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Climate Smart Agriculture: An Option for Changing Climatic Situation

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Abstract

World population is increasing day by day and at the same time agriculture is threatened due to natural resource degradation and climate change. Production stability, agricultural productivity, income and food security is negatively affected by changing climate. Therefore, agriculture must change according to present situation for meeting the need of food security and also withstanding under changing climatic situation. Projected estimates based on food consumption pattern and population growth show that agriculture production will require enhancing by 65% to meet the need of burgeoning population by 2050. Agriculture is a prominent source as well as a sink of greenhouse gases (GHGs). So there is a need to modify agricultural practices in a more sustainable way to overcome these problems. Developing climate-resilient agriculture is thus crucial to achieving future food security and climate change goals. It helps the agricultural system to resist damage and recover quickly by adaptation and mitigation strategies. Mitigation strategies reduce the contribution of agriculture system to greenhouse gas emission, and adaptation strategies provide agriculture production under changing scenarios. This chapter explains different mitigation and adaptation strategies, including farming practices and engineering approaches.

Keywords: adaptation, climate change, climate smart agriculture, mitigation, sustainable development

1. Introduction

Climate change is emerging as a major threat on agriculture, livelihood and food security of millions of people in many places of the world [1]. At the same time, many current farming practices damage the environment and are a major source of major greenhouse gases (GHGs),

that is, carbon dioxide (CO₂), methane and nitrous oxide. Annual anthropogenic greenhouse gas (GHG) emissions that are classified in Intergovernmental Panel on Climate Change (IPCC) reports as originating in 'agriculture, forestry and other land use' (AFOLU) are caused mainly by deforestation, rice cultivation practices, livestock production, soil and nutrient management. It has been estimated that AFOLU contributes to 21% of total global emission. By Food and Agricultural Organization (FAO) estimates, emissions from AFOLU stood at 10.6 Gigatonnes (Gt) of carbon dioxide equivalent in the year 2014. Large deforestation and land degradation have also reduced the carbon sequestration capacity from the atmosphere. Forestry, agriculture and land use accounts for 49 and 30% of total emission of carbon dioxide and methane, respectively. The share of nitrous oxide in total AFOLU emissions is small, but accounts for as much as 75% of global anthropogenic emissions of the gas. Forests play important role in climate mitigation by removing a large amount of GHG from the atmosphere. However, the average contribution of forests in carbon sequestration has fallen from 2.8 Gt annually in the 1990s to 2.3 Gt in the 2000s and is estimated at 1.8 Gt in 2014 [2].

Worldwide, more than a billion of farmers and their families face a great challenge of climate change because agriculture sector is the most vulnerable sector for climate change. Thus, their lives and livelihoods are directly affected by climate change, so there is an urgent need to implement many of the solutions to overcome this problem. Despite the attention paid to agricultural development and food security over the past decades, there are still about 800 million undernourished and 1 billion malnourished people in the world. At the same time, more than 1.4 billion adults are overweight and one-third of all food produced is wasted. Before 2050, the global population is expected to swell to more than 9.7 billion people [3]. At the same time, global food consumption trends are drastically changing, for example, increasing demand for meat-rich diets. If the current trends in consumption patterns and food waste continue, it is estimated that we will require 60% more food production by 2050 [4]. The International Food Policy Research Institute (IFPRI) estimated that by 2050 about 50 million more people could be at a risk of undernourishment because of climate change.

2. Impact of climate change on agriculture

Climate change is very likely to affect food security at the global, regional and local level. Climate change can disrupt food availability, reduce access to food and affect food quality [5]. Many advance technologies, such as improved crop varieties, pest control methods, genetically modified organisms and irrigation systems, are widely adopted for crop improvement. By 1880, 1.5°C of Earth's temperature had been increased [6]. It is projected that throughout the twenty-first century, India will experience warming above global level. It is also expected that India will experience more seasonal variation in temperature with more warming in the winters than in the summers. In recent years, extreme heat waves across India have extended together with warmer night temperatures and hotter days, and this trend is expected to continue. This is predicted that the average temperature will raise up to 2.33–4.78°C with a doubling in CO₂ concentrations at the end of this century. These heat waves will lead to increased variability in summer monsoon precipitation, which will result in drastic effects on the agriculture sector

in India [7]. Due to rainfall variability, changes in the frequency and severity of droughts and floods could pose challenges for farmers and ranchers and will ultimately threaten global food security [8]. Meanwhile, the rise in sea level and warming of sea water are likely to cause the habitat ranges of many fish species to shift, which could disrupt ecosystems. Overall, climate change would adversely affect over crops, animals and marine life. Along with effects of climate change on agriculture, other evolving factors that affect agricultural production, such as changes in farming practices and technology, need to be addressed.

