestic demands for fruits and vegetables is estimated at 3.34% and 3.03%, respectively (Chand, 2008). Other independent estimates also show that about 76% of fruits and vegetables are consumed fresh, whereas 22% is lost or gets wasted in the marketing channel (Acharya, 2007). Horticulture should receive greater attention in the hills after taking care of proper soil and water conservation measures. Climate change adaptations, particularly in temperate fruits and nuts requiring specific chilling hours for flowering, irrigation management and drought management are immediate research and extension issues (Ghosh, 2012).

During the last few years, consumption patterns in India have been changing discernibly in favour of fruits and vegetables, indicating significant structural shift in Indian diets. The increasing opportunities in export markets for these products coupled with the above-mentioned changes in consumption patterns have clearly laid the roadmap for the farmers to diversify in high value products that can also provide enhanced employment opportunities even on small land holdings. The emerging scenario requires renewed impetus and strengthening of resources and infrastructure in agriculture to produce high value foods and products that are in high demand by India's growing middle classes and urban dwellers and also that have overseas market opportunities. Such an agricultural production system could provide a sustainable source of income and employment in rural sector where majority of population lives. Indian agriculture is characterized by small land holdings with an average farm size of about 1.57 hectare. More than 90% of farmers have land holdings smaller than 4 hectares cultivating nearly 55% of the arable land. Farmers owning these fragmented land holdings are resource poor and generally do not have access to new technologies. But this huge human resource can sustain an intense and efficient agro-production system if provided with critical inputs like, technology, marketing and credit. The most important aspect is to ensure greater participation of small and marginal land holdings and convert their inherent weaknesses into opportunities. Over the past 40 years, the world's agricultural systems have been changing in response to population pressures (Waterlow et al., 1988). Population growth and local economics are driving both the intensification of agriculture and its extensification into the marginal lands, where risks of crop failure and environmental degradation are high. As Lal (1987) points out, 'subsistence farmers, who face famine, would consider a successful technology to be one that produces some yield in the worst year rather than one that produces high yields in the best'. Horticulture based production systems are now considered to be the most ideal strategy to provide food, nutrition and income security to the people (Chundawat, 1993; Chadha, 2002). Integration of annual crops with fruit trees yields multiple outputs that ensure production and income generation (Osman, 2003). The importance of horticulture in improving the productivity of the land, generating employment, improving economic conditions of the farmers and entrepreneurs, enhancing exports and above all, providing nutritional security to the desert dwellers, can hardly be overemphasized. Horticulture has assumed significant importance in the crop diversification in recent years, which has become essential to arrest serious land degradation and enhancing the farm income. In fact, the horticulture has also gained commercial importance with a very significant share in the economy of the region. Diversification of agriculture from traditional land use with predominantly cereal/

legume-based cropping systems to more productive and remunerative one has become a milestone to be achieved. Horticulture provides one of the few viable and most attractive alternative land use system. Apart from their contribution to the total agricultural production, their potential for providing much higher income to the farmers has been another major factor for favouring these crops.

India, with its wide variability of climate and soil, is highly favourable for growing a large number of horticultural crops. It is the fastest growing sector within agriculture. It contributes in poverty alleviation, nutritional security and has ample scope for farmers to increase their income and be helpful in sustaining large number of agro-based industries which generate huge employment opportunities. Presently, horticulture contributes 30.4% (ICAR) of agricultural GDP. The national goal of achieving 4.0% growth in agriculture can be achieved through major contribution from horticulture growth (Agarwal et al., 2016).

After the Green Revolution in mid-60s, it became clear that horticulture, for which the Indian topography and agro-climate are well suited, is the best option. India has emerged as the largest producer of mango, banana and cashew and second largest producer of fruits and vegetables in the world. The most significant development that happened in the last decade is that horticulture has moved from rural confines to commercial production and this changing scenario has encouraged private sector investment in production system management. The last decade has seen technological infusion like micro-irrigation, precision farming, greenhouse cultivation, and improved postharvest management impacting the development of horticulture industry (Agarwal et al., 2016).

11.2 Current Scenario of Horticulture in India

India is blessed with a varied agro-climate, that is very favourable for growing an oversized range of farming crops like fruits, vegetables, root tuber, ornamental, aromatic plants, healthful herbs, spices and plantation crops like coconut, arecanut, cashew and cocoa.

(i) Fruits: India incorporates a giant vary of types of fruits in its basket and account for 10% of world's total fruit production. Mango, banana, citrus, pineapple, papaya, guava, sapota, jackfruit, litchi and grape, among the tropical and sub-tropical fruits; apple, pear, peach, plum, apricot, almond and walnut among the temperate fruits and aonla, ber, pomegranate, annona, fig, Grewia asiatica among the arid zone fruits square measure vital. India leads globally within the production of mango, banana, sapodilla and acid lime and in productivity of grapes per unit expanse.

(ii) Vegetables: More than 40 types of vegetables happiness to completely different teams, namely, asterid dicot family, dicot family, leguminous, dilleniid dicot family (cole crops), root crops and leaved vegetables square measure full-grown in Asian country in tropical, sub-tropical and temperate regions. Vital vegetable crops full-grown within the country square measure tomato, onion, brinjal, cabbage, cauliflower, okra and peas. India is next solely to China in space and production of vegetables and occupies prime position within the production of cauliflower, second in onion and third in cabbage within the world.

(iii) Flowers: Although, flower cultivation has been practiced in India since times old, gardening has blossomed into a viable business solely in recent years. The augmented cultivation of up to date cut flowers like rose, gladiolus, tuberose, carnation etc.; has junction rectifier to their use for bouquets and arrangements for gifts, also as decoration of each home and work place. A growing market, as a results of improvement within the country and augmented richness, significantly, among the center category, has junction rectifier to transformation of the activity of flower growing into a burgeoning trade. Availability of various agro-climatic conditions during this country facilitates production of all major flowers throughout the year in some half or the opposite, and improved transportation facilities, have augmented the supply of flowers everywhere in the country.

(iv) Spices: Spices represent a very important cluster of farming crops and are defined as vegetable products or mixture there from, free from extraneous matter, used for flavouring, seasoning and imparting aroma in foods. The term applies equally to the assembly within the whole kind or within the ground kind. India is well known as home of spices as it produces a large sort of spices like black pepper, cardamom (small and large), ginger, garlic, turmeric, chili pepper and an oversized sort of tree and seed spices.

(v) Plantation crops: The major plantation crops include coconut, arecanut, oil palm, cashew, tea, rubber and coffee whereas the minor plantation crop includes cocoa. Their total coverage is relatively less and thus they are confined to small holdings. However, they play a very important role due to their export potential but also have domestic needs, employment generation and poverty alleviation in rural areas. India is the largest producer as well as consumer of cashew nut. The cultivation of vanilla in India was started in 90s and is confined to Kerala and Karnataka and to a lesser extent in Northeastern region, Lakshadweep, Andaman and Nicobar Islands and Tamil Nadu. India is the third largest producer of coconut and leads among 90 countries of the globe producing coconut and also occupies main position in arecanut production. The area and production of horticulture crops in India in the last decade is given in Tables 11.1 and 11.2.

Table 11.1 Area of horticulture crops in India (area 000' ha)

Crop	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18
Fruits	6383	6705	6982	7216	6110	6301	6480	6484
Vegetables	8495	8989	9205	9396	9542	10,106	10,290	10,295
Flowers and aromatic	191	760	790	748	908	912	943	955
Plantation crops	3306	3577	3641	3675	3534	3680	3677	3687
Spices	2940	3212	3076	3163	3317	3474	3535	3537
Total	21,825	23,243	23,694	24,198	23,410	24,472	24,925	24,977

Source: Horticultural statistics at a glance 2018

Table 11.2 Production of horticulture crops in India (production 000' MT)

Crop	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18
Fruits	68,466	71,516	74,878	76,424	81,285	86,602	90,183	92,846
Vegetables	133,738	146,554	156,325	162,187	162,897	169,478	169,064	175,008
Flowers and aromatic	1021	1031	2218	2647	3192	3143	3206	3277
Plantation crops	11,928	12,007	16,359	16,985	16,301	15,575	16,658	16,867
Spices	4016	5350	5951	5744	5908	6108	6988	7077
Total	223,089	240,531	257,277	268,848	277,352	280,986	286,188	295,164

Source: Horticultural statistics at a glance 2018

11.3 Horticulture for Food, Nutrition, Health Care and Livelihood Security

Both fruits and vegetables are good source of vitamins, minerals, proteins, and carbohydrates etc. that are essential in human nutrition. Hence, these are referred to as protective foods and assume great importance as nutritional security of the people. Thus, cultivation of fruit and vegetable crops play an important role in the prosperity of a nation as it is directly linked with the health and happiness of the people. Most horticulture crops are generally good sources of fibre, carotenoids, vitamin C, folate, potassium and other vitamins, minerals and bioactive compounds. Some specific vegetables are good sources of vitamins B, calcium and iron. Dried fruits are concentrated sources of energy, sugar, dietary fibre and iron. Thus, fruits and vegetables are sustainable and potential source of vitamins, minerals, carbohydrates, proteins, etc. and are now being extensively advocated as essential ingredients of a balanced human diet to meet the daily requirements for body functions, and more importantly, for the prevention of serious disorders such as night blindness and anemia due to micronutrient deficiencies, particularly in children and women (Karunakaran & Palanisami, 1998). The WHO report "Diet, Nutrition and Prevention of Chronic Diseases" 1990 recommended a goal of at least 400 g of vegetables and fruits daily (in addition to potatoes) including, within that, at least 30 g of legumes, nuts and seeds. However, as per the Recommended Dietary Allowance (RDA) of Indian Council of Medical Research (ICMR), a balanced diet should contain, besides other food items, 280 g of vegetables including tubers, and 92 g of fruits per day. The average intake of fruits and vegetables has improved in the last few years, particularly in the urban areas due to higher income levels and marked improvement in the production and availability of fruits and vegetables in the country.

In a comprehensive monograph brought out at the time of the International Conference on "Food, Nutrition and Cancer: A Global Perspective" held in 1997 in India, the following conclusions were drawn by the panel of experts: "There is a strong and consistent pattern showing that diets high in vegetables and fruits decrease the risk of many cancers, and perhaps cancer in general. The evidence that such diets decrease the risk of mouth and pharyngeal, esophageal, lung and stomach cancers is convincing, and they probably also protect against laryngeal, pancreatic, breast, and bladder cancers. The evidence that diets high in vegetables is convincing. The panel notes that such diets possibly protect against ovarian, cervical, endometrial and thyroid cancers, and that diets high in vegetables possibly protect against primary liver, prostate and renal cancers."

Carrot, rich in vitamin A, has been reported to block the division of cancer cells through the production of retinoic acid, which reverses the growth promoting effects on oncogenes, the mutated genetic material that induces cancer. Similarly, curcumin in turmeric is reported to inhibit cancer growth in 60% of colon tumors induced in rats. It acts as an antioxidant due to its anti-inflammatory properties. Tomato, the rich source of lycopene, is also reported to have an inverse association with the risk of prostate cancer. Grapefruit, on the other hand, has been reported to have the ability to reduce the low-density lipoproteins (LDL), cholesterol levels, leaving the high-density lipoproteins (HDL), the good cholesterol, intact, that helps in preventing heart attacks due to atherosclerosis. The pectin in this fruit, particularly in the rind portion, helps in reducing plaque buildup in the arteries of animals (Malhotra, 2006).

No doubt, health care of the people has been through modern medicine but still in Asia more than 80% people depend on herbs. Many of doctors now feel that modern medicine brings illness rather than wellness, and subscribe for balanced diet which protect against many disease by enhancing self-protective mechanism through many immunological advantages. The fruits (aonla, bael, jamun, papaya), vegetables (carrot, cauliflower, onion, garlic, leafy vegetables), spices (ginger, turmeric, black pepper, fenugreek, ajwian) and ornamental plants (ashoka, ficus, catharanthus) protects against various kind of diseases. The spices like turmeric, chillies and cumin in the diet have been recognized to protect against cancer. Noni (*Morinda citrifolia*) with unique characteristics is recognized as best for health care, as it provides protection against various diseases including HIV. Virgin coconut oil protects from HIV and coconut water provides all nutrients to child apparently. The fruits and vegetables contain vitamins and minerals which make them protective foods and provide ample opportunities for health care. According to the Food and Nutrition Board of the National Research Council, man and women between 23 and 50 years eat about 2800 and 2200 calories a day, respectively to maintain weight, while pregnant women and lactating mothers need additional calories of 300–500 per day than their normal requirement. The nutrient requirements tend to vary with age, gender, weight, height, physical condition, and the climatic conditions of the area where the people live. Thus, fruits and vegetable provide wider option for meeting the energy requirement for the human system. Healthier diets will improve the learning capacity of children and the working capacity of adults, leading to higher incomes and a reduction in poverty (Singh & Malhotra, 2011).

11.4 Techniques for Sustainability in Horticulture Production

Hi-tech interventions in horticulture would cover activities like high density planting, micro propagation, micro irrigation, fertigation, protected cultivation, biological control, bio fertilizers, organic farming, precision farming, use of remote sensing and GIS applications in horticulture and establishment of Precision Farming Development Centers (Government of India Planning Commission, 2001).

11.4.1 High Density Planting

High density planting can be defined as planting of fruit trees at a density in excess as compare to conventional planting method which suffices to give maximum crop yield at maturity if the individual fruit plant grows to its full normal size. In other words, it is the planting of more number of plants than optimum through manipulation of tree size and canopy. This concept emerged from Europe at the end of 1960 for temperate fruits. In high density planting, an attempt has been made to have more fruiting branches and minimum structural branches.

High density planting is one of the improved production technologies to achieve the objective of enhanced productivity of Indian fruit Industry. In India, high density planting technology has been successfully tried in banana, pineapple, papaya and recently in mango, guava, apple and citrus. Yield and quality of the produce are two essential components of the productivity.

11.4.1.1 Comparison Between Traditional and Modern Systems of Fruit Production

Attribute	Traditional system	Modern system
Tree number	Less number of trees per ha (150–200 trees/ha)	More number of trees per ha (500–1,00,000 trees/ha)
Bearing	Late in bearing with usual time of 6–8 years or more	Early in bearing with usual time of 2–3 years
Production	Low overall production per ha	High overall production per ha.
Management	Difficult to manage due to large tree size	Easy to manage due to small tree size
Establishment cost	Low cost of establishment	Higher cost of establishment
Harvesting	Manual	Mechanical

11.4.1.2 Components of HDP

(i) **Use of dwarfing rootstocks and interstock**

Crop	Rootstock	Special Characters
Mango	Vellaikolamban	Dwarfing rootstock for alphonso and Dashehari
	Rumani	Dwarfing effect on Dashehari.
Pear	EMLA, quince-C	Ultra dwarf
	OH x F333	Semi dwarf

Peach	Siberian C, St Julien X, *Prunus besseyi* and Rubira	–
Plum	Pixy	–
Avocado	Mt4	–
Ber	*Zizyphus nummularia*	–
Citrus	Citrangequat, Feronia and *Severinia buxifolia*	–
Guava	*Psidium friedrichsthalianum, P. pumilum*	Highly dwarf

Source: Singh et al. (2017)

(ii) **Use of dwarf scion**

Use of genetically dwarf scion cultivar	Dwarf cultivar	Desirable features
Mango	Amrapali	Precocious and tend to bear regularly
Papaya	Pusa Nanha	Dwarf and tend to bear at lower height
Banana	Dwarf Cavendish (AAA)	High yielding with dwarf stature
Peach	Redheaven	Dwarfing and high yielding
Sapota	PKM1, PKM3	Precocious and tend to bear regularly

Source: Singh et al. (2017)

11.4.2 Integrated Nutrient Management

Integrated Nutrient Management (INM) refers to the maintenance of soil fertility and supply of plant nutrient at an optimum level for sustaining the desired productivity through optimization of the benefits from all possible sources of organic, inorganic and biological components in an integrated manner. The nutrient management based production system of fruit crops is inherently complex to know as there is large variation in nutrient use efficiency (NUE). Current state of diagnosis of nutrient constraints in current season standing crop has minimum efficacy. Therefore, development of production-linked nutrient norms using crop specific index plant parts, needs a thorough revisit at orchard level using conventional basin irrigation versus fertigation. Application of hyper spectral analysis as proximal sensing of nutrient stress has started imparting precision to nutrient constraint diagnosis. On the opposite side, the most important constraint in making soil test ratings more purposeful is that the non-redressal of spatial variation in soil fertility within the sort of soil fertility analogues *vis-a-vis* fruit crops. Conjoint use of geo-informatics and nutrient experts as decision support tool(s) accommodating site specific nutrient management strategy, newer concept of fertigation like open field hydroponics and variable rate application as possible improvements in NUE collectively using logical relationship between canopy volume and nutrient requirement, further exploiting the nutrient-hormone and nutrient-microbe (in consortium mode) synergies have yielded definite edge over conventional methods of nutrient management options in fruit crops.

Inorganic fertilizers

Organic manures

Green manures

Biofertilizers

INM relies upon regulated nutrient supply for optimum crop growth and higher productivity, improvement and maintenance of soil fertility, zero adverse impact on agro-ecosystem quality by balanced fertilization of organic manures, inorganic fertilizers and bio-inoculant.

11.4.3 Organic Farming

Organic farming is an integrated system of horticultural production based on ecological principles, promotion of biodiversity, biological cycles and organic matter recycling to maintain and improve soil fertility and environmental sustainability. The regulations for organic crop cultivation prohibit the use of chemo-synthetic pesticides, mineral fertilizers, growth promoters and genetically modified organism. Indiscriminate use of these chemicals in conventional farming poses a serious threat to the quality of produce as well as the environment. Concern about food safety, security and environmental sustainability is increasing among scientists, administrators and environmentalists. There is a need to design resource efficient farming system for small and marginal farmers for improving their economy while meeting the quality food demand in a sustainable environment. Nutritional sources for plant are very important to achieve sustainability.

11.4.4 Organic Sources

These are the byproducts of agriculture and allied sectors. FYM, droppings, crop waste, residues, sewage, sludge, industrial waste are the sources of organic matter used for organic farming.

11.4.5 Biological Sources

Biofertilizers are otherwise called microbial inoculants, are the carrier-based preparation containing beneficial microorganisms designed to improve the soil fertility and helped in the growth of plant by their increased number and biological activity in the rhizosphere. There are two types of micro-organisms which are involved in biological nitrogen fixation and phosphate and other nutrients solubilizing:

Biofertilizer Types

S. no.	Groups	Examples
N_2 fixing biofertilizers		
1.	Free-living	*Azotobacter, Beijerinkia, Clostridium, Klebsiella, Anabaena, Nostoc*
2.	Symbiotic	*Rhizobium, Frankia, Anabaena azollae*
3.	Associative symbiotic	*Azospirillum*
P solubilizing biofertilizers		
1.	Bacteria	*Bacillus megaterium var. phosphaticum, Bacillus subtilis, Bacillus circulans, Pseudomonas striata*
2.	Fungi	*Penicillium* sp., *Aspergillus awamori*
P mobilizing biofertilizers		
1.	Arbuscular mycorrhiza	*Glomus* sp., *Gigaspora* sp., *Acaulospora* sp., *Scutellospora* sp. and *Sclerocystis* sp.
2.	Ectomycorrhiza	*Laccaria* sp., *Pisolithus* sp., *Boletus* sp., *Amanita* sp.
3.	Ericoid mycorrhizae	*Pezizella ericae*
4.	Orchid mycorrhiza	*Rhizoctonia solani*
Biofertilizers for micro-nutrients		
1.	Silicate and zinc solubilizers	*Bacillus* sp.
Plant growth promoting Rhizobacteria		
1.	Pseudomonas	*Pseudomonas fluorescens*

Source: Singh et al. (2017)

Biofertilizers are able to fix 20–200 kg N/ha/year, solubilize P in the range of 30–50 kg/ha/year and mobilizes P, Zn, Fe, Mo to varying extent. Biofertilizers are associated in production of plant growth promoting (root colonizing bacteria including the nitrogen fixing *Azospirillum* and phosphorus solubilizing *Pseudomonas* spp.) are known to produce growth hormones which often leads to increased root and shoot growth. They suppress growth of pathogenic microorganisms by productions of antibiotics and bacteriocins.

11.4.6 Bio-fertilizers and Fruit Crops

Fruit crop	Recommended bio-fertilizer	Application method
Mango (cv. Amrapali)	100%NPK + Azotobacter + vesicular-arbuscular mycorrhizae and 75% NPK + Azotobacter + vesicular-arbuscular mycorrhizae	Improves vegetative growth and productivity with quality fruits
Grapes	*Rhizobium and Azotobacter*	Improving nutritional status of vine, yield, physical and chemical properties
Guava cv. Sardar	Neem cake + Vermicompost + Azotobacter + phosphorus Solubilizers + Potash mobilizers + 100% N&P	Physico-chemical attributes of the fruits are improved and vegetative growth is also enhanced
Peach	*Arbuscular mycorrhiza*	Improves growth performance and nutrient acquisition.
Plum	*Mycorrhizal fungi*	Higher fruit yield

Source: Singh et al. (2017)

11.4.7 Orchard Management

Organic systems aim to recreate natural systems. Natural systems support several competing species, so that no single species has a consistent advantage. This is contrary to the objective of recent agricultural systems where the enterprise must maintain a permanent advantage. Several management tools are available to help organic farmers to achieve this.

11.4.8 Pest and Disease Management

Integrated pest and disease management is an approach to reduce economic damage caused by different pests and diseases. Integrated pest management is one of the key requirements for promoting sustainable horticulture and rural development. It aims at a judicious use of cultural, biological, chemical, host plant resistance/tolerance, physical-mechanical control and regulatory control methods. Application of chemical pesticides during flowering leads to destruction of natural enemies, pollinators and honey bees, human/cattle poisonings, biomagnifications and accumulation in non-target niches, deleterious effects on wildlife, development of resistance, secondary pest outbreak, pesticide residues, and soil and pollution. Indiscriminate use of pesticides has led to resurgence of sucking pests like leafhoppers, white flies and mites. Besides, a few pests like fruit borer, *Helicoverpa armigera* on tomato, diamondback moth, *Plutella xylostella* on cabbage and cauliflower, and pink mealy bug, *Meconellicoccus hirsutus* on grape are difficult to control even with repeated pesticide applications. Spraying the cover of horticultural crops may result in large-scale environmental pollution, mortality of bees, and other pollinators and birds besides animal and human health problems. High levels of pesticide residues have been detected in cabbage, cauliflower, tomato, capsicum, gherkins, leafy greens, okra, brinjal, grape, guava and spices like pepper and cardamom. Therefore, the use of biocontrol agents can provide sustainable protection from pests and diseases as well as enhancing the quality by way of pesticide residue-free produce. The practices involved in integrated pest and disease management are:

11.4.8.1 Cultural Control

The manipulation in cultural practices is one of the key components to reduce the impact of pest in the organic field which mainly includes

(a) Crops rotation with botanically unrelated crops is one of the important cultural practices, mainly followed in new plantation to manage the pest and disease problem. However, replanting in old orchard sites with the same crop should be avoided as it may carry the pest or disease (for example, *Armillaria* in stone fruit and citrus orchards, or burrowing nematodes, *Radopholus similis*, in bananas).
(b) Ploughing the soil of organic orchard for each and every year is another important cultural practice to disrupt the life-cycles of soil inhabiting pests, weeds and diseases. Ploughing at the appropriate time correct soil moisture and also minimize the environmental damage. However, it should not be practiced in steep slopes.
(c) Select cultivars having different maturity period, so that the peak period for a particular pest infestation will be different for different cultivar which may avoid the worst effects of pests at the crop’s most vulnerable period.
(d) Spacing of the crops may affect the relative growth rate of a plant and the behaviour of pests in searching for food or egg laying sites. Closer plantings may favour the spread of beneficial species within the orchard, but may also reduce air movement, increasing levels of disease incidence. Therefore, it is very important to vary the crop spacing to avoid the heavy infestation of pests and diseases.
(e) Thinning, topping and pruning of dead or diseased branches from fruit trees reduces disease incidence and maintains the vigour and productivity of the orchard significantly.
(f) Cleaning of entire orchard soil is one of the important cultural practices to destroy the pest breeding and hibernating sites by removing, destroying or composting old or fallen fruits. Cleaning of paddock borders may also reduce the pest migrations and weed infestations.

11.4.8.2 Biological Control

The biological control includes the use of natural enemies (parasites, predators and disease organisms) of pest species. These natural enemies may be introduced from external sources (mass reared and then released into the orchard). Naturally occurring predators in the orchard can be increased by conserving and encouraging existing populations. Maintaining a mixture of desirable plants in the orchard border and in ground covers will encourage predators. Some plants attract predators of certain pests like crops of *Umbelliferae* family, such as carrots and parsnips, attract parasitic wasps to control codling moth of apple. Therefore, these crops should be planted as a ground storey crop or intercrop in apples orchard to control codling moth infestation.

11.4.8.3 Mechanical Control

Mechanical control can also be used to manage the pest population under control. Corrugated cardboard bands tied around trunks of apple trees help to control the problem of codling moth. Bird netting or paper bags covering over the fruit escape the problem of flying foxes and birds.

11.4.8.4 Physical Environment

Modification of the physical environment by means of light or sticky trap is also a handy option to control pest and disease population from organic fruit orchard. Light traps and sticky traps decoy night flying insects. Further, bird scaring devices keep birds away from the orchard. Similarly, solar energy and black plastic can be used to control weeds (solarisation). Apart from these, planting of certain crops having pest inhibiting property such as canola (biofumigation) can be done to manage the pest population under control.

11.4.9 Hi-tech Horticulture and Precision Farming

Hi-tech horticulture and precision farming are two of many production practices that have been implemented in India. "Hi-tech horticulture is the deployment of modern technology which is capital intensive, less environment dependent, having capacity to improve the productivity and quality of produce. Hi-tech horticulture encompasses a variety of interventions such as micro irrigation, fertigation, protected/ greenhouse cultivation, soil and leaf nutrient based fertilizer management, mulching for *in situ* moisture conservation, micro propagation, biotechnology for germplasm, genetically modified crops, use of biofertilizers, vermiculture etc.". Precision farming is described as the mechanisms that involve the application of technologies and principles to much spatial and temporal variability associated with all aspects of horticultural production for improving crop performance and environment quality. Most of India's horticulture production hasn't done in controlled environments such as greenhouses as lot of it is done in the field. Growing structures such as greenhouses, cold frames and other controlled environments tend to be used in order to do production of crops outside the regular season. Some of the fruit crops exported by India are apples, bananas, mangoes, oranges, and apricots.

11.4.9.1 Protected Cultivation

Protected cultivation of fruits has developed very quickly and widely and now it has become an important branch in fruit cultivation. It enables some control of wind velocity, moisture, temperature, mineral nutrients, light intensity, and atmospheric composition and has contributed and will continue to contribute much to a better understanding of growth factor requirements and inputs for improving crop productivity. Activities like greenhouse construction, mulching and shade net is worth adoption. The green houses are mainly used for growing of fruit nurseries, hardening tissue culture plants, and high value crops. In the green house, both the temperature as well as humidity is kept under control by using mini/micro irrigation and fogging system as per the need of crops which are to be grown in the green house.

Its primary emphasis is on production of high-value horticultural crops. It provides control over wind velocities, moisture, temperature, mineral nutrients etc. It is expected that the area under protected cultivation may accentuate to about 84.2% for the period from 2013 to 17. Various kinds of fruits, such as strawberry, grape, peach, nectarine, flat peach, plum and citrus, have proved to be successful for protected cultivation in China. In China, strawberry cover the largest planted area, about 70% of the total production and then grape, peach and nectarine.

Among the greatest constraints in fruit crop production are lack of sunlight, fluctuation in temperature, lack or excess of moisture, weed growth, wind velocity and atmospheric carbon dioxide. These all constraints are related to the climatic factors directly or indirectly and have been reduced by protected cultivation. There is a need of protected cultivation for the quality enhancement, to increase the yield, off season cultivation, better insect and disease control, to use the resources efficiently. Protected cultivation has significant role in round the year plant multiplication, improving quality and yield, increases harvesting span, rootstock production, and enhancing vegetative and reproductive growth.

11.4.9.2 Mulching

To mitigate the hazardous effects of increased temperature on horticultural crops, a variety of practical and promising technologies have been developed and practiced in experimental farms as well as in commercial production. For instance, mulching the cultivation beds with reflective silver-color film is popularly used to improve skin colouring of apples, with increasing sunlight reflection from the bottom. Plastic mulching in combination with drip irrigation (which also supplies relevant nutrients) has become a common practice to attain high-quality and high-yield production in citrus orchards. In greenhouse cultivation of vegetables, various devices such as efficient ventilation, shading, fog cooling, heat pump, photo-selective film, etc., are developed and tested for practical use in minimizing interior temperature rise.

There is another interesting approach to overcoming climate change for horticultural crops, particularly for vegetables. With economic globalization, a variety of exotic and foreign vegetables and fruits are available in various Asian countries all-year round. In the last decade, summer temperature in East Asia has gone up to an abnormally high level, at which summer vegetables cultivated in temperate zone could not grow normally until harvest. A province in southern Japan has launched a new project to cope with this situation, and dispatched expert teams to tropical Asian countries such as Taiwan, Thailand and Vietnam to conduct a survey of promising tropical vegetables for parameters such as people's acceptability, appropriate cooking method, nutritional facts, successful cultural practices, etc. The expert teams brought back a sizable number of commercially available tropical vegetable seeds from these three countries. After intensive research on the economic and technical viability of their domestication, people's acceptance for alternative summer vegetables, stability of nutrition facts, appropriate cultural practices under local conditions, all the promising vegetable seeds were confirmed and distributed to various farmers' groups with the appropriate cultural practices. Consequently, the tropical vegetables proved to be a good alternative to summer vegetables in the temperate zones under the global warming condition.

In tropical Asia, farmers have been traditionally cultivating temperate vegetables, fruits, tea, etc., in highland areas such as Baguio, Philippines; Cameron Highland, Malaysia; Bandung, Indonesia, and so forth. Temperate horticultural crops are generally more superior in taste, quality and nutrition, have higher acceptance among consumers, and hence, command higher prices than the tropical counterparts. Urban dwellers are willing to pay more money for high-quality vegetables and fruits produced in the highlands.

11.5 Role of Biochar on Horticultural Crops

The use of biochar as a soil amendment or as ingredient for the production of novel potting soil has received increasing attention during the last decade because of the observed positive effects of biochar addition on soil quality and plant health. Mixtures of biochar and other common substrates, such as peat, have been successfully used for cultivation of plants. In some studies, biochar has been shown to have positive effects on plant health due to an increase in disease suppressiveness of the substrate (Elmer & Pignatello, 2011; Trifonova et al., 2009). However, biochar addition can also have adverse effects on plant growth due to high salt content, high pH and presence of phytotoxic compounds (Jaiswal et al., 2014). The use of biochar as a substitute part of the peat in potting soil depends on the properties of the biochar and the ratio in which biochar is mixed with other substrates. When used in horticulture, biochar should have a low salt content because of the adverse effects of salt on plant growth. The pH of biochar is too high to be used in horticulture without pH treatment. The pH can be lowered by mixing biochar with acid substrates such as peat. Other important criteria are the water holding capacity, the stability of the biochar, the nutrient content and the absence of phytotoxic compounds. The properties of biochar depend on the nature of the source material and the process conditions during pyrolysis. Thus, to use biochar as an ingredient of potting soil, the biochar production process should be optimized in order to produce biochar with favourable properties and the optimal mixing ratios between biochar and other ingredients should be formulated and tested.

The adoption of biochar for use in horticulture will depend upon the extent to which increases in crop yield can reliably be achieved. At this stage, there is little evidence as to the effect of biochar on the yield of horticultural crops or with respect to the changes in yield expected using different biochar types or for the range of key soil types and climatic conditions pertinent to horticultural production. Consequently, the financial benefits of biochar applications to horticultural producers are associated with high levels of uncertainty. It is possible that biochar may further be modified to improve its application to soil. Several scenarios can be envisaged, depending on needs and costs. One scenario has biochar combined with compost and added to soil. Several studies in Australia have been established to evaluate this combination (Blackwell et al., 2009). Biochar could be added to other moist soil amendments to reduce its dustiness, and could be added during the composting process, which could influence many chemical and biological processes and consequently the quality of the composts. Biochar could be pelletized to improve handling, although one trial with pellets by Gaskin et al. (2010) has shown a yield decline. The economics of pelletizing determines the acceptability of that product. There are currently thousands of tonnes of biochar being pelletized or granulated together with either NPK fertilizers or composts in China. It may be possible to slurry biochar with water or liquid manure if sub-surface injection is considered an appropriate method.

11.6 Carbon Sequestration

It is a process involved in carbon capture from atmosphere and its storage in reservoir. The reservoir of storage may be ocean, soil, vegetation and geologic formations. Oceans shares most of the earth's carbon, soil contains approximately 75% of the carbon pool on the land which is three times more than the amount stored in living plants and animals. Soil organic matter consisting of decomposed plant and animal tissues, microbes (protozoa, nematodes, fungi and bacteria) and carbon associated with soil minerals. Climatic condition, natural vegetation, soil texture and drainage will affect the amount and length of time of carbon storage. High level of fossil fuel combustion, and deforestation have transformed large pool of fossil carbon (coal and oil) into atmospheric carbon dioxide. The amount of CO_2 in atmosphere can be reduced by soil carbon sequestration, tree planting and ocean sequestration of carbon. Tree plantation store carbon in woody tissues and soil organic matter. The net rate of carbon uptake is greatest when plants are young and slows down with ageing of plants. If the forests are cut, the carbon they contain quickly returns to the atmosphere if the woody tissues are burnt. If the wood is used for furniture, then the carbon is detained for their life time.

Globally, as per an estimate, soil contains approximately 1500 gigatons of organic carbon to 1 m depth, more than the amount of vegetation and the atmosphere. Improved soil and water quality, decreased nutrient loss, reduced soil erosion, increased water conservation and greater crop production may result in increasing the amount of carbon stored in agriculture soil. Conservation tillage, cover cropping, crop rotation, multi-tier cropping etc. favours carbon sequestration in soil. In a study carried out by Bhatnagar et al. (2016), it appeared that a mandarin plant of 10–11 cm diameter stored 7.79 kg carbon across various plant parts.

In the present time, diversification, market orientation and commercialization, involving the introduction of new crops and varieties, increased share of horticulture in the cropping pattern, diversion into processing and export-oriented production of a large number of crops are the most important changes noticed in the recent past. Several technological innovations have been advanced in the complete value chain involving technology for orchard establishment, availability of true to type planting material, plant architecture engineering and management, mulching, fruit thinning, integrated nutrient management, water management, integrated pest and disease management, post-harvest technology, processing and marketing. The positive changes in horticulture sector have occurred because it has received the importance from all the stakeholders, public sector, private sector and farmers during the last decade. This is primarily the result of realization that diversification to horticultural crops is now the major option to improve livelihood security and health care. Keeping in view the dynamic needs of diverse stakeholders under the National Agriculture Research System, the R&D on horticulture has been undertaken in several multi-crop and multi-disciplinary institutes and the several technologies has emerged (Singh & Malhotra, 2011).

Sensors are introduced in horticulture using the latest techniques from medical and industrial research. A 3D volumetric intersection technique is used to sort tomato seedlings at a speed of 40,000 pieces per hour and measures the full 3D geometric features, which is clearly an impossible challenge when done manually. Other 3D techniques like stereo vision, time of flight and laser triangulation are introduced in greenhouse horticulture to control robots, measure the geometric quality features as flower diameter and bulb orientation or to separate target features from its agricultural surroundings (e.g., anthurium, chicory, lily bulbs). But also the interest to measure internal quality features as ripeness, food compounds, internal defects and the ability of photosynthesis capacity can be measured by spectral cameras, fluorescence techniques and X-ray. To apply integrated management on pests and diseases in the greenhouse, sensors are needed to determine pests and diseases and its magnitude automatically at an early stage (e.g., long horn beetle, botrytis, sticky plates). More future sensor applications are expected in this field (Pekkerieta et al., 2015).

11.7 Futuristic View for High-value Horticulture to Meet the Demand of 2050

- Biodiversity conservation of fruit crops is very much essential for development of newer varieties which must be having higher or wider range of adaptability against various biotic and abiotic stresses.
- It is the need of an hour to diversify crops which are of high-value in the hills, arid and coastal agri-ecosystems.
- Technological improvements accruing from Research and Development for fast-track developments like increasing production as well as productivity of fruit and vegetable crops.
- Concept of processing of fruits and vegetables is increasing at alarming rate so as to reduce Post Harvest Losses and more important to help farmers in realizing a better price. Corporate houses like Reliance Fresh, Adani Exports and ITC picked up the best quality apples for their own retail outlets. Similarly, in Andhra Pradesh, Coca-Cola, Reliance and others have been involved in procuring mangoes directly from growers for processing.
- Perennial horticultural crops have to face the impacts of climatic variability in standing plantations, but not essentially only negative impacts will be experienced.
- Use of insect-pest-tolerant crop varieties and soil-borne disease-resistant root-stocks needs to be encouraged.
- Developing cultivars tolerant to heat, drought and agronomic manipulations, including water management to match adverse climate change impacts should get research priority.

11.8 Conclusion

As awareness of sustainability issues increases, horticultural industries are becoming increasingly concerned with maintaining and protecting their resource base and the wider environment. The horticultural industries worldwide provide consumers with a variety of products, including fresh fruit and vegetables, wine, nuts, flowers and other ornamental and nursery products. There has been national and international concern for the sustainable development of horticulture depending on the region on priority basis. Quality is an important aspect of the horticulture industry, whether the horticulture crop is sold locally, regionally or internationally. Quality and productivity are intertwined and obtaining the most excellent quality of fruits and vegetables is the ultimate goal for crop producers of the Indian context. Studies on sustainable horticulture production continue across the region today, which in future seek to benefit the Indian farming community through the expansion of better horticulture crop production, and through improved technologies that will augment the global export of quality and more nutritious fruits and vegetables.

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Chapter 12
Nanotechnology for Sustainable Horticulture Development: Opportunities and Challenges

Ratna Rai, Pradyot Nalini, and Yesh Pal Singh

Abstract In the last decade, nanotechnology has emerged as a recent evolving sector in the field of science and technology. Nanoparticles due to their small size show exceptional physical, chemical, optical and magnetic properties. These unique properties of nanoparticles make them useful in horticulture for obtaining sustainability in production through their application in production of quality planting material, nano fertilizers for improving plant nutrition, nano sensors for monitoring plant health and quality of soil and water, nano pesticides for disease and pest management and improved packaging for enhancing shelf-life. Nanoparticles can be used for improving germination percentage of seeds and controlling contamination rate in *in vitro* propagation. They can also improve stress tolerance in plants against various biotic and abiotic stresses. Nanotechnology provides the possibilities of exploring nanoscale materials in the form of nano fertilizers or nano pesticides which can improve the nutrient use efficiency, enhance the efficacy and specificity of pesticides and at the same time minimize the risk of pollution to ecosystem. Smart packaging developed through the use of nanomaterials can reduce the occurrence of food-borne diseases and improve food safety by ensuring fresh and tasty purchase to the consumers. Nano biosensors can not only be used for monitoring soil and plant health but also can help in predicting the outbreak of pest or diseases, thus reducing the economic loss. Better understanding about the interaction of nanomaterials in the horticultural field, however, is required for eliminating the adverse effects of nanoparticles in the horticultural crops.

Keywords Nano fertilizer · Nano pesticide · Nano biosensor · Nano edible coating

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12.1 Introduction

Ecological balance, clean environment, mitigation of climate changes, food and nutrition security and good health are the key factors for human survival and social sustainability. The population by 2050 is predicted to be over 9 billion people, indicating many folds increase in the demand for food, water and energy supply in developing countries like India. Many international agencies like World Bank and Food and Agriculture Organization (FAO) are trying to provide solution to these complex and diverse problems through systematic and novel research in order to sustain the agriculture sector. Sustainability not only includes local environmental effects, but the effects on people, economy and the environment as a whole. The issues related to sustainability and awareness in horticultural sector is increasing day by day. The impacts of challenges can be minimized by maintaining an economically viable production system and preventing environmental degradation. Nanotechnology is a recent evolving sector which has the potential to take forward the horticulture with new tools which can enhance production of planting material, provide new and effective fertilizers, increase shelf life of produce and help in better post-harvest management, etc. in a sustainable manner. Therefore, in order to meet future demands, it is important to increase production rate of quality produce and yield, increase the efficiency of inputs and reduce wastage without adversely affecting the environment. Before nanotechnology applications integrated in an eco-friendly manner can be applied in horticulture, basic and deep knowledge of nanomaterials is required so that this technology can be efficiently utilized for sustainable horticulture in India. Nanotechnology is an interdisciplinary science which has huge applications in the fields of agriculture and biotechnology. Nanoparticles (NPs) are commonly accepted as materials where its properties differ significantly from its bulk counterparts. Earlier Ball (2002), gave the definition that, "Nanoparticles (NPs) are commonly accepted as materials with at least two dimensions ranging between 1-100 nm". But later, researchers from National Nanotechnology Initiative, USA, gave the definition that, "nanoparticles are particles that exist on a nanometre scale, i.e., below 100 nm in at least one dimension".

12.2 Properties of Nanoparticles (NPs)

Nanoparticles fall into the intermediate size range between atoms and molecules and bulk materials due to which they show exceptional physical, chemical, optical and magnetic properties. Nanoparticles exhibit large surface area to volume ratio and low melting point. They can also form suspensions due to strong interaction of the particle surface with the solvent which overcomes differences in density. NPs show diffusion property at higher temperatures and sintering takes place at lower temperature, which creates chances of agglomeration. Nanomaterials can form nanocomposites which can be used to improve the mechanical properties of existing materials. One of the interesting properties of metal nanoparticles is their optical sensitivity which is mainly due to an effect called localised surface plasmon resonance. Therefore, colloids of metal nanoparticles such as gold or silver can display distinguished colours such as red, purple or orange, depending on the shape and size which are not found in their bulk counterparts. Temperature and structure of a material determines its magnetic behaviour and the expected magnetic domains have a typical size of around 1 μm. When magnet size is reduced, the number of atoms on surface also become a fraction of the total number of atoms. As the size of the magnetic domain reaches nano range, they start showing new properties such as giant magnetoresistance effect (GMR) due to quantum confinement.

12.3 Classification of Nanoparticles

In general, nanoparticles can be classified on the basis of their:

- **Dimension:** one dimension (nano plates, nano films, etc.), two dimensions (nano fibres, nanowires, nanorods, nanotubes, etc.), three dimensions (nanoparticles, quantum dots, nanoshells, nanorings, microcapsules, etc.).
- **Morphology:** Shape (spherical, triangular, hexagonal, rod shaped, etc.); Size (10 nm, 20 nm, 35 nm, etc.),
- **Composition:** carbon and non-metallic nanoparticle, metal nanoparticle, semiconductor nanoparticle, etc.,
- **Uniformity:** uniform in shape, size, composition, etc.,
- **Agglomeration:** it is the property of nanoparticles by which nuclei of small particles fuse together to form a large nanoparticle when they are present in high concentration. It varies depending on the type and concentration of nanoparticles i.e., different metals have different agglomeration rate.

But broadly nanoparticles can be classified into two categories:

- **Organic nanoparticles:** these include carbon nanoparticles (dendrimers, liposomes, ferritin, micelles, etc.)
- **Inorganic nanoparticles:** these include nanoparticles of metals such as Ag, Au, Pd and Pt, nanoparticles with magnetic properties such as Fe_2O_3, Fe_3O_4, lanthanide oxide, etc. and nanoparticles like SiO_2, TiO_2, ZnO, quantum dots, etc. having semiconductor properties.

12.4 Synthesis of Nanoparticles

Nanoparticles can be produced by mainly three methods:

1. Physical method
2. Chemical method, and
3. Biological method (Green Synthesis)

Normally two types of approaches are used in synthesis of nanoparticles *viz.*, top-down process and bottom-up process. (i) In top-down approach, bulk materials are broken down into smaller particles of nano size with various lithographic techniques like grinding, milling, etc. (ii) In bottom-up approach, atoms assemble to form new nuclei of nanometre scale. The bottom-up process mostly uses chemical or biological methods of synthesis. Physical methods mainly used in the top-down approach, include mechanical ball milling, diffusion flame, chemical etching, thermal or laser ablation, ion sputtering, plasma arching, molecular beam epistaxis, lithography, etc. The chemical methods include precipitation, vapour deposition, atomic/molecular condensation, sol-gel process, spray pyrolysis, laser pyrolysis, aerosol pyrolysis, etc. The physical and the chemical methods although effective but are expensive, energy demanding and are not eco-friendly due to the use of various toxic chemicals like non-polar solvents, synthetic additives or capping agents. Consequently, the need for the development of a biocompatible, reliable, clean and eco-friendly process for synthesis of nanoparticles have turned researchers towards biological processes. Any plant parts such as stem, root, leaf, latex and seed, rich in active agents like polyphenols, alkaloids, flavonoids, tannins or other secondary metabolites can be used for synthesis of nanoparticles. Green synthesis of nanoparticles is a superior approach over other methods because of its simplicity, cost-effectiveness and synthesis of relatively reproducible and stable products.