Higher CO₂ levels can affect crop yields. The elevated CO₂ levels can increase plant growth particularly in plants with C₃ photosynthetic mechanism. Increased CO₂ level also reduces the quality of produce by reducing protein, nitrogen and minerals content in most plant species, including wheat, soybeans and rice; this will threaten human health. Climate change also increased pest pressures and reductions in the efficacy of pesticides; thus more pesticides will be required in future which also threatened human health [8]. Reduced grain and forage quality can reduce the ability of pasture and rangeland to support grazing livestock [9]. Climate change also affects weeds, pests and fungi infestation due to an increase in host susceptibility. The ranges and distribution of weeds and pests are likely to increase with climate change. This could cause new problems for farmers' crops previously unexposed to these species. Both historical and future estimated impacts of climate change on cereal crop yields in different locations indicate that the yield loss can be up to -35% for rice, -20% for wheat, -50% for sorghum, -60% for maize and -13% for barley depending on the location, future climate scenarios and projected year [10].

Heat stress also affects animals both directly and indirectly. Over time, heat stress can increase vulnerability to disease, and reduce fertility and milk production. Climate change also affects rainfall pattern and distribution; due to this, many areas are facing a problem of drought stress which may threaten pasture and feed supplies. Drought reduces both quantity and quality of forage available to grazing livestock. Some areas could experience longer, more intense droughts, resulting from higher summer temperatures and reduced precipitation. Changes in crop production due to drought could also become a problem for animals that rely on grain. Climate change may increase the prevalence of parasites and diseases that affect livestock. More variability in weather pattern could provide the chance of insect, pest infestation in crop plant [11]. Pasture productivity is increased by elevated CO₂ but its quality may be reduced due to high lignin concentration, low protein and digestibility. However, the quality of some of the forages found in pasturelands decreases with higher CO₂. As a result, the overall performance of cattle would be affected and require eating more to get the same nutritional benefits.

Fisheries and aquaculture, which provide at least 50% of animal protein to millions of people in low-income countries, are already under multiple stresses, including overfishing, habitat loss and water pollution [12]. Changes in temperature and seasons can also affect the timing of reproduction and migration fishes and other aquatic life. Lifecycle of aquatic animals is controlled by the temperature of aquatic system and the change in the seasons. For example, in Northwest (United States), the lifecycle of salmon may be affected by an increase in the temperature of water and this could also increase the likelihood of disease. These effects in combination of other climate impacts are projected to lead to large declines in salmon

populations [13]. The increased intensity and frequency of storms, hurricanes and cyclones will adversely affect coastal fisheries, aquaculture and mangroves.

Forests provide employment and livelihood for more than 100 million people of the world's rural poor. Forests are home to more than 80% of the world's earth biodiversity and provide ecosystem services like food, fuel, timber, medicines and shelter. Aberrant weather limits the capacity of forests to produce goods and services and also affect the people who depend on them directly or indirectly. On the other hand, temperate forest region communities will be benefitted from elevated CO₂ and temperature. While due to changes in occurrence, distribution and frequency of precipitation, this will more likely affect natural biodiversity and also adversely affect crop growth, productivity and ultimately yield [14].

India and China, the most densely populated countries of the world, to keep pace with the growing population and to sustain world food security will require maintaining at least 4–5% annual growth rate in agriculture. India supports about 17% of human and 11% of livestock population of the world just on 4.2% of water resources and 2.8% land [15]. As per recent estimates, India will need to produce about 281 million tonne (mt) food grains, 53.7 mt oilseeds, 22 mt pulses, 127 mt vegetables and 86 mt fruits by 2020–2021 [15]. In India, the average food consumption at present is 550 g per capita per day, whereas in China and USA are 980 and 2850 g, respectively [16, 17]. To meet the demand for food from this increased population, the country's farmers need to produce 50% more grain by 2020 [7]. To enhance food production is under changing climatic conditions like aberrant weather, rising CO₂ level, rising temperature and rising sea level, and we require the reorientation of agriculture from current practices to more sustainable and environmental friendly practices. In this context, scientists are more focused on climate smart or resilience agriculture (CSA). Climate resilience agriculture helps to improve food security under changing climatic situation while also reducing food waste globally [18] and minimizing danger on natural resources.

2.1. Definition

More specifically for managing agriculture for food security under the changing realities of climate, FAO has developed the 'Climate Smart Agriculture' (CSA) approach, which it presented in 2010 at The Hague Conference on Agriculture, Food Security and Climate Change [19]. United Nations (FAO) defines CSA as 'Agriculture that sustainably increases productivity, enhances resilience (adaptation), reduces/removes GHGs (mitigation) where possible, and enhances achievement of national food security and development goals'. The country will have to produce more quality food with diminishing natural resource base and changing climate. It includes an in-built property in the system for the recognition of a threat that needs to be responded to and also the degree of effectiveness of the responses.

2.2. Climate smart strategies

Many agricultural technologies and practices such as minimum tillage, different methods of crop establishment, nutrient and irrigation management and residue management can improve crop yields: nutrient and water use efficiency and reduced greenhouse gas (GHG)

emissions from agricultural activities [20]. Similarly, the use of improved seeds, rainwater harvesting (RH), Information and Communication Technologies (ICTs)-based agro-advisories and crop/livestock insurances can also help farmers to reduce the impact of climate change and variability [21]. In general, the CSA options integrate innovative and traditional technologies, practices and services that are relevant for particular location and reduce the effect of climate change and provide the opportunities to stand such changing scenario. Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. Substantial reduction in GHG emission over the next few decades can reduce the occurrence of climatic variability in the twenty-first century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term and contribute to climate-resilient pathways for sustainable agriculture.

2.3. Mitigation strategies

Mitigation practices help to reduce the emission of greenhouse gases from agriculture system because elevated greenhouse gases ultimately lead to climate change.

2.3.1. Mitigation through farming practices

A change in the system of cultivation, cultural practices, nutrient management and water management helps to reduce the emission of greenhouse gases (**Table 1**).

Conservation practices	GHG objectives	Additional benefits
Crops		
Conservation tillage and traffic control	Capture carbon and reduce emission	Improves soil, water and air quality. Soil erosion, compaction and fuel use are also reduced.
Integrated and site-specific nutrient management	Capture carbon and reduce emission	Improves water and air quality and also saves time, labour and money.
Crop diversification and crop rotation	Carbon sequestration	Improves soil and water quality and also reduces emission and water requirement and provides food security.
Animals		
Manure management	Reduces emission	Improves soil quality, crop yield, on-farm sources of biogas fuel and possibly electricity for large operations, provides nutrients for crops.
Rangeland and pasture management through rotational grazing and improved forage	Sequestration, emission reduction	Reduces water requirement, helps in withstand drought. Increases long-term grassland productivity.
Feed management	Emission reduction	Reduces quantity of nutrients. Improves water quality. More efficient use of feed.

Source: NRCS. <http://soils.usda.gov/survey/global-climate-change.html>.

Table 1. Agricultural practices and climate change mitigation.

2.3.1.1. Methane emission

Methane is about 25 times more effective as a heat-trapping gas than CO_2 . The main sources of methane are wetlands, organic decay, termites, natural gas and oil extraction, biomass burning, rice cultivation, enteric fermentation and refuse landfills. CH_4 emissions can be controlled by the following practices:

- Controlling production, oxidation and transport of CH_4 from paddy field by alteration in water management, particularly promoting mid-season aeration, by short-term drainage, direct-seeded rice (DSR) cultivation. The IPCC [6] has estimated that rice cultivation is a major contribution to global warming. Rice cultivation contributes 23% of total greenhouse gas emission from agriculture sector. Under continuous flooding, dry-DSR emitted 24–79% of CH_4 as compared with 8–22% in wet-DSR, whereas, under intermittent irrigation, the reduction ranged from 43 to 75% in dry-DSR compared with conventional tilled transplanted rice (CT-TPR). However, reduction in CH_4 emissions increased further when DSR was combined with mid-season drainage or intermittent irrigation, compared with flooded CT-TPR. The reason for low CH_4 emissions from dry-DSR is aerobic conditions, especially during the early growth stage [22]. Methane emission starts at a redox potential of soil below -150 mV and is stimulated at less than -200 mV [23].
- Improved organic matter management by promoting aerobic degradation through incorporating or composting it into soil during off-season-drained period.
- Use of rice cultivars with few unproductive tillers, high root oxidative activity and high harvest index.
- Improved management of livestock diet through the use of improved feed additives, substitution of low digestibility feeds with high digestibility ones.

2.3.1.2. Nitrous oxide

As a greenhouse, nitrous oxide is 298 times more effective than CO_2 . Forests, grasslands, oceans, soils, nitrogenous fertilizers and burning of biomass and fossil fuels are the major sources of nitrous oxide. Site-specific nutrient management (SSNM), integrated nutrient management (INM), use of slow-release nitrogen fertilizers and nitrification inhibitors, and placement of fertilizer in reduced zone helps to reduce emission of NO_2 .

2.3.1.3. Carbon dioxide

The main sources of carbon dioxide emission are decay of organic matter, forest fires and eruption of volcanoes, burning of fossil fuels, deforestation and land-use changes. CO_2 emission mitigates by carbon sequestration, soil management practices and afforestation. Carbon sequestration is one of the best strategies to mitigate CO_2 emission, which is the removal of atmospheric CO_2 into long-lived stable form.

- Carbon sequestration in soil through manipulation of soil moisture and temperature and restoration of soil carbon on degraded lands. Trees, plants and crops absorb CO_2 naturally through photosynthesis and stored as carbon in biomass in tree trunks, branches, foliage

and roots and soils [24]. Forests and stable grasslands are good sink of carbon because they can store large amounts of carbon in their vegetation and root systems in long-life stable form as compared to field crops. Soils are the largest terrestrial sink for carbon on the planet.

- Soil management practices such as reduced tillage and manuring residue incorporation. Improving soil biodiversity, micro-aggregation and mulching.