12.5 Nanoparticles for Sustainable Horticulture

The explosive rise in the world population demands higher productivity of agricultural commodities to feed the growing population. Nanotechnology has the potential in improving food production, food quality, plant protection, detection of diseases, monitoring of plant growth by remote sensing and reduce waste for "sustainable amplification" (Prasad et al., 2014). Nanoparticles are playing a remarkable role in horticulture by their application in nano fertilizers, sensors for monitoring quality of soil, nano pesticides for disease and pest management, improved packaging for enhancing shelf-life and also in production of quality planting material.

12.6 Seed Germination

Plant propagation is the process of the multiplication of plants by both sexual and asexual means. Sexual reproduction method produces offspring by the fusion of gametes, resulting in a genetically different plant from the parents due to genetic exchange that occurs during fertilization between male and female parent. Seeds are typically produced from sexual reproduction in plants. Asexual reproduction produces new individuals without the fusion of gametes and therefore the offspring are genetically identical within themselves and to the parent plant. Horticultural crops especially the cross-pollinated ones are mostly reproduced by asexual methods of plant propagation to produce identical clones but certain fruits and most of the vegetables and ornamentals can only be multiplied through seeds.

Farmers face many problems while propagating plants through seeds, as seeds of many crops exhibit different types of germination hindrances like dormancy. Dormancy may be physical, physiological, morphological or combination of more than one depending on external or internal factors. These seeds require special conditions and treatments to improve germination percentage and break their dormancy. The treatments such as stratification, scarification, high temperature, growth regulators, etc. are normally applied to enhance the germination rate. Even after breaking dormancy, sometimes plants show very less germination percentage. The chemical compounds present in seed kernels, structure of seed-coat, presence of inhibitors like abscisic acid or phenolic content in testa and the capacity of the embryo to form gibberellins, promote dormancy and adversely affect the percent germination (Hartmann et al., 1997). To overcome these problems, among the different methods applied, soaking seeds in NPs solution can definitely prove as a great option for enhancing seed germination.

Nanoparticles (NPs) of different metal oxides have antimicrobial properties and can affect seed germination percentage, photosynthetic rate, chlorophyll biosynthesis, growth rate, dry weight and plant metabolism by increasing absorption of oxygen, water and nutrients (Rezaei et al., 2015). Nanoparticles due to their small size, fall in the transitional zone between bulk materials and individual atoms or molecules. They, therefore, can effectively modify the physicochemical properties of the material including conductivity, optical sensitivity and reactivity and can also generate different biological effects in living cells (Nel et al., 2006). As compared to plant cell walls and membranes, the presence of thick seed coat makes it quite difficult for nanoparticles to penetrate into the seeds. However, carbon nanotubes can effectively enter inside the seed coat and influence the seed germination and plant growth (Srinivasan & Saraswathi, 2010). Soaking seeds with TiO_2-NPs at appropriate concentration has been found to increase the germination percentage of *Prunus mahaleb*, by loosening the cell wall which apparently helped in splitting the endocarp and thereby physical barrier to germination was removed (Goodarzi et al., 2017). TiO_2-NPs enhance the seed germination especially at lower concentrations as they encourage the penetration of capsule in the seed coat which facilitates better intake of oxygen, water and nutrients required for embryo activation and germination (Khot et al., 2012). At higher concentrations, however, TiO_2-NPs accumulate in plant organs and inhibit growth due to their low solubility. The shape and size of NPs, their chemical compounds, concentration and uptake mechanism of plant species do affect the germination percentage and seedling growth (Ruffini & Cremonini, 2009). Shah and Belozerova (2009) inoculated different combination of Si, Pd, Au and Cu nanoparticles in soil and reported that the nanoparticles significantly enhanced the germination of lettuce seeds when planted 15 days after soil incubation. Similarly, increase in germination of onion seeds at lower concentrations of ZnO NPs have also been reported by Raskar and Laware (2014) while, Almutairi and Alharbi (2015) observed improved gemination percentage in the watermelon and zucchini seeds with the use of Ag nanoparticles.

Generally, NPs trigger the antioxidant system in plants by increasing the synthesis and activity of enzymes such as ascorbate peroxidase, catalase, guaiacol peroxidase, nitrate reductase and superoxide dismutase which help in reducing H_2O_2 and superoxide radicals, eventually improving germination percentage in certain plants (Lei et al., 2008). NPs enhance scavenging of reactive oxygen species, thereby reduce oxidative damage and inhibit lipid peroxidation (Harrison, 1996). Breakdown of organic substances is accelerated along with synthesis of essential amino acids causing significant structural changes in the seed pericarp which results in breaking seed dormancy. Another possible reason for increase in germination percentage might be due to the fact that NPs create new pores on the seed coat during the process of penetration which helps in influx of nutrients and metabolite inside the seed required for rapid growth.

12.7 Micropropagation

The success of commercial *in vitro* propagation depends on many factors like donor plant, age and type of explant, culture medium and growth regulators etc. One of the major problems associated with micropropagation is encountering *in vitro* fungal and bacterial contamination which causes severe losses to micro propagated plants at different stages of growth. The endophytic bacteria remain inside the plant tissue and are mostly difficult to detected. Plants contaminated with bacteria initially do not show any symptoms and usually slow multiplication and rooting rates are observed eventually leading to death of the plant. The efficiency of sterilization methods through the available chemicals to control these *in vitro* contaminations is either very low or they are highly toxic. Mercury chloride ($HgCl_2$) is the most commonly used sterilant for controlling microbial contamination in explants but is highly toxic and has adverse effects on the environment. Similarly, incorporation of one or more antibiotics into the culture medium could overcome some of the contamination problems, but it is not always true for all microbes and they are also frequently phytotoxic retarding the plant tissue growth. Under these circumstances, finding an effective and safe substance for decontamination of the explants is very important.

Nanoparticles exhibit unique properties, among which broad spectrum antimicrobial activity against plant pathogens is widely known. The metal-based materials such as nanogold, nano silver, nano zinc and nanoscale metal oxides like ZnO, TiO_2 and SiO_2 are the commonly used nanoparticles. Several concepts have been put forward for antimicrobial activity of various nanoparticles but the exact mechanism is still unknown and is debatable. Various mechanisms existing in literature are: (i) nanoparticles are able to bind to the bacterial cell wall and penetrate it bringing structural changes in the cell membrane affecting its permeability leading to cell death, (ii) studies of electron spin resonance spectroscopy suggests that free radicals are formed by nanoparticles when they come in contact with the bacteria, damaging the bacterial cell membrane by making it porous ultimately leading to death, (iii) the nanoparticles interact with the sulphur and phosphorus present in DNA strands causing problems in DNA replication of the bacteria leading to their termination (iv) nanoparticles when interact with the bacterial cell, inhibit respiratory enzymes, leading to formation of reactive oxygen species (ROS) and finally cell apoptosis. (v) nanoparticles can affect the signal transduction in bacteria. The nanoparticles dephosphorylate the peptide substrates on tyrosine residues leading to signal transduction inhibition and thus the stopping the bacterial growth (Mittal et al., 2014). Helaly et al. (2014) applied nano Zn and nano ZnO in culture medium of banana cultures and obtained contamination-free *in vitro* cultures with no negative effect on regeneration capacity. Safavi (2014) studied the antimicrobial effect of TiO_2 nanoparticles on potato tissue culture media and confirmed that TiO_2 NPs are quite effective in reducing microbial contamination.

12.8 Growth and Development of Plants

NPs may affect the growth and development of plants either positively or negatively at all stages of life cycle depending on their type and concentration. NPs show positive effect on growth by regulating the channel proteins which control water permeability, gene activation and cell cycle (Khodakovskaya et al., 2012). Studies done by Prasad et al. (2012) suggested that nano zinc oxide (ZnO) enhanced the vigor of the seedlings favoring earlier establishment in soil, high chlorophyll content and early flowering. The NPs due to their small size can be easily absorbed by the roots through apo plastic or symplastic pathways from endodermis till xylem and then they are transported through the vascular bundles to the different parts of the plant consequently resulting in better growth. Similar type of transport is seen in NPs of mesoporous silica, and ZnO, which are transported inside the cells through endocytosis (Morales-Díaz et al., 2017). Avestan et al. (2015) investigated the effects of *in vitro* application of nano SiO_2 on growth and proliferation of apple rootstock MM106 and reported that nano silicon significantly increased fresh and dry weights, length and number of branches, and chlorophyll content in microplants. Thus, they concluded that, silicon oxide can be added to Murashige and Skoog medium for fast growth and proliferation of explants.

12.9 Abiotic Stress Tolerance

Nanomaterials (NMs) also play a major role in plant tolerance against various abiotic stresses by acting as a stimulus for activation of antioxidant enzymes, and signaling molecules for osmolytes and free amino acid accumulation (Khan et al., 2017). NMs treated plants showed increased chlorophyll content, photosynthetic rate, stomatal conductance, proline content, enhanced water use efficiency and carbonic anhydrase activity (Haghighi & Pessarakli, 2013; Siddiqui et al., 2014). Increasing levels of TiO_2 and ZnO nanoparticles in plants, increased the level of proline in the cells. These are strongly hydrophilic amino acids acting as osmolytes which reduce the water potential of the cell during dehydration and stabilize the macromolecules and sub-cellular structures along with protecting them from damage and thereby improving the plant's tolerance to environmental stresses (Rathinasabapathi, 2000). NPs attach to the plant tissue and interfere in water translocation and xylem humidity resulting in improved water use efficiency (Sahebi et al., 2015). Research findings on differential regulation of the expression of salt stress genes by nano-Si has confirmed the salt alleviating effect of NMs. Plants commonly respond to all types of stress by generating ROS. These ROS act as signal to activate plant's defense system against various stresses. NPs act as a stress stimulus by inducing generation of ROS on one hand and scavenging ROS on the other hand like antioxidative enzymes (Khan et al., 2017). Although exact mechanism is unknown but several researchers have proposed possible mode of actions of NMs under abiotic stress conditions in plants. Studies performed by Khan et al. (2014) and Tuteja and Mahajan (2007) showed that a signaling network triggers the molecular machinery which activates the defense system against a particular stress. Calcium (Ca^{2+}) plays a major role in signaling responses by acting as a secondary messenger. Mozafari et al. (2017) studied the effects of iron nanoparticles and salicylic acid (SA) on strawberry (*Fragaria* × *ananassa* Duch.) plants grown under drought stress conditions and revealed that the application of iron nanoparticles increased root length and relative water content of the strawberry plantlets by enhancing the levels of carbohydrates, proline and protein in the plantlets. Thus, they concluded that the iron nanoparticles helped the strawberry plants to cope better under stressful conditions.

12.10 Plant Nutrition

Fertilizers have a pivotal role in enhancing the food production. Most of the conventional fertilizers used in horticulture have very poor nutrient use efficiency. In reality, very less concentration (below optimum) from the applied fertilizer dose reaches the targeted site due to various limiting factors such as evaporation, drift, runoff, leaching, hydrolysis by soil moisture, photolytic and microbial degradation, etc. To overcome these losses, large-scale application of chemical fertilizers is done in developing countries, which not only causes economic loss but also leads to environmental pollution by affecting the soil nutrient balance and lifecycle of natural flora and fauna (Solanki et al., 2015). Loss of fertilizers to the environment has severe consequences such as eutrophication (Kah et al., 2018). Hence, it is high time for optimizing the use of chemical fertilizers so that they fulfill the nutrient requirements of crops but with minimum risk of polluting the environment.

Nanotechnology provides the possibilities of exploring nanoscale materials as nutrient carrier or release control vectors (smart fertilizers) which can improve the nutrient use efficiency and minimize the risk of environmental contamination

(Chinnamuthu & Boopati, 2009). A nano-fertilizer can be defined as a substance in nanometre scale that supplies nutrients to the crops. Nano fertilizers can be classified into two different categories depending on the role of the nanomaterials: (1) nanomaterials made of micronutrients and macronutrients, (2) nanomaterials acting as nutrient carriers in the form of additives. The second category is also sometimes termed as nutrient-loaded nano fertilizers or nanomaterial-enhanced fertilizers (Liu & Lal, 2015). Nano-fertilizers have properties like site targeted delivery, controlled release of agrochemicals, enhanced nutrient efficiency and reduced toxicity of delivered fertilizers (Fig. 12.1) due to their higher mobility and solubility, large surface area to volume ratio and low toxicity (Cui et al., 2010; Sasson et al., 2007). When nanomaterials are used as surface coatings, it increases the surface tension which holds the fertilizer particle strongly and helps in controlled release (Brady & Weil, 1999).

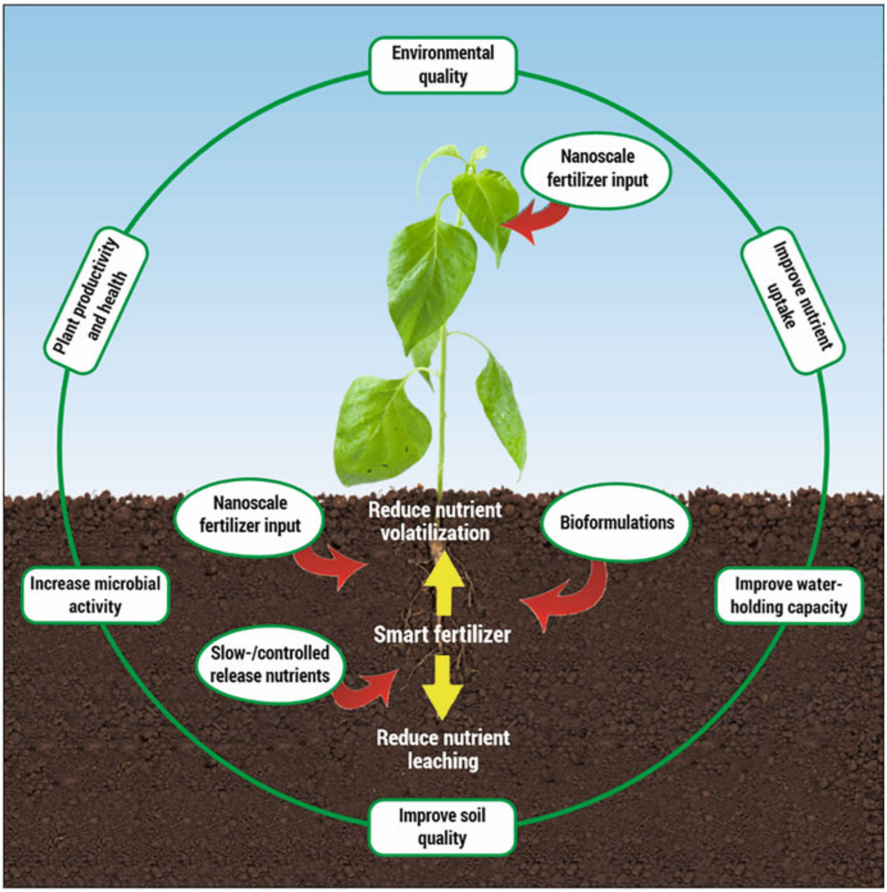

Fig. 12.1 Schematic diagram of potential smart fertilizer effects in the soil-plant system (Source : Calabi-Floody et al., 2017)

The nanoparticles are loaded with nutrients by (i) absorption (ii) attachment mediated by ligands, (iii) encapsulation, (iv) entrapment and (v) synthesis of nano size nutrients itself (Solanki et al., 2015). Kottegoda et al. (2011) synthesized urea nanoparticles modified with hydroxyapatite (HA) for slow release of nitrogen throughout the growth period of crop and reported that nanoparticles released nitrogen slowly up to 60 days of crop growth period as compared to only 30 days release in case of commercial fertilizer. The large surface area of HA might have facilitated the attachment of large amount of urea on its surface and also due to strong interaction between HA nanoparticles and urea. Similarly, polymer-based mesoporous silica nanoparticles (150 nm size) entrapped 15.5% urea inside the nanosized pores which gave a fivefold improvement in release period of urea in soil (Wanyika et al., 2012). Milani et al. (2012) also reported that monoammonium phosphate granules coated with ZnO nanoparticles showed faster dissolution rate than bulk ZnO particles.

The uptake, translocation, and accumulation of nanoparticles in plants depend on the species and age of the plant, growth environment, physicochemical property and the mode of delivery of nanoparticles. Rico et al. (2011) gave a schematic representation for the possible ways of uptake of nanoparticles by plants cell. The entry of nanoparticles is regulated by the diameter of the pores in the cell wall (5–20 nm), thus, nanoparticles smaller than the pore diameter of plant cell wall can easily enter. Nanoparticles facilitate the enlargement of pore size or induce new cell wall pores for enhanced uptake of nutrients. Nanoparticles are also reported to enter plant cell by binding with carrier proteins, aquaporin or ion channels or other membrane transporters or by forming complexes with exudates from roots, through endocytosis or through stomata or base of leaf trichome (Nair et al., 2010; Kurepa et al., 2010). Once nanoparticles have entered the cell, they can be transported either apo-plastically or sym-plastically (Rico et al., 2011).

12.11 Plant Protection

Agrochemicals such as fungicides, insecticides, herbicides, rodenticides, etc. are widely used for their wide availability, convenience in application and availability at relatively cheaper rates as compared to other methods of control. However, excess use of these pesticides can adversely affect the useful species like insect pollinators and natural enemies disturbing the ecological balance. Certain persistent lipophilic pesticides pose serious risk to human health as their formulation and active ingredients (AIs) are not stable and break down to enter the food chain. Their further retention in organisms increase at each food chain level leading to bioaccumulation. Moreover, large proportion of pesticides do not reach the target, as they get washed off by rain or are blown away by wind contaminating the soil and groundwater and also decreasing their efficiency. Frequent pesticide applications may also cause development of resistance in pests (Balaure et al., 2017). So, to mitigate these drawbacks associated with the conventional pesticide formulations, nanotechnology can be of immense help.

Nano pesticides exhibit extraordinary properties as compared to conventional ones due to their small size and large surface area to volume ratio. Nano formulation can enhance the solubility and dispersion of lipophilic pesticides in water. The rate of pesticide release can be controlled by nanoencapsulation and also effective pesticide concentration can be maintained for a longer period. Pesticides can also be protected from premature degradation through nanoencapsulation (Carvalho, 2006; Storm et al., 2001). Nano delivery systems help in site-specific delivery of pesticides which can highly enhance their efficacy and at the same time reduce the potential risk of pollution to nontargeted terrestrial and aquatic ecosystem (Chen et al., 2015). This smart delivery system not only allows more controlled use of pesticides, but also decrease the costs associated with synthesis of pesticide along with their waste management and simultaneously reduction in the chances of development of resistance. Nano pesticide formulations can be classified into various categories:

12.11.1 On the Basis of Their Use: (Kah et al., 2013)

- for increasing the solubility of pesticides in water
- for reducing the rate of release of the encapsulated pesticide
- for achieving site-specific delivery and
- for preventing early degradation

12.11.2 On the Type of Nanocarrier

- clay based nanomaterials,
- layered double hydroxides (LDH),
- lipid-based formulations,
- nanosized metals and metal oxides,
- organic polymer-based formulations,
- silica nanoparticles, etc.

12.11.3 On Their Structure and Morphology

- nanocapsules
- nanofibers
- nanospheres

– nanogels
– micelles
– nanoliposomes
– solid lipid nanoparticles (SLNs), etc.

12.12 Common Nano Pesticides Used in Horticulture

Nano capsules are vesicular structures comprising of a polymer coating or membrane surrounding an inner central cavity confining the AI (either hydrophilic or hydrophobic). Pereira et al. (2014) synthesized poly-ε-caprolactone (PCL) nano capsules containing atrazine herbicide and after testing reported that nanoencapsulation did not change the herbicide mode of action and was active only against the target organism. The nano encapsulated herbicide showed an increase in bioavailability and was proved to be more effective against the target organism as compared to the non-encapsulated herbicide. This was mainly due to the surfactants used for encapsulation of atrazine in PCL nano capsules which reduced binding of herbicide to soil colloids thereby contributing to their increased availability and reduced genotoxicity and soil pollution. *Micelles* are amphiphilic block copolymers that assemble in water to form colloidal particle with a hydrophobic micellar core surrounded by a hydrophilic shell or corona. *Nanogels* are water-swollen nanosized hydrophilic or amphiphilic polymeric chains cross-linked with each other that can swell but cannot dissolve in water (Kabano & Vinogradov, 2009). Bhagat et al. (2013) used a nanogel formulation of pheromone methyl eugenol (ME) as a bait trap to control the population of *Bactrocera dorsalis*, a harmful fruit fly.

Solid lipid nanoparticles (SLNs) are synthesized by dispersing fat particles in an aqueous phase and the dispersion is stabilized by surfactants. They have high melting point with spherical morphology. Lai et al. (2006) developed a new eco-friendly pesticide by incorporating essential oil of *Artemisia arborescens* L. into SLNs. *A. arborescens* L. essential oil exhibits pesticidal activity against *Aphis gossypii* (a pest of Cucurbitaceae, Rutaceae and malvaceae family), *Bemisia tabaci* (sweet potato whitefly), and *Lymantria dispar* L. (pest of *Quercus suber*). They reported that SLN formulations integrated with *A. arborescens* L essential oil was not only highly stable, but also prevented rapid evaporation of the AI of essential oil and controlled its slow release. Sustainable release of pesticides not only enhance the efficacy but also at the same time reduce the dose required to get the optimum effect. Prado et al. (2011) used *nanosized silica* to develop an improved carrier for all types of herbicide. They first experimented on picloram herbicide and after getting promising results, they predicted the potential use for different other herbicides. Suitable functional groups were introduced that can act as site for binding of pesticides while maintaining the efficiency of weed control. Cinnamic acid is a naturally occurring organic acid with antibacterial and antifungal activities. Park et al. (2010) synthesized an LDH-cinnamate complex and studied its antimicrobial property against *Phytophthora capsici*, a plant pathogen that causes blight and fruit rot in peppers and other commercial crops. They found that 6 days after inoculation with the pathogen, the red peppers in the free cinnamic acid soil got infected with root rot and wilted, while the red peppers in the soils treated with LDH-cinnamate complexes remained unaffected. Thus, they reported that incorporation of cinnamate inside the Mg/Al layered double hydroxide protected the AI against degradation and also rendered slow-release properties within the complexes. Anjali et al. (2012) synthesized neem-oil based nano pesticides as O/W *nano emulsions*. They used Tween 20 as hydrophilic surfactant and obtained nano emulsions with a droplet size of 31.03 nm at an oil: surfactant ratio of 1:3 and reported a decrease in LC_{50} value with decrease in droplet size. Thus, Nano pesticides prepared from natural ingredients are biodegradable and environmentally friendly and as well as are economical as they come from a renewable source.

12.13 Post-harvest Management and Shelf Life

In developing countries like India, about 40% of the losses occur during postharvest management which are mainly due to the deterioration caused by pathogens during storage and transport (Gustavsson et al., 2011). Fruits have low pH with higher moisture content and nutrient composition which makes them highly susceptible to fungal attack, while vegetables being less acidic, their spoilage is mainly caused by bacteria (James & Kuipers, 2003). Losses also occur due to improper storage and transport conditions, poor quality packaging and rough handling of the produce during harvesting. These are the main reasons for crops losses leading to low income of the producers. Increased demand for fresh horticultural produce of better quality and awareness regarding proper nutrition has motivated the food industry to use new emerging technologies for maintaining the quality and enhancing the shelf life of produce.

Nano packaging is currently one of the most emerging topic of discussion in food packaging industry. The greater surface area per mass of NPs compared to their bulk counterparts of same chemical composition enhance nano systems stability and biological activity and its use as edible coatings. The nano systems serve to incorporate antioxidants which can effectively reduce deterioration rates. A variety of nano-laminate systems are developed including nano emulsions, nano-films and nano-capsules depending on the template used i.e., planar and colloidal. The properties of nano-laminate coatings including mechanical properties, swelling and wetting characteristics and gas permeability are affected by the sequence and total number of layers, type of materials used for adsorption and also by the conditions used for synthesis like temperature, pH and ionic strength. This allows for regulation of the final properties of the coating material in order to obtain the required functionality (Flores-Lopez et al., 2015). Nano emulsions (50–500 nm) are colloidal dispersions formed by a combination of two immiscible phases and stabilized by a surfactant which makes them kinetically stable. Nano emulsions help in integration of compounds having antimicrobial and antioxidant effects into a hydrophilic polymeric matrix. Reducing the size of the oil drop gives an advantage by increasing solubility of the bioactive lipids which enhances its activity and acceptability. The lipophilic materials that can be incorporated into nano emulsions include various plant essential oils, fatty acids and secondary metabolites found in plants such as carotenoids, flavonoids, sterols, etc. (Salvia-Trujillo et al., 2017).

Polymeric nanoparticles measuring100–1000 nm in size are colloidal structures which can be divided into two types based on morphology and architecture i.e. nanospheres and nano capsules. The former is made up of dense polymeric matrix, while an oil core surrounded by a polymeric membrane form nano capsule. Common examples of polymeric nanoparticles for food applications that are biodegradable in nature are alginate, cellulose acetate phthalate (CAP), chitosan, ethyl cellulose, poly-ε-caprolactone (PCL), polylactic acid (PLA), and poly-D. L-lactide-coglycolide (PLGA) (Joyner & Kumar, 2015). Encapsulation of antimicrobial compounds using nanotechnology can solve the problems of microbial degradation and improve the quality of products. Liposomes can be used in food applications for delivery of nutrients and to increase the efficiency of antimicrobial compounds (Lasic, 1993). Liposomes can encapsulate nutrients, enzymes, proteins and flavours and control their release in the micro-environment to delay the microbial spoilage and as well as maintain the quality of food (Makwana et al., 2015). Polyphenols can be successfully incorporated into nano capsules and can be used in edible coatings for their antioxidant activity. For example, curcumin compound found in turmeric rhizome. Alginates (derivatives of alginic acid) when applied as coating materials can improve the quality of produce by reducing the size shrinkage, moisture loss, oil absorption, oxidative rancidity, sealing volatile compounds and improve sensory properties of products as they have water retention, film formation, viscosifying, gelation and stabilizing properties. In addition, alginate coatings act as barrier to oxygen and eventually control lipid peroxidation in fruits and vegetables (Dhital et al., 2017). Chitosan-based edible coatings such as alginate–chitosan nano capsules of turmeric oil and lemongrass oil are not only effective but also cheaper as compared to PLA or PCL (Natrajan et al., 2015). Carbon nanotubes have high tensile strength and elasticity, which makes them suitable for use in the development of containers. The 8 nm cavities in the nanotubes help in encapsulation of different active materials in foods. Nanofibers of diameters less than 100 nm, are known as fibrous scaffolds which can be used to encapsulate various active ingredients, modify film properties and immobilize enzymes.

12.14 Precision Horticulture

Nano biosensors of twenty-first century is the result of an integrated approach of nanoscience, electronics, computers and biology. Nano biosensors are Nano sensors consisting of immobilized bioreceptor probes which are sensitive for target analytes. These sensors can be used in integration with other technologies to facilitate molecular analysis, for e.g., lab-on-a-chip (Rai et al., 2012). Nano biosensors have large advantages over traditional biosensors such as enhanced speed, selectivity and sensitivity or specificity in detection of various microbes, contaminants, pollutants and analytes like glucose, protein, DNA, insecticides, herbicides, heavy metals, residues, etc., and has great potential for its use in different fields such as, agriculture and food quality control, environment safety, bio-defence and medical applications (Joyner & Kumar, 2015). The Nano sensors and nano biosensors can be used in agriculture to determine the presence and level of toxins in soil and water whose accumulation cause a reduction in the agricultural productivity.

Nano sensors can be used for sustainability in horticulture by diagnosing soil diseases caused by various soil viruses, bacteria, and fungi via the quantitative measurement of differential oxygen consumed in the respiration of different microbes in the soil. Nano biosensors can also help to predict the break out of any soil disease in the tested soil beforehand (Rai et al., 2012). Crystalline aluminium silicates (zeolites) are naturally occurring compounds that can hold nutrients in the root zone of plants for more efficient use of fertilisers (N & K) by either using less fertiliser for the same yield or using the same amount of fertiliser for longer periods and obtaining higher yields. Zeolites linked nano biosensors can be used to sense the deficiency of water or nutrients in either plant or soil and their release from zeolite can be controlled. In the same way, different types of nano biosensors can be used for timely release of inputs of fertilizers, insecticides and herbicides for enhanced production and reduced environmental hazards, for e.g., liposome-based biosensors for monitoring organophosphorus pesticides. Several nano biosensors are also designed to identify plant stress due to temperature, water, heavy metals, etc., which can be helpful for the farmers.

The part of horticultural production where the need for the Nano sensors is the most visible is packaging and transport. If the optimum conditions are violated for any period of time during storage or transport then the quality of food get deteriorated and the consumers remain unaware unless the package is opened or food is consumed (Joyner & Kumar, 2015). Nano sensors can revolutionize food packaging by their ability to detect the aromas, chemical contaminants, presence of gasses, pathogens and changes in microclimate. Smart packaging reduces the occurrence of food-borne diseases and improve food safety by ensuring fresh and tasty purchase to the consumers. The Nano sensors integrated into packaging can sense the storage and transport conditions such as oxygen content, temperature, pressure, humidity, pH, microbes, toxins and freshness of products by determining the fermented by-product in the packaged food. OxyDot® is a commercialized nano sensor which is used to estimate the dissolved oxygen in packaged food and drink products. Similarly, SMART DOTS designed using a low-cost pigment system, show quick response to the change in CO_2 level and temperature. RipeSense® labels is an intelligent ripeness indicator which can detect the different volatile compounds released during ripening of fruits and vegetables by changing the colour of the label from red to orange and finally to yellow. Time-temperature indication sensors are used during processing and storage of temperature sensitive foods which senses the temperature breach in reference to calibrated temperature point and changes colour depending on temperature, e.g., Fresh Check manufactured by TEMPTIMES. Toxin Guard developed by Toxin Alert, Canada, is an antibody-based biosensing approach which detects pathogenic bacteria such as *Campylobacter* sp., *E. coli*, *Salmonella* sp., and *Listeria* sp. Pathogen-specific antibodies are placed in the plastic wrap used for the food packaging and interaction of the antibodies with the contaminants gives a coloured indication of the presence of toxins or pathogens in that area (Srivastava et al., 2017).

12.15 Risk Associated with Use of Nanomaterials (NMs)

On the contrary, the properties of nanoparticles which enable them to increase plant growth and productivity and protect against various biotic and abiotic stresses, sometimes might prove deleterious to plants. Toxic effects of NMs on plants varies with the size, concentration and type of NMs, along with the mode of application. The damaging effects of NPs are associated with the obstruction of physiological, biochemical and molecular machinery of plants. Increasing concentration of NPs causes deterioration of PSII reaction center, alteration of the oxygen evolving complex and inhibition of electron transport chain (Barhoumi et al., 2015), lower number of thylakoids, reduced transpiration rate, stomatal conductance, CO_2 absorption, photosynthetic pigments and net photosynthetic rate (Da Costa & Sharma, 2016). Phytotoxic effects of NPs are also carried out by their direct binding with DNA that has been shown to cause deformation and nicking of the strand that adversely affects stability and function of the molecule (Zhao et al., 2005).

12.16 Conclusion

As a new technology, nanomaterials have gained interest because of their wide applications and potential benefits in terms of better germination, nutrients and pesticides delivery, enhancement in post-harvest shelf life and as effective sensors for labelling the products. The unique properties of these materials make them a suitable choice to be used as a major tool in sustainable horticulture. The use of biomaterials as nanoparticles can play an important role in alleviating their toxic impacts on crops and environment. Therefore, proper understanding of interactions between nanomaterials and the biological systems is required for overcoming the ecological hazards and achieving sustainability.

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Chapter 13
Sustainable Resource Utilization in Aquaculture: Issues and Practices

S. K. Das

Abstract Aquaculture is the farming of commercially important aquatic animals and plants with management protocols governed by human intervention so as to supply quality protein and materials of commercial importance towards human welfare. However, in holistic sense, besides farming, it is also inherent with conservation of the aquatic flora and fauna in the process of rearing and sustainability issues of the farming process itself and the environment as well. In comparison to other production sectors those use natural resources; efficacy of animal protein production has been proven higher in aquaculture. Moreover, aquaculture has also proved advantageous over conventional agriculture because of the multi-dimensional characteristics of the water body being the culture environment. Because of the depth dimension, productivity in aquaculture is high per unit area. Sustainable resource use in aquaculture implies judicious rationality in application and use so as to attain break-even point if not positive effect both on renewable and non-renewable resources so as to maintain congenial environment, contribute to the development of the stakeholders, and results in economic profit. However, the principal objective to produce and supply in parallel with the society's demand of aquaculture produce without impacting natural capital has become more challenging especially in the backdrop of global warming and climate change issues which is gaining more and more importance. Integration of environmentally sound farming practices coupled with effective indigenous traditional practices and above all with moral and ethical obligations of all the stakeholders towards nature.

Keywords Aquaculture · Sustainability · Issues · Climate change

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13.1 Introduction

Products of aqua-farming have long been recognized as essential foodstuffs but aquaculture in India inherits a long genesis referred long back in Kautilya's Arthashastra (321–300 B.C.) and King Someswara's Manasoltara (1127 A.D.). Despite Asia's long history of development, aquaculture became an important commercial food production system and a significant source of export earning only in the late 1960s (Chua, 1986, 1994). As stated in FAO (2006), aquaculture is the farming of aquatic organisms with substantial managerial intervention to enhance production. Farming of aquatic organisms of economic importance includes finfish and shell fish viz. molluscs, crustaceans, and, aquatic plants where regular stocking, feeding, protection from predators, disease management are done. In a broader perspective, breeding, seed production and rearing of seeds to their stock able sizes also come under the purview of aqua-farming practices.

In comparison to other production sectors those use natural resources; aquaculture has been established itself in advantageous position over animal protein production systems. Moreover, aquaculture has also been proved to be more effective compared to conventional agriculture because of the 3-dimensional advantage of the aquatic culture medium. Because of the depth dimension, productivity in aquaculture is high per unit area. Boyd and McNevin (2015) reported that because of human consumption of natural resources at a ratio of 1.5:1, regenerative capacity of the Earth is being negated. In spite of higher efficiency, as aquaculture will continue with substantial use of natural resources, it is to be ensured that efficient and judicious use of resources be followed so that the resources are allowed to be renewed at a sustaining rate besides reducing costs and augmenting economic viability of the farming process.

13.2 Indian Aquaculture

Indian aquaculture exhibited a six and half fold growth during the last two decades, where freshwater aquaculture contributed over 95% of the total aquaculture production. Three prized Indian major carps; catla (*Labeo catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*) contributed over 1.8 million tonnes (FAO, 2003) which is nearly 87% of the total aquaculture production in India. Following introduction during the 1970s, three exotic carps viz. silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*) emerged as the second most important group, altogether contributing 0.169 million tonnes. The average national productivity from inland static water bodies increased from 0.6 tonnes ha^{-1} year^{-1} in 1974 to 2.2 tonnes ha $^{-1}$ year^{-1} by 2001–2002 wherein, many farmers even achieving production levels up to 8–12 tonnes ha^{-1} year^{-1}. Optimum achievable productivity level from different culture systems has been calculated as 3–5 tonnes ha^{-1} year^{-1} in sewage-fed fish culture ponds to 10–15 tonnes

ha^{-1} $year^{-1}$ in feed based intensive pond culture systems with aeration devices. In general, freshwater aquaculture in India at present is practiced with low to moderate levels of intensification utilizing low cost inputs, especially organic manures and agriculture by-products as feedstuffs.

13.3 Resources for Aquaculture in India

Naturally endowed with vast freshwater and brackish water spread area (Tables 13.1 and 13.2), India is inherent with tremendous potentiality in the aquaculture sector. Three Indian major carps along with three exotic carps in the composite fish culture practice in the freshwater aquaculture sector continued as the backbone of inland aquaculture in India since 1970s. On the other hand, shrimp culture has been developed extensively in the coastal areas during the mid1980's because of abundant natural fry and brackish water resources especially in the estuaries of Bay of Bengal (Karim & Khandaker, 1997). Moreover, India is endowed with 8118 km long coastline and 2.02 million sq. km of Exclusive Economic Zone (EEZ) stretching along the vast geographically varied terrain and climate that support wide diversity of inland and coastal wetland habitats.

Table 13.1 Inland freshwater resources

Resources	Extent/area	Fishery practices
a. Rivers (km)	29,000	Capture
b. Canals and streams (km)	1,42,000	Capture
c. Lakes (million ha)	0.72	Capture
d. Reservoirs (million ha)	3.152	
Large	1.14	Capture
Medium	0.53	Capture
Small	1.52	Culture-based
e. Ponds and tanks (million ha)	2.85	Culture
f. Flood plain wetlands (million ha)	0.2	Culture-based
g. Swamps and derelict water bodies (million ha)	0.054	Un-classified
h. Upland lakes (million ha)	0.72	Not known

Table 13.2 Inland brackish water resources

Resources	Extent/area	Fishery practices
Brackish water (million ha)	**2.70**	
Estuaries	0.30	Capture
Back waters	0.048	Capture
Lagoons	0.14	Capture
Wetlands (Bheries)	0.043	Culture
Mangroves	0.36	Subsistence
Coastal aquaculture lands	1.42	Culture

13.4 Culturable Species

So far the genetic diversity of fishes, out of 24,600 fin-fishes in the world 2163 species (coldwater: 157; warm water: 454; brackishwater: 182 and marine: 1370) are available in India. Besides, a number of shell fishes like prawns, shrimps, crabs, scallops, oysters etc. abound in Indian waters. Even, some commercially important marine weeds are also considered highly valuable so far their cultural prospects under open sea farming are concerned.

Therefore, resources for aquaculture in India are plenty both in terms of cultivable area and culturable species. Besides comparatively cheap labour in India has made the sector more labour intensive than capital intensive, thereby incorporated the human resource more effectively with this sector even with less gender bias. Above all, the tropical climate is highly conducive for production of the cold-blooded aquatic animals including fish, and cycling of nutrients particularly the recycling of wastes generated from the farming and husbandry practices in fish farming ponds.

13.5 Legal Definition of Sustainable Agriculture

The Brundtland Commission Report stated that "Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" (UNDP, 1987). Therefore, the concept of sustainable development indicated limitations imposed by the current technological status, social organizations on environmental resources use simultaneously by the ability of the biosphere to absorb the impacts of human activities. However, 'need' is highly variable and non-elastic which changes with economic progress, societal, racial and geographical variations.

The word sustainable is a Latin derivative, *sustinere* which is literally close to *keep in existence*, implies permanence. With reference to agriculture and allied sectors, sustainability in farming systems denotes which are 'capable of maintaining their productivity and usefulness to society indefinitely. As a result, sustainable production system based on environment should be resource conserving, socially supportive, commercially competitive and environmentally sound (Ikerd, 1990). Therefore, *sustainable agriculture* practice implies horizontally integrated plant and animal production practices having a site-specific application which in the long-term:

(a) Satisfy human food, fiber, fuel and manure needs,
(b) Improve environmental quality and natural resource base,
(c) Assure most efficient use of non-renewable resources, on-farm resources,
(d) Integrate natural biological cycles and controls wherever possible,
(e) Ensures economic viability of farm operations.
(f) Improvise the quality of life of the practitioners and society as well.

13.6 Sustainable Development and Aquaculture

There has been much debate about the concepts of sustainability and sustainable development during the last two decades. Although most of the authors avoided coining a precise definition of sustainable aquaculture, a general consensus implication is that sustainable agro-ecosystem recycles materials with maximum energy efficiency and minimum foot prints over the natural resources. Jana and Jana (2013) suggested a modular depiction in which long-term sustainability has been designed through amalgamation of improved farm management practices, integrated farming, use of selective aqua chemicals and probiotics, conservation of natural resources, regulatory mechanism, and policy instruments.

13.7 Sustainability Transition in Indian Aquaculture

Following blue revolution, aquaculture has been evolved as a highly priced farming practice transited from the level of traditional artisanal activities as practiced during almost the last four decades. In other words, environmentally sound low input sustainable aquaculture (LISA) has been gradually shifted towards a more intensive production system leading to a number of environmental fall-outs viz. soil salination, reduction in agricultural crop and livestock production, changes in demographic profile, migration of artisanal fishers, destruction of mangrove forests etc. Coastal shrimp farming has also resulted in negative impacts on coastal aquatic biodiversity primarily because of wild shrimp seed collection with non-selective gears and by-catch loss (Das & Sarkar, 2010). In addition to the environmental effects, conflicts in resources uses, health and socio-politacal issues have also been emerged as major concerns in many areas. The Coastal Aquaculture Authority Act, 2005 framed the regulatory measures for practicing coastal aquaculture in a more sustainable and eco- friendly way. Moreover, National Centre for Sustainable Aquaculture (NaCSA) was established by the Marine Products Export Development Authority (MPEDA) under the Ministry of Commerce, Govt. of India in the year 2007 for uplifting the livelihood of small-scale shrimp farmers. The definition of ‘coastal aquaculture’ therein means ‘culturing shrimp, prawn, fish or any other aquatic life in saline or brackish water ponds, pens, enclosures or otherwise (Puthucherril, 2016).

13.8 Essence of Sustainable Aquaculture

Sustainable aquaculture is the farming of commercial aquatic organisms which must ensure positive economic returns as commercial venture without compromising ecological ways and means, and, ensures societal benefits in the long run. Conceptually, it has evolved through debates and discussions with somewhat consensus in factual notes that wild fisheries either have already been or being overexploited and alarming numbers of native finfish and shellfish species are becoming endangered to be extinct. Such negative environmental impacts of traditional aquaculture practices have acted as impetus to frame a comprehensive definition for the issues on, open water fisheries in the oceans and food production, and to format practitioner's guidelines for sustainable aquaculture. In spite of all these, any universally accepted definition has yet not been agreed upon, nor does an international certification mechanism on sustainability been adopted. As sustainability in environmentally supported production system like aquaculture is dynamic with respect to a number of factors viz. species of culture, intensity of operation and input usage, duration of rearing, culture environment, societal need and demand etc.; updating database from research output, learning and adoption of knowledge, refining and reassessment of methods under practices are necessary to retain and maintain ecological equilibrium in aquatic ecosystems. Aquatic species are cultured with reasonable stocking densities in the controlled euphotic zones where natural feed and compounds abound. Also, water quality is naturally conserved by eco-technological methods like ecological homeostasis up to a certain extent thereby interference in natural ecosystems is minimized in utilization of organics and vital limiting compounds.

In general, as the principal objective of sustainable aquaculture is to produce aquatic organisms keeping pace with society's nutritional requirements without degrading natural capital, integration of eco-technologically sound methods coupled with area specific indigenous traditional knowledge and techniques is highly rational in practical terms. The likely positive attribute of such strategy is that, it might be less expensive with minimum collateral environmental damage caused by massive and highly variable inputs in the production process, post-harvest processing and transport, energy, and, minimize waste generation associated with them.

13.9 Issues of Sustainability in Aquaculture

The strategies towards sustainability in aquaculture have been focused much on horizontally integrated farming fish with livestock and or agri-horticulture stems like rice-cum-fish culture; carp polyculture and composite culture, rural aquaculture, intensification of small farms, wastewater-fed aquaculture, environmental regulations and fisheries acts, trans boundary aquatic ecosystems and impact of alien and introduced species (Jana & Jana, 2013). In recent years, community participation, safeguarding stakeholders' interests, ethical issues of intensification, responsible fisheries, better management practices in aquaculture, quality control and certification, and, environmental impact assessment in the sector have come into force. The two main factors preventing the attainment of sustainable aquaculture are: (i) the fact that the development process takes place under the context of a market driven economic system and (ii) the existence of a partial set of regulations. With respect to the market driven economic system there is clear evidence that even though markets are essential components of economic activities and development, markets, by themselves they are far from perfect resource allocators (i.e., market failures due to externalities and imperfect property and use rights). Thus, market imperfections prevent the efficient allocation of natural and human made capital over time (i.e., use and conservation of the environment and the natural resource base, through the use of physical-man-made capital and technologies). On the other hand, most economies relying on market drive economic systems, expect markets to good resource allocators and have over time implemented a patched and partial set of regulations usually aimed to prevent impacts with respect to the *Natural Enabling Environment* (NEE) refers to the environment and the natural resources base required to develop aquaculture as a human activity (APEC, 2009). Very few economies have set regulations or initiatives to prevent and correct the effects of impacts on the Social and Cultural Environment and on Human livelihood. Towards orienting aquaculture sector in a sustainable production practice encompassing all the facets of stakeholders, it should:

(a) Conserve natural resources and biodiversity
(b) Achieve the least degradation of the environment
(c) Utilize techniques and technologies appropriate to situation and site
(d) Generate profit or economic benefits in excess of costs
(e) Foster minimal social disruptions and conflicts and
(f) Provide for community needs.