2.3.2. Mitigation through transgenic crops

Agriculture contributes significantly to greenhouse gas (GHG) emissions. As indicated by researchers, there is a need to give priorities to develop new varieties of crops cultivars that can reduce GHG emissions in farming systems [25]. In this regard, GM crops have been contributing to lower GHG emissions through reducing fuel use, due both to less pesticide applications and increasing the area grown under conservation agriculture (CA), which involves practices such as 'no-till' or 'reduced-till'. It is reported that, in 2012, GM crops were grown roughly on 12% of the world's arable land, which reduced over 26.7 billion kg of carbon dioxide (CO₂) or the equivalent of removing nearly 12 million cars from circulation with a total reduction [26]. Genetically modified crops such as Roundup Ready™ modify the plants through genetic engineering so that they can take more carbon from atmosphere and convert it to oxygen [27].

Crops are bred for N-use efficiency (NUE) because this trait is a key factor for reducing N fertilizer pollution, improving yields in N-limited environments and reducing fertilizer costs. There are various genetic engineering activities which improve NUE in crops [28]. The alanine aminotransferase gene from barley, which catalyses a reversible transamination reaction in the N-assimilation pathway and enhances NUE, appears to be a target for plant breeding option. Keeping N in ammonium form will affect how N remains available for crop uptake and will improve N-recovery, thus reducing groundwater and the atmosphere pollution. There are genes in tropical grasses such as *Brachiaria humidicola* and in the wheat wild relative *Leymus racemosus* that inhibit soil nitrification by releasing inhibitory compounds from roots and suppressing nitrosomonas bacteria [29]. Engineering nitrogen fixation for self-fertilizing crops can also help to reduce the use of synthetic fertilizer. The ultimate goal is to transfer the molecular machinery for nitrogen fixation into non-N₂-fixing plants so that they will fix atmospheric N₂ [30]. The process is very complex and challenging because N₂-fixing nitrogenase enzyme is adversely affected by oxygen produced during photosynthesis. But agriculture would be revolutionized if plants can be engineered to fix their own nitrogen; this would free agriculture from synthetic nitrogenous fertilizers and significantly decouple it from the fossil fuel industry [31].

About one-fifth of global CH₄ emissions are from enteric fermentation in ruminant animals. Apart from various rumen manipulations and emission control strategies, genetic engineering is a promising tool to reduce these emissions. The most practical and rapid mitigation procedure may be to reduce the per cow CH₄ emission through animal breeding and genetic selection for feed efficiency as it is permanent and cumulative [32]. Other options like manipulation in diet composition, supplementation of feed additives and selection of forage plants of high quality for breeding provide solution for reduced CH₄ emission from enteric fermentation.

2.4. Adaptation strategies

Adaptation is a key factor that will shape the future severity of climate change impacts on food production. To deal with the impact of climate change, the potential adaptation strategies are as follows:

2.4.1. Adaptation through transgenic approaches

Transgenic approaches are one of the many tools available for modern plant improvement programmes. This approach involves manipulation of genetic material and the fusion of cells beyond normal breeding barriers. The most evident example of genetic engineering is 'transgenic' technology which involves the insertion or deletion of genes and creating genetically modified organisms (GMOs). In genetic engineering or genetic transformation, the genetic material is modified by artificial means. It involves isolation and cutting of a gene at a precise location by using specific enzymes. Identification and transfer of stress-tolerance gene into plant provide improved productivity and adaptation to abiotic stresses. Hence, the transformation of major crop species with genes from any biological source (plant, animal and microbial) is the most powerful tool for molecular plant breeding. Transgenic plant can be used as sources of new cultivars and they are also extremely useful as proof-of-concept tools to dissect and characterize the activity and interplay of gene networks for abiotic stress resistance. Transcription factor (TF), and genes involved in adaptation to extreme temperature, drought or salinity in crops are [33] as follows:

1. Involved in sense, percept and transduction of signal.
2. Mechanisms of stress response for adaptation and abscisic acid (ABA) biosynthesis for enhancement for drought adaptation.
3. Genes involved in transportation, detoxification and signal transduction as well as TF tolerance to salinity.
4. Some associated to reactive oxygen species (ROS), modification of membrane and production of chaperon, late embryogenesis abundance (LEA) proteins, osmoprotectants/ compatible solutes and TF are continued in crop genetic engineering for temperature extremes.

2.4.1.1. Heat

Plant responses to high temperature vary with the degree and duration of high temperature and the plant type. Plants have various mechanisms to cope with high temperatures, for example, by maintaining membrane stability, or by ion transporters, proteins, osmoprotectants, antioxidants and other factors involved in signalling cascades and transcriptional control [34]. The activity of the enzymes CAT, glutathione S-transferase (GST) and APX was more enhanced in the cultivar and showed better tolerance to heat stress and protection against ROS production. Upregulation of different genes helps the plant to withstand the stress conditions and also adaptation to stress [35]. Stress plants receive the internal and external signals by different interrelated or independent pathways which are used to control various

responses for its tolerance development [36]. Some stress-associated genes such as ROB5—a stress-inducible gene isolated from brome grass—enhanced the performance of transgenic canola and potato at high temperatures [37]. Likewise, researchers introduced hsp101—a heat shock protein gene from *Arabidopsis*—in basmati rice. This transgenic rice had a better growth in the recovery phase after suffering heat stress [38].

2.4.1.2. Drought

Several drought-tolerant transgenic plants, including rice, tomato, soybean, maize, barley and *Arabidopsis* have been developed. Such genetically engineered plants have generally been developed using gene-encoding proteins that control drought-regulatory networks. Stress-signalling networks in drought responses are made of intercellular communication systems, intracellular signalling systems and transcriptional-regulatory complexes [39]. Some important proteins like protein kinases, receptor-like kinases, transcription factors, some enzymes related to osmoprotectant or plant hormone synthesis, and other functional and regulatory proteins [40] play an important role in plant defence during drought stress. NAC, AP2/ERF, bZIP and MYC orchestrate regulatory networks are major transcription factor families of plants, which underlie drought stress tolerance [41]. Enhanced adaptation to drought could be provided directly by metabolites such as trehalose, mannitol, glycinebetaine or indirectly through regulation of gene expression through TF and kinases in signal transduction [42]. The *Arabidopsis*' HARDY (HRD) gene improved WUE by enhancing photosynthetic assimilation and reducing transpiration [43]. Further research by a multinational seed company [44] revealed that the encoding gene cold shock protein B (CspB) from *Bacillus subtilis*, a soil bacterium, allows the transgenic maize plant to react more quickly to drought, slowing its growth and conserving water, thereby making water available for key plant functions after the onset of drought stress. The DroughtGard™ hybrid maize was bred and released for farming in the USA in 2013. Under stress, a DroughtGard™ hybrid used 261 mm of water from the soil while the control used 338 mm of water from the soil. Under drought stress, a maize plant begins producing sugars such as trehalose, which can be broken by the glycoside hydrolase enzyme trehalase. When this sugar is not destroyed, the plant shows enhanced adaptation to drought stress.

2.4.1.3. Salinity

The damaging effects of salt accumulation in agricultural soils have severely affected agricultural productivity in large swathes of arable land throughout the world [45]. Salt-affected land accounts for more than 6% of the world's total land area. Climate change also causes salinity due to effect on soil water and increase in temperature. Therefore, there is an urgent need to develop salt-tolerant varieties of crop through conventional breeding and transgenic approaches. Genes enhance tolerance in plant against salinity by employing several mechanisms such as by limiting uptake rate of salts from soil and further transport of salts inside plant system, regulate leaf development and the onset of plant senescence and adjust the ionic and osmotic balance of cells in roots and shoots. Salt tolerance mechanism varies with the plant species; however, the capacity to maintain low cytosolic Na⁺ is thought to be one

of the key determinants of plant salt tolerance [46]. Transgenic plants accumulated more K^+ , Ca^{2+} and Mg^{2+} and less Na^+ in their shoots compared with non-transformed controls. The most promising genes for the genetic engineering of salinity tolerance in crops, as noted by scientist [47], are related to ion transporters and their regulators, as well as the C-repeat-binding factor [48]. The successful use of transporter genes has been observed in several plants. He et al. developed transgenic cotton plants with AtNHX1 expression and revealed that plants produced more fibre content and generated more biomass under salt stress in a greenhouse condition [49]. Increased fibre yield was due to superior photosynthetic performance and higher nitrogen assimilation rates in the transgenic plants compared with wild type. Moghaieb et al. developed transgenic tomato plants by isolating gene (which produce ectoine, a compatible osmolite) from bacteria and inserting in tomato plant [50]. He reported that transgenic plant produced a high amount of ectoine under saline conditions, which led to increased sink capacity for photosynthate in root and also enhanced water uptake, and increased the photosynthetic rate under salt stress through enhancing cell membrane stability [51].

2.4.2. *Developing climate-ready crops*

Development of new crop varieties with higher yield potential and resistance to multiple stresses (biotic and abiotic) will be the key to maintain yield stability. Several drought tolerance varieties have been released in South and Southeast Asia. For example, in 2010 the variety Sahbhagi Dhan, released and notified in India, showed a consistently good performance under transplanted low-land conditions and rain-fed direct-seeded upland [52]. Singh reported 108% higher yields with Sahbhagi Dhan compared with popular local varieties under water-scare situation [53]. Sahbhagi Dhan needed one to two irrigations only to yield 4.7 t ha^{-1} . Likewise, Sahbhagi dhan, IR64-Drought1, is another climate-ready rice [54]. Nitrogen use efficiency may be reduced under the climate change scenarios because of heavy precipitation and high temperature which increase leaching and volatilization losses, respectively. But at the same time, elevated CO_2 concentration causes plant growth and development which leads to increased demand for nitrogen. So, there is a need to develop the improved root system of plant for nutrient and water absorption. Genetic engineering is the best option for pooling all the desirable traits in a plant to get the ideal plant type for adverse climatic situation.