13.10 Measures in Indian Aquaculture

With the above issues and objectives inherent within, Indian aquaculture sector should incorporate the following measurers so as to achieve sustainability:

(a) To take steps for conserving and propagating the indigenous fish species particularly the minor fishes and the environment of culture-the water bodies herein
(b) To effectively monitor/restrict unauthorized introduction of exotic species considering their ecological impacts upon the native species
(c) To functionally integrate aquaculture with other farming sectors like agriculture, animal husbandry and others so as to minimize risk and maximize resource utilization efficiency.
(d) To recycle and reuse wastes and farming sector by products for production of valuable animal protein so as to minimize environmental pollution and establish the facts in practice that waste is nothing but a misplaced wealth
(e) To adopt multi-trophic aquaculture which involves farming of species like shellfish, seaweed and carp alongside the targeted farmed species viz. salmon, trout, or shrimp in a vertically integrated design. Such farming design reduces waste generation and accumulation thereby, helps improve water quality
(f) Not to run for achieving maximum productivity but to ensure production practice with a moderate level of intensification
(g) To ensure people's participation effectively with this sector and above all
(h) To ensure strong political will which is the key factor in discussing the subject of sustainability either in aquaculture or in any spheres of resource utilization.

13.11 Climate Change and Sustainability

In recent years, global warming and climate change has been an important point of discussion throughout the globe in addressing sustainability issues in agriculture among others. The primary manifestation of such ecological changes is sea level rise, irregularity in precipitation and rain fall patterns, increased occurrence of drought and flood, increased occurrence and severity of tropical cyclones. Such phenomena very often resulted in increasing water stress which in turn adversely affected aquatic ecosystems, wild fisheries and fishers' livelihood patterns (Cruz et al., 2007; Handisyde et al., 2006; Das et al., 2013). As most of the Asian artitional fishers live in anthropogenically perturbed areas and are depend upon aquatic resources for their sustenance, they are mostly vulnerable to climate variations (FAO, 2011). As a result, the multidimensional impacts of fisheries and aquaculture in contributing poverty alleviation of the coastal populations in this geographical region are threatened by climate change. Moreover, as the productive agricultural lands in this zone are located in the vicinity of floodplain lakes, ox-bow lakes and reservoirs, marshes and swamps, adaptation strategies towards sustainability in aquaculture is imperative to establish linkages between fisheries, aquaculture and agriculture considering area specific variable agro- climatic zones. Besides, wild capture fisheries in these regions very often act as capital generators for agriculture and livestock and if the fishing system is challenged with stress, the potential of the other components is bound to be reduced (WFC, 2007).

13.12 Impact of Climate Change on Aquatic Resources

The consequence of climate change on aquatic resources are potentially huge and there is imminent fallout from increase in thermal stress and from changes in mean annual values and variability of precipitation (Anderson et al., 1991; Sarma et al., 2009). Heat waves are expected to amplify in magnitude and frequency under anthropogenic climatic variation (IPCC, 2014a, b, 2018). Projections indicated that an increase in temperature by 2–3.5 °C would reduce net agricultural income by 25% and without additional mitigation, global temperature is to increase by 3.7–4.8 °C. Because of the increasing atmospheric temperature, the sea level will rise by approx. 50 cm by 2100 (IPCC, 2014a; IMD, 2017). The increased occurrence of late summer and pre-monsoon thunderstorms, monsoon breaks and frequent short duration intense drought, non-seasonal rains, delayed monsoon and changes in seasonality, and winter rains in Asia have also been predicted by Sarkar et al. (2017) which might further stress the aquaculture sector if the trend continues.

With the existing predictions and climate warming backdrops, scarcity of water in the Ganga river basin will bound to be magnified and even may be critical with regards to ecosystem goods and services derived from the inland water bodies including riverine fisheries and aquaculture. Therefore, sustainability of riverine fisheries and aquaculture activities in the concerned basins will be poised to serious threat out of the climate changing scenario. Das (2009) expressed concerns that with the increasing demand, balancing the needs of the aquatic environment and related stakeholders might be difficult in near future. The sustainability issues of coastal aquaculture and fisheries in India will be maximally impacted as the Indian coastline of 7517 km is vulnerable with water intrusion and increase in coastal salinity as a consequence of climate change. Therefore, it is extremely pertinent to the aquaculture operators and associated stakeholders to adopt climate resilient practices towards sustainability.

Increasing surface water temperature in the sea and river is likely to alter habitat and feeding niches, affects metabolisms, breeding and migration pattern and ultimately catch and harvesting patterns which are crucial to sustainability of both capture fisheries and aquaculture. IPCC (2014b) predicted that a rise in temperature as low as 1 °C could have a profound impact on survival and the geographical distribution of different fresh water and marine fish species. Dey et al. (2007) observed advancement on the onset of breeding of Indian major carps by 1 month during the last decade which was primarily attributed primarily by the effect of increased water temperature and shifting of the rainfall pattern facilitating early maturation and spawning. Potential climate change-induced stresses on wetland fisheries were identified as water stress (95%), wetland accretion/ sedimentation (85%), proliferation of aquatic macrophyte (70%) and loss of wetland connectivity (65%) (Sarkar et al., 2019).

13.13 Carbon Sequestration and Aquaculture Sustainability

As carbon di-oxide and methane were identified as the major green house gases towards climate change via increasing environmental temperature, it has become a serious point of debate whether aquaculture can act as a source of carbon or helps in sinking the same. As the low intensive low input aquaculture strategies are generally practiced in most of the tropical and sub-tropical aquaculture practicing countries, in terms of carbon sequestration and carbon budgeting, they appear to be more sustainable compared to the intensive aquaculture technologies being practiced in other parts of the globe. The Central Inland Fisheries Research Institute has developed C budgeting strategy to quantify the rate of total carbon sequestration per annum taking into account the operating biotic and abiotic components of the system. This would help in explaining the differences in C sequestration potential of different type of wetlands and in quantifying the ‘commercial blue C’ in the form of fish crop harvested from the system as a spinoff of the C-cycle (Sarkar et al., 2019).

13.14 Technology Scouting and Prioritization Towards Climate Resilient Aquaculture

To attain and retain sustainability in the aquaculture sectors with the perspective of environmental warming and climate change, it is imperative to select appropriate technologies which are suitable and climate smart. The National Mission on Sustainable Knowledge for Climate Change (NMSKCC) under Department of Science & Technology (DST), Government of India has scouted about 778 technologies that are subdivided into 11 sub-categories following different foresight techniques with respect to agriculture and allied disciplines. The top ten technologies under each sub-category were shortlisted following a logically drawn quantitative Multi Criteria Decision Analysis (MCDA) technique. Primarily, in the MCDA method, technologies are prioritized using five broad parameters viz. Social, Technological, Environmental, Economy and Policy (STEEP). Three steps were followed to prioritize technologies (Das, 2019). These technologies need immediate attention for validation in various agro-ecological regions in cognizance with all the concerned stakeholders' participation.

The key issues of climate change related to agriculture are (i) effect on crops (ii) implications on water availability (iii) impacts on livestock and milk production iv) effect on freshwater and marine fisheries. Considering the above potential impacts an urgent need has been felt for developing climate smart sustainable agriculture (CSSA) in India. This will be an integrated approach to achieve sustainable agricultural development for food security under climate change (Das, 2019).

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Chapter 14
Cotton Leaf Curl Virus Disease Status in *Bt* Cotton Hybrids in Punjab, India

Rupesh Kumar Arora and Paramjit Singh

Abstract Cotton, popularly known as the “White Gold”, is an important *Kharif* crop of the South Western Region of Punjab (India). *Bt* cotton refers to transgenic cotton, have an endotoxin protein inducing gene from soil bacterium *Bacillus thuringiensis*.

Insect-pests and diseases are the major biotic constraints in the production and productivity of the cotton crop in *Bt* and Non- *Bt* cotton varieties/hybrids. Among the diseases, viral disease i.e. Cotton leaf curl virus disease (CLCuD) is predominating in the cotton belt of Punjab in Northern India. Maximum areas of the cotton belt of the Punjab are under the *Bt* cotton hybrids in which an incidence of CLCuD are noticed although the disease severity varied in *Bt* and Non-*Bt* cotton varieties/ hybrids but the *Desi* cotton are found to be immune.

Variation in the disease severity might be due to prevalence of new virulent strains or combination of strains causing CLCuD in the changing environmental conditions. As per an information reported regarding strains from the literature i.e. Cotton leaf curl Burewala virus (CLCuBuV) which came into occurrence over a time, became a serious threat to the cotton cultivars not only in Punjab but throughout the Northern India. The attack of Cotton leaf curl virus disease (CLCuD) leads to frequent resistance breakdown among the *Bt* cotton hybrids and varieties. The 100% plants can be infected with the CLCuD having, with varying disease severity grade. Although, the plants infected in initial stages by CLCuD are more drastically affected the yield as compared to the plants infected at later stages. However, the CLCuD can be managed by adopting the integrated approaches to manage the vector (whitefly) of the CLCuD in cotton.

Keywords Cotton leaf curl virus disease (ClCuD) · *Bt* cotton hybrids/varieties · Resistance breakdown · Virulent strains · Time of sowing

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14.1 Introduction

When India became independent in 1947, the cotton scenario was hardly satisfying with production of 2.3 million bales as against mill consumption of 4.4 million bales of cotton, 40% of the most productive area going over to Pakistan and 95% of the mills remaining in India, were responsible for this gloomy scenario. Since the area, which went over to Pakistan was growing long and medium staple cotton, India suffered in quality front also. Extension efforts of the Governments of cotton growing states, with emphasis on extension of area and use of improved package of practices including use of adequate quantities of fertilizers, had salutary effect on both area and production of cotton. In less than a decade, the area and production stood at 8 million hectares and 4.2 million bales, respectively. During the next decade the production rose further to 5.3 million bales. There was no looking back thereafter and production continued to grow with area remaining static around 7.5 million hectares. It is at this point of time (1967) that the project widely known as AICRP was launched by ICAR(Indian Council of Agricultural Research) which gave great fillip to cotton research and its multidiscipline and Multilocation approach of improvement revolutionized in an enhancement in the seed cotton yield of cotton in a short span of time. The production and productivity of 5.3 million bales and 114 kg lint/ha in 1967 rose to 12 million bales and 280 kg ling/ha in 1991–92 respectively. Improved varieties and advent of hybrids, improved production and plant protection technologies, as well as extension efforts in disseminating these technologies have contributed to the progress in production and productivity. Qualitative improvement of cotton was also achieved due to development of varieties and hybrids of long and extra long staple (Paroda & Basu, 1992). Although, there is substantial increase in cotton production but an increase in yield is not as high as that for other crops.One of the important reason is due to the existence of the major biotic constraint in cotton crop i.e. Cotton leaf curl virus disease (CLCuD) transmitted by the whitefly. There were an number of reports in the literature regarding an incidence of CLCuD in all the cotton varieties and hybrids. None of the *Bt* cotton hybrids is noticed till date in Northern India which is immune to CLCuD. An epidemics of CLCuD in cotton crop was alsl noticed in the history. In this Book chapter, glimpse on the status of CLCuD in *Bt* cotton hybrids in Punjab in India will be noticed.

14.2 Hybrid Cultivars of Cotton

India is not only the first, but the only country who grow hybrid cotton on a large scale since seventies. It was at the Cotton Research Station, Surat that the first versatile hybrid H 4 (Hybrid 4) of intra hirsutum of cross (G-67 Am. Nectanless) was evolved. Similarly, hybrid Varalaxmi released in 1972 in India was the first interspecific (*hirsutum x barbadense*) cotton hybrid of the world.

The presence of high exploitable level of heterosis for seed cotton yield and its components, and the release of H4 and Varalaxmi hybrids for large scale cultivation in Central and South Cotton led to initiate systematic efforts for the development and testing of hybrids in North India. The main aim was to develop good quality and yield oriented hybrids suitable for cultivation in the cotton growing traits of Northern Zone and to explore the possibilities of introducing H4 and other hybrids in northern zone by studying its agronomy and plant protection measures.

Feteh was the first intra-hirsutum hybrid developed and released by PAU, Ludhiana for cultivation in the Punjab States in 1994. It was the first hybrid recommended in the northern India. At the same time the first intra arboreum hybrid LDH 11 was developed at PAU, Ludhiana in the Punjab State. Another intra-hirsutum hybrid LHH has been released for the Punjab State. This is the first cotton leaf curl virus resistant hybrid which has been released by PAU, Ludhiana in 1998.

14.3 Introduction of Bt-Cotton Hybrids

Bollworm complex is the major limiting factor to cause significant yield losses in cotton. Though Indian cotton area is first in the world but it is third in its production. Like many other parts of the world, the major reason for low productivity is damage caused by insect pests—notably by bollworm complex. In cotton crop, number of insecticides sprayed which valued a lot. Till date, none of the effective measures develop to manage Bollworm as at present Pink bollworm incidence is being noticed in the *Bt* cotton hybrid also. Hence, some variety should be develop which would be bollworm resistant. It can be done only through transgenics in the form of *Bt* cotton as there is no source of resistance to the bollworms. *Bt* cotton refers to transgenic cotton, which contains endotoxin protein inducing gene from soil bacterium *Bacillus thuringiensis*. The *Bt* cotton is of two types viz. bollgard which confers resistance to bollworms and roundup ready cotton which confers resistance to herbicides. Now there are two versions of bollgard i.e. the bollgard I contains Cry I Ac *Bt* gene in its genome while the bollgard II is the next generation transgenic Bt cotton which has combination of two genes viz. Cry 1 Ac and Cry 2 Ab into its genome and is more effective than bollgard I. Major advantages of *Bt* cotton include increase in yield, protection from bollworms, reduction in pesticide use etc.There are some limitations of *Bt* cotton which include high cost of seed mainly, effectiveness only upto 120 days, ineffective against sucking pests and promotes malpractices such as mixing of non-*Bt* seed with *Bt* seed and sale of F_2/F_3 seeds etc. Another major risk is that secondary pests such as mealy bug, whitefly and tobacco caterpillar were found to become economic pests due to less sprays on *Bt* cotton.

With the introduction of the *Bt* cotton hybrids, the farmers are more inclined to grow the *Bt* cotton hybrids in the South Western region of Punjab. Benefits of *Bt* technology are realized in farmer's community well, as it eradicates the need of spray against Bollworm pests (American Bollworm, Spotted Bollworm etc.) and allows uniform picking with considerable increase in yield. Initially, insecticide sprays were severely decreased against the Bollworm pest but it leads to the resurgence of the secondary pests (whitefly), which acts as the vector of CLCuD in cotton.

14.4 Cotton Leaf Curl Virus Disease–Earlier Reports

Cotton leaf curl virus disease (CLCuD) earlier known as African leaf curl of cotton was reported for the first time from Nigeria on *Gossypium peruvianum* and *G. vitifolia* by Farquharson in 1912. In India, CLCuD was first reported from Indian Agricultural Research Institute (IARI), New Delhi in 1989 and from farmers field in Sri Ganganagar, Rajasthan in 1993 (Ajmera, 1994; Varma et al., 1993) and Ferozpur district of Punjab adjoining to Pakistan border on *G. hirsutum* and afterwards it spread to entire North India in a short span of 4–5 years. The major constraint in cotton production now in North India is the cotton leaf curl virus disease, transmitted by the vector whitefly (Monga, 2014). Kranthi (2015) reported that there were two outbreaks of CLCuD in cotton in India, that is during 1993 and 1996.

14.5 Cotton Leaf Curl Virus Disease

Cotton leaf Curl Virus Disease (CLCuD), an important viral disease, caused by gemini virus belonging to family Gemini viridae, genus Begomovirus and transmitted by the vector whitefly (*Bemisia tabaci*). An infection at initial stages leads to drastic effect on the crop growth, yield, fibre quality etc. and CLCuD infected plants becomes stunted with twisted internodes. The disease was first noticed and initiated by small vein thickening (SVT) type symptoms on the lower sides of the young upper leaves of plants with netted like appearance. Later on, upward/downward leaf curling occurs. Leaves remain small, thickened and appears as a cup shaped, small leaflets (enations)/leaf-like outgrowths develop on the undersides of leaves on the main and lateral veins. Plant height, number of fruiting bodies and yield are drastically affected and reduced in the diseased plants.

14.6 Disease Rating Scale

The disease rating scale was finalized during AICCIP workshop and is being used with new modifications/suggestions till date for the screening or categorizing the plants against CLCuD (Monga, 2014). PDI of CLCuD in Cotton can be calculated by using the following formula:

$$\text{Per Cent Disease Index (PDI)} = \text{Average Grade}/\text{Maximum Grade} \times 100$$

**Disease index up to 30 with moderately resistant reaction will be permitted for varietal advancement or recommended to the farmers for the cultivation (Table 14.1).

14.7 Status of Cotton Leaf Curl Virus Disease (CLCUD) Virulent Strains in Northern India

As we all know that the (*Gossypium hirsutum* L.) hybrids and varieties are susceptible to the CLCuD and leads to the emergence of the disease complex symptoms i.e., an increase in the variants of the Cotton leaf curl Virus. The disease caused by one or more strains or new strains of existing virus or mixing of virulent strains caused the CLCuD disease complex, is the major factor for the frequent resistance breakdown among the *Bt* cotton hybrids and varieties against the viral diseases. Due to the combination of existing or new strains or some prevalent of some virulent

Table 14.1 Disease rating scale for cotton leaf curl virus disease

Disease severity (grade)	Symptoms	Disease index	Disease reaction
0	Complete absence of disease symptoms (immune)	0	Immune/ disease free
1	Symptoms of vein thickening on few upper leaves (small vein thickening)	0.1–10	HR
2	Small vein thickening + Main vein thickening + cupping and curling on few upper leaves	10.1–20	R
3	Top one-fourth of the plant affected with vein thickening, cupping and curling, leafy enations	20.1–30	MR
4	Half of the plant affected with vein thickening, cupping and curling, leafy enations	30.1–40	MS
5	Three-fourth of the plant affected with vein thickening, cupping and curling, leafy enations	40.1–50	S
6	Severely stunting of the plant with above symptoms	>50	HS

Source: Monga (2014)

strains of the CLCuD, variations in the severity of the CLCuD in the different locations of the cotton belt of the South Western Region of Punjab were noticed. At present, CLCuD-begomovirus species, Cotton leaf curl Multan Virus (CLCuMuV), Cotton leaf curl Kokhran Virus (CLCuKoV) and Cotton leaf curl Alabad Virus (CLCuAlV) have been identified in India (Ahuja et al., 2007; Rajagopalan et al., 2012; Kumar et al., 2010). Cotton leaf curl Rajasthan virus (CLCuRV) and Cotton leaf curl Burewala virus (CLCuBuV), were identified as predominant viruses in Cotton growing areas of North Western India.

14.8 Cotton Leaf Curl Virus Disease (CLCUD) and Its Drastic Impacts

CLCuD still being a serious limitation among other biotic and abiotic constraints for the cotton production. It was appeared as first epidemic during 1992–93 and declined the cotton yield up to 32% (Ali et al., 1995) and second epidemic was occurred during 2002–03 in Pakistan (Rajagopalan et al., 2012). The extent of losses vary with the degree of severity. The infection of CLCuD is depends upon the stage of crop, population of whitefly. More than 60% losses when the plant infection at seedling stage (Chopra et al., 1999).

The *Bt*-cotton hybrids now cultivated in about 94.75% area of the NW India are susceptible to this disease in the present condition (Monga et al., 2011.; Godara et al., 2015; Bhattacharyya et al., 2017). All the genotypes of *G. hirsutum* are susceptible to the CLCuD disease (100% infection) (Monga et al., 2011) whereas *G. arboreum* (Desi Cotton) are immune to the disease.

Arora and Singh (2016) conducted an experiment during the *Kharif* seasons of 2 succeeding years 2014–15 to determine the resistant source in cotton hybrids. They screened the 65 *Bt* cotton hybrids and 1 non-Bt cotton hybrid LHH 144 against the CLCuD. They examined all plants for the incidence and severity of CLCuD and collected the data within 30 days intervals up to 120 DAS of the crop. They revealed that out of the total 65 entries only the non-*Bt* LHH 144 showed highly resistant reaction towards CLCuD. Zubair et al. (2017) reported that CLCuD is a determinant problem in Indian subcontinent and it cause great economical losses to the cotton production.

14.9 Management of the Cotton Leaf Curl Virus Disease in Punjab

An integrated approach should be followed for the management of the Cotton leaf curl virus disease (CLCuD) and management strategy was mentioned in PoP of PAU,Ludhiana.

1. *Bt* cotton hybrids and varieties recommended by PAU, Ludhiana should be adopted for the cultivation in Punjab. Un-recommended ones must be avoided.
2. Sowing of the Cotton crop should be done latest by May 15, 2019 as the late sowing leads to aggravate the CLCuD severity.
3. *Desi* cotton varieties are immune to the CLCuD. *Desi* cotton varieties i.e. LD 1019, LD 949 and FDK 124 must be popularized among the farmers to enhance the area.
4. Cultivation of American cotton should be avoided around citrus orchards and adjoining to okra crops.
5. In early stages of the crop, CLCuD infected plants should be eradicated and destroyed from time to time as Eradication is the primary steps to check and widespread of the viral disease but it is not practically possible in cotton field if the large number of the plants are infected.
6. Clean cultivation in cotton crop should be adopted. Eradication of the weeds must be done in the fields and in the bund or areas adjoining the field. The weeds (i.e., *Kanghibuti* and *Peelibuti*) may act as the host reservoir of the vector whitefly, responsible for the transmission of CLCuD.
7. Volunteer ratoon cotton plants during off-season may be destroyed as it can be the reservoir host of the inoculums.
8. Judicious use of fertilizers especially, Nitrogen as the more application of Urea aggravates the attacks of insect pests (vector) of CLCuD.

If the attack of CLCuD is established then initially Neem based biopesticide (Nimbecidine or Achook) @ 1.0 l/acre or Homemade neem extract @1200 ml/acre will be selected for spray to manage the vector(whitefly) of CLCuD in initial stages and later on if the population of whitefly were enormous then go for the application of recommended chemical insecticides (Ulala 50 WG (Flonicamid), Osheen 20 SG (Dinotefuran), Lano 10 EC(Pyriproxyfen), Oberon/Voltage 22.9 SC (Spiromesifen), Dantotsu 50 WG (Clothianidine), Applaud 25 SC(Buprofezin) with appropriate dosages. It must be noted that for the spray of any insecticides, fix type solid cone nozzle must be used for the thorough coverage of plants and tank mixing as well as use of readymade insecticidal mixtures must be avoided as it may lead to resurgence of the vector (whitefly) of CLCuD in Cotton.

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Chapter 15
Management of Plant Diseases Through Application of Biocontrol Agents in Climate Smart Agriculture- Review

Deepak Singh, Poly Saha, K. Levish Chongloi, Ashish Kumar Gupta, M. A. Ansari, and N. Prakash

Abstract The management of plant disease almost based on chemical pesticides. The huge uses of pesticides is ecologically harmful, continuously use of pesticides lead to resistance development in pathogens against pesticides. Now necessary to provide pesticide free technologies for disease control. The durability of resistant varieties are not stable. Now need to encourage alternate techniques for plant protection such as management of plant pathogens through biopesticides. Last one decades, its has been observed that biological control has become as effective alternative method for the control of plant diseases to avoid the huge application agrochemicals in agriculture. The number of biological control agents are available for their uses, screening of its to find out the potential as biocontrol agents for management of plant diseases. Biocontrol agents have a many advantages such as growth inhibiting potential against pathogens, rhizosphere competence and ability to produce high quality of antibiotics. These biological control activities are inhibit growth and multiplication of soil borne plant pathogens either directly or indirectly various mechanism. The main mechanisms of biocontrol are parasitism, antibiosis, competition for nutrients and space, cell wall damage/degradation by lytic enzymes and induced disease resistance. The last one decades successful research works on biological control are indicated that plant diseases/pathogens can be eco-friendly manage by the biocontrol agents.

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Keywords Biological control · Systemic resistance · Plant diseases management and eco-friendly

15.1 Introduction

After the green revolution continuously use of pesticides in agriculture resulted in a huge damage in ecosystem, pesticide tolerance and disease resistance has been also recognised along with different climate change vulnerability. So, today, there are very hard rules for the uses of chemical pesticide and there is a need to remove the highly harmful chemicals from the market and time to time highly hazardous pesticides also banded due to several reasons. These facts warned to increase the crop productivity with minimum use of pesticides in agriculture system that leads to minimum damage in ecosystem. For the immediate or quick management of plant diseases by using the harmful pesticides are burning issue for both environment and health concern. Now highly need to search a sustainable and cost effective technology to manage the plant diseases for highest crop production with minimum damage of climate. For the eco-friendly management of plant diseases, biocontrol agents like *Trichoderma* spp., *Pseudomonas fluorescens*, *Bacillus subtillis* has been recommended by several research workers. It has been realized that continuously use of pesticides against any plant pathogen for their management under such condition resistance occur against particular pesticides in the pathogens. Beside that bioagents have many qualities to protect the plant against the pathogen due to the triggering systemic acquired resistance inside the plants and in many cases the uptake of essential micronutrients may increase, so that the better crop growth and yield has been noticed.

15.2 Mode of Action of Biocontrol Agents for Management of Plant Diseases

Biological control agents (BCAs) reduce plant disease by the following very prominent mechanism like induction of host resistance, antagonism, hypovirulence. The mechanisms of action of antagonist against plant pathogens/diseases has been summarized in Fig. 15.1. Following are five important components of mechanisms of antagonist.

15.2.1 Antibiosis

In this mode of action suppression of pathogenic microorganism by other organism due to secretion of toxic or inhibitory compound (mainly antibiotics) by other

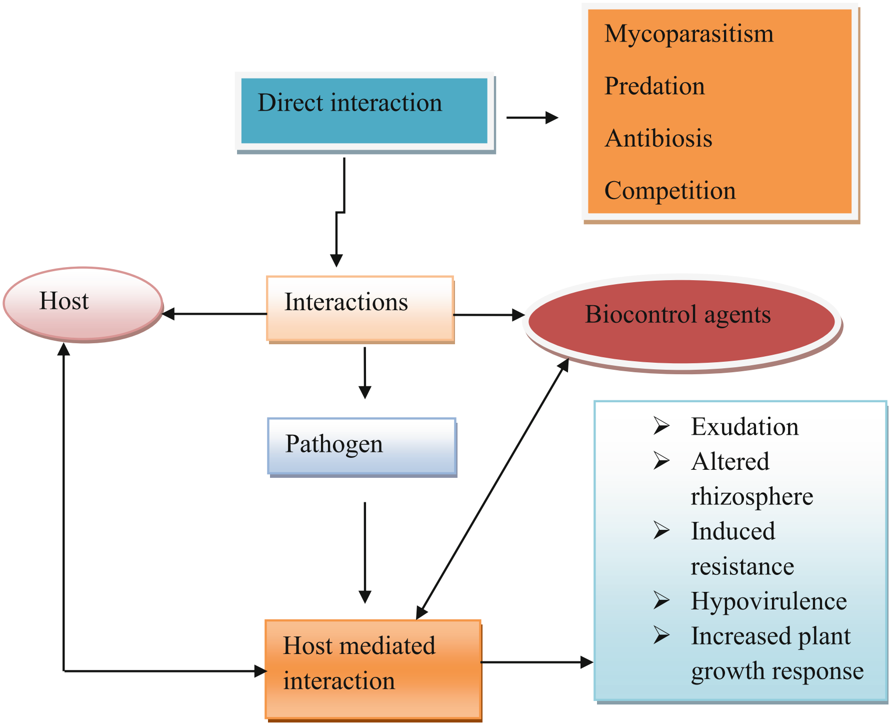

Fig. 15.1 Mechanism of biological control of plant pathogen

organisms. The range of inhibitory compound from hydrogen cyanide (HCN) to enzyme and the mainly microorganism involved are in fungi *Trichoderma* and *Gliocladium* and *Bacillus* and *Pseudomonas* in bacteria. Trichoderma strains highly effective against fungal plant pathogens, they acted either indirectly by completion for nutrients and space, increased plant growth because its produced plant growth hormones. After the application of *Trichoderma* strain in soil for management of soil borne pathogens, first colonize with their host and penetrate plant root tissues after that its started changes at morphological and biochemical level in plant, which is responsible to induced systemic resistance (Bailey & Lumsden, 1998). In mycoparasitism one fungus directly attack on another fungus, in this series of steps involved like including recognition of host, attack on their host, penetration and finally killing the host. The *Trichoderma* have cell wall degrading enzymes (CWDEs) such as glucanases, chitinolytic and proteases are considered important or mycoparasitism. The first commercial biocontrol agent successfully to control crown gall disease by *Agrobacterium tumefaciens* by agrocin 84 antibiotic. Strain of *Pseudomonas* spp. producephenazine 1-caboxylic acid, phenazine-1-carboximide, antranilic acid, diacetyl phloroglucinol, pyoluteorin, pyrrolnitrin and viscosinamide that is inhibit the growth and sporulation of targeted pathogens.

15.2.2 Competition

In this mechanism indirect interaction started between pathogens and biocontrol agents for food and physical space (Lorito et al., 1994).Generally, nutrient competition to have key role in reduction of disease. Generally biocontrol agent decreases the availability of a particular substance therefore restricted the growth of the pathogen. Its has been observed that biocontrol agents uptake the more efficiently available substance than the pathogens (Nelson, 1990; Handelsman & Parke, 1989; Harman & Nelson, 1994). *Fluorescent pseudomonads* produce siderophores that have very high affinities for iron that preventing the growth of other microflora (Loper & Buyer, 1991). Ahmad and Baker (1987) reported that when *Trichoderma* species, applied as a seed treatment or soil treatments, Its will grow along plants specially inside the root system. The majority of microorganisms has been died due to lack of food under adverse condition, so that competition occurs among the microorganism for limited nutrients and space that is called biological control of fungal phytopathogens (Chet et al., 1997). The uptake of iron is very urgently require under iron starvation condition of filamentous fungi for their survival, most fungi produce siderophores for utilization of environmental iron (Eisendle et al., 2004). In addition, *T. harzianum* T35 effectively control the *Pythium* when was the iron availability and *Fusarium oxysporum controlled by T. harzianum* T35 through competing for both rhizosphere colonization and nutrients (Tjamos et al., 1992).

15.2.3 Mycoparasitism

When one fungus parasitizes another, this phenomenon generally called mycoparasitism, In another way, it can be define the direct attack of one fungus on another. Under this mechanism *Trichoderma* generally produce glucanases, chitinases and cellulases, that is cell wall degrading enzymes, which degraded the cell wall of the host fungus (Fig. 15.2) and later released oligomers from the pathogen cell wall (Howell, 2003). For detection of other pathogen *Trichoderma* produced hydrolytic enzymes to find out the presence of another fungus near to him (Harman et al., 2004). Mcintyre et al. observed that in mycoparasitism mechanism involves changes in morphology like coiling of fungal mycelium and formation of appressorium like structures penetration in the host. The following required for the production of pathogenesis related enzymes (Howell, 2003),

15.2.4 Induction of Host Resistance

Trichoderma spp. generally activated induced systemic resistance (ISR) and systemic acquired resistance (SAR), the signalling pathways that are regulated with

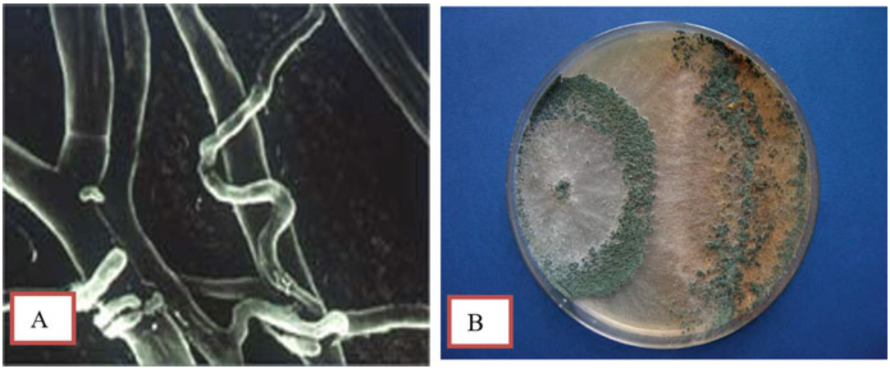

Fig. 15.2 (**a**) Coiling of *Trichoderma* hyphae on *Rhizoctonia solani* (**b**) Mycoparasitism of *Trichoderma harzianum* on *Sclerotinia sclerotiorum*

jasonate (JA) and ethylene (ET) (Van der Ent et al., 2009). Shoresh and Harman (2008) introduced 205 proteins through several genes in maize by *T. harzianum* T22. Tuzun and Kloepper (1994) noticed that salicylic acid (SA) and jasmonic acid very quickly accumulated in the vascular tissue or epidermal cell of plant after invasion of *Trichoderma* inside the plant that responds. *Trichoderma* produced xylanase and peptaibols has shown to enhanced the plant defence (Druzhinina et al., 2011).

Disease suppression through the induced resistance in host in an alternative and quite difference, mechanism of biological agents. It has been found during recent years that rhizosphere bacteria (rhizobacteria) applied to seed or roots induce systemic resistance response expressed against pathogen infecting aerial tissues. For instance, when *Pseudomonas fluorescens* was applied to roots of carnation and the stems were inoculated 1 week latter with *Fusarium oxysporum f.* sp. *dianthi*, the vascular wilt causing fungus, the incidence of disease was reduced as a result of increase the resistance of the host. Similarly the resistance was introduced to leaf pathogens such as *Colletotrichum orbiculare* and *Pseudomonas syringae* in cucumber and bacterial blight (*Pseudomonas syringae pv. Phaseolicola*) in bean with the inoculation of biological control agents. This induction of resistant as appeared was presumably due to the production of a signal molecules by the colonizing BCA, which activates systemic acquired resistance (SAR) pathway resulting in release of pathogensis-related (PR) proteins. More recent evidences suggest that different biocontrol agents may be operate through different pathways district from the above mentioned typical systemic acquired resistance response, when the bioactive strain of *Pseudomonas fluorescens* was applied to the roots of Arabidopsis plants, resistance to both a vascular wilt fungus and foliar bacterial pathogens was subsequently increased but there was no accumulation of pathogenesis related (PR) proteins or salicylic acid in disease reaction. The capacity of *Trichoderma* strains to provide the protection against root pathogens and its also have antagonistic impact for pathogen (Chet et al., 1997). Strains of *Trichoderma* when added it rhizosphere zone in plants, its protect plants with many type of plant pathogens like viral, fungal and bacterial, due to the induction of resistance mechanisms (Harman, 2006; Harman et al., 2004).

15.2.5 Enhancement of Rhizosphere Colonization of Biocontrol Agents

The biocontrol agents are well known for high root colonization capacity and invasion in root system during growing period over a considerable time. Also, the biocontrol agent have unique ability to colonize the host and also inhibit the pathogen infection at sites from pathogen attack. *Trichoderma* released cysteine rich hydrophobin- like proteins, which may be help colonize and attach to plant roots (Samolski et al., 2012). All the good quality traits of *Trichoderma* are linked with the capacity of species to very fast grow and fully colonize the rhizosphere. Sometimes cellulose binding with proteins enhance the root penetration by Trichoderma (Zhang et al., 2012).

15.3 Management of Plant Diseases by Application of Biocontrol Agents

15.3.1 Application of Biocontrol Agents in Management of Vegetables Diseases

Potato is most important vegetable crops in India. It has been noticed that potato plants are suffering with many fungal, bacterial and viral diseases and its causes significant yield. Recently *Phythophthora infestans* showed resistance against fungicides under this situation biopesticide is alternative approach for management of plant diseases. The antagonistic fungal population may be considered as one of the factors which also plays as key role in germination and yield of potato (Dwivedi, 1988). Methods for friendly potato disease management allows organic tropical Indian production systems to prosper though there are reports of use *Trichoderma* bioformulations in management of late blight of potato in North eastern India (Selvakumar, 2008; Basu, 2009). Success in mycoparasitism of potato scurf pathogen *(R. solani*) by use of *T. harzianum* by Pandey and Pundhir (2013), further can be taken as the future of biological management of this important disease.

In India both cauliflower and cabbage are the most important vegetables crops. The major plant diseases like club root caused by *Plasmodiophora brassicae*, leaf spot by *A. brassicae*, leaf blight by *A. brassiciola*, black rot by *Xanthomonas campestris*, wire stem by *Rhizoctonia solani*, which cause significant loss in crop yield. The performance of *Trichoderma* and *Aspergillus* against *Sclerotinia sclerotiorum* causing rots in cabbage and cauliflower has been proven in a IDM programme for their successful (Sharma et al., 2001; Zewain et al., 2004). Sharma and Sain (2005) and Sharma et al. (2005) observed the reduction in survibility of sclerotial bodies of *Sclerotinia sclerotiorum* due to the application of *Trichoderma* spp., which also promoted the biocontrol activity. Ahuja et al. (2012) observed that in integrated pest management, the incidence of major pests of cauliflower decreased and higher curd production was recorded in the IPM fields because application of talc based formulation of *T. harzianum*.

In Chilli mostly fungal diseases like damping off caused by various fungal pathogens, which are widely prevalent in the country. The *T. harzianum, T. viride* and *T. hamatum* are successful bio-control agents against important diseases of chilli like anthracnose, damping-off and chilli dieback successfully controlled by the *T. harzianum, T. viride* and *T. hamatum*. In other study by Mathur et al. (2006) observed that positive interaction of *T. harzianum* with *R. solani* was observed in the rhizospheres of chilli cultivars, its indicating the efficacy of *Trichoderma* spp. for the management of chilli diseases. Kapoor, 2008 evaluated that the positive interaction of *T. harzianum* with *R. solani* was observed in the rhizospheres of chilli cultivars. Kaur et al. (2006) demonstrated that efficacy of *Trichoderma species* on *C. capisci* causing fruit rot in vitro condition. An in vitro experiment was also conducted to evaluate the effect of eight isolates of *Trichoderma* species by Muthukumar et al. (2011) and they found that a *Trichoderma* isolate TVC3 was able to inhibit the mycelial growth of pathogen as well as promoting the plant growth. In another study using coco-peat enriched with *T. harzianum* for raising disease free and healthy seedlings which also reduced wilt incidence in tomato was suggested for better health and growth and reduced incidence of tomato wilt and chilli root rot (Sriram et al., 2010). In another study, fungal isolate Vasanth Kumari and Shivanna (2013) who observed that antagonistic fungi- *F. oxysporum, C. globosum and T. harzianum* could be used to control anthracnose of chilli.

Tomato is another important vegetable crop in India, but it is susceptible to many fungal, bacterial and viral diseases that cause significant losses. Among them, the tomato diseases caused by soil-borne fungi remained a challenging task to manage. The application of a number of *Trichoderma* species of *Trichoderma,* not only reduced the disease incidence but also increased the yield of vegetable crops. The *Trichoderma* isolate successfully controlled collar rot of tomato (Dutta & Das, 2002). More than 50% growth of *P. aphanidermatum* inhibited by *T. harzianum* isolates *in vitro* condition and its also found to be compatible with Bavistin, Captan and Vegfrugard, respectively (Sharma & Sain, 2003a, b).

The systemic resistance induced by *Trichoderma* species against stalk rot caused *S. sclerotiorum* in tomato and cauliflower was reported by Sharma and Sain (2004) and also noticed that the *T. harzianum* isolates more superior than *T. viride* isolates in induction of systemic resistance. The effect of *Trichoderma* species similar in tomato and cauliflower further confirmed. Under pot culture experiments, the damping off of tomato caused by *P. aphanidermatum* successful control by *T. viride* and *P. fluorescens* (Manoranitham et al., 2000). In similar pattern, Sharma and Sain (2003a, b) assessed the performance of commercially available and formulations of bioagents and plant nutrients against wilt of tomato. For the management of damping-off of tomato caused by *P. aphanidermatum* Jayaraj et al. (2006), developed a carrier based formulation of *T. harzianum* strain M1. Baranwal et al. (2011) reported that by using bioagents and organic amendments, tomato wilt caused by *F.oxispoium f.* sp. *lycopersici,* it can be successfully manage in field. Onion is also another important vegetable crop in India. The control of purple blotch has been widely studied, Prakasam and Sharma (2012) studied that the effective isolates of *T. harzianum* and *T. viride*, reported that its has been significantly reduced disease in susceptible onion. The foliar blight of onion successfully controlled by biological management and IDM (Shahnaz et al., 2013). *In vitro* evaluated the performance of bio-agents for Stemphylium blight and purple blotch of onion, he find out that among the tested bioagents, However the *T. viride* was effectively inhibited the growth of both disease pathogen (Mishra & Gupta, 2012).

15.3.2 Application of Biocontrol Agents for Management of Oilseed Crop Diseases

Indian mustard is the major oilseed crops for India. Now need to focused on the eco-friendly management of major diseases of oilseed crops by employing *Trichoderma*. Meena et al. (2004) in vitro study observed that *T. viride* have compatibility with fungicides like mancozeb and carbendazim and its showed excellent result to control mycelial growth of *Alternaria brassicae* over control. Gaur et al. (2010) observed that mixed formulation of *T. hamatum* (HP20) and *T. viride* (Tv-1) were performed well in field trials either used as seed treatment or foliar application. Meena et al. (2011) studied that bio-agents, *T. harzianum, P. fluorescence* against the blight revealed that their efficiencies were at par with chemicals.

Soybean is the third important oilseed crop. Several researchers has been worked out that management of root, seed and foliar diseases in eco-friendly IDM technology. Khodke and Raut (2010) carried out the work for management of root rot or collar rot of soybean by using fungicides as seed treatment and soil application, *Trichoderma* spp. and their combinations. Mishra et al. (2011) observed that maximum germination was achieved due to seed treatment with thiram, carbendazim and *Trichoderma* spp. The efficacy of *Trichoderma* and plant growth promoting rhizobacteria, *P. fluorescens* were tested under glasshouse and field conditions against many soil-borne plant pathogens viz., *R. solani, S. rolfsii* and *M. phaseolina* responsible for root and stem rot disease of soybean. Jat and Agalave (2013) reported that *Trichoderma* species inhibited the growth of many seed-borne fungi like *(Penicillium chrysogenum, Rhizopus nigricans, Aspergillus flavus, Penicillium notatum Alternaria alternata, Fusarium oxysporum, Curvularia lunata, Fusarium moniliforme)* and which affects the yield in many oil seed crops. Pant and Mukhopadhyay (2001) reported that the seed and seedling rot complex of soybean caused by *R. solani* successfully managed by using biocontrol agents *G. virens* and *T. harzianum*.

The groundnut crop affected with more than 50 pathogens, but only few diseases are economically important like rust (*Puccinia arichidis*), collar rot (*A. niger van tiegham*), alfalfa root (*Aspergillus flavus*), early leaf spot (*Phaeoisriopis arichidicola*), stem rot (*S. rolfsii*), root rot (*M. phaseolina*), late leaf spot (*Phaeoisriopis personata*). Sreedevi et al. (2012) optimized the substrate for chitinase production in *T. harzianum* isolated from rhizospheric soils of healthy groundnut plants and found that enzyme the production was influenced by the concentration chitin. The systemic study on induce systemic resistance was laid by Sreedevi et al. (2011), isolated *Trichoderma* from the rhizosphere of groundnut and tested their antagonistic activity, under *in vitro* and biochemical changes in *T. harzianum* treated plants. Sharma et al. (2012) laid out the trails specially on the groundnut root rot disease which caused by pathogen complex, He noticed that by the use of *T. harzianum* in the form of powder and liquid formulation successfully control the disease. Kishore et al. (2001) reported the antagonistic potential of 16 numbers of *Trichoderma* isolates against *A. niger* in crown rot of groundnut in vitro as well as under greenhouse conditions and found them superior in comparison to fungicide treatment. Rakholiya and Jadeja (2010) tested three fungicides viz., mancozeb, tebuconazole and vitavax power, two bioagents viz., *T. harzianum and P. fluorescens* and one insecticide (chlorpyriphos) against stem and pod rot of groundnut caused by *S. rolfsii* and found that *T. harzianum* provided maximum protection to the crop.