2.4.3. *Crop diversification*

Major shift in terms of diversification of agriculture into crops, commodities, enterprises and cropping/farming systems is called upon to revert the process of degradation of natural resources, rejuvenations of waste lands and also to make agriculture a profitable business. Diversified agricultural systems may be a productive way to build resilience into agricultural systems. Crop diversification helps farmer against aberrant weather conditions like early season drought, late season drought and dry spell during crop growth season. Intercropping of soybean + pigeonpea (4:2), pearl millet + pigeonpea (3:3), pigeonpea + green gram (1:2) and cotton + green gram (1:1) are more economic than monocropping [55]. Due to growing income and urbanization, demand for high-value food products, such as fruits, vegetables, dairy, meat, eggs and fish, is increasing. This is reducing the demand for traditional rice and wheat. Diversification of rice-wheat system

(RWS) towards high-value commodities will increase income and result in reduced water, fertilizer and other resource uses. Pulses have a positive impact on soil quality because they help fix nitrogen in the soil. Nitrogen-fixing pulse crops have a lower carbon and water footprint as compared to other crops. For instance, the water footprints to produce a kilogram of beef, pork, chicken and soybeans are 43, 18, 11 and 5 times higher than the water footprint of pulses. In fact, one study showed that 1 kg of legume only emits 0.5 kg in CO₂ equivalent, whereas 1 kg of beef produces 9.5 kg in CO₂ equivalent. So the inclusion of pulses in crop rotation and intercropping system shows better productivity, sustainability and environmental safety benefits [56].

2.4.4. Alteration in land-use pattern

Change in location of crop and livestock, adjustment in cropping pattern, planting time and methods, fertilizer and pesticide use pattern, and other management practices help to reduce the risk of climate. Alternate land-use management practices also reduce disease and pest outbreak and provide remunerative production under aberrant weather situation.

2.4.5. Changing cropping season

Yield instability is reduced by changing planting time which reduce the impact of temperature increase-induced spikelet sterility and also avoid flowering period to coincide with the hottest period. Crop calendar provides the information about crop location and cropping pattern based on weather pattern which helps the farmer for growing crop according to the occurrence of weather events. Cropping systems may have to be altered to the growth of suitable cultivars, increasing crop intensities (i.e. the number of successive crop produced per unit area per year) or planting different types of crops. Farmers will have to adapt to changing situation by changing crops. Singh et al. showed that the lentil varieties Pusa Vaibhav and Mallika matched well with Sahbhagi Dhan in drought-prone area [57]. Both lentil varieties are of medium duration and suitable for rice-fallow areas of eastern India.

2.4.6. Conservation agriculture

Conservation agriculture (CA) is defined as resource-saving agriculture crop production that strives to achieve acceptable profit together with high and sustained production level while concurrently conserving the environment. It also enhances natural biological process above and below the ground. CA is characterized by three linked principles, namely

- I. *Minimum mechanical soil disturbance*: Excessive tillage of agricultural soils may result in short-term increases in fertility, but will degrade soils in the medium term. Structural degradation, loss of organic matter, erosion and falling biodiversity are all to be expected.
- II. *Permanent organic soil cover*: Keeping the soil covered and planting through the mulch will protect the soil and improve the growing environment for the crop.
- III. *Diversification of crop species grown in sequences/association*: Diversification of crop or cropping system helps farmers in terms of risk minimization. It provides opportunity to crop for efficient utilization of natural resources and also maintain soil fertility.

Conservation agriculture-based resource conservation technologies (RCTs) under precision laser land levelling are helpful to improve water productivity [58]. Retention of carbon (C) in arable soils has been considered as a potential mechanism to mitigate soil degradation and to sustain crop productivity. The mean annual input of organic biomass/residues to soil from all crops varied with aboveground yield responses of the crops and treatment types. The total estimated C input ($12.1 \text{ Mg C ha}^{-1}$ in 3 years) under mungbean residue + direct-seeded rice (DSR) followed by zero-tilled wheat (ZTW) with rice residue (RR) retention and zero-tilled relay summer mungbean (MBR + DSR-ZTW + RR-ZTMB) treated plots was 117 and 127% higher than DSR-ZTW and transplanted rice followed by conventional tilled wheat (TPR-CTW) treatments, respectively [59]. Jat et al. also reported that various components of CA increase crop growth and productivity [60].

2.4.7. *Efficient utilization of resources*

The resource-efficient technologies comprises those technologies which improve resource use efficiency and provide immediate economic benefits like conservation of natural resources (water, soil, biodiversity and climate), reduce production cost, reduce environmental pollution and ultimately increase yield and income of small and marginal farmers. Resource-conserving practices like zero tillage can allow farmers to sow wheat sooner after rice harvest, so the crop heads and fills the grain before the onset of premonsoon hot weather. The resource conservation technologies (RCTs) in rice-wheat system (RWS) also have pronounced effects on mitigation of greenhouse gas emission and adaptation to climate change. Grace et al. reported that the emissions of GHGs from RWS in Indo-Gangetic plains (IGPs) have a global warming potential (GWP) of $13\text{--}26 \text{ Mg CO}_2 \text{ ha}^{-1}\text{yr}^{-1}$ [61]. These approaches of crop management should be coupled with the measures of crop improvement for wider adaptation to climate change. Rice-wheat cropping systems (RWCS) of the IGP of India are tillage, water and energy intensive and an important source of greenhouse gas (GHG) emission. ZTW – DSR and zero-till wheat + surface application of rice residue – Direct-seeded rice showed the lowest global warming potential (GWP) and GHG intensity. Adoption of these systems in the Indian IGP can reduce GWP of the conventional RWCS (CTW-TPR) by 44–47% without any significant reduction in the system yield. This was mainly due to prolonged aerobic condition under DSR which led to low CH_4 emission (82.3–87.2%) as compared to TPR. However, frequent wetting and drying led to higher denitrification emissions of N_2O (60–70%) in DSR system. Neem oil-coated urea was found to be effective in reducing N_2O emission from ZTW (17.8–20.5%) leading to lower GWP as compared to CTW. Application of rice residue in ZTW treatment also reduced N_2O emission (11–12.8%) [62].