15.3.3 Application of Biocontrol Agents for Management of Pulses Crop Diseases

Chickpea is one of the most popular pulse crop in India but it frequently attacked mainly by fungal pathogen after that its contributing more than 50% of the major pulses crop production in India. chickpea wilt incited by *F. oxysporum f.* sp. *ciceris.* Chand and Singh (2005) tried to control chickpea wilt with *T. viride*, *G. virens* and *T. harzianum* in combination along with plant extracts, Among the tested treatment *T. viride* and *Allium sativum* bulb extract were the most suitable. Manjunatha et al. (2013) reported that the dry root rot of chickpea caused by *M. phaseolina* successfully control by the combination of *T. viride* and *P. fluorescens*. Prasad et al. (2002) evaluated the potential of two antagonistic fungi viz., *T. harzianum* (PDBCTH 10) and *T. viride* (PDBCTV), its found them effective against wilt and wet root rot of chickpea. The efficacy of *T. harzianum* singly and in combination with chemicals like carbendazim and *Aspergillus niger* was also reported (Poddar et al., 2004). Sharma et al. (1999) reported *T. harzianum* very effectively inhibited the mycelial growth of *S. sclerotiorum* causing stem rot in chickpea. Prasad and Rangeshwaran (2000) found modified wheat bran-kaolin granular formulation of *T. harzianum* to be effective against *R. solani* under field conditions. Dubey et al. (2007) reported that for the management of several pulses pathogens, the various isolates of *Trichoderma* species has been characterized and evaluated. Several formulations has been developed on *Trichoderma* based biopesticides among them Pusa 5SD found more suitable for seed treatment as well a Pusa bio pellet for soil application (Dubey et al., 2009). For the management of pulse crops diseases, namely dry root rot of chickpea, these formulation were found very effective (Dubey et al., 2011), wilt of chickpea (Dubey et al., 2013) and dry root rot of mungbean (Dubey et al., 2009) and Pusa 5SD also found compatible with the most widely used insecticides like imidacloprid and thiamethoxam and an integrated module has been developed for the management of major diseases of mungbean (Dubey et al., 2013).

15.3.4 Application of BCAs in Cereals Crop for Management of Plant Disease

Rice (*Oryza sativa* L) is the most important cereal crop in the world, but its yield significantly reduced by several diseases caused by the fungal, bacterial and viral pathogens. The several species of *Trichoderma* evaluated in combination with chemical by many researchers, those are very effective against rice diseases. *Rhizoctonia solani* caused sheath blight of rice which one is one of the most common and destructive disease in rice reported by several researchers in India. The various important information/ reports are available on how to successfully control the sheath blight of rice through biocontrol agents. The combination of biocontrol agents study has been done by Rao et al. (2013) and they reported that brown leaf spot of paddy can effectively control by *T. harzianum* and *Pseudomonas fluorescens*. Soil and FYM (1:1) in combination promoted highest growth of both fungal and bacterial antagonists tested (Gangwar & Sharma, 2013). Application of *Trichoderma* with pesticides has also been addressed by various workers. Chakravarthy et al. (2011) tested tolerance capacity level of 26 number of isolates *Trichoderma spp.* against pesticides and their antagonistic potential for *R. solani* and he found that *T. reesei and T. longibrachiatum* as most effective in respect to inhibiting the growth of the survival structure like sclerotial bodies. Das and Hazarika (2000) reported that *T. viride* and *T. harzianum* along with chemicals were found effective to control sheath blight of rice. *R. solani* very effectively control by T. viride (Sriram et al., 2000). However the Khan and Sinha (2005, 2007) reported that *T. harzianum* and *T. virens* effective in foliar application against sheath blight of rice.

Maize field which suffers from various plant pathogens like soil borne, air borne and seed borne. As per available research information, the several important maize diseases successfully managed by Trichoderma based pesticides. Sankar and Sharma (2001) indicated that charcoal rot disease caused by *Macrophomia phaseolina* successfully control by *T. viride* and also enhanced the growth of crop. The efficacy of *T. harzianum* has been evaluated by Khedekar et al. (2010) against leaf blight caused by *Helminthosposium turcicum* and he recorded the similar results. In an another set of experiments by Bhandari and Vishunavat (2013), efforts were made to test the efficacy of *T. harzianum* against ear rot of maize caused by *Fusarium moniliforme,* where Th3 strain showed 73.33% growth inhibition of *F. moniliforme* indicating it's further use for in vivo trials. In another study by Pal et al. (2013) the potential of garlic and turmeric extracts, at 0.25%, 0.5%, concentrations and *T. harzianum* were exploited for enhancing the seed germination of maize indicating the importance of use of *Trichoderma spp*. for the enhancement of seed germination in various crops.

15.3.5 Application of BCAs for Abiotic Stress Management in Crops

Its has been proved that through biopesticide/biocontrol agents (BCAs)very effectively plant diseases can be control but sometimes its has been noticed by researchers at the field level efficacy of biopesticides/BCAs is very less due to extreme stress condition of environment. For the success of fungal biopesticides at field level proper moisture is highly required for spore germination of BCAs, but certain areas in India, atmospheric moisture is very low and high temperature, under such type of condition not suitable to germinate the spore of BCAs. So its reduce the efficiency of BCAs. This is a key issue to commercialization and popularization of BCAs at farmer's level. The acceptance level of the BCA is less at commercial scale for the control of plant diseases than chemical pesticides. In ecosystem BCAs and microbes boths are an integral component of our agricultural part. The nature of boths its colonize the spermophere, roots, phyllosphere and rhizosphere, after that established to organic relationships with plants and they are capable to change their physiological process after that its may be increase the tolerance level in plant against to biotic and abiotic stresses. The mechanism of BCA has been describe in Fig. 15.3.

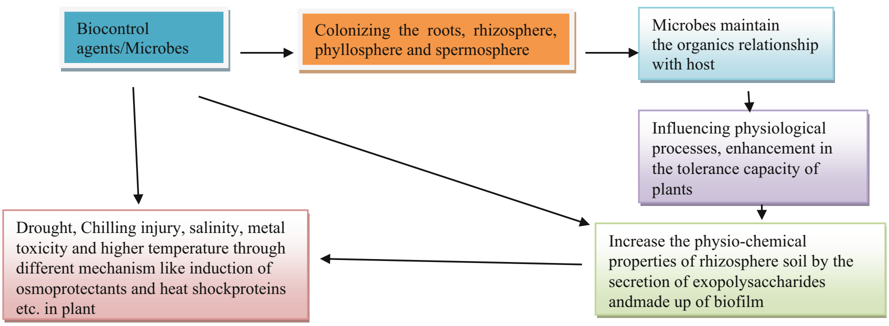

Fig. 15.3 Mechanism of Biocontrol agents under abiotic stress condition in field

After the application of *T. harzianum* in soil under osmotic stress conditions, the water absorption and uptake of nutrient both may be increase due to good root growth in plants (Harman et al., 2004). In various studies it has been found that root colonization by *T. harzianum*, its increased enzymes level inside the that leads to the accumulation of phytoalexins and phenols compound that inhibit the growth and sporulation of plant pathogens (Harman, 2006). Mastouri et al. (2010) reported that similar mechanism was noticed in better germination of *T. harzianum* strain T-22 recorded in treated seeds of tomato exposed to biotic stressor physiological stress. PGPR- induced the resistance that is called "induced systemic resistance" its happened due to physical and chemical changes inside the plants that increase the tolerance level against abiotic stresses (Yang et al., 2009). AI Karaki and Hammad (2001) observed that under salinity stress condition arbuscular mycorrhizal symbiosis increased the stability of host plants.

15.4 Reduction of Stress in Crops Through Trichoderma

It has been well proven that under adverse environment condition *Trichoderma* species enhance the survivability of crop due to increasing the plant tolerance level. During BCAs-plant interaction in rhizosphere, Several researchers has been observed that during BCAs-plant interaction in rhizosphere, due to the well-developed root architecture its increase the water absorption. *Trichoderma* improve over all the health of plant to face the adverse condition like drought (Malinowski & Belesky, 2000) and can also induce systemic resistance to abiotic plant stress including water deficit, salt and temperature stress. Singh et al. (2004) found that if wheat seed treated with *Trichoderma,* it provided better tolerate against drought stress due to good root growth. Viterbo et al. (2010) systemically demonstrated that if arabidopsis and cucumber plants treated with *Trichoderma,* its better performed in salt stress condition.

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Chapter 16
Role of Modern Agro-Ecosystems in the Origin of New Plant Pathogens

Delna Rose S. and Geeta Sharma

Abstract The ecosystem which prospers on an agricultural land and encompasses various crop species and the analogous native microorganisms, plants, and animals is known as Agro-ecosystem. Throughout the development of domestication, selection and cultivation of prudent host genotypes escort to the concurrent selection for pathogen genotypes that are redesigned to the stipulated individuals in the specified agro-ecosystem. With the development and escalation of novel agro-ecosystem, a highly encouraging environment is provided by the increasing host population for selected pathogens that can grow along with the developing agricultural host. Host shift or host jump is a phenomenon by which a pathogen infects a non host species. In a host shift, the alternate host is a close relative of the previous host, whereas host jump includes a new host that is taxonomically aloof from the former host. There are examples of host shifts where diseases emerge due to introductions of fungal pathogens into vernacular host populations in new areas by virtue of exchange of plants at word wide level. The predominant unifying idiosyncrasy in all arising diseases is the environmental and genetic resemblance of the agricultural ecosystem in which the pathogens originated.

Keywords Agro-ecosystems · Host shifts · Host jumps · Evolution

16.1 Introduction

Knowledge of where, when, why and how a plant pathogen originated is imperative for durable plant protection. In modern agriculture, crop protection relies greatly on resistance genes bred into resistant cultivars, genetic engineering and pesticides. Frequent reports of breakdown or varietal resistance and pesticide resistance (antibiotics, fungicides) are a blow to the plant pathologists, plant breeders, genetic

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engineers and all other scientists who invest their time, talent and funds in their development. Therefore, learning about the origins of plant pathogens can be helpful:

- To get the information how pathogen is able to breach the resistance at genetic level or shows resistance to pesticide. Disease resistance or failure of pesticide occurs, because pathogens metamorphose. Genetic diversity is a pre-requisite for evolution. Genetic heterogeneity of a pathogen population is governed by mutation, recombination, gene flow and selection.
- To get information on genetic pool to search the sources of resistance. Since, the pathogen and host coevolved over time, for plant pathogens that pop up across host tracking are the closely related wild species of the crop and if a plant pathogen emerged via host jump, the original host is probably the reliable sources of resistance**.**
- To provide insight into the ultimate geographical dissemination of the pathogen that is demarcated by environmental factors. A pathogen that is developed in a cold and dry climate cannot be able to sustain entirely different climatic conditions (phylogeography).
- Keys to develop new and improve the existing disease management strategies. Knowledge about the science of the evolutionary potential of pathogens can guide the strategies to reduce the chances of development of resistance in genes, fungicides, and antibiotics to maximize their efficacy and minimize the losses that result from their loss of efficacy.
- For the assessment of the risks posed by prospective future pathogens (McDonald & Linde, 2002; Zaffarano et al., 2008; Stukenbrock & McDonald, 2008; McDonald, 2014, 2015).

An ecosystem (eco from Greek word '*oikos' meaning* household) can be defined as a community of living organisms along with the abiotic factors of their ecosystem like air, water and soil which interacts together (Hatcher, 1990). The ecosystem that develops in an agricultural field, i.e., population of the crop(s) being grown, weeds and volunteer plants, the plant's microbiome, the indigenous soil microbiome, soil fauna, insects, animals and all other biotic components present in the field, that interacts with the air, water and mineral soil to behave as a system is called as the agro-ecosystem. Agriculture ('agri' from Latin word '*ager*' meaning soil and '*cultura'* meaning tillage) originated in the Fertile Crescent of Middle East, 12,000 years before present. A plant that is domesticated is called as a crop. Today, agriculture is a business. Modern agro-ecosystems are well structured production units for high quality produce for direct consumption or for processing. Agro-ecosystems differ from each other with the duration of crop, crop architecture (herb, shrub, creeper, vine, tree etc.) cropping system, culture media and production practices. The protected cultivation structures like polyhouses, glasshouses are in itself a different type of agro-ecosystem. When compared to natural ecosystems, agro-ecosystems have the following distinguishing characters:

Greater environmental homogeneity that is brought about by leveling of the land, tillage of soil, divisions into fields and plots, channels of irrigation water, uniform availability of nutrient by fertilization etc.,

- Due to predominance of a few major crops that are grown as monocultures, there is lower species diversity. There is genetic homogeneity even at the subspecies level where a single, popular cultivar is grown over vast stretches of land.
- Commercial agriculture aims at higher yields, i.e., more production per unit area for which lower spacing is preferred. This results in higher crop density that facilitates the transmission of pathogens to uninfected neighboring plants.
- Continuous interventions by the farmer in supplying uniformly water and nutrients, cultural practices, crop protection practices etc.

Therefore, from an epidemiological point of view, all these characters facilitate multiple disease cycles of the pathogen and make them restorative for the origin of host-specific, highly aggresive plant pathogens. Agroecosystems are stimulating faster origin and evolution of plant pathogens, than what would have been possible under natural conditions (Stukenbrock & McDonald, 2008; McDonald, 2014).

So, the question is, what is the critical role played by agro-ecosystems in the origin and spread of plant pathogens? And, how can we sustain the existing crop protection strategies (which hugely depends on resistant genes and pesticides), without compromising on the yield of agricultural produce?

16.2 Evolution of New Pathogens in Agro-Ecosystems

16.2.1 Host Tracking/Pestification

Domestication is an evolvement process which gets triggered by selection of individuals from wild plant populations on the basis of agronomic traits (Clement, 1999). It was the first step in the development of cultivated plants, which began over 13,000 years ago when humans began agriculture. Eventually, crop plants have diverged so remarkably from their wild ancestral species that they are classified as distinct species and, in some cases, their wild ancestors are not easily identifiable (Singh, 2009). Under this model, it is proposed that with the development of crop specific agro-ecosystem and during the process of host domestication, the host plant and pathogen coevolved (Stukenbrock & McDonald, 2008). For the first time, the term pestification was introduced to explain the consequences of domestication of rice on *Magnaporthe oryzae,* the fungal pathogen associated with it (Saleh et al., 2014). The process of 'Pestification' can be defined as the one in which a pathogen earlier surviving in the wild becomes adjusted to living and non living elements of crop ecosystem (DeGracia et al., 2015). Therefore, for pathogens that were associated with the ancestors of crop species, followed their host crop plants in the process of domestication, changes in the environment linked with the changes in ecosystem from wild to domesticated may have resulted in remarkable differentiation in

Table 16.1 Examples of plant pathogens originated in agroecosystems by pestification model

S. No:	Plant-Pathosystem	Timescale	Centre of origin of Crop	Centre of origin of Pathogen	References
1	*Mycosphaerella graminicola* on wheat	10,000–12,000 YBP[a]	Fertile Crescent	Fertile Crescent	Stukenbrock et al. (2007)
2	*Magnaporthe oryzae* on rice	10,000 YBP	SE Asia	SE Asia	Couch et al. (2005), Saleh et al. (2014) Gladieux et al. (2017)
3	*Ustilago maydis* on maize	6000–10,000 YBP	Mexico	Mexico	Munkacsi et al. (2008)
4	*Venturia inaequalis* on apple	2000–4000 YBP	Central Asia	Mountains of Kazakhstan	Gladieux et al. (2010)
5	*Pseudomonas syringae* pv. *Actinidiae* on kiwi fruit	1980 onwards	East Asia	China	McCann et al. (2017) Vanneste (2017)

[a]*YBP* Years Before Present

population, due to reductions in flow of genes between wild populations of host plants and cultivated plants and by rise in mating within the crop populations (Munkacsi et al., 2008).

The selection and cultivation of beneficial genotypes of host causes selection for the genotypes of pathogen which is well acclimatized to the specific host and their specific agro-ecosystem as a consequence of domestication. Accompanying the development and spread of novel agro-ecosystem, a highly congenial environment is supports the developing host population, for the evolution of selected pathogens with greater adaptability in agricultural host (Stukenbrock & McDonald, 2008).

In the host-tracking model, the centre of origin of the pathogen is anticipated to be consisted with host's origin. Analytical tools (molecular markers (SSR, SNP and microsatellites) and clustering methods etc.,) were used to test the proposed evolutionary models. The pathogen's domestications may not necessarily be as old as the time of beginning of agriculture. It is certainly a recent happening when new crop species were grown, such as triticale or kiwi fruit, and the development of related agro-ecosystems occurred (Stukenbrock & McDonald, 2008).

The origin of diseases in plants and their association with plant domestication is concealed by time (McCann et al., 2017). Domestication of most of the crops was done centuries – even millennia – ago, thus restricting the chances to understand the concomitant emergence of disease in them. One of the exception is Kiwifruit (*Actinidia* spp.) whose domestication began in the 1930s, and the outbreaks of *P. syringae* pv. *actinidiae* (PSA) causing canker disease of Kiwifruit, was first mentioned in the year 1980s. Thereby validating studies of a pathogen in the preliminary phase of blooming from anticipated population source associated with wild *Actinidia* species (McCann et al., 2013). A few examples of phytopathogens originated using pestification model in agro-ecosystems are summarized in Table 16.1.

16.2.2 Host Shifts and Host Jumps

Shift in the hosts or host jump is the summons through which pathogen starts to infect non host or a new host species which were formerly unaffected. In a host shift, the alternate host is a close relative of the previous host, whereas a host jump demand a new host that is taxonomically far from the former host (Stukenbrock & McDonald, 2008). Host shift speciation is speciation by specialization onto a new host. A subset of population of fungal pathogens acclimatize on a novel host, thus become incapacitated of infecting its previous host, due to reduction in the gene flow from the pathogenic fungal population which causes disease in the host-of-origin (Giraud et al., 2010). The globally conveyed rice-infecting pathogens of *Pyricularia oryzae* originated as a consequence a single host shift from Setaria millet to rice in China, keeping in view that both the host plants Setaria millet and rice were domesticated in China and were thought to be aligned with each other in the prophase of Asian agriculture (Couch et al., 2005). *Rhynchosporium secalis*, the barley scald pathogen is assumed to have shifted from their wild grass progenitors to cultivated rye and barley crop in the initiation of agriculture (Zaffarano et al., 2008). Although first record of *Rhynchosporium* sp. was in rye in the late nineteenth century period (Oudemans, 1897), but it was observed in 1990s, on triticale, near about 30 years after the triticale crop was introduced. The probable reasons for the shift in the host from rye crop to triticale may be due to the genome forwarded by the wheat progenitor lacked the scald resistance genes or may be due to recent emergence of novel pathogenic strains of *Rhynchosporium* sp. from the pathogen population which cause infection in rye crop (Welty & Metzger, 1996).

Table 16.2 Examples of pathogens originated via host shifts

S. No:	Plant pathogen	Original host	New host	Time scale	Place	References
1	*Magnaporthe oryzae*	Setaria millet	Rice	10,000 YBP	China	Couch et al. (2005) Gladieux et al. (2017)
2	*Rhynchosporium* spp.	Weedy grasses of *Agropyron* spp.	Barley and rye	1200–3600 YBP	Fertile Crescent	Zaffarano et al. (2008, 2011) Torriani et al. (2014)
3	*Rhynchosporium secalis*	Rye	Triticale	1996 onwards	–	Zaffarano et al. (2008)

Table 16.3 Examples of pathogens originated by introductions

S. no	Disease	Pathogen	Introduced		References
			From	To	
1	Chestnut blight	Cryphonectria parasitica	Asia	North America and Europe	Woolhouse and Gowtage-Sequeria (2005)
2	Dutch elm disease	*Ophiostomaulmi* and *O. novo-ulmi*	Holland	North America and Europe	Brasier (2000) Brasier and Mehrotra (1995)
3	Cypress canker	*Seiridium cardinal*		Europe and America	Graniti (1998) Danti and Rocca (2017)
4	Jarrah decline on Eucalyptus marginata	*Phytophthora cinnamomi*	SE Asia	Australia	Hansen (2015)
5	Late blight of potato	*Phytopthora infestans*	South America	Europe	Goodwin et al. (1994)

In this case, it is concluded that it is not necessary for the geographical origin of the host to be in agreement with that of the pathogen. In an agro-ecosystem, a novel pathogen can arise either from a wild host population or from some other crop species. Wild plant or weeds present in the vicinity of agricultural fields, forms a major source of new plant pathogens (Stukenbrock & McDonald, 2008). Examples of pathogens originated by host shifts are given in Table 16.2.

On a global scale, human interference has greatly influenced the ecosystems and environment, disrupting the natural barricades to spread of organism and resulting in unusual distribution of organisms (Kolar & Lodge, 2001). The pathogens associated with their specific host moves along with movement of domesticated host plants into new areas could lead to the simultaneously introduction "domesticated" pathogens into new regions where they may infect the "wild" hosts and increase the risk of infection of cultivated crops by new microbes that might shift their host preference from wild plants to cultivated host plants (Zaffarano et al., 2008). Many reports of recent emergence of diseases due to establishment of fungal plant pathogens into new areas are also considered as a result of the Host Shift phenomenon. A newly infected host may have lower degree of resistance to that particular pathogen and the pathogen may posses high level of virulence, due to the lack of co-evolution in a novel host pathogen complex (Stukenbrock & McDonald, 2008).

Fungal invasions are the most evident cause of epidemics caused by non native pathogenic fungal species. Near about 65–85% of plant pathogens present worldwide were estimated to be non native to the location where they were recorded. Intrusions by these pathogenic organisms can have serious ecological, economic and social outcomes. *Phytophthora infestans*, which is a causal organism of late blight of potato led to the European epidemic of Great Irish Famine during 1845–1849, is a classical example (Desprez-Loustau et al., 2007). Other examples may include the invasion of *Cryphonectria parasitica* and *Phytophthora cinnamomi* in the USA, and

American chestnut (*Castanea dentata*), the Japanese chestnut trees (*C. crenata*) devastation were considered as the most important source, that were traded throughout the country. The pathogens were unable to differentiate among their host plants. Differentiation was found, as in the case of differentiation in *C. parasitica* betweent Europe and North America (Giraud et al., 2010). Examples of pathogens originated by host shifts due to introductions are given in Table 16.3.

A classic example of host jumps in plant pathogens is the fungi associated (symbionts) with grass in the family Clavicipitaceae (Ascomycota, Hypocreales). *Claviceps purpurea* causing ergot of rye and *Neotyphodiumcoenophialum* causing endophyte of tall fescue are the best characterized species. It is an example of interkingdom host jumps as the grass symbionts in Clavicipitaceae is a group that has originated from animal pathogen through a dynamic process. There have been reports about of 5–8 unidirectional and independent interkingdom host jumps that were observed among fungi of clavicipitaceous group, including 1 to plants, 1–2 to animals, and 3–5 to fungi, (Spatafora et al., 2007).

16.2.3 Horizontal Gene Transfers

Horizontal gene transfer (HGT) is described as the steady amalgamation of genetic material following transfer between singles. HGT does not include the transfers with the help of meiotic or mitotic activities, which is termed as vertical gene transfer process (Rosewich & Kistler, 2000). In this situation, a non-pathogenic microbe or a weak pathogen acquire genes responsible for pathogenecity and gets cahnged into a virulent pathogen (Stukenbrock & McDonald, 2008). The terms interspecific and lateral gene transfer can be used interchangeably for Horizontal gene transfer to elaborate the flow and fixation of DNA sequences between species. This indicates to the transfer of a gene from one isolate to another by the methods which do not involve asexual cell division, parasexual exchange between compatible isolates and sexual processes involving gamete fusion (Oliver & Solomon, 2008). The process of Horizontal gene transfer (HGT) can cause variations in the genomes of microorganisms, enabling them to adjust to changing environments, and hosts. HGT has played an eminent role in the evolution eukaryotic microbes by development of phytopathogenic traits, specifically oomycetes and fungi (Soanes & Richards, 2014).

Plant pathogenic fungi have the ability to quickly adapt to the altering environments and can also bridle development of disease resistance genes in plants. This can be carried by single effector genes mutations of the pathogenic microbes which enable them to circumvent recognition by the host crop plant. Additionally, the techniques like horizontal chromosome transfer (HCT) and gene transfer (HGT) enables these pathogenic microbes to infect a wide range of hosts. There are evidence about the horizontal gene transfer of the ToxA gene from *Stagonosporanodorum* to *Pyrenophoratritici-repentis* enabled the latter fungus to be pathogenic in wheat crop. A chromosome, responsible for pathogenecity from pathogenic *Fusarium oxysporum* f. sp. *lycopersici* when transferred to a non

Table 16.4 Examples of pathogens evolved by HGT or HCT and their mode of increased virulence

S. No	Fungus	Effector gene (s)	Gene products	HGT/ HCT	Role in pathogenicity	References
1	*Pyrenophora tritici-repentis*	*ToxA*	Necrogenic ribosomal peptide	HGT	Essential to cause disease on wheat	Friesen et al. (2006)
2	*Nectria haematococca*	*PEP*	Several enzymes including pisatine demethylase	HGT	Essential to cause disease on pea	Liu et al. (2003)
3	*Cochliobolus heterostrophus (race T)*	*Tox1*	T-toxin; long chain polyketides	HGT	Essential to cause disease on corn	Yang et al. (1996)
4	*Cochliobolus carbonum (race 1)*	*TOX2*	HC-toxin; cyclic peptide	HGT	Essential to cause disease on corn	Walton (2000)
5	*Alternaria alternate (apple strain)*	*AMT*	AM-toxin; cyclic peptide	HCT	Role in pathogenicity and host specificity	Akagi (2009)
6	*Fusarium oxysporum*	*SIX*	Ribosomal peptides	HCT	Several have role in pathogenicity	Ma et al. (2010)

pathogenic *Fusarium* sp. by HCT, made it virulent to tomato. Some of the pathogens such as, *Alternaria* sp. can open out their host range through transfer of a group of genes which codes for host specific toxins by HCT of which enabled them to become pathogenic on new hosts crop such as Apple, Japanese pear, Strawberry and Tomato.

HGT or HCT could be a more efficient mechanism for the emergence of a new pathogen or extend the host range of a pathogen than sexual recombination. HGT or HCT can facilitate adaptation in fungi to novel host crop. Acquiring highly virulent genes such as genes encoding host selective toxins and other pathogenic genes by HGT or HCT can modify the host range of a fungal pathogen or can even lead to development of new pathogen from a nonpathogenic microbe. The techniques of HGT and HCT were not clearly understood and more research is required in this field to understand the mechanisms involved (Mehrabi et al., 2011). Few examples of HGT and HCT are given in Table 16.4.

16.2.4 Hybridization

There is proportionality between evolutionary possibilities of inhabitants and level of genetic variation, which is engendered by sexual recombination between genetically distant individuals. Rapid evolution can be accomplished by hybridization between species, which unites the potential of two or more genome (Brasier, 2000). Increase in infectivity or high disease severity in many fungal pathogen system, have been cognated with recombination and hybridization (Gibson et al., 2014). One of the lucrative evolutionary strategy is inter-specific hybridization between pathogens in which two different genomes combine to promote diversion in a saltational manner, resulting in new combinations of characters, along with those associated with pathogenic factors that greatly differs from their progenitors (Stukenbrock & McDonald, 2008; Depotter et al., 2016). Transfer of a restricted genes among different species, is facilitated by the horizontal gene transfer where as in case of interspecific hybridization entire genomes are involved and can lead to alteration in number of chromosomes, changes in ploidy levels, or extensive rearrangement of genes (Schardl & Craven, 2003).

When a desirable hybrid progeny was able to infect a new host other than those that have been previously infected by either of the parental population, there is a possibility that the newly formed hybrid progeny might have a more level of fitness compared to either of its parents and can proof pathogenic to the new host species (Brasier et al., 1999; Stukenbrock & McDonald, 2008). For example, previously none of the *Alnus* sp. was reported to be infected by any *Phytophthora sp.* But later some of the *Alnus* sp. were susceptible to the interspecific hybrid of *P. fragariae* and *P. cambivora* (Brasier et al., 1999). Allopatric species, are more likely to show hybridization as they lack effective genetic barricades against hybridization and come into contact more frequently in the same habitat (Brasier, 2000; Stukenbrock & McDonald, 2008). With the intensification of world trade in planting material there are more chances for hybridization between previously allopatric fungal pathogens and more is the risk of introduction of their associated pathogens into new biogeographic environments. Increased level of disturbances has lead to increased stress levels on plants such as ecological disturbance causes stress effects on plants. Habitat disturbance, climate change, pollution, geographically 'off-site' planting and crop breeding, all these factors may result in more frequent encounters between different pathogens (Brasier & Mehrotra, 1995; Brasier, 2000).

Ophiostoma novo-ulmi, a pathogen with a migratory history from the 1940s to the 1990s clearly explains how the "escape" of plant pathogenic fungi other than certain selection limitations of its prevalent surroundings offers opportunities for evolution of new traits. It also depicts about the traditional focus of concern that introduced exotic plant pathogens can posses a greater risk to the crop ecosystem. Keeping in mind the mentioned facts, impact of the disease—must include all the risks related to rate of occurrence of evolution in pathogen population and the rise of new or altered pathogens (Brasier, 2000). Organisms of natural ecosystem with slower reproducing rates such as trees, shrubs are more vulnerable to pathogenic evolutions. Among all the plant pathogens, pathogens having a limited range of dispersal, like Phytophthoras (soil-borne) are at higher risks. Some species of Phytophthoras may possess more potential for interspecific hybridization due to their ability to cause infection in wider range of host plants. Other groups of pathogen which are at higher risk may include those which require insect vectors for their dissemination. Oak wilt and Dutch elm disease are the examples are classical examples. By "host jumping," the vectors may play an important role in bringing different introduced and resident pathogens into contact with each other (Brasier, 2001).

Table 16.5 Examples of novel plant pathogens evolved by hybridization

S. No	Host and disease	Parental species	Reported from (location)	References
1	Poplar leaf rust	*Melampsora medusae* and *M. occidentalis*	New Zealand	Spiers and Hopcroft (1994)
		Melampsora mendusae and *M. larici-Populina*	U.S.A (Pacific North-West)	Newcombe et al. (2000)
2	Dutch elm disease	*Ophiostoma ulmi* and *Ophiostoma novo-ulmi*	Europe and South –West Asia	Brasier et al. (1999)
3	Primula and Spathiphyllum root rot	*Phytophthora cactorum* and *Phytophthora nicotianae*	Netherlands	Manin't Veldt et al. (1998)
4	Alder bark necrosis	*Phytophthora cambivora* and a relative of *Phytophthora fragariae*.	Western Europe	Brasier et al. (1999)
5	*Silene* spp. anther smut	*Microbotryum lychnidis-dioicae* and *Microbotryum silenes-dioicae*	U.S.A	Refregier et al. (2008)
6	Powdery mildew of triticale	*Blumeria graminis tritici* and *Blumeria graminis secalis*	Europe	Menardo et al. (2016)

Hybridization enables organisms to acquire new traits to colonize new habitats, it may also be one of the reasons for colonization of novel hosts by the pathogens. Triticale, a hybrid crop made by human, by crossing wheat and rye was introduced in agriculture in the 1960s. Initially the crop was immune to powdery mildew disease but since 2000s the infections by the pathogen were reported on the crop. Recent studies have showed that, *Blumeria graminis* f.sp. *triticale,* the causal agent of powdery mildew of Triticale emerged from crossbreds of two subgroups of *B. graminis*, causal agent of powdery mildew disease of wheat and rye (Menardo et al., 2016). Agroecosystems provide host population in wider areas, and the genetic and environmental uniformity of these monocultures over vast areas is also favorable for the propagation of fit pathogen genotypes (Stukenbrock, 2016). Examples of emergence of novel plant pathogens by hybridization is given in Table 16.5.

16.3 Unifying Role of Agroecosystems

It did not happen that all the disease related to crop plants will occur in all the areas they are cultivated. For the causal agent to cause infection in the host plant its presence must be there at the susceptible stage of the plant coinciding with the environmental conditions being favorable for the occurrence of disease. In some cases, a serious disease may become unimportant one when new disease management technologies are applied. Visa versa, disease with little impact may emerge as the most severe and devastating disease with alterations in cultural practices followed in agricultural ecosystems (Bandyopadhyay & Frederiksen, 1999). Human activities effects on the environment like crop intensification for higher production and global trade and other factors such as may lead to the emergence of new plant diseases (Zaffarano et al., 2008).

Use of highly developed technology in agriculture, for more effectiveness and higher profits and to produce surplus food to meet the demands of growing population, resulted in significant alterations in the agricultural practices. Crop intensification, use of high yielding cultivars, applications novel crop management practices, alterations in choice for food and related policies for food safety, policies for trade of food items, import and export of commodities and movement of people has greatly affected agricultural patterns. All these modifications have certainly resulted in tremendous modifications in various agricultural components (Bandyopadhyay & Frederiksen, 1999). This section explains some of the attributes of agriculture system, which are major driving forces for the appearance of new plant pathogens.

Highly homogeneous or uniform environment of the agroecosystems is one of the major driving factors that can lead to the emergence of plant pathogens (Stukenbrock & McDonald, 2008). The high host densities and host populations with genetic uniformity in coordination with different cultivation practices often create uniform environments that lead to stable pathogen populations and provide favorable conditions for development and transmission of plant diseases (Zaffarano et al., 2008). Pathogen transmission is easier, which also causes an increase in pathogen virulence in the agro ecosystems with increased planting density and high genetic uniformity of host populations (Read, 1994). Natural ecosystems, however has a huge variability and high genetic diversity thus does not promote the pathogen build up as it is there in case of agro ecosystems. Presence of larger population size of pathogen and more variant genotypes of pathogens in agricultural ecosystems increases the opportunities for the pathogens to cause multiple infections in the same host (McDonald, 2014).

Lack of genetic diversity in the host crops in prevailing agro-ecosystems is the root cause for evolution of pathogen. Since the time of emergence of the concept of agro-ecosystems ~12,000 years ago, there have been a steady decline in crop genetic diversity in agro-ecosystems all around the world to make some improvisations in crop cultivation practices, including use of the wave of green revolutions led to the introduction of genetically uniform, high yielding varieties and larger areas coverage with same crop has resulted in replacement of locally-adapted but genetically diverse land races, further depleting genetic diversity and increasing the environmental homogeneity present in agro-ecosystems all over the world. There are various benefits of highly mechanized modern industrial agro-ecosystems which are practiced all around the world such as extremely productive food factories providing sufficient food for the people but there are also few drawbacks that wider area coverage with genetically uniform crops are highly favorable for evolution of pathogens (Stukenbrock & McDonald, 2008). The same factors are responsible for increase in population size of pathogens, causing increase in genetic diversity, more chances of mutations, higher chance of selection. These modifications in agro-ecosystems, over time have increased the evolutionary potential of plant pathogens (fungi, bacteria, viruses) in terms of domestication and adaption according to the prevalent agro-ecosystems (McDonald, 2014).

Cereal rusts and powdery mildew diseases of cereals have gene-for-gene interaction with their hosts and thus have resulted in Boom-and-bust cycles. In most of the cases, variety with a highly effective single resistance gene is cultivated in larger agricultural area (the "boom"). In order to survive the pathogens acclimatize themselves to overcome the effect of that particular resistance gene present in the agro-ecosystem by modifying themselves into new genotypes that could easily conquer this resistance gene (the "bust"). The evolution of the local pathogen population leads to the "breakdown" of genetic resistance through recombinants, selection for mutants, or immigrants that can even cause infection in resistant cultivar (McDonald & Linde, 2002).

The other most prominent reason is mono cropping over large agricultural lands. Fields planted with a single crop in several hectares of land, contain large number of plants. Consequently, the presence of the corresponding pathogen will also be prevalent over larger areas. In large pathogen populations there are more chances of appearance of mutants and they have various options to produce more varied recombinants leading to increase genetic diversity (Stukenbrock & McDonald, 2008).

The third most important factor includes the global trade in crops and germplasm all around the world coupled with less efficient quarantine and monitoring systems (Stukenbrock & McDonald, 2008). Agricultural productivity, worldwide, is greatly hampered by a large number of severe forms of plant diseases. With the expansion of international trade and the concept of resource sharing among the countries the global exchange of agricultural commodities has increased and the easy in movement of people and goods from one country to another has led to the introduction of new pathogens. Emergence of new diseases has not only resulted in yield losses in crops, but also has adversely affected the revenue generated from export since every country is now more concerned about the phytosanitary issues which are associated with the norms of international trade. Movement of the vectors across national boundaries has also increased the threat of disease spread. Sorghum ergot, potato late blight, citrus tristeza and karnal bunt of wheat are some of the important examples of diseases caused by introduction of plant pathogens or vectors (Bandyopadhyay & Frederiksen, 1999). Plant populations are on average 16% more resistant to allopatric pathogen strains than they are to strains that occur within the same population (Laine et al., 2011).

16.4 Steps to Prevent or Slow Down the Emergence of Plant Pathogens in Agro-Ecosystems

Improve the monitoring methods and efficiency to detect the emergence of new pathogens and following all the measures to prevent the spread of disease (Stukenbrock & McDonald, 2008). Invasion of foreign pests may enter through any agricultural commodity gain entry into a disease-free country. With the increase in global trade it is difficult to prevent the entry of harmful plant pathogens. Therefore we need to be more attentive and prepared to prevent the entry of such harmful invasive species. The most prior step is to have complete knowledge to analyze the risk associated with the entry of exotic pathogens and the measures to control it. Protecting agricultural biodiversity against the threat of occurrence of plant diseases caused by invasive pests is need of the hour and it requires certain legal restriction to prevent the entry of harmful invasive alien species (Bandyopadhyay & Frederiksen, 1999).

Re-engineering of agroecosystems is needed to avoid the continuous appearance of novel plant pathogens. Many strategies needed to be followed to slowdown or reduce the chances of rise of novel pathogens. The main purpose of these strategies will be to maintain the genetic diversity into the agriculture systems, to make it less favorable for pathogen emergence. Ways to increase heterogeneity will include faster and more complex crop rotations so that genetic diversity of crop can be increased by cultivating mixtures of species, and by reducing the coverage of a particular crop in agricultural land. Growing multilines or by cultivating different cultivars of the same host plants can increase the genetic diversity of monocultures in space and time (Stukenbrock & McDonald, 2008).

There are a number of examples of major resistant genes being overcome by new races pathogen which provides proof that selection is highly favored in agro ecosystems which follows monoculture and are based on genetic uniformity of crops. A large number of strategies can be followed such as gene deployment in which cultivars with major resistant gene can be grown in different regions which can reduce the selection pressure on the pathogen. The other important strategy is the gene pyramiding method in which several major genes are inculcated into a single variety expecting that the pathogens will not be able to breach the resistance. Another feasible option is growing of mixtures of cultivars with different resistance genes to generate disruptive selection through time and space. These strategies prevent directional selection by favoring different mutant alleles or genotypes at different times and places, reducing the rate at which the mutant allele or genotype increases in frequency. Modern agroecosystems has not completely utilized the potential of gene rotations and mixtures (McDonald & Linde, 2002). Combining agriculture forestry or practicing mixed cropping systems can increase environmental heterogeneity. It is evident that modifications in existing practices of agriculture and forestry systems is not an easy task and it may come with many political, sociological and economic constraints. If somehow we manage to establish such agro-ecosystem we can head towards more sustainable agricultural system and reliable food production for the increasing population (Stukenbrock & McDonald, 2008).

16.5 Recently Emerging Plant Diseases in India

Very little research work has been done in India about origins of plant pathogens in agro-ecosystems. Table 16.6 shows a list of few recently emerging diseases in India.

16.6 Future Prospects

The commercial agriculture and its modified agroecosystems have resulted in an accelerated rate of evolution of new pathogens and new races of existing pathogens. This situation demands for improvement in the monitoring techniques and use of more advanced technologies for easy and quick detection of new pathogens when they emerge. This will require more technological interventions in monitoring and diagnosis and skill development of the scientists to remain updated.

Quarantine procedures needs to be stricter and needs upgrading to detect the new pathogens. As global trade in agriculture is expanding rapidly with sale of seeds and planting material as well as exchange of germplasm, the potential threat of introduction of new pathogens or virulent strains persists. Therefore, the strictness in quarantine should be maintained. In addition, the detection methodologies need constant up gradation to cope up with the new challenges.

Further research is required in actual processes involved in HGT and HCT as they are poorly understood now. Since HGT and HCT are very rapid mechanisms of pathogen evolution, more clarity about the actual mechanism that is occurring during these processes would be very useful.

There is need for more research on re-engineering agro-ecosystems to ensure sustainability. Agro-ecosystem research from a plant pathology point of view is still lacking attention from the plant pathologists. Re-engineering agro-ecosystems to slow down the pathogen emergence has several social, economic, political repercussions. In addition, no general set of principles will work for all the regions. This is

Table 16.6 Emerging plant diseases in India

S. No	Pathogen	Host	Disease	References
1	*Fusarium fujikuroi*	Rice	Bakane	Gupta et al. (2015)
2	*Fusarium moniliformae*	Sugarcane	PokkahBoeng	Vishwakarma et al. (2013)
3	*Puccinia horiana*	Chrysanthemum	White rust	Dheepa et al. (2015)
4	*Cotton leaf curl virus*	Cotton	Cotton leaf curl disease	Sattar et al. (2013)
5	*Xanthomonas auxonopodis*pv*punicae*	Pomegranate	Bacterial blight	Mondal and Mani (2012)
6	*Burkholderiaglumae*	Rice	Bacterial panicle blight	Mondal et al. (2015)

an aspect that requires in detail study followed by practical recommendations. Also, an agro-ecosystem re-engineering research team should have members from scientists, farmers, policy makers and politicians.

In India, there is need for more research on the role of agro-ecosystems on origins of plant pathogens. As discussed in the previous point, In Indian plant pathology research scenario, very little work is done about the origins of plant pathogens that too from an agro-ecosystem view point. The country having world's second largest population should be focusing on this aspect so that whatever agriculture productivity we have now can be further improved and whatever technologies we have today can be used for a long term.

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Chapter 17
Microbial Stewardship- The Integral Component of Sustainable Development

T. H. Shankarappa and B. Subramanyam

Abstract In the beginning of twentieth century, one of the biggest questions asked was, how to feed the increasing population? The developments in science and technology along with revolutionary approaches in adoption of modern scientific methodologies have found solutions to that problem. Adverse effects of these revolutions have affected the balance in different ecosystems. Intensive cropping systems have led to indiscriminate use of chemical fertilizers and pesticides which have created unsustainable soil health conditions. Disturbing the equilibrium of ecosystems by excess use of chemicals is at an alarming rate in recent times. Rapid industrialization and excess indulging of technologies in cropping systems have consequentially led to changes in weather patterns also. This has further lead to the dependency on controlled cropping systems which are also unsustainable in long run. Present technologies employed to overcome these problems are neither eco-friendly nor efficient. Further, they seem to generate secondary compounds which could be even toxic to the environment. Microbial functions in enhancing nutrient availability, plant protection and soil health maintenance have been proven beyond doubt. The mutualistic behaviour of microbes with ecosystems is a considerable strategy to employ them for sustainable development. Bioremediation strategies are promising in overcoming the accumulation of toxic substances. Microbial stewardship seems to be an essential component of sustainable development.

Keywords Soil health · Ecosystem · Mutualistic behaviour · Secondary compounds · Bioremediation

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17.1 Introduction

The stress for agricultural production is growing every day. An intensive agricultural production which is utilising non-renewable resources inadvertently is depleting them at a very faster rate than ever before. Further, discharge of industrial effluents to natural water bodies are polluting the environment and disturbing the functioning of ecosystems (Browne et al., 2013). Today's agriculture is a major and significant cause in increasing the production of global warming gases which affects biosphere stability. The strategies of sustainable development are to be implemented carefully on a global scale looking into various initiatives on a priority basis for sustainability. Sustainable development considers intersections among environment, society and economy (Altieri, 2004), where much of the sustainability depends on soil conservation as the soil hosts numerous environmental, ecological functions and innumerable diversity of microbes.