2.4.8. *Integrated nutrient management*

Integrated nutrient management (INM) system or integrated plant nutrient supply (IPNS) system is a practice which aims at achieving a harmony by efficient and judicious use of chemical fertilizers in conjunction with organic manures, use of well-decomposed crop residues, green manures, recyclable waste, compost including vermicompost, using legumes in cropping systems, use of bio-fertilizers and other locally available nutrient sources for sustaining soil health and amelioration of environment as well as enhancing crop productivity on

long-term basis [63]. Minimum soil disturbance of reduce tillage, integrated and judicious use of different nutrient sources may enhance soil organic carbon marginally and the carbon sequestration rate varied from 62 to 186 kg ha⁻¹ yr⁻¹. Based on the study, it can be recommended that the substitution of 50% of the recommended N with organic source increases crop yields and soil carbon in semi-arid rain-fed systems of India [64].

2.4.9. Site-specific nutrient management

Site-specific nutrient management (SSNM) is a plant-based approach for managing the nutrient requirements of crop. It provides principles and tools for supplying nutrients as and when needed for plant to achieve high yields while optimizing the use of nutrients from indigenous sources. Applying the right nutrient source, at the right rate, at the right time, in the right place is essential to nutrient stewardship. LCC-based urea application can reduce GWP of a rice-wheat system by 10.5% in LCC₄ treatment as compared to blanket application [65].

2.4.10. Relocation of crops

Climatic variabilities such as increased temperature, CO₂ level, drought and floods would affect the production of crops. However, the impact will be varied across crops and regions. There is a need to identify the regions and crops that are more sensitive to climate changes/variability and relocate them in more suitable areas.

2.4.11. Harnessing indigenous technical knowledge of farmers

There is a wealth of knowledge on the range of measures that can help in developing technologies to overcome climate vulnerabilities. There is a need to harness the indigenous technical knowledge and fine-tune them to suit the modern situation. Ecological-based traditional knowledge could provide insights and viable options for adaptive measures.

2.4.12. Integrated Farming System (IFS)

Monocropping in flood- and drought-prone area is risky practices for farmers. Dependence on single enterprises not only increases the risk of crop failure but also leads to food, income and environmental insecurity especially in rain-fed area. Integrated farming system (IFS) modules minimize risk from a single enterprise in the face of natural calamities, and diversified enterprises bring in the much needed year round income to farmers in monocropped paddy-growing areas and improve their livelihoods and resilience to extreme weather events. Integrated farming system is defined as the integration of different interrelated, interacting and interdependent farm enterprises which are suited to agroclimatic condition socio-economic situation of the farmers. Integrated fish-duck farming and Rice-fish-poultry farming have been developed for small and marginal farmers [55].

2.4.13. Integrated pest management

Several factors mainly climatic factors such as variability in rainfall and changes in temperature would affect the incidence of pest, disease and host susceptibility of major crops, because

climate is continuously changing which will potentially influence the pest/weed-host relationship by affecting the pest/weed population, the host population and the pest/weed-host interactions. To adopt in this situation, some of the potential strategies are as follows:

Develop diseases and pest resistance cultivars,

Adopt integrated pest management with more emphasis on biological control,

Improve forecasting of pest using recent tools and techniques such as simulation modelling,

Develop location-specific crops, cultivars and alternative production techniques that are resistant to infestations and other risks.

2.4.14. Better weather forecasting and crop insurance schemes

Weather forecasting at different spatial and temporal scales would be significant tool for adaptation in agriculture under future climate change scenario. Information and Communication Technologies can also play a great role to disseminate the information [66]. Weather forecasting and early warning systems will be very useful in minimizing risks associated with climatic adversaries. Information and Communication Technologies could greatly help the administrators and researchers in developing contingency crop plans and also reduce the risk of aberrant weather. Efficacious crop insurance schemes should be evolved to help the farmers in reducing the risk of crop failure due to these events. Low-cost access to financial services could be a boon for vulnerable farmers. Micro-finance has been a success among rural poor, including women. Rainwater harvesting, drip irrigation, laser land levelling, furrow-irrigated raised bed planting, drainage management, cover crop method, site-specific nutrient management, green manuring, integrated nutrient management, intercropping with legume, contingent crop planning, improved crop varieties, seed and fodder banks, zero tillage/minimum tillage, agro-forestry, concentrate feeding for livestock, fodder management and integrated pest management are some promising climate smart practices [67].