Sustainable use of soil is possible by minimizing the use of agrochemicals and identifying eco-friendly alternatives for nutrient management and for pest and disease control. Enhancing the biodiversity of soil bio agents and minimizing the stress factors for soil ecosystem functioning could naturally improve the sustainability of soils (Vitousek et al., 1997). Microorganisms do play an important and often critical role in functioning of ecosystems and in maintaining a sustainable production in the biosphere. A recommended approach for sustainable and healthy crop production is by employing the soil microbial communities. This chapter focuses on innate microbial capabilities of plant growth promotion, nutrient cycling, bioremediation and their unique niche in functioning of biosphere and ecosystems. Also, development of potential microbial strains and microbial component-based technologies are discussed as essential global initiatives that are required for sustainable development.

17.2 Microbes, the Suitable Substitutes for Agrochemical Fertilizers

Soil microorganisms mediate plant uptake of nutrients from soil and are essential components of healthy soils that support vegetation (Rajendhran & Gunasekaran, 2008). Most of the plants nutrients, though present around them are unable to be used by plants in the absence of bacteria, they are usually locked up in organic matter. The role of microorganismsin nutrient recycling is well established and is essential to mineralise and to make them available for plant uptake (Rasche & Cadisch, 2013). Flow of nutrients from source to sink in different ecosystems is mediated by bacterial activity majorly, especially determined by rhizosphere microflora. Rhizosphere, is the region of soil that surrounds the roots and has greatest concentration of effective microorganisms which can influence plant growth positively (Hiltner, 1904). Rhizopshere harbours wide range of microbes such as

Table 17.1 Proportion of Nitrogen fixation by different means on a global scale

S. No.	Nitrogen fixation factors	Quantity of Nitrogen fixed (10^6 metric tons per year)
1	**Abiotic**	
	Commercial	Around 50
	Combustion	Around 20
	Natural lightning	Around 10
	Abiotic total	**Around 80**
2	**Biotic**	
	Farming land	Around 90
	Non farming land	Around 50
	Oceans	Around 35
	Biotic total	**Around 175**

Bezdicek and Kennedy (1998)

bacteria, algae, fungi, protozoa, actinomycetes *etc*. All these microbes occupy a unique niche in the rhizosphere. The extent of their association and dependence varies with the plants (Veena et al., 2009).

Fungi are involved majorly in organic matter decomposition, and therefore a major group of microorganisms in nutrient cycling. However, arbuscular mycorrhizal fungi (AMF) are considered to be one of the most important and extensively studied fungi for the activities of biofertilizers and biopesticides (Nadeem et al., 2014). The roles of microorganisms in stimulating the plant towards improved growth and enhancing crop yields have been well recognised by the scientific community. Extent of nitrogen and phosphorus supplied or mobilized through microbes has been studied and is remarkably high. Also, microorganisms effect the plant growth by having an innate association with plants, where they infect the plant and remain inside the plant tissue as endophytes. The diversity of endophytic bacterial species is also wide. The plant growth promoting bacteria belong to different genera, such as *Azospirillum*, *Azotobacter*, *Bacillus*, *Burkhulderia*, *Pseudomonas, Rhizobium* etc. are known to function synergistically in promoting plant growth (Maheshwari, 2013). Fungi are found to be more efficient in recycling of agro-residues to a maximum extent *via* secretion of enzymes (Shankarappa & Geeta, 2013; Gurumurthy et al., 2018).

Interestingly, microbial inoculation to soils is known to enhance root colonization of microbes and thus increase nutrient availability for plants minimizing the use of chemical fertilizers (Ahemad and Kibret, 2014). Microbial inoculation is more effective for plant nutrition and pest management if they are a combination of bio agents than mono inoculants. Combinations of Rhizobacteria, endophytic bacteria and AM fungi have proved to be better in enhancing crop production (Perez et al., 2007).The combined use of endophytic bacteria and plant growth promoting rhizobacteria are believed to be highly effective than their single inoculation which has proved to be a novel approach in recent studies. At global scale the estimates of nitrogen fixation by biological means and by non-biological means indicate the potentiality of biological systems in fixing the major plant nutrient, nitrogen (Table 17.1).

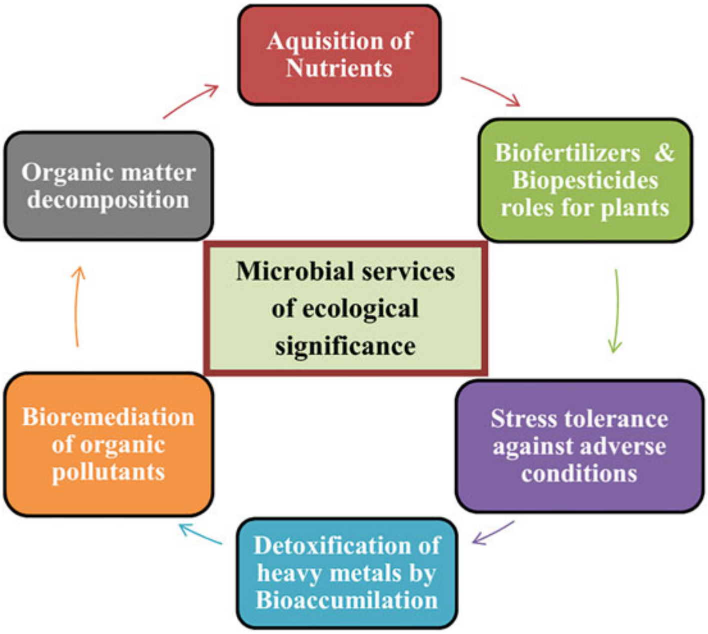

Fig. 17.1 Microbial services of ecological significance for sustainablity

Basically, microbes have evolved in diverse ecosystems and in adverse conditions. During the process of their evolution, they have acquired various mechanisms to thrive in extreme conditions. Their mechanisms of survival are also the services of ecological functioning and stability. Establishment of microbial populations in varied niches are depicted in the context of ecological significance for considerations of sustainable development (Fig. 17.1). Degradation and decomposition of organic matter is a prime service of microbes for any ecosystem's functioning. Meanwhile, nutrient acquisition by decomposition of organic matter and providing those nutrients for associated plant taxa as well as enabling plants to survive in various stress conditions are critical aspects. Unique mechanisms of alleviating metal toxicity, bioaccumulation, bioremediation and many others are inseparable links in sustainable developmental strategies.

Bandi and Sivasubramanian (2012) have reported unique effect of inducing systemic resistance (ISR) against pests due to microbial inoculation. Different mechanisms of environmental acclimatization, pest resistance, tolerance towards heavy metals and high salt concentrations as well as extreme pH makes a positive impact on plant growth, productivity and ecosystem functioning for microbial inoculation (Ahmad et al., 2016; Nadeem et al., 2016). The allelopathic substances produced by bacteria are known to serve in biological control against pests (Sessitsch et al., 2004). The specificity of microorganisms against pathogens makes them most effective bio pesticides as they more environmentally friendly

(Kachhawa, 2017) and thus help to foster environmental sustainability. Their use reduces the harmful effects of agrochemicals which are to used otherwise to manage the pest.

Though fungal pathogens are highly lethal to plants, the presence of bacteria that produce hydrolytic enzymes in soil counter acts fungal pathogens by producing antibiotic substances and by inducing systemic resistance in crop species (Sessitsch et al., 2004).Population of microbial community in rhizosphere fluctuates very much, and is very much responsive to type of plant species, environmental factors such as soil moisture and temperature regimes and physico chemical conditions of soil (Galazka et al., 2017).Although we have knowledge about the role of microbes on plant growth, still we need to know much about unculturable microorganisms. These unknown microbial populations present in the rhizosphere need to be elucidated for their functions as well as specific role in ecosystems to be known as their significance.

17.3 Microbial Role in Plant Growth Enhancement

The microbial functionalities such as nitrogen fixation, production of phytohormones, solubilisation of nutrients, production of siderophores and ACC deaminase directly influence plant growth promotion. N_2 fixing microorganisms contribute up to two third of N fixed worldwide via the process of biological nitrogen fixation by reducing N_2 to ammonia (Kim & Rees, 1994). They are generally classified as symbiotic, associative and free-living nitrogen fixers. Symbiotic microorganisms such as rhizobia with leguminous plants contribute significant proportion of BNF (Zahran, 2001), in addition to other nitrogen fixing microorganisms for plants in significant quantities.

It is interesting to note that bacteria are produce up to 60 times more plant growth regulating phyto hormones than plants themselves (Camerini et al., 2008; Oves et al., 2013;Karthik et al., 2016). Phytohormones are complex in nature and their synthesis by plants involves considerable amount of energy and nutrients, as against bacterial synthesise. The latter produce significant amounts of these phytohormones and release them to plants resulting in pronounced positive effects on plant growth, especially in stress conditions (Table 17.2).

The effectiveness of phytohormones produced by microorganisms in improving crop productivity has been clearly demonstrated (Zahir et al., 2010). The effect of microbial inoculants that produce phytohormones (Table 17.2) that help plants in tolerating different stress conditions is well documented (Zhang et al., 2006). Microbial activities of nitrogen fixation and solubilisation of P, K and Fe mainly along with improvement in soil aggregate stability could reinstate the fertility status of degraded soils (Rashid et al., 2016).

Organic matter decomposition and solubilisation are the key steps in nutrient cycling. The main mechanism in the solubilization of P, K, Fe, and Zn is lowering of pH by production of organic acids. Apart from rhizosphere acidification, release of

Table 17.2 Plant growth promoting microorganisms for growth and yield sustenance

S. No.	Microbial agent	Effect on plant growth
1	*Klebsiella* sp., *Pantoea* sp., *Enterobacter* sp	Combined inoculation of PGPR improved the growth and IAA contents in maize (Rodrigues & Forzani, 2016).
2	*Azotobacter chroococcum*	Reduced environmental stress on plants and improved plant growth (Viscardi et al., 2016).
3	*Bradyrhizobium* sp.	Improved seed and straw yield of soybean along with increased the N, P and S contents (Raja & Takankhar, 2018).
4	*Rhizobium* sp.	Enhanced root and shoot growth of wheat (Kamran et al., 2017).
5	*Azorhizobium caulinodans*	Improved the number, weight of leaves and roots in wheat (Liu et al., 2017).
6	*Bradyrhizobium* sp.	Enhanced the plant N and P uptake, and nodulation in peanut (Argaw, 2018).
7	Arbuscular mycorrhizal (AM) fungi	Improved plant growth and controlled the negative impact of drought stress (Salloum et al., 2017).

bound P is also influenced by production of phosphatase, phytohormones, antibiotics *etc*. Solubilisation of Zn by *Bacillus* strains is known to include many other mechanisms apart from production of organic acids, such as secretion of chelating compounds, amino acids, vitamins, phytohormones, oxidoreductive systems and proton extrusion (Wakatsuki, 1995).

Biocontrol of soil borne pathogens by siderophore production is another activity of bioagents of microbial origin. Siderophores are low molecular mass iron chelating compounds produced by microbes which solubilise iron and increase its availability for microbes and plants (Machuca et al., 2007). Enhanced plant growth and nutrient uptake has been reported due to inoculation of siderophore producing rhizobacteria (Rajkumar et al., 2010).Siderophores are also known to solubilise Fe even from minerals and organic compounds when Fe concentrations are low (Khan et al., 2009). They also form stable complexes with heavy metals and neutralize the toxic effect of heavy metals (Rajkumar et al., 2010).Thus, siderophore producing microbes are helpful in making Fe bio-available by chelation of Fe from mineral and organic compounds and help in uptake of Fe and other minerals in nutrient-deficient soils.

The key microbial roles that are integral components of sustainable agriculture and development are depicted in the picture (Fig. 17.2). The potentiality of these microbial roles is yet to be explored to a better extent. The ecological functionalities of nutrient cycling organic matter decomposition, bioremediation, degradation of recalcitrant and xenobiotics are invariably dependent on microbial populations of soil. Whereas the microbial capabilities of phytohormone synthesis, stress tolerance, detoxification and production of nanoparticles enhances their usage as eco-friendly technologies for development. Advancement of science and research could lead to development of novel tools from microbial genetic resources and molecular tools.

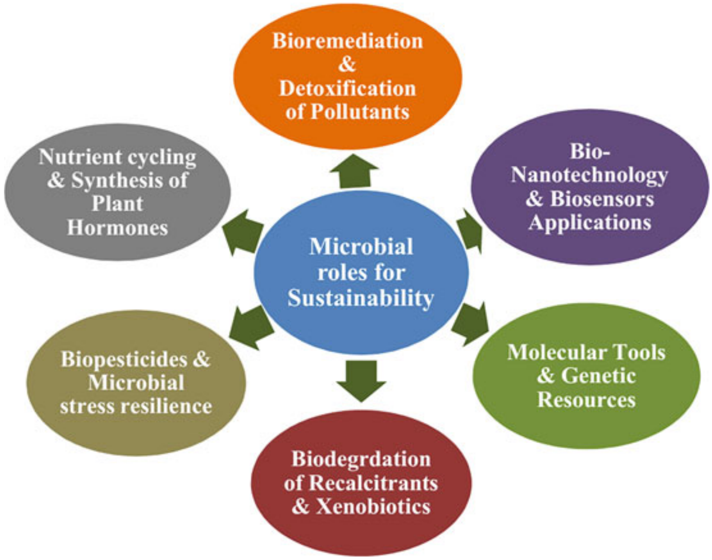

Fig. 17.2 Microbial functionalities of significance for sustainable development

17.4 Microbial Capabilities in Detoxification of Polluted Ecosystems

Microorganisms are being employed to remove pollutants of environments and to remediate contaminants from soils; it has a significant impact in terms of reducing their toxic effectsin our living environments (EPA, 2016). Microbial agents have the capabilities to detoxify pollutants and are hence employed for remediation activities (Uqab et al., 2016). PGPR which fall under bioremediation can be efficiently employed to reinforce plant growth in such affected problematic soils, degraded soils and water bodies by detoxification from the environment (Gouda et al., 2018). They contain enzyme systems that could mineralize industrial effluents (Pandey et al., 2007) via process called bioremediation. The list of microorganisms used in bioremediation is listed in Table 17.3.

Bioremediation process involves transformation of aromatic compounds to harmless or less toxic compounds by microorganisms and to degrade recalcitrant and xenobiotic materials (Xu et al., 2017). Xenobiotics refer to chemically complex compounds that are resistant for degradation. Screening studies have revealed bacterial strains that efficiently degrade the xenobiotic/recalcitrant compounds. Degradation of industrial effluents by fungi, algae, and yeast has been demonstrated (Olguin, 2003). Studies on use of mixed cultures for detoxification process and for in situ application need to be emphasised.

Polycyclic aromatic hydrocarbons (PAHs) are organic pollutants, most are carcinogens and mutagens. They possess complex structure, high hydrophobicity and difficult to degrade qualities which pose a long-lasting hazard to the environment

Table 17.3 Potential microorganisms of bioremediation

S No.	Microbial agent	Bioremediation potential
1	*Aspergillus foetidus*	Decolorized several azo dyes (Sumathi & Phatak, 1999).
2	*Brevibacillus laterosporus* MTCC 2298	87% decolorization within 24 h American Dye Manufacturing Institute (Kurade et al., 2011).
3	*Bacillus* sp. ADR	Decolorized different azo dyes between 68% and 90% (Telke et al., 2011).
4	*Pseudomona putida*	Removed 95% color and 92% COD textile effluent (Babu et al., 2011).
5	*Bacillus* and *pseudomonas*	Reduced the toxicity and concentrations of pollutants (Fosso-Kankeu et al., 2011).
6	*Bacillus licheniformis* LS04	Removed more than 80% color in 1 h at pH 6.6 or 9.0 (Lu et al., 2012).
7	*Tinctoporiaborbonica*	Decolorized pulp and paper industry waste (Senthilkumar et al., 2014).
8	*Penicillium oxalicum*SAR-3	Decolorized the dyes (Saroj et al., 2014).
9	*Aspergillus Niger*	Decolorized of pulp and paper industry effluent (Kamali & Khodaparast, 2015).
10	*Lenzites elegans* WDP2	Decolorized congo red, brilliant green, malachite green and by 99, 93 and 21% respectively (Pandey et al., 2018).

(Johnsen et al., 2005). However, successful bioremediation of these compounds as cost-effective, feasible, and natural process has been documented (Anwar et al., 2016). Variety of microorganisms, such as bacteria, fungi and actinomycetes are capable of bioremediation, however, bacteria are considered to be highly reliable (Johnsen et al., 2005). Although, prolonged exposure of microorganisms to certain agrochemicals have resulted in lower efficiency, still they can be used to bioremediate pesticide-contamination (Khan et al., 2009). Their ability to degrade pesticides for carbon or energy source makes them eco-friendly candidates to detoxify chemicals as well as elimination of harmful substances from the environment (Qiu et al., 2009; Reddy et al., 2016).

The gradual decreases in effect of individual pesticides haveled to the use of combination of pesticides against pests (Moreby et al., 2001). To degrade such complex pesticides genetically engineered microorganisms (GEM) inoculants are found to be effective (Zhang et al., 2016). Heavy metals released as waste by anthropogenic activities are the major pollutants. They could be detoxified by selected Microbial strains which have developed resistance for heavy metals and thus could be the agents of bioremediation and detoxification of heavy metals. Chemiosmosis in microbes is found to be very effective in accumulating heavy metals within the microbial body (Nies, 1999). Substitution of essential nutrient elements with the toxic pollutants in microbial cells could affect them adversely (Nies, 1999). Different mechanisms of resistance to toxic heavy metals has been

Table 17.4 Specific biocontrol agents of plant pathogens

Biocontrol agent	Target plant pathogen and disease
2, 4-diacetylphlorogLucinolProduced by *Pseudomonas fluorescens* F113	Controls *Pythium spp* damping off
Agrocin 84 Produced by *Agrobacterium radiobacter*	Controls *Agrobacterium tumefaciens* crown gall
Bacillomycin D produced by *Bacillus subtilis* AU195	Inhibits *Aspergillus flavus* and prevents Aflatoxin contamination
Bacillomycin, FengycinFZB42 produced by *Bacillus amyloliquefaciens*	Controls *Fusarium oxysporum* wilt
Xanthobaccin A produced by *Lysobacter* sp. strain SB-K88	*Aphanomycescochlioides* damping off
Iturin A produced by *B.subtilis*QST713	*Botrytis cinerea* and *R. solani* damping off
Mycosubtilin produced by *B. subtilis* BBG100	*Pythium aphanidermatum* damping off
Phenazines produced by *P. fluorescens* 2–79 and 30–84	*Gaeumannomyces graminis* var. *tritici* take-all
Pyoluteorin, Pyrrolnitrin produced by *P. fluorescens* Pf-5	*Pythium ultimum* and *R. solani* damping off
Pyrrolnitrin, Pseudane produced by *Burkholderia cepacia*	*R. solani* and *Pyriculariaoryzae* damping off and rice blast
Zwittermicin A produced by *Bacillus cereus* UW85	*Phytophthora medicaginis* and *P. aphanidermatum* damping off

Source: Pal and McSpadden (2006)

noticed in microbial cells such as sequestration, reduction of metals by enzymatic activity, sorption reactions, release of extracellular polymeric substances (EPS) and many more of such mechanisms (Liu et al., 2004; Xu et al., 2017).

Different mechanisms that are efficient and that could be employed for heavy metal removal have been identified (Liu et al., 2004; Xu et al., 2017). Bioaccumulation is a mechanism that could concentrate and retain heavy metals in the cells of microbes. This mechanism is most effective in decontaminating soil and water bodies (Akhter et al., 2017). Studies have been taken up identify microorganisms from polluted environments for bioremediation purposes and for of xenobiotic compounds (Ahemad, 2012). Bioaugmentation is another process wherein microorganisms detoxify polluted soils (Emenike et al., 2016; Fauziah et al., 2017). Several microbial isolates have been identified with special mechanisms to remediate polluted environments (Emenike et al., 2016).

Phytoremediation is another ecofriendly approach for detoxification of heavy metals which also indirectly relies on microbial number and diversity. Improving the activity of beneficial microorganisms in rhizosphere could significantly improve phytoremediation process as well (Ojuederie & Babalola, 2017). The effect of inoculation of different microbial agents on plant pathogen has been listed below in Table 17.4.

17.5 Microbes, the Evergreen Sources of Sustainable Development

The microbial activities in rhizosphere change and respond to various biotic and abiotic stress factors of rhizosphere. Studies on mechanisms of pants and rhizosphere microflora sensing the stress factors and activation of response are being clearly understood for their optimization and deployment. The role of microbial populations in alleviating or combating the stress factors that could be detrimental to plants and natural ecosystems are being discussed for their practical applications.

17.5.1 PGPR as Biocontrol Agents

PGPR affect plant growth directly as well as indirectly, direct promotion of plant growth is mainly by supplying the plant with a compound that is synthesized by the rhizobacteria which facilitate the uptake of certain nutrients from the rhizosphere environment (Glick, 1995). The indirect promotion of plant growth is by preventing the infection and diseases of plant pathogens. A particular PGPR may affect plant growth and development by using one or more of these mechanisms. Bacteria that reduce the incidence or severity of plant diseases are often referred to as biocontrol agents whereas those that exhibit antagonistic activity toward a pathogen are defined as antagonists (Beattie, 2006). The bacterial antagonistic activities is ensured through synthesis of hydrolytic enzymes, such as chitinases, glucanases, proteases, and lipases, that can lyse pathogenic fungal cells (Neeraja et al., 2010), compete with pathogens for want of nutrients and suitable colonization sites at the root surface, they also regulate the plant ethylene levels through the ACC-deaminase enzyme, this regulation of ethylene levels in plants is triggered in response to stress induced by the infection and production of secondary metabolites viz. siderophores, bacteriocins and antibiotics. Bacteria produce a battery of compounds having antimicrobial properties that include broad-spectrum antibiotics, organic acids, lytic agents (lysozymes, several types of exotoxins and bacteriocins) having bactericidal action. Antibiotics, bacteriocins and siderophores are the most effective compounds recognized to possess PGPR as well as biocontrol abilities on phytopathogenic organisms.

17.5.1.1 Siderophores

Siderophores are small peptidic molecules containing side chains and functional groups that can provide a high-affinity ligands to ferric ions. Bacterial siderophores are classified into four main classes (carboxylate, hydroxamates, phenol catecholates and pyoverdines). Wide number of siderophores have been identified in culturable microorganisms, they are produced to meet the iron requirement, where the bacteria have evolved highly specific pathways like siderophores. Siderophores are secreted to scavenge and transport iron in to their cell, from their surrounding environments, forming a ferric-siderophore complex that can move by diffusion. Siderophores can chelate ferric ion with high affinity and extracts iron from most mineral or organic complexes. The reduced ferrous (Fe^{2+}) form of iron is unstable and is readily oxidized to the ferric (Fe^{3+}) form under aerobic conditions at acidic pH, where a poorly soluble iron is unavailable to biological systems. The bacteria, *Pseudomonas* sp. possess highly potent siderophores. The pyoverdin is one potent siderophore produced by *Pseudomonas*, pyoverdin has the ability to inhibit the growth of bacteria and fungi which does not produce siderophores or those which produce less quantity of siderophore in iron-depleted media. Kloepper et al. (1980) had isolated *P. putida* B10 strain that produce pseudobactin, a siderophore that can suppress *Fusarium oxysporum* in soil deficient in iron.

Three major groups of siderophores are identified in microorganisms; they are hydroxamate, catecholate (phenolates) and carboxylate (complexones) siderophores. Hydroxamate siderophorer are produced by bacteria and fungi, they possess hydroxamate groups, C (=O) N-(OH) R, where R is an amino acid or a derivative. Hydroxamate siderophores absorption is more strong at 425 and 500 nm when bound to iron. (Messenger & Ratledge, 1985). Catecholate (phenolates) siderophore, is produced by species of *E. coli, S. typhimurium* and *K. pneumonia* and is the typical prototype of the catecholate siderophore. Agrobactin and parabactin are produced by *Agrobacterium tumefaciens* and *Paracoccusdenitrificans* respectively. *Pseudomonas* produces a mixed catecholate-hydroxamate siderophore (Leong & Neilands, 1982). Carboxylate (complexones) siderophore is different from catecholates and hydroxamates. Rhizobactin is the best characterized carboxylate type siderophore with a novel structure, is produced by *Rhizobium meliloti* strain DM4, it is an amino poly carboxylic acid containing iron- chelating groups like ethylene diamine dicarboxyl and hydroxy carboxyl moieties. Staphyloferrin A, produced by *Staphylococcus hyicus* DSM20459 (Schwyn & Neilands, 1987), is another member of this class of complexon siderophores.

17.5.1.2 Bacteriocins

Bacteriocins are the molecules of microbial defense systems. Bacteriocins are not antibiotics, they commonly have a very narrow killing spectrum and are only toxic to bacteria of closely related species to the producing strain. The colicins proteins (bacteriocins), are produced by some strains of *Escherichia coli,* which are most common bacteriocins produced by genera of Gram-negative bacteria. Pyocins are another well-known bacteriocins produced by *P. pyogenes* strains. Cloacins produced by *Enterobacter cloacae*, marcescins by *Serratia marcescens* and megacins by *B. megaterium* (Cascades et al., 2007) are other common bacteriocins. The bacteriocins produced by *Bacillus* spp. are considered to possess broad spectrum action. They inhibit wide range of microorganisms *viz*. Gram-negative and Gram-positive bacteria, yeasts or fungi.

17.5.1.3 Antibiotics

The production of one or more antibiotics is one of the property of associated with microorganisms, particularly plant growth-promoting bacteria (Glick et al., 2007). Antibiotics are heterogeneous group of organic, low-molecular-weight compounds that are deleterious to the growth or metabolic activities of other microorganisms at very low concentrations (Duffy, 2003). The antibiotics either kill or reduce the growth of the target pathogen. The various antibiotics are produced by PGPR and regulate plant pathogens as seen Table 17.4. There are six classes of antibiotics related to the biocontrol of root diseases. They are diffusible antibiotics belonging to phenazines, phloroglucinols, pyoluteorin, pyrrolnitrin, cyclic lipopeptides and hydrogen cyanide (HCN). Lipopeptide bio surfactants produced by *Pseudomonas* and *Bacillus* species is the latest and highly potential antibiotic implied in biocontrol of pathogenes including bacteria, fungi, protozoa and nematodes (Raaijmakers et al., 2010). Similarly, pyrrolnitrin is an antibiotic produced by the *P. fluorescens* BL915 strain that suppress *Rhizoctonia solani* damping-off in cotton plants. The 2,4-diacetylphloroglucinol (DAPG) produced by pseudomonads, causes membrane damage of *Pythium* spp. and suppress their growth, it is particularly inhibitory to zoospores of oomycete (de Souza et al., 2003). Phenazine, produced by pseudomonads, suppress *Fusarium oxysporum* and *Gaeumannomyces graminis* pathogenes (Chin-A-Woeng et al., 2003). Polymyxin, circulin and colistinare other antibiotics produced by *Bacillus* spp. which are active against Gram-positive and Gram-negative bacteria, as well as many pathogenic fungi. The antibiotics zwittermicin A (aminopolyol) and kanosamine (aminoglycoside) produced by *B. cereus* UW85 strain (Silo-Suh et al., 1994), suppresses oomycete and contributes to the bio-control of alfalfa damping off.

17.5.1.4 Induced Resistance (ISR and SAR)

Induced systemic resistance (ISR) is imparting active plant defense responses to infection by phytopathogens. It is the effective defense strategy developed by plants in response to appropriate stimuli such as pathogen infection. Rhizobacteria-mediated ISR resembles pathogen-induced systemic acquired resistance (SAR), where both render resistance to uninfected plants against infection by plant pathogens of fungi (Kirk & Schafer, 2015), bacteria (Dubois et al., 2017) and virus. It is also extended to infection by nematodes and insects (Eski et al., 2017). Specifically, *Pseudomonas* and *Bacillus* spp. are the rhizobacteria that trigger ISR. The terminology, ISR is used to depict induced systemic resistance promoted by non-pathogenic rhizobacteria or PGPR, irrespective of the signaling pathway involved in this process, while the term SAR is used to describe salicylic acid-dependent induced resistance triggered by a localized infection. Induction of SAR is through salicylic acid (SA) and ISR is through jasmonic acid (JA) and ethylene (ET) signaling pathways. These signaling molecules coordinate the defense responses are sufficient

Table 17.5 New promising biologicals which could replace chemical pesticides

S No.	Biologicals	Target pests
1	*Talaromyces flavus* strain SAY-Y-94-01	Anthracnose of *Glomerella cingulata* and *Colletotrichum acutatum* (Ishikawa, 2013)
2	*Trichoderma harzianum* (derived products)	*Fusarium* root rot (Kirk & Schafer, 2015)
3	*Bacillus thuringiensis var. Tenebrionis (*strain, Xd3-Btt-Xd3)	Alder leaf beetle (*Agelastica alni*) (Eski et al., 2017)
4	Oxymatrine (alcaloid)	*Spodoptera litura*, *Helicoverpa armigera*, *Aphisgossypii* (Rao & Kumari, 2016)
5	*Lactobacillus caseistrain* LPT-111 (fermentation products)	*Xanthomonas fragariae* Angular leaf spot (Dubois et al., 2017)

to induce resistance. The protection mediated by ISR is significantly less than that obtained by SAR but ISR and SAR together provide a better protection than each of them alone.

There are several biocontrol agents being produced worldwide to manage the pest. Around 700 products derived from microorganisms are available worldwide. Some promising microorganisms of biocontrol potential are listed in Table 17.5. In India, around 16 commercial Bt preparations, 38 fungi and 45 viruses that are available as bio control agents are expected to replace at least 10 per cent of chemical pesticides.

17.5.2 Microbes with Enhanced Osmotic Stress Tolerance

The symbiotic association of mycorrhizal fungi with plants and several PGPR microbial populations are known to ameliorate the effective of drought and salinity problems on plants by better regulation of plant water status and by many other mechanisms, in general leading to increased plant resistance to osmotic stress conditions (Aroca et al., 2012).

17.5.3 Role of Microbes in Phytoremediation of Contaminated Soils

The associative microbial population of plants is understood to enhance the remediation capability of plants. The associative effect of plant microbial population is being presently employed as technology of improved phytoremediation to detoxify toxicants of soil ecosystem (Azcon et al., 2013). The process of remediation by plants is possible only when the plants involved and microflora associated were able to survive in polluted environment. Mainly heavy metal detoxification and degradation of xenobiotic compounds is attempted by phytoremediation (Azcon et al., 2013).

17.5.4 Effect of Plants in Developing Their Rhizosphere Microbial Community

Current research is realizing that plants have their beneficial microbial community in rhizosphere, plants can structure their roots to allow associated microbial communities to establish, both for diversity and functions (Achouak & Haichar, 2013). Stable isotope probing (SIP) together with fingerprinting approaches as a molecular detection tool are helpful to analyze the impact of the plant species on their rhizosphere microbiome. It is confirmed that there is differential impact for each target plant species on the genetic and functional diversity of the plant-associated bacterial communities. The specificity of plant exudates in rhizosphere of each plant species does influence the establishment of selective microflora and further form associated microflora of that plant (Hirsch et al., 2013).

17.5.5 The "Biased Rhizosphere" Concept

The concept of "biased rhizosphere" refers to the mechanism of provoking, activity of selected microorganisms in rhizopshere by production of special compounds by plants. Studies on better understanding and reprogramming of plant transport functions and that of microbial uptake of secreted nutrients is essential, and the consequent time-course changes in the microbial community structure can enhance the competitiveness and persistence of bacteria in the biased rhizosphere. These aspects finally lead to improved plant health and agro-ecosystem productivity.

17.5.6 Scientific Advancements, Fostering Novel Microbial Tools for a Promising Future

17.5.6.1 Bio Nanotechnology

The field of nanotechnology has given rise to different nanomaterials which are in the forefront of application in various fields (Kumar et al., 2003). The need for synthesis of materials by eco-friendly means is emphasized in general context. Hence, the possibilities of synthesis of nanoparticles by biological means have been explored. Bio nanotechnology is a new field which envisages use of microbes for the synthesis of nanoparticles.

Microbial synthesis of inorganic materials is a known fact. The biotechnological applications such as remediation of toxic metals by bacteria (Stephen & Macnaughton, 1999) and fungi (Mehra & Winge, 1991) is very well understood, their potentiality as eco-friendly nanoparticles to clean up the affected environments have been explored in the recent past. Natural synthesis of inorganic materials at nano scales need to be developed, it is a novel and unexplored area of research in which microbes are used for the biosynthesis of nanomaterials (Sastry et al., 2004).

17.5.6.2 Fungal Synthesise of Nanoparticles

Synthesis of nanoparticles by fungal agents has been proven in recent times. Though fungal production of biosynthetic is in large quantities and are good to culture them in invitro conditions, their genetic modification for a desired character such as for nanomaterial synthesis is not simple compared to prokaryotic bacteria. A large-scale screening of microbial isolates resulted in yielding of large quantities of metal nanoparticles (Ahmad et al., 2003). Studies have proved the capabilities of different categories of microorganisms such as bacteria, yeasts, algae, fungi, and actinomycetes in their biosynthetic capability nanoparticles.

17.5.6.3 Microbial Biosensors

Biosensor refers to an analytical device capable of biological sensing and a transduce to produce a signal. Most commonly, enzymes are used as biological sensing elements in fabrication of biosensors (Mulchandani & Rogers, 1998). The purified enzymes are very specific, involves costly and tideous processes. Microbes can be the alternatives foe enzymes although they are less specific than enzymes. Scientific advancements through engineering it is made possible, of microbes to increase the concentrations of existing enzymes or to express desired foreign enzymes in the host cell (Belkin, 2003). Many physical and chemical methods are now available to immobilize microbes on to transducers or support matrices (Mulchandani & Rogers, 1998).

Biosensors for environmental, food, military, and biomedical applications have been developed and recent developments in microbial genomics as well as DNA technology may result in the development of microbial biosensors for extreme conditions and with more specific applications in the future.

17.6 Conclusion and Future Prospects

Green revolution, industrialization and urbanization have affected fertile lands, healthy ecosystems and have contaminated soil and water resources. This paper has reviewed the potentialities of microbial mechanisms for sustainable development and amelioration of degraded soils and affected ecosystems as well as to sustain the environment with the use of microorganisms. It demonstrated that microbes are effective substitutes for beneficial effects of agrochemicals and can detoxify sewage, industrial effluents and petroleum products. Microbes have mechanisms to decontaminate polluted sites, to degrade organic recalcitrant and to detoxify inorganic compounds. In addition, plant growth promoting mechanisms of microbes reduce the need for agrochemicals. This review reveals the multifaceted capabilities of microorganisms that make them successful as biofertilizers, biopesticides in different cropping systems and as effective detoxicants in polluted environments. The possibilities of genetically engineering microbes and using combinations of microbes as inoculants for specific objectives will enable them to be novel microbial tools in nature. However, the un-culturability of several microorganisms and complexity of their mechanisms indicate that only the tip of iceberg has been understood, while the vast majority of possibilities with microbial agents is yet to be unravelled.

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Chapter 18
Clubmosses (*Huperzia* Bernh.) of North East India: Genetic Resources, Utilization and Sustainability

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Abstract The Club mosses, sometimes called as Tassel ferns of the genus *Huperzia* Bernh. (Lycopodiaceae) are hanging ferns best known throughout the world for their graceful foliage and used extensively as ornamental epiphytes. They are characterized by dichotomously branched vegetative stems with isomorphous sporophylls bearing kidney-shaped sporangia. They are also known as wonder moss due to their highly medicinal and pharmacological significance, thereby playing a domain role in treatment of multiple ailments like schizophrenia, neuromuscular disorders, impairments in motor functioning, Alzheimer's disease, Parkinson's disease, myasthenia gravis, dementia, organophosphate poisoning, treatment of contusions, strains, swellings etc. Many of the club mosses are rich source of lycopod alkaloids like huperzine A, lycopodines, lycodines, phlegmarines, carina–tumine etc. which are used in treatments of the various disorders of brain. In the North Eastern states of India which is comprised of eight (8) states, altogether thirteen (13) species of club mosses are recorded, out of which three (3) club mosses, viz. *Huperzia phlegmaria* (L.) Rothm., *Huperzia serrata* (Thunb.) Rothm. and *Huperzia squarrosa* (G. Forst.) Trevis. are extensively used for their medicinal, ornamental and cultural significances. In Manipur, these ferns are considered highly sacred and used in many important religious and cultural ceremonies by the Meitei community. *Huperzia serrata* is used as an ingredient of herbal drink in states of Nagaland, Arunachal Pradesh and Meghalaya. As the club mosses has high economical prospect both medicinally as well as ornamentally, they are exploited on large scale from their natural habitat. Active trading on large scale is carried out between local plant

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collectors and buyers in most of the North Eastern states. This very area is the point where the question of species sustainability of club mosses becomes very crucial. For the time being, there are no scientific researches on species diversity database, propagation protocols, guidelines for harvesting, value addition, and marketing strategies for commercial activities. There are no special monitoring cells for formulating out the conservation status of the club mosses of North East India, and no legislatures to check the illegal harvesting of the club mosses. In the present paper, the species diversity of *Huperzia* in North East India is discussed with special reference to their utilization and sustainability, and special guidelines on harvesting and recommendations on conservative measures are also studied.

Keywords Club Mosses · Species Diversity · Medicinal · Ornamental · Sustainability · North East India

18.1 The Club Mosses: Distribution and Morphology

The common club mosses or tassel ferns, *Huperzia* Bernh. (Lycopodiaceae) are epiphytic lycopods native to New Zealand, Australia, China, India, Malaysia, Australasia, Africa Madagascar and Pacific Islands. They are seedless vascular plants and are regarded as one of the oldest groups of plants on Earth and grow in high altitude ranging between 1500 to 3000 m. Known for their grace and beauty, they make a stunning specimen hanging in corridors, lawns, gardens, arboreta, verandas, glass houses, etc. (Jones, 1987; Singh et al., 2015). In many parts of the world, they are used as basket ferns and also adorn the bouquets due to their long-lasting lust green looks for many days without drying up. They usually grow in moist forests and can also adapt to terrestrial and lithophytic conditions if given proper nutrition and water. However, they usually prefer light shaded climatic conditions and a humus-rich soil for their growth and nourishment (Vashishta, 1995; Kholia, 2010).). Earlier, all the club mosses were included in the genus *Lycopodium* L., but later place them in the genus *Huperzia* based on their dichotomous branching, growing habit, nature of strobili, ornamentation of spores (Wilce, 1972; Holub, 1985, 1991).

Plants are erect, differentiated into aerial pendulous stem and rhizomes which perform the function of root for attachment to substrate and for acquisition of nutrients, water and to retain moisture. Unlike in higher ferns, true roots are absent in club mosses and can be seen only on aerial stem portion. Shoots are either determinate with entire plant dying after several years of spore production or indeterminate (entire plant not dying after several years) and grows in clustered to decumbent nature. A unique feature of dichotomous branching in regularly isotomous condition is observed in all the club mosses. Leaves are microphyllous, often stalk less, crowded as in the case of *H. squarrosa* or sparsely arranged as in *H. phlegmaria*, monomorphic or varying in shape or size according to seasonal growth patterns and the margins may be dentate to entire. Sporophylls are mostly isomorphous with vegetative leaves, terminal in nature and most of the sporangium remains exposed and assume a reniform-shaped. Spore ornamentation in *Huperzia* is pitted (foveolate) to shallowly groove in most cases, and the proximal surfaces remain unornamented. Gametophytic structures are simple, minute, sub-terranean in nature, non-photosynthetic, mycorrhizal and linear to elliptic in outline.

18.2 Species Diversity and Growing Condition

A total of 415 species of *Huperzia* are distributed throughout the world and around 20 species were recorded from India (Ghosh et al., 2004; Singh & Singh, 2010). After compilation of various works in North East India (Arunachal Pradesh, Assam, Meghalaya, Manipur, Mizoram, Nagaland, Tripura, Sikkim), a total of 13 species have been reported from the eight (8) states which is about 65% of the reported Indian species showing great diversity of club mosses in this region. Among the North Eastern states, Arunachal Pradesh represents maximum diversity of *Huperzia* with a total report of 10 species followed by Sikkim with 7 species. A representation showing the distribution of club mosses in the NE states is highlighted in Table 18.1 and Fig. 18.1.

Most of the species under the genus *Huperzia* grows as an epiphyte in deep cool interior forest with abundant humidity. It prefers low intensity of light and grows along with other epiphytic ferns (*Nephrolepis*, *Microsorium*, *Pyrrosia*, *Davallia*, *Oleandra*), mosses, orchids etc. Some of the common repository host trees include *Stereospermum personatum* (Hassk.) Chatterj., *Alnus nepalensis* D. Don, *Ficus religiosa* L., *Toona ciliata* Roem., *Castanopsis cuspidata* (Thub.) Schott. etc. New sporophylls are produced usually during the rainy season and grow luxuriantly (Clarke, 1880; Bir et al., 1989).

18.3 Wonder Mosses: Medicinal and Chemical Properties

Many species of *Huperzia* possess high medicinal value and included in many Encyclopaedias of the world including the Chinese Medicinal Herbs, United States Pharmacopoeia, Encyclopaedia of Herbs and Herbalism, American Folk Medicine etc., and spotted in few prestigious world database plant repositories like Wealth of India, as potential medicinal plant under FAO of United Nations (Stuart, 1979; Meyer, 1973). Species under the genus contains a large group of alkaloids called Lycopodium alkaloids, which are extensively used in treatment of various diseases of brain like Alzheimer, Parkinson, schizophrenia, dementia, swelling of brain, myasthenia gravis, contusions, strains etc. (College, 1985; Chang & Butt, 1987; Ma, 1997; Ma & Gang, 2004; Sun et al., 1999). Besides, it is also used for traumatic injury, rheumatic pain, arthritis, sore throat, edema and urticaria in Chinese medicine (Karthik et al., 2011; Wang et al., 2016). The aerial parts contain rich source of key alkaloids like Huperzine (Hup A, Hup B, N– methyl–huperzine), Huperzinine,

Table 18.1 Distribution of *Huperzia* in the North East States of India

Huperzia sp.	Distribution	Reference
Huperzia cancellata (Spring) Trevis.	Arunachal Pradesh	Fraser-Jenkins (2012)
Huperzia ceylanica (Spring) Rothm.	Arunachal Pradesh, Meghalaya	Chandra et al. (2008)
Huperzia dixitiana P. Mondal & R.K. Ghosh	Arunachal Pradesh	EIA Directorate (2013)
Huperzia fordii (Baker) Holub	Sikkim	Kholia (2011)
Huperzia hamiltonii (Spreng.) Trevis.	Arunachal Pradesh, Sikkim, Assam, Meghalaya	Singh et al. (2012)
Huperzia herteriana (Kümmerle) T. Sen & U. Sen	Arunachal Pradesh	EIA Directorate (2013)
Huperzia petiolata (C.B. Clarke) R.D. Dixit	Sikkim, Meghalaya, Arunachal Pradesh, Manipur.	Rawat et al. (2014)
Huperzia phlegmaria (L.) Rothm.	Arunachal Pradesh, Assam, Manipur, Meghalaya, Sikkim,	Singh et al. (2012)
Huperzia pulcherrima (Wall. ex Hook. & Grev.) T. Sen & U. Sen	Mizoram, Arunachal Pradesh, Manipur Meghalaya, Sikkim, Tripura	Bir et al. (1989) and Rawat et al. (2014)
Huperzia quasipolytrichoides (Hayata) Ching	Arunachal Pradesh	Chandra et al. (2008)
Huperzia selago (L.) Bernh. ex Schrank & Mart.	Sikkim	Kholia (2011)
Huperzia serrata (Thunb.) Trevis.	Sikkim, Arunachal Pradesh, Assam, Meghalaya and Manipur, Mizoram, Tripura	Sharma et al. (2017)
Huperzia squarrosa (G. Forst.) Trevis.	Sikkim, Assam, Meghalaya, Manipur, Nagaland, Mizoram	Yumkham and Singh (2011) and Sharma et al. (2017)

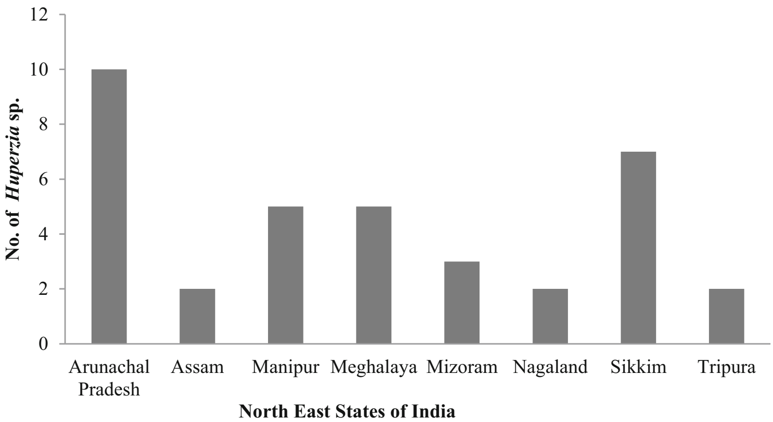

Fig. 18.1 Reported No.of *Huperzia* sp. from NE states of India

Hupermine A, Huperphlegmines A and B, Lycopodine and Carina–tumine (Hirasawa et al., 2014; Yang et al., 2016). Huperzine A also formed an ingredient of dietary supplement for memory loss and mental impairment and sold in large scale in many parts of the world. This drug has high antioxidant and neuroprotective properties, shows effectiveness against seizures or status epilepticus (Coleman et al., 2008). Huperzine alkaloid extracted from club mosses has also been shown to enhance memory in adolescent middle school students and used in several disorders of brain function.

All lycopods including the club mosses are the source of *Lycopodium* alkaloids and around 141 alkaloids have been isolated so far (Ma et al., 2007; Hirasawa et al., 2009). Comparison of all the existing literature on the uses of club mosses per country wise basis, it was observed that the Traditional Chinese Medicine used this plant most extensively in treating schizophrenia, Alzheimer's disease, swellings and organophosphate poisoning (Ma, 1997). One of the most important alkaloids is Huperzine A (Hup A) and have better penetration through blood brain barrier and also a powerful reversible inhibitor of acetyl cholinesterase (Wang et al., 2006). According to Li (2008) and Bai et al., (2000), Huperzine A possesses beneficial effects in improving the global clinical status, general cognitive function, behavioural disturbance and functional performances in Alzheimer's disease. It also shows effective against the reduced acetylcholine levels in the brain and glutamate induced neuronal death, which are the most common neuronal disorders manifested in patients with Alzheimer's disease. It also enhanced memory power in children who had language and impairments in motor functioning (Liao et al., 2002). According to Singh and Singh (2010), the Hup A content in *H. phlegmaria* is 345.23 ± 0.18 μg/g. Besides, various alkaloids of this species have been isolated, *viz*, Anhydrodihydrolycopodine, hydroxylycopodine, lycodoline, fawcettidine, lycophlegmarine (Southon & Buckingham, 1989). According to Rouffiac (1963), both *H. squarrosa* and *H. serrata* shows the presence of Lyconesidine C, lycopodine, lycodine 8–Deoxy–13–dehydro–serrstinine, epidihydrofawcettidine and lycoflexine. Other prominent alkaloids include Methylphlegmarine, Phlegmarine Lycophlegmariols A–D and Hupermine A (Nyembo et al., 1978; Inubushi & Harayama, 1982; Ma & Gang, 2004; Wittayalai et al., 2012; Hirasawa et al., 2014; Wang et al., 2016). The amount of Hup A in case of *H. squarrosa* is 378.83 ± 0.33 μg/g and 80.16 ± 0.17 μg/g in *H. serrata.* According to Lallement et al. (2002), Huperzine A extracted from *H. serrata* is a high-ranking candidate for a prophylactic agent to prevent brain injury from organophosphate nerve gas poisons. A wide range of alkaloids are isolated from *H. selago* and includes acrifoline, lycopodine, 6 α - hydroxylycopodine, lycodoline, isolycodoline, serratidine, selagoline and 6-hydroxyhuperzine A (Dan et al., 2004). Besides, many of the medicinal club mosses found in India are highlighted in Wealth of India and listed as essential raw material having potential to yield drugs of medicinal properties (WOI, 1985).

18.4 Species Exploitation in North East India, Conservation Status and Sustainability

Club mosses have high medicinal values and used traditionally by many communities of North East India. It is extensively used in fever, rheumatism, bruises from accidents, to relief pain from strains, swelling of limbs etc. In Manipur, these plants are known as *Leishang* and are considered as a sacred by the Meitei community. Stems either in dried or fresh form is used in various cultural ceremonies like marriages, welcoming of new born babies, worshipping of local deities and fore-fathers (Yumkham & Singh, 2013). In Nagaland and Meghalaya, twigs of *H. squarrosa* and *H. phlegmaria* are used in decoration of wall, corridors, hall entrances, in flower arrangements, bouquets (Jamir & Rao, 1988). Some ethnic tribes like Tangkhul, Maring, Mao, Kuki etc. used to take the dried powder of stems as herbal drink. It is believed to enhance memory power, body stamina and infertility problems (Yumkham et al., 2016). Another potential club moss is *H. serrata* which is used as a component of herbal tea in remote places of Arunachal Pradesh, Nagaland and Meghalaya. It is also used as dietary supplement, as remedy for memory loss, mental impairment and possesses antioxidant and neuroprotective properties against free radicals (Patel et al., 2014). Besides, the plant extract is used in traditional medicines of various communities in Asian countries including the Indian Ayurveda, Homeopathy and the Chinese Herbal Medicine. It is used in snake bites, rheumatism, cold, to improve blood circulation in women during menstrual cycles, strains, bruises, contusion, bleeding injuries, to treat inflammation inflicted from burns and inflammation (Khirwadkar et al., 2014). Major species of the genus are exploited on large scale from the forest and sold in local markets because of their medicinal and horticultural purposes. All the available plant resources are harvested from the wild, and as for now there is no propagation or harvesting protocols (Fig. 18.2). Depletion of forest, soil erosion due to shifting cultivation, conversion of forest area into cultivable land and felling of suitable repository trees for timber and fire woods, illegal logging/ trade in forest region, over exploitation and inappropriate harvesting for horticultural and other purposes like medicine, ethnic cultural rites etc. are some of the major threats for the growth of these fern groups. According to India State of Forest Report of FSI (2011), firewood constitutes the major source of cooking in India (853 million people). As the genus *Huperzia* are highly vulnerable species exploited worldwide, many species are placed under different categories in view to their conservation status. They are recognised as Rare (IUCN, 1997), also as Rare Species of Western Ghats of Southern India (Maridas & Raju, 2010), Rare Species of India (Chandra et al., 2008), Rare and Endangered Species of India (Bir, 1987), Rare Species of Meghalaya (Baishya & Rao, 1982), Rare Species of Nokrek Biosphere Reserve, Meghalaya (Singh et al., 2012). Different countries also placed these club mosses as Near Threatened Species of Queensland (Forster et al., 2010), Endangered Species of Philippines (DENR–PAWB, 2007). The club moss species *H. quasipolytrichoides* is placed under the critically endangered lycophytes of China (Dong et al., 2017).

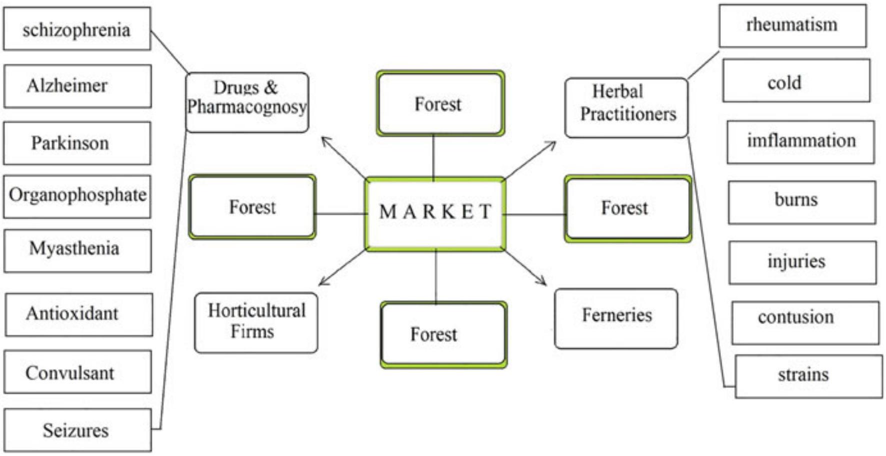

Fig. 18.2 Digrammatic representation showing pathways of trading activities in NE States and pharmacological activities of *Huperzia*

With the growing human explosion catapulted with overexploitation of plant resources mainly for food and medicines, survival of club mosses has become a threat. At this moment, we need a mechanism that defines the species sustainability and also at the same time meeting the needs of mankind without compromising the resources for future generations. The International Institute for Sustainable Development (IISD), a unit to promote human development and environmental sustainability has developed a political policy framework for establishing measurable entities and metrics linked to sustainability index. It consists of six (6) core areas in formulation of any framework on sustainability (Boulanger, 2008).

- international trade and investment
- economic policy
- climate change and energy
- measurement and assessment
- natural resource management
- role of communication technologies in sustainable development

18.5 Recommendations: The Conclusion

Natural products from plant resources have become a source of alternative medicine against the conventional chemical agents. As the club mosses are highly valued as medicinal herbs, efforts should be made for systematic characterization, documentation and data basing of all the available species diversity occurring in the entire hot spot diversity rich North Eastern states of India. Critical research on breeding methodologies, harvesting and post harvesting protocols suitable to the land and people should be formulated. Emphasis must be given to propagate club mosses based on vegetative propagules like rhizome division, bulbils formation and stem cutting techniques. According to MaAuliffe (2001), the only potential threat to the survival of club mosses is wild collection from their natural habitat for medicinal and horticultural purposes. Establishment should be made to formulate effective mechanism to curb the illegal trafficking of these vulnerable ferns from wild without proper guidelines. Some of the important recommendations and future action plans are listed below.

- To formulate best propagation protocols based on vegetative reproduction as sexual spores requires around 5–8 years to germinate and subsequent production of planting materials.
- To study the most efficient method on harvesting, transportation of plant resources from remote to urban areas, preservation, processing, packaging and effective storage.
- To study the marketable value addition, isolation of bioactive components and identify the nutraceutical potential.
- To study the biotic and abiotic factors, disease resistance, identification of pest, nutrition and fertilizers, suitable repository host trees.
- To identify target groups and develop entrepreneurial skills among traders of club mosses, effective commercialization and subsequent up gradation of skills.
- To establish a novel mechanism for evaluation, communication and initiation of procedures involved in delivering concepts on sustainable utilization of plant resources, identifying issues and challenges.
- Enactment of legislations, rules and regulations for effective strategies towards conservation keeping in view the cultural and ethical practices of local tribal bodies.
- To integrate all the entities including the scientific, economic, environmental and social issues while taking up any implementation programmes on club mosses.
- To initiate an exclusive evaluation work comprising taxonomic revisions and field explorations so as to document the relatively poorly understood club mosses in terms of taxonomy and conservation.
- To prepare a precise red list of ferns and alike species comprising the medicinal tassel ferns/club mosses especially of this diversity rich North Eastern States of India.

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Chapter 19
Impact of Climate Change on Soil Carbon-Improving Farming Practices Reduces the Carbon Footprint

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Abstract Carbon dioxide (CO_2) is the major cause of global warming and involvement in climate change between 1750 and 2007. Concerns about carbon (C) overloading in the atmosphere have sparked international attention in agricultural soils' ability to act as carbon sinks. In India and elsewhere, the effects of improved cropland management practices (when from traditional system to residue return, crop rotation and no-till) on soil C have been indecisive and inconsistent for various extents of management changes and soil depths. Searches of many databases suggest that these enhanced techniques can only store carbon at the soil's surface (0–10 cm) for a short period of time. (CAB Abstracts, Agricola, Web of Science, Scopus, Natural Resources Index and Agriculture), and by investigating the all references which are cited to extract the published reports/data on the issue. This process has released a lot of carbon into the atmosphere, resulting in poor levels of soil organic carbon storage in agricultural soils, especially in the tropics. With future land use change expected to increase even more, adopting optimal land management techniques to croplands as a potential carbon sink option to store carbon permanently (a century or more) while also improving soil condition and therefore productivity is

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critical. Based up on the extensive study of published work, this chapter aimed to analyse the consequences of new and sustainable land management options on soil carbon and its sequestration which is considered as a novel strategy and soil stewardship practices to build soil-crop resilience and mitigate climate change impacts with potential to offset carbon dioxide emissions.

Keywords Climate change · Soil health · Sustainable land management and carbon sequestration

19.1 Introduction

The intelligentsia of the developed world perceives climate change as a biggest threat to humanity therefore; they apply more resources towards climate change studies to decipher its clear impact on global food security. Our planet is home to above 7 billion people and this number is expected to reach 9 billion by 2050. According to a report by FAO in 2015, about 795 million people globally suffer chronic undernourishment. Over 250 million people are directly affected by climate change induced desertification and land degradation in arid and semi-arid areas on this planet. Another one billion people are residing in 100 nations classified as high-risk areas due to climate change. These are some of the world's poorest and most disadvantaged people. Therefore, desertification and land degradation needs more attention from researchers and governments keeping in mind the global food security. India is one of the affected countries by this issue plus it is home to about 18% of world's population and 15% global livestock population on merely 2% of global land area. In 1951 India had per capita land availability of 0.91% which has dramatically reduced to 0.32% in 2001 and is expected to further shrink to 0.09% by 2050. Apart from that, soil loss rates in 39% of the area exceed the acceptable threshold, and 11% of the region falls into the extremely severe category, with soil loss exceeding 40 t/ha/year, resulting in lower productivity. (Venkateswarlu & Prasad, 2012). It may be noted that climatic changes and its variations are recognized as one of the major factors contributing to land degradation. These statistics emphasize that ever degrading land is under increased pressure.

Being a country closer to the equator, India is going to face huge brunt of global warming. It is estimated that if carbon emissions continue to cruise at the current rate, a 0.4–2 °C temperature rise is expected during kharif 2070 and 1.1–4.5 °C during rabi 2070, while rainfall is also expected to go up by 10% by the same time. In the north eastern states of India, a 0.64 °C annual temperature elevation is expected between 2011 and 2040 and 5.15 °C by the end of centennial. Also dates of monsoon start are definitely expected to shift whereas climate extremes such as cold waves, droughts and floods are going to intensify future. It is also predicted that a 0.09 mm/day increase in annual mean precipitation in the near future, and 0.48 mm/day by the end of the centennial is inevitable. (Das et al., 2012).

In these circumstances, raising agricultural output, improving soil-crop resistance to climate change, and lowering agricultural emissions are all triple imperatives that necessitate different sets of actions.

Environmentally and socially responsible, climate-smart agriculture (CSA) attempts to improve production while lowering carbon sequestration and greenhouse gas emissions. Sustainably managed land (SLM) is a key component of CSA. SLM involves the use of land use systems with better management approaches that allow people to maximize socio-economic dividends from land while conserving or increasing ecological services provided by land resources. Soil organic matter is critical for sustaining soil health under SLM, and it's getting more attention currently because of carbon sequestration potential in soil. Following the long-term change of native woodland and pasture to crop land, organic carbon (OC) levels in soil, which are directly proportional to the quantity of organic matter contained in soil, are currently estimated to have fallen by an average of 42% and 59%, respectively Stockmann et al. (2013). Based up on the extensive study of published work, this chapter aimed to analyze the consequences practices on soil carbon and its sequestration which is considered as a novel strategy and soil stewardship practices to build soil-crop resilience and mitigate climate change impacts with potential to offset carbon dioxide emissions.

19.2 Climate Change on Soil Carbon

Between 1750 and 2007, carbon dioxide (CO2) was contributed the most to global warming and consequently climate change (IPCC, 2007). Its influence is expected to continue if it continues to accumulate unchecked in atmosphere. Soils are the major sinks of this carbon and store about 4 times more carbon than plant biomass (Stocker et al., 2013) and two times that of atmosphere. However, there no clarity on the impact of climate change, on global soil carbon stocks. In reality, there has been not enough research on the impacts of warming on soil C sequestration and GHG fluxes in agro-ecosystems. In an incubation experiment conducted by Hassan et al., (2015) under a temperature of (5–45 °C) showed that total organic carbon (TOC) decreased with increasing temperature from 5–35 °C and observed maximum TOC of 14.7 g kg1 at 5 °C, and minimum of 1.76 g kg1 at 45 °C. Although it is generally known that the rate of carbon loss from soils increases as the soil temperature rises, certain published literatures contradict this (Brevik, 1997; Coughenour and Chen, 2002; Hättenschwiler et al. 2013). Biochemical systems in the soil microbes that are responsible for decomposition may be able to keep this rise in control. However, data reported by Karhu et al. (2014) contradict the previous expectation, since he discovered that decomposers do not limit their respiration rates when temperature rises in the majority of situations. Rising temperatures may cause soils to release more carbon than previously thought.

Carbon and nitrogen are the major constituents of soil organic matter. Soil properties like soil structure, water holding capacity, cation exchange capacity and nutrient delivery mechanisms are highly influenced by SOM. Now, soils with optimal organic matter are highly productive but the question is, how C and N changes as a result of climate change may affect soil health. The world of soil has several ecosystems going on inside it, be it root microbe or microbe-microbe relationships but climate change scientists have paid very dismal attention to the effect of climate change on soil ecosystems (De Vries et al. 2012). Berg et al. (2010) noted that soil ecosystem interaction can shape up the diversity and heath of above soil flora and fauna. Therefore, it is important to study soil ecological relationships in detail (Fischer et al., 2014).

19.3 Sustainable Land Management (SLM)

To satisfy the issues of increasing production, reducing harmful gas emissions, and improving soil-crop to wellbeing during climate change, sustainable agricultural methods are necessary. Sustainable Land Management (SLM), a vital element of climate smart agriculture, is on hand to help farmers improve their soil-crop hardiness to climate change, as well as reduce agriculture's contribution to climate change by lowering GHG emissions and boosting carbon storage capacity of soil. SLM is a land use management approach which allows farmers to maximize socio-economic dividends from land while maintaining or increasing natural services. It was created out of a workshop conducted in Chiang Rai, Thailand in 1991. Through three major processes, SLM delivers carbon benefits, including carbon conservation, emissions reduction, and carbon sequestration For example, many native forest and grassland ecosystems store substantial amounts of carbon in their soil. As the most cost-effective method of climate mitigation and ecosystem resilience, this millennia-old terrestrial carbon storage should be prioritized for conservation.

Agricultural practices such as biomass burning (which emits CO_2, CH_4 and N_2O), tillage (which emits CO_2), deforestation (which emits CO_2, CH_4 and N_2O), dredging of wetlands (which emits CO_2 and N_2O), and uncontrolled grazing (which emits CO_2 and N_2O) have all contributed to the increase in global warming. Because soil carbon is the most basic resource for land use, it is at the heart of most SLM methods. Subsistence farming techniques do not invest in soil quality enhancement, erosion control, water management and judicious fertilizer use. The usage of traditional techniques has grown as a result of amendment applications (World Bank, 2010). Soil carbon is at the heart of most SLM approaches since it is the most basic element of soil. Soil carbon is stored in the soil, typically in conjunction with organic components, and has a strong relationship with soil quality, which is ability of soil to function optimally in both nature and agro-ecosystems. Soil C concentrations in India are naturally low (0.2 to 0.5%), especially in low rainfall arid and semi-arid areas (Srinivasarao et al., 2012). Most cultivated soils have SOC concentrations of less than 5 g/kg, compared to 15 to 20 g/kg in virgin soils (Lal, 2004). Global soil carbon lost from agricultural soils is about 50Gt (1 Gt = 1 billion tonnes). On the other hand, some of this carbon may be recovered via sustainable land management.

Table 19.1 Crop yields as influenced by one ton of carbon in the root zone

Crops	Potential yield increase (kg/ha)
Maize	200–400
Rice	10–50
Wheat	20–70
Soybean	20–30
Cowpea	5–10
Millet	50–60

Source: Lal (2011)

Table 19.2 Effect of land use managements having carbon sequestration potential on increase in crop production mt/year on different continents

	Continents			
Crops	Africa	Asia	Latin America	Total
Maize	0.8–1.3	4.1–8.2	4.5–6.9	9.4–16.4
Rice	0.1–0.2	4.1–6.9	0.2–0.3	4.7–7.4
Wheat	0.2–0.4	2.9–4.9	0.5–0.6	3.6–5.9
Soybean	0.02–0.03	0.3–0.5	0.7–1.2	1.0–1.7
Beans	0.1–0.2	0.4–0.7	0.3–0.5	0.8–1.4
Millet	0.6–1.0	0.4–0.7	0.01–0.01	1.0–1.8
Total	3.5–5.7	13.5–23.7	6.6–10.1	23.6–39.5

Source: Lal (2003)

Deep-rooted crops and grass pastures, for example, can help in enhancing carbon content using new technology. Soil carbon sequestration is aided by conservation tillage, crop residue mulch, green manuring, agroforestry, integrated nutrient and water management. These improved land management methods can help farmers increase soil carbon. Crop yields, reduce rural poverty, reduce greenhouse gas emissions and subsequently climate change. Long-term experiments that provide a means of evaluating sustainable land management systems in agriculture have shown that increasing the SOC pool in the root zone by 1 ton C/ha/year can improve crop yields by tonnes per year according to the government (Table 19.1) through SLM technologies can result in an improvement in crop yields (Lal, 2011). The improvement in grain production owing to increased SOC is estimated to be between 24 and 40 mt/year across Africa, Asia, and Latin America. (Lal, 2003, Table 19.2).

19.4 Impact Analysis

Under published literature and using online database, a number of new and sustainable or climate smart agricultural practices will be discussed below which are important in carbon sequestration can help in mitigation greenhouse gas emissions, lead to a resilient agro-ecosystem and also improvise agro output.

19.4.1 Crop Residue Management and No-Tillage

Agro-ecosystems rely on crop residues as a renewable resource. Management of crop residues have a significant impact on soil health, crop productivity and greenhouse gas emissions. No tillage means to leave at least 30% crop residue and sowing without disturbing the soil. This system improves structure of soil, SOC, reduces soil erosion, soil water conservation, reduces temperature fluctuations, and improves soil quality and environmental regulatory capacity. (Fig. 19.1). (CTIC, 2004). Getting the most out of this enormous resource will take a long time. For example, in India and elsewhere, there is a dearth of quantitative data on the soil C stock's response to agricultural residue management and no-till practices for a variety of soil depths and implementation years. In India, a small number of studies have shown that using no-till with full residue retention boosted soil carbon up to a depth of 5–10 cm (Hazarika et al., 2009; Naresh et al., 2012; Devi et al., 2015. The literature, on the other hand, is riddled with contradictory findings. No-tillage has been discovered to sequester carbon in the soil by certain studies. (Rasmussen et al., 1980; Kern & Johnson, 1993; West & Post, 2002; Sa & Lal, 2009; Gonzalez-Sanchez et al., 2012), while others have found no impact or opposite results (Rasmussen et al., 1980; Kern & Johnson, 1993; Gonzalez- Sanchez *et al* West & Post, 2002; Baker et al., 2007; Blanco-Canqui & Lal, 2008; Sa & Lal, 2009). In this regard, Saha (2010) discovered that after three years of continuous maize-Indian mustard sequence in the semi-arid conditions of New Delhi, SOC and MBC were substantially enhanced in minimal tillage in the semi-arid environment of New Delhi. Residue retention was higher than conventional tillage at the surface of the 0–0.15 m layer, but there was no obvious difference in soil carbon between treatments in mustard (Table 19.3). In soils deeper than 10–15 cm, which is the topic of this discussion, positive impact of such a management on soil C content or stock was not observed. When it comes to carbon storage, the top 0–10 cm of soil is where it is most likely to be lost due to environmental and management stresses. As a result, it's critical to see if this farming

Fig. 19.1 Zero-till plot in linseed established at Research Farm, Bihar Agricultural University, Sabour, India with soil cover by previous crop residue

Table 19.3 Soil organic carbon and microbial biomass carbon at 0–0.15 m soil depth as influenced by tillage and crop residue management practices in maize and mustard

	SOC (g/kg of soil)		MBC (mg/g of soil)	
Treatment	Maize	Mustard	Maize	Mustard
Conventional tillage	5.8	6.4	220	232
Conventional tillage + residue incorporation	6.3	6.6	225	250
Zero tillage	5.7	6.6	223	248
Zero tillage + residue retention	6.7	6.9	253	270
CD ($P = 0.05$)	0.8	NS	31	35

Source: Saha (2010)

method can maintain surface soil C over an extended length of time (100 years or more).

19.4.2 Agro-Forestry

Agro-forestry is a land utilization that includes trees, crops, shrubs and livestock. Agroforestry maintains optimum soil organic matter and biological activity. Water and nutrient losses are reduced, and soil erosion and runoff are controlled. To enhance crop yields by altering the microclimate and lowering crops and animal stress, trees are planted. In the irrigated agro-ecosystem, a poplar (Populusdeltoides) based agro-forestry is a feasible alternative land use method which prevents soil degradation and ensures stable long-term bio-production. Among farmers in northern India, poplar planting has become more popular because of its deciduous nature, fast growth, market acceptance and excellent intercropping potential (Fig. 19.2). India's 96 million hectares of agro-forestry have a carbon sequestration potential of 25 t/ha (Singh & Sharma, 2007), although there is significant variation depending on biomass output in different areas. (Singh & Sharma, 2007). (Pandey, 2007). A wide range of carbon sequestration numbers have been reported in poplar-based systems (Chauhan et al., 2010; Rizvi et al., 2011), which are depending on tree geometry, clones used, site characteristics, management features, and other factors (Chauhan et al., 2010; Rizvi et al., 2011).

19.4.3 Land Use Changes

It is clear that between 1880 and 2010, India lost a substantial amount of grasslands, shrublands, and woods, followed by a growth of crops and built-up regions (Tian et al. 2014). In India, forest areas have dropped by 26 million hectares (from 89 mha in 1880 to 63 mha in 2010) while grasslands/shrublands have fallen by 20 million hectares (from 45 mha to 25 mha) (Table 19.4). Total farmland area, on the other

Fig. 19.2 Wheat is commonly grown under the canopy of poplar trees in Punjab (India) for sustainable use of soil-water resources and carbon sequestration in site-specific situation. It is an agroforestry system

Table 19.4 Land use scenario of India from 1880 to 2010 (Area in million ha)

Year	Cropland	Forest	Built-up
1880	92.6	89.7	0.46
1950	110.1	71.1	0.74
1970	120.4	64.7	1.02
2005	135.0	65.1	1.7
2010	140.1	63.4	2.04

Source: Tian et al. (2014)

hand, has expanded by 48 million hectares (from 92 mha in 1880 to 140 mha in 2010). Such changes are the result of human-induced development, which resulted in a 600% increase in population from 20 crores to 120 crores in the twentieth centennial, which was accompanied by economic expansion (especially after 1950s). This transformation might have contributed large carbon to atmosphere as land use change is large contributor to human induced carbon emission and greatly influence the carbon budget in ecosystem (Tan et al., 2009). Obviously, the increasing human population has continually stressed the environment. The need to satisfy food demand has pushed for clearing of forests to be replaced by agricultural lands. Crop land expansion has usually meant forest degradation and deforestation, which reduces carbon stock and storage and contributes up to 14% of global carbon emissions (Kumar et al., 2010). The conversion to croplands also decreases primary production and lowers SOC (Tan et al., 2009), resulting to below-standard soil organic carbon sequestration levels of agricultural soils, particularly in the tropical region (Cruvinel et al., 2011. Turning these lands into carbon sinks would be monumental. With future land use change predicted to intensify more, land use management practices become necessary for croplands as a viable carbon sink option.

19.4.4 Biochar and Other Soil Amendments

Biochar production as a soil supplement is presented as a unique technique to combat climate change, with the potential to avoid 1.8 to 9.5 Pg (1015 g) CO2-C equivalent emissions annually (Woolf et al., 2010). Biochar's miraculous ability to mitigate climate change as a soil supplement comes from the combination of biochar's high stability and long-term carbon sequestration potential (Singh et al., 2012). By Generation of biological energy by proteolysis and nearly zero N_2O and CH_4 emissions from biomass decomposition, boosting agricultural productivity and lowering nitrogen oxide emissions from the soil, biochar systems can help reduce climate change. Purakayastha et al. (2013) in a fifteen-week investigation of biochar carbon stability reported 2.34% carbon loss in maize biochar to 4.49% in rice biochar. Maize biochar had the least carbon mineralization of the biochar, indicating that it has a higher potential for long-term carbon sequestration. Under the wheat-pearl millet cropping system, biochar application resulted in the largest amount of carbon in the soil. According to the conclusions of a recent modeling research (Woolf et al., 2010), biochar additives to soil can yearly trap an amount of carbon equal to 12% of current anthropogenic CO_2 emissions if done sustainably. A maximum carbon abatement capability of 1–1.8 giga tonne (Gt) C per year is expected by 2050. It has been estimated that by 2100, biomass pyrolysis combined with soil storage may sequester or offset hundreds of gigatons of CO_2 emissions, which is a significant proportion of the amount needed to avoid global warming. SOC priming by biochar has yet to be defined in terms of its long-term direction, persistence, and degree of priming.

19.5 Conclusion

Rapid population growth amidst this rampaging climate change makes food security undoubtedly the most pressing issue of our times. Agriculture withstands the worst of this dilemma because this sector is most affected by climate change. Agriculture and the land-use changes associated with it, on the other hand, account for about 1/3 of global CHG emissions. While maintaining ecological and social responsibility, sustainable land management aims to strengthen farmer resilience to the effects of global warming by reducing GHG emissions and carbon sequestration. So far, there has been no quantitative analysis of the soil C stock's reaction to these treatments for a wide range of depths and implementation years. Due to the fact that it is imperative to evaluate the possibilities of better management strategies to maximize carbon storage or decrease carbon loss within soil layers/profiles and over time Due to this, it is necessary to conduct in-depth studies on how soil C responds to better agricultural practices across India's diverse agricultural ecologies.

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Chapter 20
Impacts of Plastic Leachate on Life Traits of Micro-Crustacean Across Two Generations

Thanh-Son Dao, Qui-Hien Phan, Thi-My-Chi Vo, and Thi-Phuong-Dung Le

Abstract Plastic production and use have increased dramatically for the last decades, with total production of more than 300 million tons worldwide. However, less than 5% of plastic materials has been recovered consequently the continuous increase of plastic production and quantities over time in the environment, especially in water bodies. Plastic pollution and its impacts are of environmental, ecological and human health concerns. Micro-crustaceans play an very important function in aquatic ecosystem and are model organisms (e.g. *Daphnia*) for toxicological investigations. Plastics can have many additives on their surface which can leachate to surrounding habitats in certain physiochemical conditions. Substances leaching from plastic products acutely caused the immobility of *Daphnia magna.* However, responses of the animals to plastic additives upon long-term exposures are not yet fully understood. In this study, we assessed the fitness of *D. magna* including survivorship, maturation and reproductive capacity, upon exposure to domestic water-pipe plastic leachate at the concentration of 0, 10, 50 and 500 mg plastic per liter over the period of 21 days for parent *D. magna*. Then the offspring from the control and 500 mg plastic L^{-1} parents were continuously exposed for 2 weeks to the same medium as their parents were. The results showed that the plastic leachate at the tested concentrations did not adversely affect on survivorship of *D. magna*, both parent and offspring. However, the leachate stimulated the maturation of the *Daphnia*. The lowest leachate concentration slightly influenced on the reproduction of mother *Daphnia*. However, the higher leachate concentrations caused a strong reduction in reproduction of the exposed *Daphnia* in both generations. We have firstly found the chronic effects of plastic leachate across two generations of *D. magna*. Population development of *Daphnia* would be negatively impacted

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upon continuously long-term exposures to plastic in nature. *In situ* investigations on the effects of plastic emission on zooplankton structure and abundance are highly suggested.

Keywords Plasticizers · Toxicity · *Daphnia magna* · Life history traits · Generational effects

20.1 Plastic Emission, Occurrence and Distribution in Aquatic Environment

Originated from petroleum sources, plastic consists of a family of organic polymers including polyvinylchloride, polyethylene, polystyrene, polypropylene, and nylon (Anderson et al., 2016). Plastic production and use have increased dramatically for the last decades, with total production of more than 300 million tons worldwide (Coppock et al., 2017). However, less than 5% of plastic materials has been recovered (Auta et al., 2017). This would result in the continuous increase of plastic production and quantities over time in the environment. Asia countries (e.g. China, Indonesia, Philippines, Vietnam) have contributed highest amount of plastic emission on into environment in the world as the consequence of mismanaged capacity of plastic waste (Jambeck et al., 2015). In water bodies, plastics could be buoyant, neutral and sink depending on its composition, density, and shape (Anderson et al., 2016). Around half of produced plastics tend to submerge or settle in waterbodies but turbulence and storm activities could resuspended and redistributed plastics in water column. Biofouling onto microplastics (MiPs) when happened would increase the plastics density and weight leading to the sinking to bottom in waterbodies (Anderson et al., 2016).

Plastics could accumulate close to cities and urbanization but also be found in remote regions (e.g. polar area) depending on physical factors e.g. wind, water current (Anderson et al., 2016) and human activities during transportation, trading, travelling and tourism. Plastics from inland contribute to about 80–85% of marine litter whereas approximately 18% plastics in sea are from aquaculture and fisheries (Anderson et al., 2016; Auta et al., 2017). Storms, flood, and strong wind could sweep plastics from land into water bodies quickly. Plastic debris and fragment are worldwide distributed upon variety of sizes and shapes. Generally, MiPs are pieces with size of smaller than 5 mm (Anderson et al., 2016). The plastic particles with size of smaller than 10 nm are defined as nanoplastics (Cole et al., 2011). Investigations on plastics have just been focused during the last decades and reflected that lakes, reservoirs and oceans are sinks of plastics especially MiPs (Anderson et al., 2016). MiPs in environment can be from primary or secondary sources (i) those are manufactured purposely for particular industrial or domestic application such as exfoliating facial scrubs, toothpastes, nail polish, hair coloring, bath gels, and resin pellets used in the plastic industry (so called primary MiPs), and (ii) those formed from the breakdown of larger plastic items in environment (so called secondary MiPs; Auta et al., 2017).

MiPs are widespread in aquatic systems such as reservoir, lakes, rivers and seas. One of the largest MiPs sources to marine environment was sewage from washing clothes which contained a lot of fragments and fibers (Li et al., 2016). Seriously, wastewater treatment plants could not fully removed MiPs (Anderson et al., 2016). Hence, they could release a large amount of MiPs in the treated wastewater into nature (Auta et al., 2017). Freshwater systems could receive plastics by three main ways (i) effluent discharge from wastewater treatment plants, (ii) overflow of wastewater sewers during high rain events, and (iii) run-off from sludge applied to agricultural land (Anderson et al., 2016). Though marine plastic pollution is more severe in Asia (Jambeck et al., 2015), there have been more investigations on MiPs occurrence in American and Europe (Phuong et al., 2016) with the highest abundance of more than 334,000 fragments per m^2 (North Pacific Central Gyre) and 370,000 particles per km^2 (Pacific Ocean). It was reported that approximately 5 kg of MiPs in facial cleaners was discharged into waste stream annually. It is estimated that the US people consumed around 2.4 mg MiPs per person out of their personal care products daily hence emitted more than 260 tons of polyethylene MiPs yearly (Auta et al., 2017). Denmark emitted about 21,500 tons of MiPs yearly of which around 10–25% was associated with sewage from tyres and textiles, whereas Norway did around 8000 tons annually (Auta et al., 2017). Waller et al. (2017) noted that from 4.4 to 50 kg of MiPs out of personal care products entering the Southern Ocean annually. About 2 billion microplastic fragments entered the Californian coastal waters via two rivers within three days (Auta et al., 2017). Globally in an estimation, there were nearly 270 million tons from more than 5 trillion particles, 92% are MiPs (Auta et al., 2017). However, microplastic concentrations in marine waters were different in the world. For example, the concentrations around Japan sea (~ 1.72 million pieces per km^2) were within the range with that in San Francisco Bay (up to two million particles per km^2), but 10 and 27 folds higher than those in the North Pacific and the world oceans, respectively. Between 1,500 and 9,200 particles of MiPs per m^3 of sea water were reported elsewhere (Auta et al., 2017).

Macro- and microplastic occurrence has been reported in lakes and rivers from Western countries to Asian ones such as Mongolia (Eerkes-Medrano et al., 2015) and Vietnam (Lahens et al., 2018; van Emmerik et al., 2018). In water, microplastic abundance was largely varied, from 1–1000 of pieces m^{-3}. However, quantitative reporting on aquatic microplastic concentrations in the world has been limited (Anderson et al., 2016). The concentration up to 20,264 MiPs km^{-2} was found in Lake Hovsgol, Mongolia (Auta et al., 2017). Lahens et al. (2018) estimated that waterbodies (rivers, canals, creeks) in Hochiminh City, Vietnam, received high MiPs in the emission from the city consequently high microplastic concentrations in the water, 172,000–519,000 fibers m^{-3}, and 10–223 fragments m^{-3}. The microplastic levels in treated domestic effluent could be up to 5.5 mg L^{-1} (Lasee et al., 2017). It is important to note that thought here was no more plastic emission into the nature, the quantity of MiPs would likely increase because of fragmentation of macroplastics already in the environment (Eerkes-Medrano et al., 2015).

MiPs can be found in sediments and in different organs of aquatic animals (Anderson et al., 2016). In marine environment, MiPs can make up 3.3% of sediment weight (Auta et al., 2017). Abundance of MiPs could be found between 6–9.4 g m^{-2} in shoreline and lake bottom sediments (Anderson et al., 2016). The concentrations of MiPs could be around 81 μg MiPs g^{-1} sediment from India, varied between 12–62 particles g^{-1} sediment from mangrove area in Singapore, and from 340–4757 particles m^{-2} in beach sediment in South Africa (Auta et al., 2017). MiPs posed risk to aquatic environments because of their long resistance and being consumed by aquatic animals (Anderson et al., 2016) especially unselective filter feeders.

20.2 Plastic Toxicity

Recently, MiPs in nature have been attracting scientists because they can cause severe impairments on living things (Chae and An, 2017). MiPs enter aquatic animals (e.g. zooplankton, fish, water birds) through their oral consumption directly and indirectly by feeding on the MiPs in environment or eating their microplastic-ingesting preys (Anderson et al., 2016). Therefore, the microplastic levels in the animals can be accumulated and magnified through food chains (Eerkes-Medrano et al., 2015). The larger sizes of MiPs are less ingested than the smaller ones by the feeders in aquatic environment. MiPs have been found in many benthic and pelagic organisms such as planktonic animals, crayfish, shrimps, molluscs, coral, worms, barnacles, sea cucumbers, fish and water birds. Once entering the animal bodies, MiPs can be excreted or egested back to the surrounding environment, but they can also be retained and immobilized in the animal organs and tissues, depending on the species (e.g., reviewed by Anderson et al., 2016; Auta et al., 2017; Nelms et al., 2018). MiPs can cause physical and chemical impairments on the exposed organisms such as moving prevention, gill and intestine blockage, stresses, painfulness, developmental inhibition (Auta et al., 2017). The toxicity of MiPs could be related to the physical clogging and energy cost, the leachate of the internal plasticizers, and the external pollutants from environment attaching onto the surface of MiPs (Anderson et al., 2016). Furthermore, plastics could alter the environmentally physical and chemical characteristics such as light intensity reduction in waterbodies and sedimentation components (Eerkes-Medrano et al., 2015).

Planktonic organisms are among the first living things in aquatic food chains negatively affected by plastics. The adsorption of nanosized polystyren by the living algae (*Scenedesmus, Chlorella*) was assumed as the reason of the reduced photosynthesis, the promoted contents of antioxidant enzymes (Bhattacharya et al., 2010), chlorophyll reduction or even the inhibited population growth (Besseling et al., 2014). Several previous researches indicated that MiPs chronically impaired the life history traits of marine animals. Following exposure to polystyrene beads, the food feeding rate of copepod *Centropages typicus* significantly reduced (Cole et al. 2011). This result was comparable with the researches of Ayukai (1987) and

Fernandez (1979) that also indicated that algal ingesting of the copepod *Acartia clausi* and *Calanus pacificus* were significantly decreased by the presence of MiPs. A reduction in algal feeding caused exposure to MiPs could have the numerous consequences in the copepod health, e.g., decreased survival, growth and fecundity (Dagg, 1977; Ayukai, 1987). Similarly, Jeong et al. (2016) reported that MiPs caused the increase of oxidative stress and antioxidant enzymes activities, but the decrease of fitness of *Brachionus koreanus* such as reproductive characteristics, development and life. The nano-polystyren at the exposed concentrations between 0.22 and 150 mg L^{-1} impacted fecundity and offspring size of *D. magna,* especially malformations happened from the concentration of 30 mg L^{-1} (Besseling et al., 2014). Over four generations of *D. magna* exposed to MiPs evidenced the negative influences on survival rate, growth, reproduction and population growth rate (Martins and Guihermino, 2018). Additionally, MiPs in the range of 20–1000 nm could be found in cells and oil storage droplets in freshwater *Daphnia* (Rosenkranz et al., 2009). Moreover, chronically impacts of polyethylene particles on growth and reproduction of the amphipod, *Hyalella azteca*, were the consequences of feeding reduction caused by slower egestion along with longer residence time for this contaminant in the digestive tract of the organisms (Au et al., 2015).

The blue mussels (*Mytilus edulis*) were also demonstrated to be able to ingest and accumulate polystyren beads in their gut cavity (Browne et al., 2007), contained around 0.6 microplastic fragment per individual (Phuong et al., 2018) and their filtering activities coupled with pseudofece were inhibited in the presence of this contaminant (Wegner et al., 2012). Pittura et al. (2018) found the localization of MiPs in hemolymph, gills and digestive tissues of the marine mussel (*Mytilus galloprovincialis*). The same authors also observed the negative effects of a plastic absorbance compound (benzo(a)pyren) on the transcriptional variations of antioxidant and stress genes of the animal. After exposed to polylactic acid MiPs at the concentration of 80 μg L^{-1} over the course of a 60-day exposure, the oysters (*Ostrea edulis*) were under stress that was indicated by the elevated respiration rates in the animals (Green, 2016). Phuong et al. (2018) reported that each Pacific oyster (*Crassosteea gigas*) collected from the French Atlantic coasts could accumulate around 2.1 microplastic fragments in its body. In another study, body width of larvae of sea urchin (*Tripneustes gratilla*) was reduced upon exposure to polyethylene microspheres (300 spheres mL^{-1}) over a 5-day period (Kaposi et al., 2014). MiPs also reduced the food filtering rate and significantly changed in neuro and oxidative enzyme activities of the freshwater bivalve *Corbicula fluminea* (Olivera et al., 2018). Likewise, polystyren-NH_2 and polystyren-COOH were attributed to cause cell-specific apoptosis and general stress, respectively, in the sea urchin *Paracentrotus lividus* during 48 h post-fertilization (Della Torre et al., 2014). The polyvinylchloride particles did not only reduce the lipid reserves but also increase the inflammatory response and oxidative stress in the lugworm, *Arenicola marina* (Wright et al., 2013; Browne et al., 2013).

Larger fish fed and accumulated more MiPs in the digestive tract, and the microplastic concentrations in fish were higher in summer than spring due to the increased food uptake with size and seasonal differences in feeding behavior (Beer et al., 2018). The rainbow fish (*Melanotaenia fluviatilis*) fed microbeads (personal care products) and accumulated high polybrominated diphenyl ethers in its tissue (ca. 115 pg g^{-1} ww). However, the Europe perch (*Perca fluviatilis*) ingested and accumulated polystyren MiPs consequently growth reduction, hatching prevention, feeding and behavior alteration, and even olfactory sense impairment which increased the susceptibility to its predators (Wardrop et al., 2016). The seabass fish (*Dicentrarchus labrax*) acutely exposed to MiPs resulted in significantly change on neuro, oxidative and energy-related enzyme activities and behavior of the fish (Barboza et al., 2018a, b).

Plastics may have several plasticizers (e.g. bisphenol A, phthalates, trace metals) added as layers on their surface. Bisphenol A is known as an oestrogen-like compound strongly affecting reproductive capacity and growth in crustaceans and insects at the levels from ng L^{-1} to µg L^{-1}. Phthalates have been showed to cause molecular and whole-organism effect in both vertebrates (e.g. fish) and invertebrates (Cole et al., 2011). Besides, phthalates desorbed from plastics were accumulated in the gut of organisms resulting in disorder of biological processes such as endocrine disruption, behavioral alteration (Li et al., 2016). In addition, surface of MiPs can attract dissolved trace metals in surrounding environment (Holmes et al., 2014) and this process would enhance the metal levels on the MiPs being fed by aquatic animals. Similarly, MiPs having large surface can trap and concentrate harmful organic pollutants (polybrominated diphenyl ethers, polychlorinated biphenyls and dichlorodiphenyltrichloroethane) in aquatic environment (Mato et al., 2001; Anderson et al., 2016). For example, polychlorinated biphenyls concentration desorbed from MiPs was one million-time higher than in the surrounding water (Betts, 2008). There was a positive correlation between polybrominated diphenyl ethers in great shearwater seabirds (e.g., fat tissues) or North Pacific pelagic seabirds and the amount of ingested plastic debris (Ryan, 1988; Yamashita et al., 2011). Plastics could also serve themselves as substrates for bacterial communities hence becoming vectors for pathogens in aquatic ecosystems which are poorly understood (Anderson et al., 2016). Therefore MiPs with high potential could induce a lot of negative influences at many aspects including biochemical and physiological responses, behaviors, developmental processes, and life history traits in animals and human beings (Auta et al., 2017).