CSA practices and technologies adopted include the following:

1. Improved crop varieties for higher yield.
2. Varieties suitable to cope with drought.
3. Direct-seeded rice.
4. In situ moisture conservation.
5. Water harvesting and its storage.
6. Laser land levelling.
7. Practicing minimum tillage by using zero-till drill or a happy seeder.
8. Nutrient management by using green seeker, leaf colour chart and chlorophyll metre.
9. Managing irrigation by using tensiometer.
10. Accessing weather information through SMS.
11. Residue retention.

12. Site-specific nutrient management.
13. Legume integration and cropping system diversification.
14. Use of solar pump.
15. Use of a mobile phone app helps to calculate how much fertilizer to apply throughout the growing season.

2.5. Climate smart agriculture in India

Climate change and its variability are emerging as the major challenges influencing the performance of agriculture and its sustainability [68]. Long-term changes in shifting weather patterns result in changing climate, which threaten agricultural productivity through high- and low-temperature regimes, increased rainfall variability and rising sea levels that potentially deteriorate coastal freshwater reserves and increase the risk of flooding. The challenge becomes pronounced in the case of unusual or extreme changes in climate, typified by droughts, floods, heat waves, and so on, the frequencies of which are predicted to increase in the future [69]. Developing countries, like India, are more vulnerable to such shocks because of their heavy dependence on agriculture and lack of technical and financial resources to cope up with them [70]. Climate change (and global warming) impacts all sectors of human life. In this context, ICAR started NICRA project to overcome the climate change vulnerability.

2.6. National initiative for climate-resilient agriculture (NICRA)

This programme was started by ICAR during February 2011 with the following objectives:

- a. Increase the resilience of Indian agriculture to climate change and climatic variability by development and implementation of production and risk management strategies.
- b. Demonstration of site-specific technologies on farmer's field.
- c. Enhancing the capacity of scientists and other stakeholders for climate-resilient agriculture research and its application.

Smart agricultural practices in India promoted by ICAR are as follows:

1. Rejuvenation of farming in cyclone- and flood-prone coastal agro-ecosystems through land shaping,
2. Staggered paddy nursery as a contingency measure for drought,
3. Water efficient direct-seeded rice cultivation technology,
4. Drum-seeded rice for improving water use efficiency,
5. Short-duration rice cultivar for drought tolerance,

6. Drought-tolerant short-duration finger millet varieties for late season drought in south interior Karnataka,
7. Short-duration crop varieties suitable for late sowings,
8. Crop diversification for livelihood and food security, sustainability,
9. Flood-tolerant varieties impart resilience to farmers in flood-prone areas,
10. Improving the resilience of poor farmers reclaiming cultivable wastelands,
11. Community tanks/ponds as a means of augmentation and management of village level water resources,
12. Individual farm ponds for improving livelihoods of small farmers,
13. Jalkund—low-cost rainwater-harvesting structures,
14. Check dam-storing excess runoff in streams,
15. Rainwater harvesting and recycling through temporary check dam,
16. Enhancing resilience through improvement in conveyance efficiency,
17. Recharge of wells to improve shallow aquifers,
18. Integrated Farming System modules,
19. Captive rearing of fish seed—a livelihood opportunity in flood-prone areas,
20. Management practices to tackle cold stress in backyard poultry,
21. Shelter management for small ruminants to tackle heat stress and rain storm,
22. Small-farm mechanization through Custom Hiring Centres for farm machinery,
23. Improved planting methods for increasing water use efficiency and crop productivity,
24. Zero-till drill wheat to escape problem of terminal heat stress,
25. In situ incorporation of biomass and crop residues for enhancing soil microbial population and soil health,
26. Village level seed banks for reducing seed shortages,
27. Improved fodder cultivars to solve the problem of fodder scarcity.

3. Conclusion

Climate smart strategies like choice of suitable crop and cultivars, integrated farming system, site-specific nutrient management, residue management, intercropping with legume, conservation agriculture-based resource conservation technology, agro-forestry and crop diversification can help minimize negative impacts to some extent and strengthen farmers by sustainably increasing productivity and income. Location-specific medium-range weather

forecasting will play a major role in designing agricultural practices especially in the event of extreme climatic event like high rainfall, drought, frost, hailstorms and heat waves. Water-saving technologies and water-harvesting structures to enhance the availability of water at critical stages of crop growth will be important practice in chronically water-deficient areas. Crop insurance will provide economic security in case of heavy crop loss due to climatic extremes like flood, drought and hailstorms especially to small and marginal farmers. In general, the CSA options integrate traditional and innovative practices, technologies and services that are relevant for particular location. Thus, to meet food security we need such smart agricultural practices which are sustainable, economic and environmentally sound.

4. Future thrust

Precise and accurate weather forecasting for different location will help to make contingent plan for different crop and cropping systems. Researches on precise water, nutrient and pesticide application technologies suitable for small and marginal farmers are needed. Researches on crop residue management, minimum tillage and mulches need to be developed. Development of IFS models is done for different locations keeping in view of farmers resources in that locality. Breeding and biotechnological approaches for crop and varieties need to be developed for adoption in changing climatic scenario.

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