So far, there have been many investigations on the impacts of the contaminants held by plastic on organisms, e.g. inflammatory responses, reduced survival, behavioral modifications, weight loss in lugworm (*Arenicola marina*) were demonstrated as the results of the accumulation of nonylphenol, triclosan, phenanthrene, polybrominated diphenylethers-47, and polystyren in the gut (Browne et al., 2013; Besseling et al., 2013). Polyethylene terephthalate was showed to cause endocrine disrupting effects and decreased reproductive output in mudsnails (Wagner and Oehlmann, 2009). The attached organic pollutants onto surface of MiPs could result in negative effects on the consumers, and could be transferred to predators including human beings through the food chains (Chae and An, 2017). The compounds leaching from plastic products (e.g. artificial leather, floor coating, children's handbag) were showed to cause acute toxic effects (immobility) for the water flea *Daphnia magna*, with 48 h-EC_{50} of leachates between 5 and 80 g plastic material L^{-1} (Lithner et al., 2009). Similarly, Dave and Aspegren (2010) acutely exposed *D. magna* to leachates from 52 textile products and found the 48 h-EC_{50} ranged between <1 and > 182 g L^{-1}. Giraudo et al. (2015) found that the flame retardant and also main used plasticizer Tris (2-butoxyethyl) phosphate (TBOEP) caused the mortality of 50% of the test *D. magna* within 48 h treatment at the concentration of around 147 mg L^{-1}. The chemical also impacted gene transcription related to proteolysis, protein synthesis, and energy metabolism in *D. magna* upon a chronic exposure. Seriously, the TBOEP at low concentration (10 μg L^{-1}) resulted in the reduction of body size (width and length), reproduction and molting in *D. magna* over three generational exposures (Giraudo et al., 2017). Although toxicity of plastic microspheres to several aquatic organisms have been tested and reported, detrimental impacts of plastics and plasticizers on aquatic animals are underestimated (Chae & An, 2017). Responses of aquatic animals in general and zooplankton in particular to MiPs and plastic additives upon long-term exposures are not yet fully understood (Eerkes-Medrano et al., 2015; Li et al., 2016).

20.3 The Impacts of Plastic Leachate on Micro-Crustacean, *Daphnia Magna*

20.3.1 Materials and Methods

In this study, we used a drinking water pipe made of polyvinylchloride as the main plastic material for leachate preparation of the toxicity test. The water pipe is a very popular product and commonly used for water supply system in houses and under ground in Vietnam. It is estimated that at least 1.5 million tons of polyvinyl chloride are disposed annually in the United States whereas 30–50% of vinyl produced ends up in the trash stream (Thorton, 2002). The plastic leachate was prepared according to Lithner et al. (2009). Briefly, the plastic pipe was cut into small pieces of 2–3 cm long and 50 g of polyvinylchloride pipe was placed in a glass bottle containing 1 liter of distilled water. The bottle was then placed out door under sun light for 15 days. Water containing compounds from plastic was used for the testing with freshwater micro-crustacean *Daphnia magna.*

The *D. magna* (from Micro BioTest, Belgium) was raised in ISO medium (Dao et al., 2010) and fed with living green alga *Chlorella* sp. and YTC, a rich nutrient mixture (US. EPA, 2002). The alga *Chlorella* was cultured in Z8 medium (Kotai, 1972). The animals were incubated under laboratory conditions at the temperatures of 24 ± 1 °C, light intensity of less than 1000 Lux, and a photo regime of 14 h light: 10 h dark (APHA, 2012).

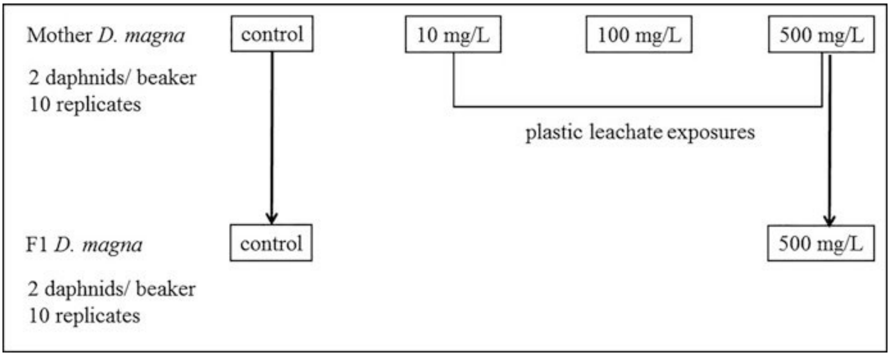

Fig. 20.1 Experimental set up; 10, 100 and 500 mg L^{-1} were the concentrations of plastic leachate used for exposure to *Daphnia magna*

The experiments to evaluate the toxicity of plastic leachate to crustaceans were conducted according to APHA (2012) and Dao et al. (2017). There were 2 experiments for mother *D. magna* and its offspring. For the mother (F0) exposures, the micro-crustaceans aged less than 24h were used for the test. *Daphnia manga* in ISO medium (without plastic leachate) was considered as control batch. Exposed organisms were carried out by adding additional leachate into the ISO medium. The *D. magna* was treated with leachate from 10, 100 and 500 mg L^{-1} of plastic. Though the test concentrations in this study were higher than the recorded one in the nature (5.5 mg L^{-1}; Lasee et al., 2017), we assume that plastic concentrations in environment could be increased in the future because of the increasing production and use and unmanaged emission of this materials in the world. Besides, a previous investigation used up to 100 g L^{-1} of plastic leachate for exposure to *D. magna* (Lithner et al., 2009). In each treatment, 20 neonates of *D. magna* were incubated in 10 glass beakers (2 daphnids per beaker; Fig. 20.1) and fed *ad libitum* with *Chlorella* sp. and YTC as mentioned above. The medium and food were totally renewed 3 times weekly and the incubation lasted for 21 days. The life traits of mother *D. magna* including survival, maturation and reproduction were daily monitored.

For the second experiment, offspring (F1) from the control and the highest plastic leachate treatment (500 mg L^{-1}) were randomly chosen and used for experiment. The F1 from the control were raised in ISO medium (leachate free), while the F1 from the leachate treatment were continued to raise in the same leachate concentration as their mother (500 mg L^{-1}; Fig. 20.1). The second experiment lasted for 14 days and the recorded end points were survival and reproduction of the F1 *D. magna*.

The Kruskal-Wallis test, Sigma Plot 12.0, was applied to evaluate the significant difference of the maturity between the control and plastic leachate exposure.

20.3.2 Results and Discussion

20.3.2.1 Effects of Plastic Leachate on Life Trait of Parent *Daphnia Magna*

The survival proportion of *D. magna* in control and plastic leachate exposures varied between 85% and 90% after 21 days of incubation (Fig. 20.2). Hence the survivorship of the animals among the treatments was similar (APHA, 2012) and the plastic leachate at the tested concentrations did not impact on survival of *D. magna*. Our record is in agreement with a previous investigation in which the plastic leachates from drinking water pipe at the concentration up to 100 g L^{-1} did not acutely cause the immobility on the *D. magna* (Lithner et al., 2009). Martins and Guihermino (2018) did a chronic exposure of *D. magna* to MiPs (1–5 μm in diameter; 0.1 mg L^{-1}) and found a 10% difference of the survival rate between control and plastic treatment which supported our result. The leachate from drinking water pipe could contain polyvinylchloride and a high amount of phthalates, among others (Lithner et al., 2009). Phthalates could cause the disorder of molecular and cellular processes and behavioral changes in animals (Cole et al., 2011; Li et al., 2016). However, the compounds and some other plasticizers in the pipe leachate may not be high enough to induce high mortality for the *D. magna*. Further chemical analyses to characterize and quantify the plastic additives in the leachate of this study are highly recommended.

The mother *D. magna* in control reached their maturity at the age of around 6.3 days. However, the animals in the treatment with plastic leachate of 10, 100 and 500 mg L^{-1} matured at around 5.7, 6.2 and 6.0 days old, respectively (Fig. 20.3a). The earlier maturation of *D. magna* treated with plastic leachate, compared to control, was significantly recorded at the 10 mg L^{-1}($p = 0.01$) and 500 mg L^{-1} ($p = 0.03$).

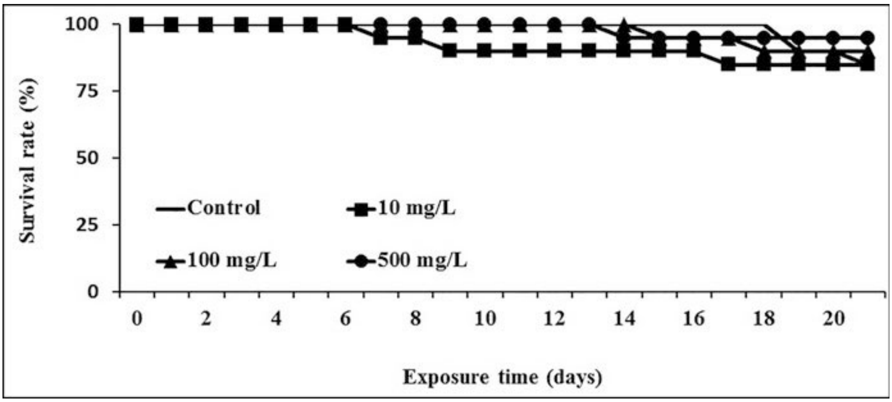

Fig. 20.2 Survival proportion of mother *Daphnia magna* incubated in plastic leachate for three weeks

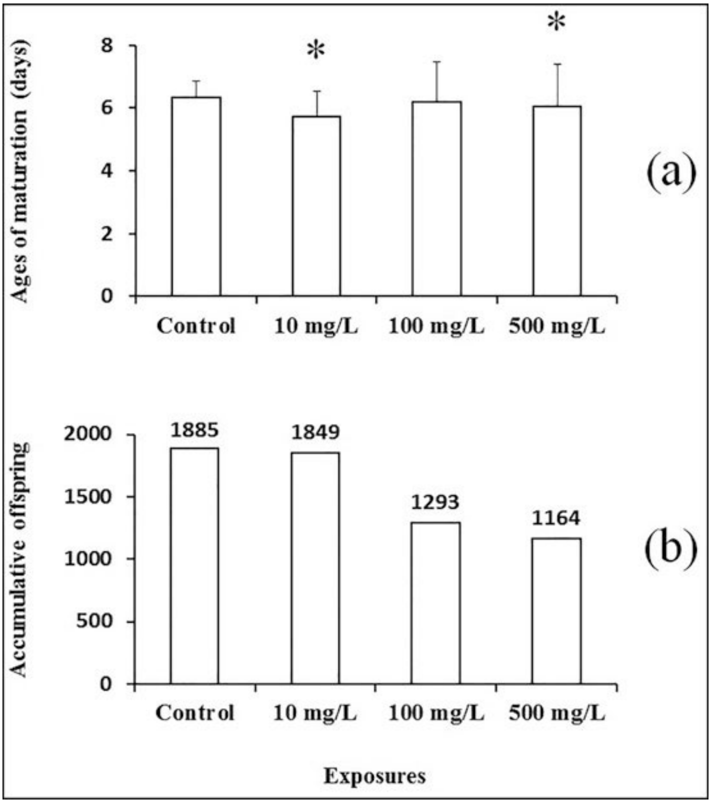

Fig. 20.3 Maturity (**a**) and reproduction (**b**) of mother *Daphnia magna* exposed to plastic leachate

During three weeks of incubation, mother *D. magna* in the control, 10, 100 and 500 mg L^{-1} produced 1885, 1849, 1293 and 1164 neonates, respectively (Fig. 20.3b). It could be said that the number of neonates in control and the 10 mg L^{-1} exposure were comparable. However, there was a significant reduction of the total neonates in the other treatments (100 and 500 mg L^{-1}) compared to the control (~ 62–68%). Therefore, we found an evidence for a big decrease in population development of *D. magna* in the plastic leachate exposures.

The polyvinylchloride plastic pipe could contain the additive phthalates and maybe bisphenol A which are endocrine disrupting compounds (EDCs). The EDCs induce disorder of physiological processes in animals hence could stimulate or enhance the maturation of *D. magna* during exposure. Besides, some other toxins, natural or xenobiotics (e.g. microcystin, ampicillin) at low concentrations (5–50 μg L^{-1}) could cause an earlier maturity age of *D. magna* (Dao et al., 2010; Vo et al., 2018). Therefore, in our study the additives in plastic leachate maybe at not high concentrations would have a similar physiological influence on maturation of *D. magna* which needs further studies to clarify.

MiPs upon exposure could physically and chemically cause the energy cost to mother *D. magna* and strongly reduce the total offspring number (Martin and Guihermino, 2018). Plasticizers such as phthalates and TBOEP at very low concentrations impacted on molecular and cellular processes in *D. magna* chronically, hence energy diminish for other activities, growth and reproduction capacity (Lithner et al., 2009; Giraudo et al., 2015, 2017). Besides, the polyvinylchloride plastic could release vinylchloride into water which enters animals causing damage in the livers, kidneys and lungs. Vinyl chloride could also interact with other compounds to form new substances in animals' liver where they may cause damage to the animals (US DHHS, 2006). Thorton (2002) noted that metals such as lead, cadmium, and organotins are among the additives of polyvinyl chloride which could leach to environment and are potent toxic to living things. These helped to explain the lower accumulated neonates from mother *D. magna* treated with plastic leachate (100 and 500 mg L^{-1}) than those in the control in the current study. Our study revealed a quite environmentally effects of plastic emission in aquatic habitat because the leachate was used for bioassay. Our observation contributes to the understanding on the toxicity of plasticizers to freshwater zooplankton.

20.3.2.2 Effects of Plastic Leachate on Life Trait of Offspring *Daphnia Magna*

The investigation on offspring (F1) *D. magna* revealed that continuous exposure to plastic leachate (500 mg L^{-1}) for 2 generations did not cause a negative effect on survival rate of the animals as both control and exposure had the same survivorship of 80% after 14 days of incubation (Fig. 20.4a). However, the total neonates from the plastic treated F1 were 435, approximately 82% compared to the control (Fig. 20.4b).

Martins and Guihermino (2018) reported that continuously exposed to MiPs for two generations caused mass mortality and reproduction of *D. magna*. Interestingly, leachate from quite high plastic concentration in our study (500 mg L^{-1}) was not potent enough to the survival of *D. magna*. Probably the concentrations of additives in the leachate of the current investigation did not exceed the level causing high mortality on the animals. The activity of antioxidant enzyme, catalase, in *D. magna* was suppressed by the plastic additive phthalates and TBOEP (Giraudo et al., 2017). Probably un-characterized plasticizers in the current study also possess the inhibition capacity to antioxidant enzyme activities. The inhibition is once strong and long enough would lead to energy cost to maintain normal processes and behaviors of the animals consequently fecundity and reproduction decrease. Though the continuous exposure to plastic leachate reduced the reproduction, this life trait seems to reflect the adaptation/tolerance of the *D. magna* because the accumulative neonates of F1 (82% compared to control) was higher than that of F0 (62%). Study on a more multi-generational exposure of *D. magna* to plastic leachate (e.g. 5–6 generations) is suggested for more understanding and extrapolation on the long-term responses of *D. magna* to plastic *in situ*.

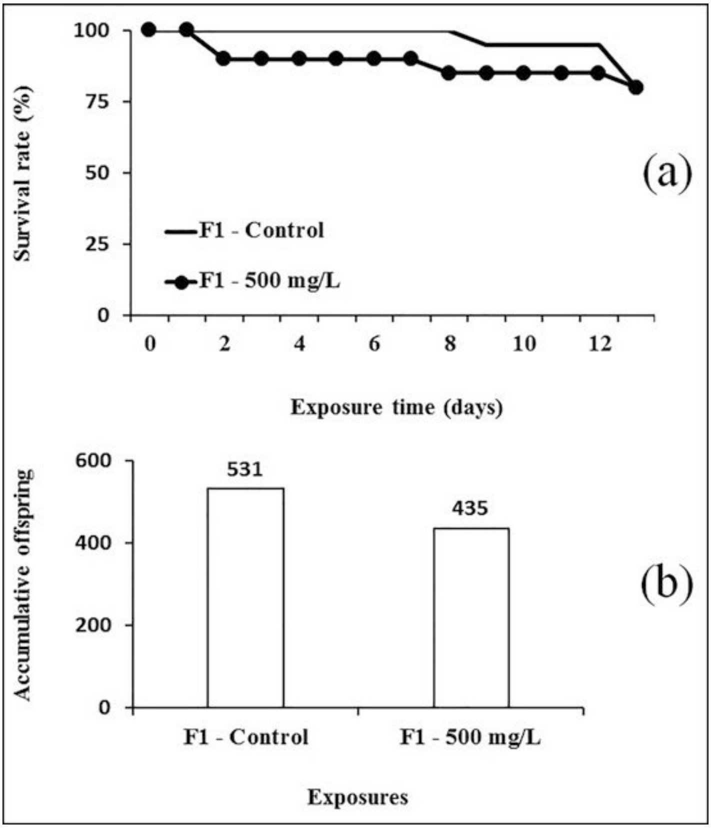

Fig. 20.4 Survival proportion (**a**) and reproduction (**b**) of F1 *Daphnia magna* exposed to plastic leachate

20.4 Managemental Challenges of Plastic

There have been bans on microplastic application into personal care products and cosmetic in Canada, USA, and several countries in Europe such as the Netherland, Austria, Luxembourg, Belgium, Sweden (Anderson et al., 2016). However, the occurrence and distribution of MiPs in freshwater systems have just got attention, and policy actions for MiPs in freshwater bodies are not as developed as those seas and oceans. MiPs, while abundance in lakes and rivers, are not subjected to regulation (Eerkes-Medrano et al., 2015). Awareness, mitigation or reduction of plasticizer use for plastic manufacturation was considered in Europe (e.g. Denmark, Germany, the Netherland) and USA (Thorton, 2002). Though the dumping plastic garbage is not allowed, many people are not aware of the forbidden on the plastic disposal into oceans (Li et al., 2016). Plastics could be degraded upon different processes such as biological, photo-oxidative, mechanical, thermo-oxidative, and hydrolysis (Anderson et al., 2016). For example, the macro-sized polyethylene, polypropylen, and nylon are degraded firstly by UV-B photo-oxidation followed by thermo-oxidation, to form MiPs or nanoplastics (Anderson et al., 2016). The UV fragmentation of plastics is hindered by low temperature and oxygen concentration. Therefore, the plastic degradation is faster on land and beaches than in water systems (Anderson et al., 2016). On the contrary, many plastics are resistant to degradation by micro-organisms (Auta et al., 2017). It could take from centuries to millennium to fully mineralize plastics in nature (Anderson et al., 2016). MiPs are very hard or even not possible to clean up because of their ubiquity in freshwater and marine systems in the world (Li et al., 2016). The sources, distribution, fate, impacts and degradation of MiPs are not fully understood in freshwater and marine environments (Eerkes-Medrano et al., 2015; Anderson et al., 2016) which enhances the concerns of scientists on environmental, ecological and human health. The prevention and potential management measures of MiPs are of challenges due to their tiny size for visualization making them hard to be removed (Auta et al., 2017). Thus, MiPs are known as very tough recalcitrant in aquatic systems, and the leaching of additives is more likely challenged in environment (Anderson et al., 2016).

20.5 Concluding Remarks

Plastic production, emission, occurrence and distribution in aquatic environment and biota bodies have become hot topics of environmental, ecological and human health issues worldwide. Plastic pollution and toxicity have been attracted with a lot of investigations both *in situ* and in the laboratory conditions. Plastics themselves and plasticizers as well as bio-fouling on plastics are quite well known. Studies on the bioaccumulation and detrimental impacts of MiPs and plastic additives on aquatic animals have been sharply increasing during the last decade. Apparently, aquatic biota in plastic-polluted water bodies are sink and source of MiPs in the food chain. Plastics and plasticizers could cause variety of negative influences on aquatic organisms such as photosynthesis inhibition, inhibition on molecular and cellular processes, physiological and behavioral alterations, impairment on life history traits and population development from generation to generation. The current case study firstly reported the responses of *D. magna* upon chronic exposures to plastic leachate from drinking water pipe including a slight vary of survivorship, strong maturity stimulation and high reproduction reduction. Population development of *D. magna* would be negatively impacted upon continuously chronic exposures to plastic in nature. Monitoring on plasticizers in tap water (in relation to polyvinyl chloride plastic pipe) is highly suggested in developing countries because of the lacking information and low level of safe guideline in drinking water (e.g. 2 μg L^{-1} of vinyl chloride; US DHHS, 2006). Although there have been many investigations on plastic accumulation and toxicity, the adverse effects of plastics and plastic additives (leachates or purified chemicals) on marine and freshwater organisms are underestimated and not fully understood. Managementally, the bans on some plastic production and use have been issued in Western countries. This has not been become in force in many developing countries. Together with the risks to environmental, ecological and human health evaluation, plastic treatment technologies are in urgent needs. There had better been means and laws on plastic reduction, reuse, recycle and replacement.

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Chapter 21
Climate Smart Agriculture and Water Management: Issues and Challenges

D. S. Gurjar, R. S. Meena, K. K. Meena, and G. S. Yadav

Abstract Climate Smart Agriculture (CSA)—a set of best management practices, is mostly based to achieve three major objectives sustainably enhance productivity and income in agriculture, building resilience and bolstering the adoptive capacity of system to climate change and minimize the greenhouse gases (GHGs) emission from agriculture production system without jeopardizing the system productivity and functions. Climate smart water management in agriculture may a pertinent strategy to achieve the objectives of CSA. Thus, this chapter is contrived to discuss the present status, issues and challenges of water management in agriculture. Chapters also provides all possible solution on water management and technologies related to water which are resilient and adopted well under changing climatic scenarios that can apply at a scale of farm to regional and national level. There are certain strategies for climate smartly sustainable agricultural water management are also described in this chapter.

Keywords Agricultural water management · Climate-smart agriculture · Climate change · Capacity building · Irrigation

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21.1 Introduction

Of the different sector of economy (e.g., service, industry, manufacturing, agriculture, etc.), agriculture is greatly impacted by changes in climate and other climate related variability. The adverse effects of changing climate on agriculture are witnessed around the globe (FAO, 2010). A 1/3rd of present population will be added in 2050 and this additional 2 billion population will accommodate the developing nations throughout the world. A major part of the rural population is anticipated to inhabit the cities. Continuation of existing income-consumption growth trends will demand around 60% increase in agricultural production by 2050 (FAO, 2013). Climate change, increase in droughts, cyclones, extreme precipitation events and heat waves and increased unpredictability of weather patterns, are the major challenges in achieving this task due to adverse impacts on agriculture. Moreover, it has been witnessed that the reduction in number of rainy days, heavy rainfall events, late on-set of monsoons, mid-season droughts etc. adversely affected the crop production in recent years, (Sikka et al., 2016). Strategic adaptation to changing agro-climate scenario, low-emission-unit outputs, and robust conservation of natural resources is imperative to maintain global food security and achieve sustainable agricultural development. Adverse impacts of climate change on agriculture are already evident with the increasing incidences of climate-extremities and unpredictability of weather patterns that can threateningly decline the productivity and significantly lower the farm incomes in vulnerable agro-ecosystems, thereby affecting the global food economy. Smallholders and developing countries have been predicted to suffer more intensely by these changes (FAO, 2013). Therefore, it is an urgent need to transform the present agriculture into climate-smart agriculture and water management as climate smart agriculture water management for sustainable food security to rapid growing world population. In developing countries of the world, climate smart water management in agriculture can play an active role for enhancing economic growth and poverty eradication.

21.2 Climate-Smart Agriculture

CSA is a unified approach/concept/initiative to address climate change challenges which was proposed by Food and Agriculture Organization (FAO) through a background paper was prepared for International Conference on Agriculture, Food Security and Climate Change held at Hague (FAO, 2010). The CSA includes the three dimensions of sustainable development *i.e.,* social, economic, and environmental by jointly addressing the global food security and climate-challenge. CSA a set of best management practices, is mostly based to achieve three major objectives sustainably enhance productivity and income in agriculture, building resilience and bolstering the adoptive capacity of system to climate change and minimize the emissions of greenhouse gases from agriculture production system without jeopardizing the system productivity and functions. Climate smart water management in agriculture may a pertinent strategy to achieve the objectives of CSA (FAO, 2010). The major emphasis of CSA is to make production systems more resilient; that is, improving the capability of robust performance in the face of adverse climate-scenarios in order to safeguard output and income. Moreover, CSA requires a major shift in the way of management of natural resources such as land, water, soil nutrients and vegetation for utilization of these resources more efficiently and effectively in sustainable manner. By improving the various components of climate smart agriculture, the overall efficiency, adaptation capacity, resilience, and mitigation possibilities of the production systems can be strengthened (Chowdhury & Bajracharya, 2018).

21.3 Water Management as Major Component of CSA

Soil and nutrient management and water management are the keys of various components of CSA like pest and disease management, resilient ecosystems and genetic resources, as well as harvesting, processing, and supply chains (FAO, 2010). Of the various components of CSA, water is most crucial component for climate change which has greater impacts on agriculture due to climate change (UN-Water, 2010). Moreover, water has a central role in both the crop and animal production including fisheries, and the ecosystem-management including forests, rangeland and croplands. In combating the effects of climate change, and to support CSA, the advent of agriculture water management (AWM) technologies will be main center of the strategic adaptation towards global climate change. AWM can be referred to as a "planned development, distribution, and use of water resources to meet predetermined agricultural objectives. It is an overarching term that includes soil and water conservation and irrigation management". A wise and efficient use of water in agriculture help in addressing the problem of climate change and solve the root of problem that is access to water. AWM techniques are significant as using them helps to achieve the climate smart goals of sustainably increasing agricultural productivity, enhancing resilience through efficient water use, removing GHGs, and enhancing food security (Chowdhury & Bajracharya, 2018).

21.4 Agricultural Water Management: Global Status

Around 12% (1.5 billion ha) of the global land area is categorized under cultivated land area and 27% comes as pastureland for livestock production out of the total global land area of world (13 billion ha). It was estimated that the globe's cultivated land area increased by 13%, while population more than doubled during 1960–2000 (de Fraiture & Perry, 2002). Agriculture sector consumes highest share of global water use as it used 70% of global freshwater resources (FAO, 2013). Agricultural

Table 21.1 Agricultural cultivated land across the world (millions of hectares)

Particular	Area (Mha)	
	Year 1961	Year 2009
Irrigated land	139	301
Rain-fed land	1229	1226
Total cultivated land	1368	1527

Source: FAO (2011a)

water use share varies from region to region and country to country. In food importing and developed economy countries, agricultural water use is about 40%. Around 95% of the countries have agriculture as the primary economic activity (UN Water, 2006). Rain-fed areas contributes most of the world's agricultural production. Globally only 20% of agricultural land area comes under irrigated condition which has been expanded 117% since 1961 (Table 21.1) (FAO, 2011a). World's largest consumptive water withdrawal and use sector is an irrigated agriculture. Due to significant losses during distribution and application of water in agriculture, irrigation water withdrawal tends to exceed irrigation water requirement (FAO, 2012a, b).

21.5 Impacts of Climate Change on Agricultural Water Management

Impact of climate change on world's agriculture is mainly due to changes in water resources quantitatively and qualitatively. Every element in the water cycle will be impacted due to climate change (UN-Water, 2010). Increased evaporative water demand, erratic precipitation, variations in river runoff and groundwater recharge are the major factors through which agriculture can be affected due to climate change impacts on available water. Global atmospheric temperature may be risen due to climate change has been linked to the increased water demands for evapotranspiration by crops and natural vegetation, which will potentially result in more rapid loss of soil moisture. It may also affect the rainfall patterns and distribution that may lead to more frequent crop failures. The situation could be even more threatening on increased occurrence of extreme weather events such as floods and drought. Dry spells, and abrupt rainfall during the cropping season have been anticipated to occur with an increasing frequency and intensity. Hence, soil moisture and the productivity of rain-fed crops may directly affect with this type of situation. Moreover, the rising temperatures may be expected to accelerate the hydrological cycle which results the increasing evaporation from land and sea (Turral et al., 2011). Further, river runoff may reduce due to reduced precipitation in arid and semi-arid areas. Climate change impacts on glaciers lead to snow melting, and change the timing and flow-dynamics of rivers receiving their water. However, these circumstances may not necessarily affect the overall rate of mean annual runoff. Local groundwater recharge is often governed by the aquifer-characteristics, the recharging processes and changes in rainfall. Hence, the impact of climate change on groundwater recharge is difficult to predict. As runoff may decline in arid and semi-arid areas which likely, however, reduces the aquifer recharge (Bates et al., 2008; Turral et al., 2011). Agriculture in coastal areas, particularly river deltas may, finally, affects with expected rise in sea levels due to climate changes. Along with the upstream changes, higher sea levels could result in an increased risk of floods and saltwater intrusion in estuaries and aquifers.

21.6 Major Issues and Challenges in Agricultural Water Management Under Changing Climate

The issues related to impacts of climate change on agricultural water management must be considered in a wider context. Issues are as follows; increased demand of water in all sectors, deterioration of water quality; and high competition for water at community, aquifer, and the river-basin levels coupled with lower global water use efficiency (<40%). Besides of these major issues, there are certain challenges in agricultural water management which includes i. policy issues and institutional challenges, ii. Financial and economic concerns, iii. the problems relating to declined investmentsiv. challenges on available technology and water resources; and supply-mechanisms to ever growing demand, vi. poverty and lower income in rural sector, and vi. ecological and sustainability issues.

21.7 Climate Smart Agricultural Water Management

Climate smart agricultural water management is the proper use of options for climate change adaptation in water management technologies. Adaptation in water management technologies is classified as (1) Investments in water management (2) Integration of Land, water and crop management and (3) Policies, institution and capacity building in the field of agricultural water management. Further, these adaptation water management technologies are need to be applied at fields and farms scale, at irrigation schemes level, in watersheds or aquifers level, in river basins level and at the national level. Options for climate change adaptation in water at different scales are illustrated in Table 21.2.

Table 21.2 Climate change adaptation options in agricultural water management technologies at different scales

Options	Field/ farm	Irrigation scheme	Watershed/ aquifer	River basin	National
1. Investment					
(a) Harvesting and storage of rain-water at on-farm	X				
(b) Development of groundwater resources	X				
(c) Irrigation infrastructure modernization		X			
(d) Breeding for resistance to droughts and floods	X				
(e) Construction/enhancement of dam	C	X	X	X	
(f) Drainage	X		X	X	
(g) Introduction of appropriate fish species	X		X	X	
2. Land, water and crop management					
(a) Enhancing soil moisture retention capacity	X				
(b) Changing cropping pattern and diversification	X				
(c) Adapting cropping (and fish harvesting) calendar	X				
(d) Supplementary irrigation	X	X			
(e) Deficit irrigation		X			
(f) Alternate wet and dry rice production system	X	X			
(g) Drainage and flood management		X	X	X	
(h) Irrigation scheme operation improvement		X			
(i) Integrated water resources management				X	
(j) Adaptation of dam operation rules				X	
(k) Riparian habitat restoration or creation in rivers				X	
3. Policies, institutions and capacity building					
(a) Climate proofing of I&D infrastructure		X	X	X	
(b) Reallocation of water (between or within sectors)	X	X	X	X	X
(c) Strengthening land/water right access	X	X	X	X	X
(d) Crop insurances	X				
	X	X	X	X	X

(continued)

Table 21.2 (continued)

Options	Field/ farm	Irrigation scheme	Watershed/ aquifer	River basin	National
(e) Improved weather forecasting capacity					
(f) Improved hydrological monitoring			X	X	
(g) Development of flood/droughts				X	X
(h) Review of food storage strategies					X

Source: adapted from Turral et al. (2011), FAO (2013)

21.8 Adaptation of Climate-Smart Agricultural Water Management Technologies at Field and Farm Level

Adaptations of irrigation technologies in response to climate change in agriculture are considered as climate smart agricultural water management technologies. Agricultural water management technologies at field/farm level are not necessarily designed as per climate change but it can be selected as per the need of climate change. At field/farm level, climate smart water management technologies are those technologies which may capable to enhance the irrigation water use efficiency. It may include micro-irrigation, mulching, on farm water storage and new crops & varieties with better resilience to dry spells and flood. Risk of climate change on agricultural water management may be minimized through increasing agricultural diversification, including better integration of multiple allied sectors in agriculture. It may also resilient the farming system. Adaptation of systematic measures at grassroot level to respond the increased frequency of floods and intensive rainfalls are critically needed to enhance overall resilience of the existing agricultural systems. Moreover, a combination of optimal drainage and erosion-control mechanisms are also needed to avoid long-term ill-effects such as soil salinization.

21.9 Adaptation of Climate-Smart Agricultural Water Management Technologies at Irrigation Scheme Level

The major interventions for adapting to climate change in irrigation schemes are modernization of irrigation infrastructure, dam construction/enhancement, supplementary irrigation, drainage and flood management. Precise management practices, water requirement-based robust alarming systems, and better water allocation mechanisms are the key requisites of modern irrigation systems (FAO, 2007). Sustained water supply within the irrigation systems can be easily achieved through intermediate storage mechanisms; and a need-based, point-access to the groundwater that could further enhance the overall resilience of the system. For promoting better water use and reducing water wastage, water pricing and the establishment of water markets may be advocated as demand management tools. Above-mentioned options are effective in some places and not effective in other places typically due to several aspects including administration, technical, and policy reasons. The other simpler and more effective options may be as follows; limiting seasonal allocations to users or to groups of users and promoting productive water use behavior.

21.10 Adaptation of Climate-Smart Agricultural Water Management Technologies at Watershed, River Basin and National Levels

An integration of newly developed policies with the active investments in infrastructure and management will be significantly helpful towards climate-resilience in modern agricultural systems, particularly with reference to the water management. Higher frequency and intensity of climate-extremities demand urgent adjustments in the storage capacity and management of dams and river protection. Flood management plans may need to be combined with infrastructure upgrades, land planning, early warning and insurance schemes which can be better mitigate the impact of climate change on occurrence of floods. Moreover, there is an urgent need to shift from "drought emergency response" to "drought management plans" that include prevention, preparedness, relief and rehabilitation in addition to the long-term measures to promote a resilient, drought-resistant agricultural system (FAO and NDMC, 2008).

21.11 Strategies for Climate Smart Sustainable Agricultural Water Management

At regional, national and global scale, among the different sectors of economy, agriculture consumes major share of fresh water. Thus, managerial and technological interventions, human resource management innovations, and policy level interventions are needed to increase the use efficiency of water in agriculture. The CSA based strategies will help in achieving the sustainable waters management in agriculture. Some of strategies for enhancing use efficiency of agriculture water are:

(i) Reduce loss of water through conveyance, distribution, application networked/channels by adopting the new cutting-edge technologies like GIS, remote sensing and telemetry.
(ii) Precise designing and proper maintenance of sprinkler waters application systems improve water use efficiency and minimize water and soil related hazards.

(iii) Development of localized irrigation system for farmers for increasing water use efficiency
(iv) Proper irrigation scheduling as per crop demand and critical crop growth stage
(v) Development of irrigation advisory centers or facilitates in rural or country sides
(vi) Appropriate treatment of saline and grey waters before application in agriculture
(vii) Adoption of good agronomic practices
(viii) Improved irrigation techniques like subsurface irrigation (SSI); regulated deficit irrigation (RDI); Fertigation (efficient fertilizer application); and chemigation for efficient management of weeds and soil borne diseases should be adopted and promoted
(ix) Reuse of waste water or marginal water for agriculture
(x) An effective participation of public, school students, NGO and other stakeholder in planning, monitoring and implantation water policy will be ensured.
(xi) Capacity building program on efficiency water management, waters saving, waste water treatment and other water related issues should be organized with proper participation of stakeholder at various levels like, village, districts, state, national and global level.

21.12 Conclusion

Agricultural water management will be the major focused area under climate change as sustainable agricultural production is based on efficient water management in agriculture. Adaptation of climate smart agricultural water management technologies at field/farm, river basin/watershed and national level are needed for climate smart agriculture. Strategies for climate smart water management in agriculture are needs to be formulated and implemented for sustaining agricultural production and food security under the current situation of rapid growing population.

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Chapter 22
Decoding the Enigma of Drought Stress Tolerance Mechanisms in Plants and its Application in Crop Improvement

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Abstract Drought stress is a worldwide production constraint in agriculture. In many poorer countries, providing irrigations in dry and dryland areas seems unreachable task. Therefore, we need to grow such genotypes which are able to resist drought stress through morphological modifications and physiological signaling mechanisms. Different plants respond differently to water stress. Plant traits that can be utilized for selecting genotypes suitable for drought prone areas are Chlorophyll fluorescence, Chlorophyll content, Accumulation of reactive of oxygen species (ROS), antioxidants, Concentration of potassium (K^+) in leaf tissues, Electrolyte leakage (EL), Leaf relative water content (RWC) and Proline accumulation. Many plants are able to escape or avoid drought stress by adjusting the growth cycle or transpiration water loss and *boundary level resistance*. Among various mechanisms, osmotic adjustment, abscisic acid and induction of dehydrins helps to confer tolerance against drought injuries by maintaining high tissue water potential. Antioxidant defense against drought stress tolerance includes several enzymes such as superoxide dismutase, catalase, peroxidase, ascorbate peroxidase and glutathione reductase and several non-enzymatic components. Extensive studies on transcriptome elucidate important roles of PGPRs in drought stress tolerance. ABA and ethylene are well studied to date and proved to be activated and provide tolerance during water deficit conditions. Other major hormones like auxin, CKs, and GA are also involved significantly during drought but the molecular mechanisms related to these

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hormones are partially understood. Moreover, the other growth regulators such as brassinosteroids, SA, and jasmonic acid are also significantly involved to cope with drought. All the different drought signaling mechanisms include some known genes, promoters and transcription families, therefore genetic manipulations in conferring the drought stress tolerance in crops through selections or gene introgression is a strategy for future, if the pathways to different mechanisms are known.

Keywords Drought · PGPRS · Reactive oxygen species · Osmoprotectants · Chlorophyll · Enzymes

22.1 Introduction

Drought stress is a worldwide crop production constraint (Teran & Singh, 2002). Like soil and air water is also vital for the plant life. Plants use water to transport nutrients and other substrates in their systems where chemical reactions and sink production occurs apart from merely keeping cells hydrated. Drought stress impairs several visible and invisible physiological processes in plants (Gull, 2018). Drought in itself is a very complex issue to understand as it affects plants in conjunction with high temperature, atmospheric moisture, intensity of sunlight soil fertility, soil PH and soil salinity. Apart from these external factors, some internal factors such as morphological and physiological capabilities of plants as manifested by genotypic potential and makeup of plants are also responsible for drought. Genetic makeup is mentioned because some genotypes are not designed for drought stress by nature and it doesn't make them any inferior because horses are for courses. But it is the genotype of plant which decides the required structural and physiological remedies to counter drought stress. In this regard different genotypes use different physical and physiological mechanisms to tolerate or resist drought stress, which may include compromises in outputs or growth time. When plants are sensitive to drought stress but still maintain optimum economic output, it is called as drought tolerance but when a plant is completely unfazed by drought stress, that plant can be termed as resistant. There is also a third category of susceptible plants which like resistant plants do not sense drought and keep on being busy with normal growth functions and suddenly wilt when drought stress is prolonged. When screening for drought stress many traits such as yield, root/shoot biomass production, root length, root angle, canopy temperature and transpiration are seen as desirable for drought stress tolerance in lentil (Hassan et al., 2017). Sofi et al. (2017) reported that a drought stress resistant plant is able to maintain a lower canopy temperature and optimum transpiration whereas a tolerant plant will compromise on vegetative output or decrease growth rate but maintain a significant seed yield. Plants are effected by drought stress at morphological as well as molecular levels and symptoms or effects are evident in plants at different stages at which drought stress occurs. The effects of drought stress largely depend on the time at which water deficit occurs but irrespective of phenological stage at which it occurs, end product i.e., growth and yield is definitely going to be affected. First major effect of drought stress on plants

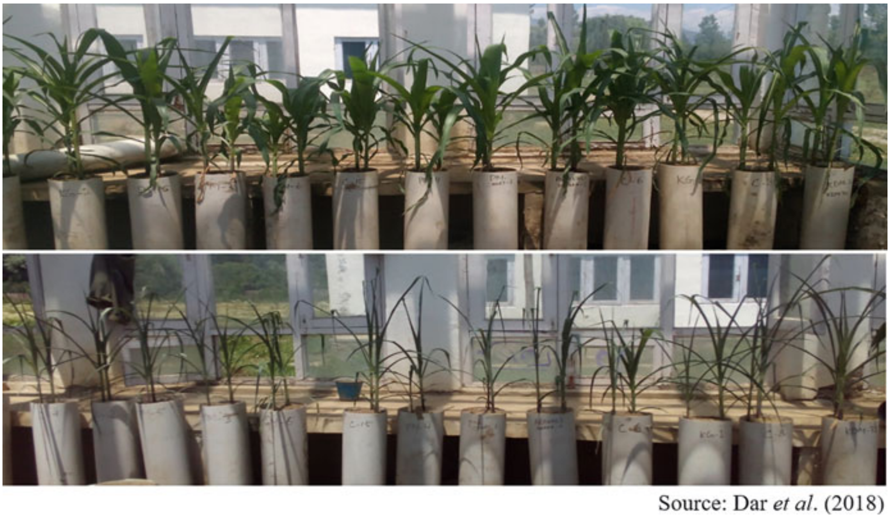


Fig. 22.1 Comparison between well-watered and plants under drought stress. (Source: Dar et al., 2018)

after sowing in soil is poor germination and if somehow some pants germinate, crop stand will be poor (Harris et al., 2002): (Fig. 22.1). The methods of grown in all living organisms are cell division, cell enlargement and cell differentiation. It includes complex interactions of genetic, physiological, ecological and morphological events. The basic idea of existence of plants depends upon these events. Drought stress primarily impairs cell growth by reducing turgor pressure of cells (Taiz & Zeiger, 2006). Cell elongation also gets severely affected due to inability of fluid movement within the xylem because of reduced water potential. It could be summarized that prolonged drought stress halts plant growth and development, resulting in poor flower production and grain filling. Due to poor partitioning of assimilates and reduced activities of starch and sugar-synthesizing enzymes, grain-filling is poor. Plant water relations are affected by canopy temperature, cell water potential, water content, transpiration rate and stomatal resistance. Siddique et al. (2001) reported that wheat and rice plants under water stress had lower relative water content as compared to non-stressed ones. These plants possessed considerably shrunken leaf water potential, water content and transpiration rate, resulting in an increase in leaf temperature when exposed to drought stress. Drought results in poor nutrient uptake and reduced levels of nutrients in plant tissues. A vital impact of water deficit is on absorption and transport of nutrients in plants. Reduced concentrations of the nutrient ions in the plant tissues might be the result of poor nutrient uptake, unloading mechanism and reduced transpiration flow. Grossman and Takahashi (2001) observed that, drought denies plants the energy required for assimilation for NO^{-3}/NH^{+4}, $PO_3{}^{-4}$ and $SO_2{}^{-4}$ as these ions are processed through ATP consuming processes before they could be utilized in physiological processes meant for growth. Drought stress significantly reduces leaf area index (LAI), impaired photosynthetic machinery, premature senescence and reduced assimilation of substrates necessary for plant growth. Stomatal closure because of drought additionally ends up in restricted carbon dioxide (CO_2) uptake this may probably result in hyperbolic status to damage of plant organs due to excessive sunlight (Cornic & Massacci, 1996). Degradation of photosynthetic pigments, broken photosynthetic apparatus and impaired activities of enzymes involved in Calvin cycle are some other major effects of drought stress (Anjum et al., 2003). The balance between assembly of ROS and their scavenging, i.e., antioxidant defence mechanism which leads to oxidative stress in plasma membrane is critically disturbed during drought stress.

22.2 Physiological Traits Related to Drought Tolerance

22.2.1 Chlorophyll Fluorescence (CF)

Chlorophyll *a* molecules in PSII complexes re-emit light upon de-excitation in dark-adapted leaves. This phenomenon is, called as Chlorophyll fluorescence (Lu & Zhang, 1999) and emitting of light is quantitatively termed as quantum yield of CF (Φ_F). CF in leaves is estimated on the basis of certain parameters. Important CF parameters to study under drought conditions are F_V/F_M, F_0/F_M, Φ_{PSII} and PI_{ABS} (Banks, 2018). Where F_0 is minimum CF yield in dark adapted state (DAS) and F_m is the maximum yield of the same. The parameter Fv means difference between F_0 and F_m or variable fluorescence. F_V/F_M is the ratio of variable fluorescence to maximum fluorescence and this parameter used to study the potential efficiency of PSII. F_0/F_M increases in drought stressed plants. The parameter Φ_{PSII}, gives the rate of linear electron transport and thus overall photosynthesis rate. These values are also calculated in light adapted state (LAS) which are off course lower than that of DAS. The values of F_0 and F_M in LAS are also important to calculate parameters like Φ_{PSII} and PI_{ABS}. F_0/F_M increases in drought stressed plants. PI_{ABS} is a new model, which contains multiple parameters and is often called as performance index. It gives information about F_v/F_M as well as V_J, where V_J is CF yield at 2 milliseconds. CF is closely related to photosynthetic and the physiological state of plant. Therefore; CF is, used as a robust non-destructive and reliable tool for understanding the photosynthetic ability of plants grown in water deficit environment.

22.2.2 Chlorophyll Content

Chlorophyll content in leaves is severally, affected by drought stress and level of chlorophyll deterioration is different in different plants. It does so by either destroying chlorophyll molecules or inhibiting its synthesis (Montago & Woo, 1999). Plants reduce chlorophyll content as a response to minimize excess energy absorption and as a response to oxidative damage by excess light. Under drought stress, light having even lower photon flux density (PFD) is damaging and considered high intensity (Zlatev, 2009). In a study by Pirzad et al. in 2011, it was observed that both water deficit and excess of it can significantly reduce chlorophyll concentration of leaves. Different genotypes respond differently to drought stress when it comes to chlorophyll content, therefore this trait may be used to screen early for drought tolerance.

22.2.3 Reactive Oxygen Species (ROS) and Antioxidants Accumulation

Accumulation of ROS free radicles like, O^- , $^1O_2$, OH^- and other reactive compounds like, H_2O_2 cause membrane damage, peroxidise lipids, oxidize proteins as well as damage nucleic acids (Sharma et al., 2012). Whenever rate of synthesis of ROS is higher than the rate of its scavenging, ROS becomes oxidatively damaging. Hyper accumulated ROS induced drought stress is reported in various studies (Sharma et al., 2012). Malondialdihyde (MAD) also increases during drought stress which is related to peroxidation of lipid membranes. Therefore, drought stress also causes membrane damage (Yuan et al., 2016). The quantification of scavenging activity can be done through the monitoring of antioxidant enzyme activity. Superoxide dismutase (SOD), peroxidase (POD) and catalases (CAT) are some known ROS scavenging enzymes. SOD, CAT and POD are reported to be increased under drought stress. This means that ROS accumulation increases to injurious levels during drought.. This needs such breeding efforts to overexpress antioxidants under drought stress. However, moderate accumulation of ROS is beneficial and is reported to help in secondary signaling for drought. Therefore more research attention on ROS is needed.

22.2.4 Potassium (K+) Concentration in Leaf Tissues

Physical function of water in plants is cell growth and enlargement, which it does so by maintaining the turgidity of cells. Potassium is an osmolyte and helps in osmotic adjustment (Marschne, 2011). Cell growth is maintained in declined cellular water potential by increasing concentration of solutes in plant cells (Romheld & Kirkby, 2010). Potassium is the major ion, which is accumulated in leaf cells in response to drought stress. Studies on role of potassium in adapting to water stress may guide scientists in selection of optimum fertilization and soil management practices to achieve an optimum ionic balance in plants under water deficit.

22.2.5 Electrolyte Leakage

Electrolyte leakage (EL) is emerging as a new technique in the assessment of various stresses in plants. Root electrolyte leakage (REL) and shoot electrolyte leakage (SEL) are the indices commonly used. They impact the integrity of cell membrane. Water is stored inside cells as well as in extra cellular parts i.e. both apoplast and symplast. Apoplast generally contains pure water whereas solution in symplast contains a number of ions. Under drought stress due to accumulation of ROS membrane integrity is compromised which leads to electrolyte leakage. Hence, leakage of ions across the cell membrane can indicate the health of cell membrane. Khan et al. (2019) observed that electrolyte leakage was also correlated with abiotic stress in chickpea. To assess salt, heat, water and biotic stress tolerance, EL has been effectively used as an index (Kamanga et al., 2018). Khan (2020) used EL as an index to evaluate chickpea genotypes under cold stress, it was observed that cold tolerant genotypes were able to maintain membrane stability as they restricted electrolyte leakage whereas in susceptible genotypes EL was on the higher side.

22.2.6 Relative Leaf Water Content (RWC)

Leaf water potential has lately been replaced by RWC as an index in understanding drought tolerance in crops (Hassanzadeh et al., 2009). RWC is considered as best criterion for drought screening. Dar et al. (2018) and Gull et al. (2018) observed correlations between drought tolerance and relative water content in maize and cowpea respectively. RWC is an indication of eater balance in plants. More studies are needed to reveal growth factors and traits that maintain RWC in achieving drought tolerance.

22.2.7 Proline Accumulation

Accumulation of osmoprotectants that are a part of normal metabolism helps in mitigation of drought stress in plants through enhanced water retention thus maintain the structural integrity of the cell membranes (Hare et al., 1998). However, the type of such osmoprotectant metabolites differs in plant species (Silvente et al., 2012). Conservation of such metabolites among different species has, also been reported. Glycine betaine, trehalose, taurine and proline are some of the known osmoprotectant metabolites (Bowne et al., 2012). Various studies have reported a positive correlation between proline accumulation and drought stress tolerance (Hayat et al., 2012). Detailed pathway of proline synthesis and its role in osmoprotection is discussed in Sect. 22.3.3.1.

22.3 Drought Stress Tolerance/Resistance Mechanisms

22.3.1 Strategies Employed by Plants During Drought

Manifestation of drought tolerance involves responses at physiological, morphological and molecular levels. It can be a single, a combination of a few or a holistic response to drought stress involving all three above mentioned levels. Some of the strategies of plants using morphological and phenological adjustments in play during drought stress are mentioned below.

22.3.1.1 Drought Escape

In the escapence phenomenon of drought stress tolerance plants utilize shortening of life cycle, i.e. flowering or seed setting before drought occurs. Flowering time is associated with drought acculturation, while a shortened life cycle can lead to drought escape (Araus et al., 2002). Plant genotype and its interaction with environment determines the crop duration. Selection of short duration genotypes or early flowering types is desirable when a particular environment is under terminal drought. However, crop yield is positively correlated with crop duration, any shortening of life cycle can be detrimental to crop yield (Sofi et al., 2017).

22.3.1.2 Drought Avoidance

Maintenance of leaf water potential and normal transpiration rate during water deficit by absorbing water from deeper layers of soil through a prolific root system is termed as avoidance of drought. The root traits such as root biomass, root length, root density, root angle, root biomass partitioning and root depth are the main drought avoidance traits that contribute to final yield under terminal drought environments. Dar et al. (2018) reported that a root angle of 45^{o} is desirable for maintaining water absorption under drought stress as the soil area covered by roots at this angle is maximum. A deep and rigorous root system is desirable for absorption of water from lower water potential soil colloidal surfaces (Kavar et al., 2007). According to Richards et al. (1986) waxy bloom on leaves is considered as a desirable trait for drought avoidance as it helps in maintaining optimum water potential in the leaves.

22.3.1.3 Structural Modifications

Schuppler et al. (1998) observed that plants generally reduce leaf area to reduce transpiration loss as an adaptation to water deficit. Plants with smaller leaves are predominantly adapted to dry environments. Recently maize hybrids are developed by many private companies with traits like erect leaves to suit hotter climates of tropical India. Such varieties succeed in keeping minimal contact with sunlight and

Source: Dar *et al*. (2018)

Fig. 22.2 Variation in root biomass concentration in different genotypes of maize that drought tolerant plants were not only deep rooted but maintained significant root density at 0–15 soil depth. (Source: Dar et al., 2018)

reduce hyper water loss meant for keeping the canopy cooler. Leaf pubescence and hairy leaves also mitigate heat and water stress by conserving water. Such traits are termed as *boundary level resistance***.** It is shown that the quality of root architecture is important in better absorption of water stress as opposed to mere quantity of roots (Dar et al., 2018) (Fig. 22.2). Root shoot ratio is another trait of interest in drought tolerance. It has been reported that wheat cultivars having dwarfing genes *rht1* and *rht2* had lower root biomass and were susceptible to drought (Miralles et al., 1997). It is understood that plants having shorter shoot would definitely have smaller roots but breeding efforts are needed to identify genotypes that can push more biomass into roots, as shorter height is considered as a desirable trait to prevent lodging and produce higher yield. Other than root modifications, some plants may shed leaves to reduce transpiration area under water deficit.

22.3.2 Physiological Mechanisms

22.3.2.1 Cellular and Tissue Water Conservation

Drought resistant genotypes are able to maintain higher relative water content than susceptible ones. However the comparison between morning and afternoon water content within the foliage is a better scale to understand variability in LWC for drought response. Osmotic adjustment is important for maintaining optimum physiological activity for an extended period throughout water stress. Accumulation of solutes causes the lowering of osmotic potential of cells which pulls water inside the cells to maintain turgor pressure. Reducing the rate of transpiration can be the best way to conserve water in cells and tissues. To do that, plants close stomata through ABA or antioxidant signaling mechanisms. Not only these but, development of waxy cuticle or silicaceous depositions on epidermis can also be efficient structural modifications to ward off unnecessary water loss. The best way possible to conserve water in cells and tissues is to reduce growth rate by reduced activities of growth hormones like GA. Many such possible remedies, which may be morphological, physiological, metabolic, or genetic ultimately preventing unnecessary water exhaust through cell membrane, are discussed in this chapter under different headings.

22.3.2.2 Antioxidant Defense

Antioxidant defence in plants includes enzymes such as SOD, PODs (ascorbate peroxidase) dehydro/mono ascorbate reductase, glutathione reductase (to inhibit GSH) (Pastori et al., 2000) and CATS and amino acids (Cystine) and ascorbate etc. These components function as ROS scavengers (Fazeli et al., 2007; Gong et al., 2005; Orvar & Ellis, 1997). One type of deoxyribonucleic acid glutathione reductase encodes the cytosolic isoforms (Stevens et al., 2000) whereas the other type targets GSH reductase proteins in chloroplast and mitochondrion (Chew et al., 2003). Among the enzymatic mechanisms, superoxide dismutase (SOD) dismutates two molecules of O_2^- into oxygen and hydrogen peroxide (Fig. 22.3) which is converted to water by peroxidase or catalase (Apel & Hirt, 2004). Drought tolerance is often

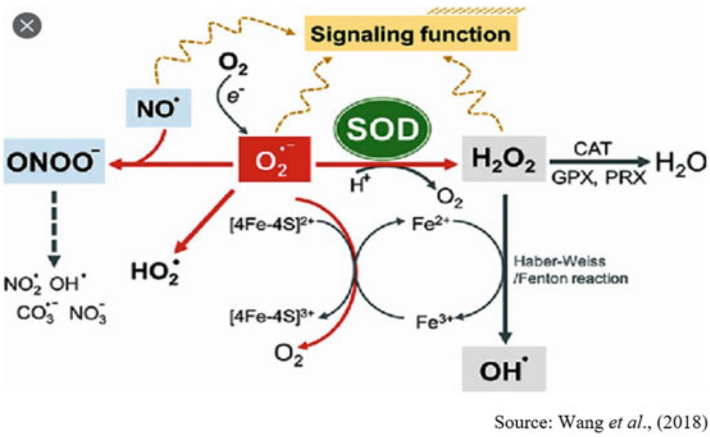


Fig. 22.3 Scavenging of superoxide ion by SOD and conversion of resultant hydrogen peroxide into water by catalase and peroxidases. (Source: Wang et al., 2018)

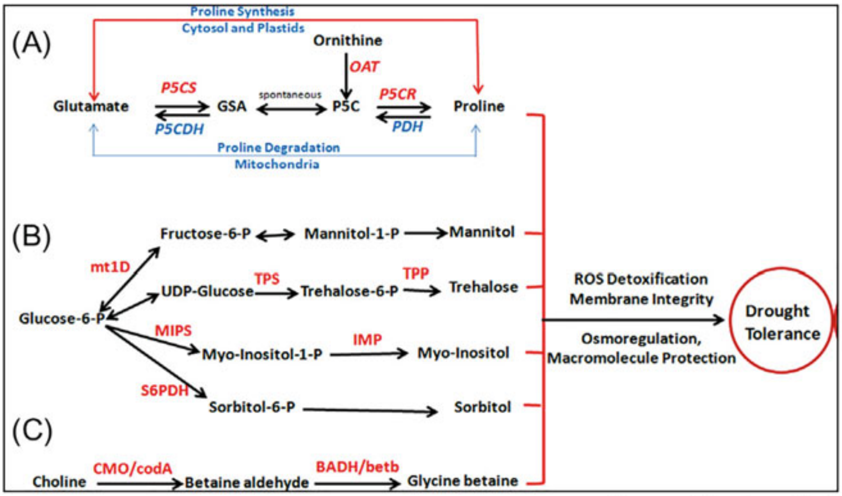
associated with the activity of AO enzymes. Carotenoids and abietane diterpenes also scavenge $^1O_2$ and lipid peroxy-radicals, as well as restrict lipid peroxidation and superoxide generation under drought (Deltoro et al., 1998). During drought stress transcripts of GSH genes is observed to be high which indicates its role in scavenging of ROS and consequently drought stress (Ratnayaka et al., 2003). Thus, enhanced SOD activity imparts oxidative stress tolerance (Pan et al., 2006). Biological membranes are the first organelle affected by abiotic stresses. Stability and integrity of cell membranes is necessary in drought stress (Bajji et al., 2002) and is an index in drought tolerance assessment (Premachandra et al., 1991). Several *QTLs* have been mapped rice under drought stress for membrane stability at different phenological stages (Tripathy et al., 2000). Dhanda et al. (2004) used membrane stability as a parameter to screen germplasm for drought stress**.** Gnanasiri et al., 1991 reported that maintenance of optimal K nutrition in maize is vital in ensuring membrane stability. Crowding and increased viscosity of tissues due to reduced cell size under drought stress results in protein denaturation and membrane fusion. Signaling molecules such as glutamate, glycine betaine, manitol, sorbitols, polyols, fructans, proline, trehalose and sucrose are associated with prevention of such adverse molecular interactions (Folkert et al., 2001).

22.3.3 Genes Involved in Osmoprotectant Regulation

Osmoprotectants play a significant role in protein and membrane stability during drought stress (Giri, 2011). Common osmoprotectants active in plant systems during drought stress are; amino acids, polyols and sugars and glycine betaine (GB) (Fig. 22.3).

22.3.3.1 Proline Accumulation

Proline accumulation is vital in the manifestation of drought stress tolerance. It acts as an antioxidant and osmoprotectant. As mentioned in Fig. 22.4a, Glutamate is converted by Δ1- pyroline-5-carboxylate synthetase (*P5CS*) into proline and Δ1-pyroline-5-carboxylate reductase (*P5CR*). Proline degradation occurs in mitochondria using proline dehydrogenase or proline oxidase (*PDH* or *POX*) to produce P5C which is further converted to glutamate by pyroline-5-carboxylase dehydrogenase (*P5CDH*). Both *P5CS* and *PDH* are important in proline synthesis and degradation. Overexpression of moth bean *P5CS* in transgenic *Nicotiana* plants resulted in salt and drought tolerance and overexpressed *Arabidopsis P5CR* (*AtP5R*) gene in *Glycine max* enhanced tolerance under heat and water deficit conditions (De Ronde et al., 2004). These findings clearly elucidate the importance of proline in drought tolerance.



Source: Singh *et al*. (2019)

Fig. 22.4 Osmoprotectant biosynthesis pathway. (Source: Singh et al., 2019)

22.3.3.2 Polyols and Sugars

Sugar levels and carbon metabolism are critically affected by drought. In algae and some halines Polyols act as osmoprotectants e.g. glycerol, trehalose, mannitol, D-ononitol, and Sorbitol. Mannitol 1-phosphate dehydrogenase (*mtlD*) gene synthesizes mannitol. In transgenic tobacco and *Arabidopsis*, overexpression of this gene enhanced mannitol production increasing abiotic stress tolerance. The expression of the *mtlD* gene is important in wheat abiotic stress tolerance including drought (Abebe et al., 2003). *imtl* gene encoding myo-inositolomethyl-transferase enzyme of ononitol biosynthesis pathway when overexpressed in *Nicotiana* plants showed enhanced tolerance to salt and drought stress (Sheveleva et al., 1997). The gene, *Stpd1* (Sorbitol_6_phosphate_dehydrogenase) codes for the accumulation of sorbitol. *Diospyros kaki* transgenic plants expressing apple *Stpd1*, accumulated sorbitol and displayed higher photosynthetic activity and better growth (Gao et al., 2001). Akram et al., 2015 observed that trehalose pre-treatment induced drought tolerance in radish plants. In *E. coli otsA* and *otsB* genes are responsible for trehalose production. Garg et al. (2002) observed that when a fusion gene *TPSP* (trehalose-6-phosphate synthase/phosphatase), developed from *otsA* and *OtsB* was overexpressed in rice, it improved abiotic stress tolerance. *T6P* also helps in signaling stress response aside from osmoregulation and molecular chaperony.

22.3.3.3 Glycine Betaine

Glycine Betaine acts as an osmoprotectant in living organisms. It helps in regulation of cell volume under hypertonic conditions. Its activity is more pronounced in young tissues as compared to older plant parts, which can help, in well-being of new leaves in plants as older ones should be shed anyway to reduce unnecessary load under drought stress. It is derived (methylated) from glycine. GB accumulation happens in plants when exposed to drought stress and high temperature (Giri, 2011). Many plants cannot naturally accumulate GB, however, transgenic plants expressing genes for GB synthesis have been reported in various plant species. Glycine betaine can be synthesized from choline by *choline monooxygenase* and *Betaine aldehyde dehydrogenase* in bacteria (Fig. 22.4c). Bacterial genes *codA* and *betB* encode for these two enzymes. Transgenic plants having these genes can synthesize GB (Giri, 2011). Beneficial effects of exogenous application of GB during drought stress are also reported. It reduces cation levels inside cells and increasing the activity of antioxidant enzymes (Raza et al., 2014). It also preserves thermodynamic stability of several macromolecules as it is not only an osmolyte but also acts as a zwitterion. It is present in Poaceae and Chenopodiaceae families. The selections of high GB activity lines in cereals and introgression of this trait in adapted varieties shall be desirable in fighting against harmful effects of drought stress on membranes and macromolecules.

22.3.3.4 Osmotin

Stress-responsive proteins of PR-5 pathogenesis-related group include osmotin and osmotin-like proteins (OLPs). OLPs also perform a dual role of defence against drought stress (Chowdhury et al., 2017). Their true mechanism is still unknown but transgenic tobacco plants having gene for osmotin production made them tolerant to salinity, wounding, infection, and drought stress (Barthakur et al., 2001). It has been observed that, in crops like wheat, tomato, and soybean (Goel et al., 2010; Noori & Sokhansanj, 2008; Subramanyam et al., 2012) expression of the osmotin gene bestowed abiotic stress tolerance including drought. Osmotin also increases the accumulation of proline in plant cells which is necessary for quenching ROS (Zhang et al., 2004). Under drought and salt stress, high K^+/Na^+ ratio is desirable in plant tissues. Osmotin like proteins (OLPs) round up excess Na^+ ions and compartmentalize them into vacuole, thus maintaining the ionic balance in plants during drought (Kumar et al., 2016).

22.3.3.5 Dehydrins

Yang et al. (2012) proposed that dehydrin play an important role in dehydaration mitigation by acting as molecular chaperones in membrane stabilization. They inactivate or prevent the aggregation of proteins during dehydration. Several studies using transgenic plants revealed that dehydrin gene when overexpressed, has a desirable effect on drought tolerance. Overexpression of *OsDHN1* in rice bestows high tolerance to abiotic stress including drought stress (Kumar et al., 2014). *OsjDHN* is reported to do sub-functionalization under polyethylene glycol (PEG) induced drought stress (Verma et al., 2017). Production of rice *ShDHN* gene transcripts and drought tolerance are positively correlated (Liu et al., 2015). Evolutionary conservation of dehydrin production traits is, well documented during domestication of some 11 oryza species and subspecies (Verma et al., 2017). *OsHDN* gene overexpression in transgenic rice proved desirable against both natural and induced drought stresses (Singh et al., 2019).

22.3.4 Redox Regulatory Machinery in Plants During Drought Stress

Drought stress significantly damages homeostasis machinery in plants (Halliwell, 2006). Reactive oxygen species (ROS) are byproducts of electron transport chain (ETC) in cellular organelles under all conditions. However, under dehydration, ROS accumulation increases to injurious levels. Enzymes that regulate oxidants are already named in this chapter. Some of the important enzymes active in redox regulation and genes behind these enzymes are discussed below.

22.3.4.1 Enzymatic ROS Regulation during Drought

Superoxide dismutase (SOD) an antioxidant enzyme which is one of the initial responses to oxidative stress under drought. *AhCuZnSOD* gene of groundnut when overexpressed in transgenic *Nicotiana tabaccum* improved growth water deficit conditions (Negi et al., 2015). Another gene *TaMnSOD* from *Tamarix albiflonum* enhanced drought tolerance by reducing oxidative stress damage in transgenic plants (Zhang et al., 2014). Catalases and Peroxidases reduce hydrogen peroxide content in peroxisomes, cytosol and chloroplasts respectively. Harmful free radicals and singlet oxygen ($^1O_2$) are scavenged by alpha tocopherol in plants. (Espinoza et al., 2013). The tocopherol cyclase gene is responsible for production of tocopherol in *Arabidopsis*. This gene when overexpressed in transgenic tobacco improved growth under water deficient environment (Woo et al., 2014). Therefore selections of plants for higher alpha tocopherol or SOD activity can provide tolerance to drought stress. If natural variation for these characters is absent in germplasm then introgression strategies can be followed by crossing with transgenic isogenic lines. Glutathione is a key ROS scavenging molecule (Foyer & Noctor, 2005). GSH synthesized by γ – ECS (glutamyl-cystenyl synthetase) and GS (glutathione synthetase) in two steps. The proportion of GSH is key in maintaining cellular redox state. Nahar et al. (2015) in *vigna radiata* observed better performance under drought stress after external application of GSH. γ-ECS transformants have also been proved to be better performing under PEG and ABA induced osmotic stress (Sengupta et al., 2012).

22.3.5 Hormonal Regulation of Drought Tolerance in Plants

Extensive studies on transcriptome elucidate important roles of PGPRs in drought stress tolerance. The role of two growth retarding hormones viz: ABA and Ethylene is already established to be detrimental in response to drought stress. Other growth hormones like, Auxin, Cytokinin, Gibberlins, Jasmonic acid, Salyclic acid, and Brassinosteroids are also involved in drought stress responses. Possible roles and mechanisms of these phytohormones are discussed below.

22.3.5.1 Auxins

Auxin is known to maintain apical dominance and helpin root development. A deep and robust root system is important for absorbing water from deeper layers of soil when its dry under drought. auxin biosynthesis involves *YUCCA* genes as the key factor and these genes are drought-induced, although molecular mechanism is to be decoded. Mapping of these genes and association analysis are needed to understand their true function and subsequent selections of genotypes expressing these loci may help in manifestation of drought stress tolerance. *MIZ1* (*MIZUKUSSEI1*) gene is a regulator of hydrotropism, and results in reduced lateral root mass. Plants expressing this gene had reduced auxin levels in pericycle cells. This inhibition can be dealt with by the external application of auxins in *Arabidopsis* (Moriwaki et al., 2011). This study further cements the role of auxin in enhancement of root architecture. Micro-array analysis shows that plants under water deficit have upregulated transcripts of auxin responsive factors (ARFs). Micro RNAs like miR167 and miR164 regulate auxin responsive (Guo et al., 2005; Kinoshita et al., 2012) in *Arabidopsis*, and thus regulate root biomass production. miR167 reduces amount of IAR3 transcript. Under drought stress miR167 is reported to be downregulated to elevate levels of ARFs (Kinoshita et al., 2012). *miR393* is a water stress-induced miRNA that removes transcripts of *TIR* and *AFB2* gene, thus reducing lateral root biomass (Chen et al., 2012). Thus higher auxin levels are desirable in root development and consequently drought stress tolerance.

22.3.5.2 Cytokinin

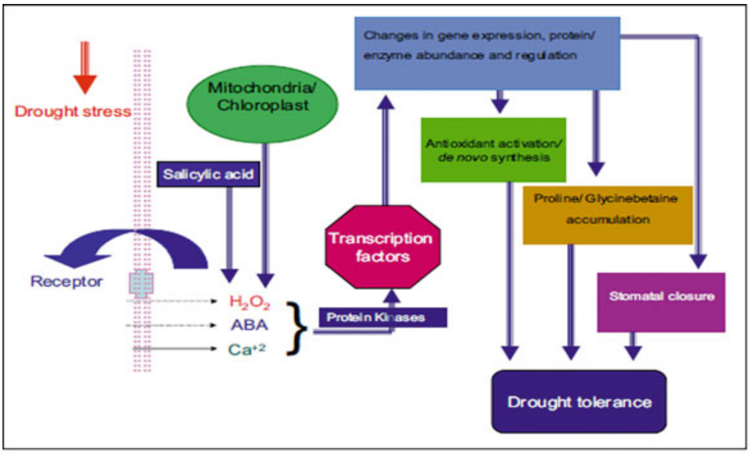
Cytokinins (CKs) are PGPRs that regulate cell division and differentiation. CK levels are downregulated during drought stress (Merewitz et al., 2010). Peleg et al. (2011) reported that external application of cytokinins in rice on foliage improved drought tolerance. phosphate-isopentyl transferase (*IPT*) gene is responsible for synthesis of cytokinin in plants. Overexpression of this gene in transgenic tobacco exhibited drought tolerance. More downregulation of drought responsive as compared to upregulation was observed in the root tissues of plants transformed with *IPT* gene. From this it can be inference that either cytokinin or IPT gene is involved in drought stress responses (Rivero et al., 2010). Mackova´ et al. (2013) Cytokinin oxidase/dehydrogenase1 (*CKX1*) responsible for cytokinin degradation when enhanced by the root-specific promoter *WRKY6* resulted in low levels of cytokinin in root tissues and subsequent increase in lateral root biomass. From these studies, it can be said that in water deficit conditions, lower concentration of cytokinins in roots whereas higher IPT level in shoots increases drought tolerance.

22.3.5.3 Gibberlins

GA levels are known to be downregulated during drought stress in maize. The three di-oxygenase genes "GA20", "GA3", and "GA2" involved in gibberlic acid biosynthesis were overexpressed in *Arabidopsis* under 35S promoter under drought stress (Wang et al., 2008) and the results suggested that lower levels of GA are favourable in drought stress tolerance. Upregulated GA2-oxidase helps in reducing GA levels in drought effected tolerant plants. Although plants become short and stunted during drought due to reduced metabolism, photosynthesis and off course lower GA levels but artificial increase in GA levels is not a remedy to counter drought and enhance growth (Litvin, 2015). Plants in fact respond to drought by downregulating GA synthesis to prevent aggressive growth load. This can be an adaptive advantage to crops growing in excessively dry areas (Vettakkorumakankov et al., 1999). Genotypes having dwarfing genes can achieve reduced above ground biomass when experiencing drought. Palcobutrazol (PAC) is a chemical that inhibits GA synthesis by interfering with *ent*-Kaurene oxidase prebenting its conversion to *ent*-Kaurenoic acid during GA biosynthesis pathway (Litvin, 2015). It can be exogenously applied to reduce GA levels mildly as harshly reduced levels of GA can stunt growth to dangerous levels. They also observed that GA signaling gene "*DELLA*" is independent of PAC or GA levels. This gene is involved in cross talk between ABA and GA during drought stress and consequent ABA mediated antioxidant activity and transpirational cut. Therefore marinating minimal levels of GA and overexpression of "*DELLA*" gene can aid in drought stress tolerance. In the same study it was also observed that *DREB* transcription factor also reduces "*GAox*" expression thereby reducing intermodal distance in tomato plants. *Expansin* genes, which are associated with GA action were also downregulated during drought stress. (Litvin, 2015) The above results completely prove that GA is lowered in plants during drought stress as an adaptive response. But, is reducing GA levels in plants during drought stress can be an answer? Therefore, a strategy involving negative GA mediated drought stress tolerance requires more research attention.

22.3.5.4 Abscisic Acid

Abscisic acid is a growth-retarding hormone that is a negative regulator of many developmental processes in plants. Tung et al. (2008) reports that, overexpression of *NCED3* gene which is involved in BA biosynthesis showed more water use efficiency and drought tolerance. Reduction in transpirational water loss is very important in drought tolerance. This is brought about by ABA dependent stomatal closure. ABA binds to membrane receptors like "*PYR*", "*PYL*", "*RCARs*" present in the plasma membrane of guard cells where it generates peroxide signaling molecule which releases Ca^{2+} ions from cell membrane leading to closure of stomata via outwardly rectifying Potassium (Ma et al., 2009). Receptors like pyrabactin resistance "PYR", pyrabactin resistance1-like "PYL", and abscisic acid receptor proteins regulator (*RCARs*) recognize Abscisic acid. Under optimum water conditions, sucrose non-fermenting 1-related protein kinase 2s *SnRK2* binds with phosphatase type 2Cs (*PP2C)*-like ABA insensitive-1 and 2 "ABI1", and "ABI2". But under drought stress ABA binds to the *PP2C*s. Then *SnRK2* becomes free and phosphorylates many ABA-responsive factors (ABFs) and helps in drought tolerance (Fujii et al., 2009). The *SWEET15* gene, which regulates sugar transport across is upregulated in senescence leaves of plants having *ABA* receptor (*PYL*) overexpressed (Zhao et al., 2016). Escape of drought also includes bud dormancy to see off drought period. Bud dormancy is regulated by ABA. *CACGTGT* motif in promoters of several bud dormancy genes, are recognized by *ABA*-related basic leucene zipper transcription families (*bZIP TFs*) (Shen & Ho, 1995) (Gonza´lez-Grandı´o et al., 2013). This further cements the role of ABA in bud dormancy and consequently drought stress escape. ABA causes old leaves to fall i.e. senescence, which helps in mobilization of assimilates towards seeds and fruits, which is pivotal during water deficit conditions. (Fig. 22.5)



Source: Farooq *et al*. (2009)

Fig. 22.5 Drought signaling mechanism involving ABA. (Source: Farooq et al. 2009)

22.3.5.5 Ethylene

Ethylene is another growth retardant which is known as fruit ripening hormone. Ethylene biosynthesis is catalyzed by The 1-aminocyclopropane-1-carboxylic acid synthase "*ACS*". Aminocyclopropane-1-acid carboxylic oxidase "*ACO*" converts *ACC* to ethylene. ACC acts as a signal molecule when drought occurs, it is transported to the tissues undergoing stress, there it is converted into ethylene, which reduced growth rate in maize (Sairam et al., 2008). "*RD29A*" and "*RD29B*" are most important genes that are upregulated during drought stress. The promoter of "*RD29A*" has 2 cis-acting components, which are ABA-responsive element "*ABRE*" and dehydration-responsive element "*DRE*". *RD29B* is activated by ABA only (Yamaguchi-Shinozaki and Shinozaki, 1994). Ethylene responsive factors are known to be binding with the drought responsive promoters *RD29* genes (Cheng et al., 2013). These ERFs increase assimilation of Ethylene in water stressed tissues, which provides drought tolerance by inhibiting vegetative growth. However, ethylene production in plants is only beneficial when the occurrence of drought is after booting stage, whereas at earlier stages, it may have negative effects.

22.3.5.6 Brassinosteroid

Polyhydroxy steroids called as brassinosteroids are another category of PGPRs having distinctive growth promoting properties (Bishop & Yokota, 2001). They have a positive role in drought tolerance but true mechanisms have not been yet deciphered. Epibrassinolide (EBR) treatment of seedlings is reported to increase antioxidant production which helps in scavenging of ROS (Kagale et al., 2007). Sairam (1994) reports enhanced performance and membrane stability of susceptible wheat cultivars under drought stress upon treatment with brassinosteroids. EBR treated *Arabidopsis* plants possessed higher accumulation of transcripts of drought marker genes (*RD29A*, *ERD10*, and *RD22*. These genes act as molecular chaperones and reduce protein aggregation under water deficit. ABA-responsive factors like "*LPT4*" and ABA-marker gene "*RD22*" were upregulated under BR treatment (Divi et al., 2010). This suggests that there is a possible interaction between ABA and BRs. Therefore studies are needed to decipher exact relationship between these two.

22.3.5.7 Salicylic Acid

Salyclic acid is a different type of phytohormone that helps in disease resistance through mediation of systemically acquired resistance. It is also known to assist against abiotic stresses. Reports of drought tolerance by exogenous application of SA on plants are numerous (Korkmaz et al., 2007). Pretreatment of plants with 0.1–0.5 mM of SA results in reduced levels of ROS free radicles (Harfouche et al., 2008). Arabidopsis mutants; "adr1", "myb96-1d", "siz1", "acd6", and "cpr5" were drought tolerant as these enteries accumulated SA. Their performance was enhanced upon exogenous supplementation with SA (Miura & Tada, 2014). SA is reported to enhance the expression of *LTI29* and *LTI30* genes. These genes have been reported to be significant for dehydrin production (Puhakainen et al., 2004). Dehydrins have direct involvement in drought stress tolerance as has been discussed earlier in this chapter (Brini et al., 2007). It can be thus concluded that SA plays a significant role in secondary signaling for drought stress tolerance by enhancing dehydrin production.

22.3.5.8 Jasmonic Acid

Precise role of Jasmonic acid (JA) in drought response is yet to be deciphered (Riemann et al., 2015). The plants exposed to drought accumulate higher proline and antioxidants. Exogenous application of JA or MeJA enhanced AO activity (Nafie et al., 2011) and proline accumulation (Mahmood et al., 2012). *12-OPDA* is a biosynthetic intermediate of Jasmonic acid which is upregulated during drought stress. Conversion of *12-OPDA* to JA is inhibited due to drought stress signaling. Transgenic plants of *Arabidopsis* having ABA levels constant and optimum with varied production of *12-OPDA* had reduced stomatal opening in high *12-OPDA* producing ecotypes (Savchenko et al., 2014). JA also interacts with other phytohormones such as ABA, SA, and BRs etc in hormone signaling mechanisms during abiotic stress. De Ollas et al. (2015) reported that JA interacts with ABA in drought stress responses. Under drought stress jasmonate_Isoleucine concentration increases which leads to complex formation between rice Oscoi1 and JAZ protein gene which leads to the degradation of JAZ (Jasmonate Zim Protein) this signals the transcription of rice *bHLH148* gene resulting in drought tolerance (Yang et al., 2019).

22.3.6 Molecular Mechanism of Regulatory Elements During Drought Stress

Genomics studies have efficiently helped in understanding the role of regulatory proteins active in plants during drought (Hirayama & Shinozaki, 2010). Regulation of drought stress responsive genes is accomplished by Transcription factors (TFs), protein kinases and phosphatases by signal perception and transduction (Wani et al., 2013). Tfs are most important in gene regulation. These TFs are made up of two domains viz. DNA binding site and regulation site. The binding site is conserved in these TFs whereas regulation sites vary in structure and function. Some of the important Tfs directly or indirectly involved in drought stress response regulation are discussed here.

22.3.6.1 *MYB* Transcription Factor Family

The *MYB* (myeloblastisis) transcription factor family regulates gene expression in various plant systems including metabolism and response to biotic and abiotic stresses (Dubos et al., 2010). MYB TFs have two domains. One is conserved (N terminus) which is used for binding to DNA whereas the variable domain (C terminus) is involved in gene regulation. A variation in expression of about 65% of MYB genes in rice has been reported (Katiyar et al., 2012). Transcriptome data collected in the **"GENEVESTIGATOR"** database showed that under drought stress, 51% of *MYB genes in arabidopsis were upregulated whereas* 41% were downregulated (Katiyar et al., 2012). Virus-induced gene silencing (VIGS) of "*NbPHAN*" Tf, resulted growth impairment and susceptibility to drought in *Nicotiana benthamiana* (Huang et al., 2013). *NbPHAN* is involved in ABA-auxin signaling network which regulates lateral root growth. Overexpression of TF *MYB96 in Arabidopsis* resulted in stomatal closure and thus drought tolerance. The Two other *Arabidopsis* guard cell specific genes *AtMYB44* and *AtMYB15* were also showed increased expression under ABA treatment as well as abiotic stresses. *MYB* TF *GbMYB5* enhanced antioxidant activity and consequent scavenging of ROS (Chen et al., 2015). MYB21 in arabidopsis is reported to be involved in ABA-JA cross talk and regulation of flower development and maintenance when expressed under drought stressed environment (Su et al., 2013). Thus, it can be summarized that *MYB* TFs maintain homeostasis during drought stress by regulating genes responsible for stomatal opening, antioxidant activity and flower growth.

22.3.6.2 Ethylene Response Element-Binding Factors (AP2/ERF) Family

APETALA2 Tf commonly known as ethylene response element-binding factor (*AP2/ERF*) family, which is also involved in regulation of drought responsive genes (Xu et al., 2011). It consists of a conserved domain (AP2/ERF) which acts as a DNA binding domain (Song et al., 2013). On the basis of number and relatedness of this domain, it is divided into four subfamilies viz. Apetala 2 (*AP2*), *RAV*, dehydration-responsive element-binding protein (*DREB*), and Ethylene responsive factor (ERF) (Rashid et al., 2012). In rice, *DREB2* family genes viz. *DREB2A* and *DREB2B* were upregulated under water deficit environment (Nakashima et al., 2014). Overexpression of rice *DREB2B* in *Arabidopsis* plant exhibited drought tolerance in an ABA independent manner (Matsukura et al., 2010). Similar results were reported in many crops like tomato, rice, tobacco and wheat when DREB1 gene was overexpressed (De Paiva Rolla et al., 2014; Nakashima et al., 2014; Phuong et al., 2015; Shavrukov et al., 2016). *DREB1F* TF of *Oryza sativa* also enhances ABA assisted drought tolerance (Wang et al., 2008). Characterization of various other *APETALAs* of rice is being done to understand their involvement in drought stress tolerance (Abogadallah et al., 2011). The expression of these Tfs is also reported to enhance the accumulation of proline and other osmoprotectants (Joshi et al., 2016).

22.3.6.3 Basic Leucine Zipper Transcription Family (*bZIPs*)

These TFs also have two terminals like MYB family, one N terminus which is conserved acts as binder and C terminal which is leucine rich, performs dimerization (Wang et al., 2015). *bZIPs* also play significant role in drought tolerance by regulation of expression of drought responsive genes (Llorca et al., 2015). Like ERF TFs, overexpression of *bZIP* of rice like *OsbZIP23*, *OsbZIP46*, and *OsbZIP16* also enhanced drought tolerance (Tang et al., 2012). *TabZIP60* expression in Arabidopsis improved tolerance against various abiotic stresses in an ABA sensitive manner (Zhang et al., 2015). *ABF4/AREB2, AREB1, and ABF3 TFs* also enhanced drought tolerance by reducing transpirational water loss in experimental *Arabidopsis* (Fujita et al., 2011). From these findings, it can be inference that bZIPs do enhance positive drought response in conjunction with each other. Thus, their functions under drought stress might be supplementary (Yoshida et al., 2010).

22.3.6.4 Zinc Finger Transcription Factor Family (*ZFPs*)

Zinc finger proteins are also important in abiotic stress tolerance (Sun et al., 2010). Zinc-finger TFs consist of 23 subfamilies, and "*WRKY*" is a family that is actively involved in abiotic stress tolerance (Li et al., 2014). WRKY is reported to work in conjunction with ABA signaling mechanisms. Proline accumulation and drought-responsive *OsDREB1A* TF gene are reported to be enhanced by *ZFP252* (*TFIIIA C2H2 ZF*) TFs (Xu et al., 2008). *GhWRKY41/SpWRKY1* TFs regulated stomatal functioning and ROS accumulation in transgenic Tobacco (Li et al., 2015). Certain TFs from *Setaria italica* (*SiWRKY066/082*) and *Panax ginseng TF* (*PgWRKY1*) are involved in hormonal regulation of drought tolerance (Nuruzzaman et al., 2016). *WRKY46* from *Arabidopsis* is involved in ABA and auxin induced enhancement of root biomass (Ding et al., 2015). Wheat *ZFPs* (*TaZFPs*) are also reported to be performing regulatory functions under water deficit conditions (Cheuk & Houde, 2016). Such studies cement the role of ZFPs, especially WRKY in PGPR responses, Transpiration regulation and antioxidant activity under drought stress.

22.3.6.5 NAC (NAM, ATAF1/2 and CUC2) Transcription Factor Family

TFs like, *NAM* (no apical meristem), *ATAF 1/2* (*Arabidopsis* transcription activation factor), and *CUC2* (cup-shaped cotyledon) are three types of TFs in NAC family. These TFs also have conserved N terminal, but their C terminal is transcription regulator (Nuruzzaman et al., 2012). Various studies suggested that NAC regulate drought stress responses. *NAC2/6* and *NAC10* genes abiotic stress increased abiotic stress tolerance including water stress in rice (Jeong et al., 2010. Exogenous application of phytohormones such as auxin, ethylene, and ABA enhanced the expression of NAC (Sperotto et al., 2009). Expression of several Tfs of rice such as, *NAC071/NAC5/ NAC009* and *NAC6* was also induced by drought, salinity, and ABA (Takasaki et al., 2010). Overexpression of "*ANAC019* and *ANAC055*" in *Arabidopsis* impart drought tolerance by targeting JA/ABA dependent drought responses (Bu et al., 2008). *Oryza sativa NAC045* gene enhanced drought and salinity tolerance in rice by targeting drought responsive genes viz. "*OsLEA3-1* and *OsPM1*". Such reports suggest a significant role of NAC transcription factors in manifestation of drought tolerance.

22.4 Conclusion

From the above discussed topics, it is evident that drought tolerance is a complex phenomenon comprising of mechanisms in work at molecular, physiological and morphological/structural levels in plants. Major highlights of these mechanisms are development of robust root architecture, transpiration reduction, antioxidant activity, molecular and phytohormone signaling and gene regulation. Enhancement of these processes in plants can help in drought stress mitigation. Chlorophyll fluorescence is a non- destructive method of understanding, efficiency of photosystem and photosynthetic activity. Various studies have reported that while performing CF studies, we should include different CF parameters like F_0/F_M , F_V/F_M,Φ_{PSII} and PI_{ABS} etc and reliance on only one parameter like F_V/F_M is not beneficial under drought conditions. Some drought tolerant plants have ample abilities to perform these responses optimally but selections, introgression and TF induced enhanced gene expression as well as phytohormone signaling can be done by breeders can bring about drought tolerance crop varieties. Cross talk between phytohormones like JA and ABA as well as signaling for activation of stress related genes is an important area of thrust. During evaluations of germplasm under drought conditions, parameters like EL, Chlorophyll fluorescence (CF), accumulation of proline, glycine betaine, polyols/sugars activity of different drought responsive phytohormones especially JA, BRs, ABA and antioxidant enzymes should also be included; their correlations with morphological traits viz. root biomass, root angle, root length, root depth, root shoot ratio, RWC, CTD (canopy temperature depression), transpiration rate, LAI, SPAD, and other yield attributing traits should also be studied. This may help in selection of better genotypes suitable for growing in dry areas. Some compounds like JA, EBR and GB, can be exogenously applied to plants under dry conditions. Such compounds can trigger positive drought responsive genes and pathways. Transgenic expression of the Tfs or signaling genes is also promising. Crossing of cultivated types with wild relatives or insitu hybridization to bring about desirable transformations will be desirable for future in agriculture. Due to the advent of genomics, mapping for genes and *QTLS* have become easier. These approaches enable high throughput Marker-Trait associations, which can help to understand genes and QTLS responsible for drought stress tolerance. Another important aspect to understand is that, intensive focus on breeding for drought stress tolerance may result in reduced yields in crops can be a bitter sweet. Therefore, the focus of such efforts should be on increasing yield under stress conditions. Furthermore, studies should be focused to completely decipher the mechanisms and interactions of different systems of drought stress responses as role of many PGRs and signaling molecules is not fully understood.

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