Climate-Smart Agriculture: Assessment and Adaptation Strategies in Changing Climate

12

Muhammad Arif, Talha Jan, Hassan Munir, Fahd Rasul,
Muhammad Riaz, Shah Fahad, Muhammad Adnan,
Ishaq Ahmad Mian, and Amanullah

Abstract

Climate change is the most critical threat to food security amid increasing crop demand. This increasing demand for food has been previously tried to be met through the use of synthetic fertilizers and effective application of weed- and pest-controlling chemicals. However, these methods of increasing crop productivity rely on finite resources and are often unsustainable. They are now proven to be posing a great threat to the environment and causing a negative change in the planet's natural climate. Fortunately, the threat has been realized by scientists, and the world has started to lay the foundations for sustainable intensification of agriculture and to heighten the resilience of crops to climate change. The solutions discovered so far are numerous with many of them not yet tested. Climate change assessment is the first priority in this regard. Much of the recent researches have demonstrated a multi-scale and multidimensional nature of climate change to assess the potential effects of climate change on agriculture and the options for adaptation. These options for adaptation have been different in different regions of the world with clear differences among strategies in rich and

---

M. Arif (✉) · T. Jan · Amanullah
Department of Agronomy, The University of Agriculture, Peshawar, Pakistan
e-mail: marifkhan75@aup.edu.pk

H. Munir · F. Rasul
Department of Agronomy, University of Agriculture, Faisalabad, Pakistan

M. Riaz
Department of Environmental Sciences and Engineering, Government College University, Faisalabad, Pakistan

S. Fahad · M. Adnan
Department of Agricultural Sciences, The University of Swabi, Swabi, Pakistan

I. A. Mian
Department of Soil and Environmental Sciences, The University of Agriculture, Peshawar, Pakistan

V. Venkatramanan et al. (eds.), *Global Climate Change and Environmental Policy*,
https://doi.org/10.1007/978-981-13-9570-3_12

poor countries. The pressure for adaptation is greatest in poor countries where the adaptive capacity is least abundant. Adaptation to climate change could be autonomous (market-driven) or planned. Both of these adaptation strategies are driven by certain measures. Some adaptation strategies are easily achieved with the help of existing technologies, some need development of new technologies while others just need policy and institutional/market reforms. Numerous researchers have tried to assess and give tools for the potential impact of climate change which are largely based on modelling techniques. Indeed, models are useful tools for assessing this potential impact and evaluating the options for adaptation, yet they do not match the level of real solutions that could be brought about by efficient adaptive human agency. The importance of agriculture as performance is useful in counterbalancing the modelling approaches towards mitigating the negative impacts of climate change. The adaptation and mitigation strategies are and should be social phenomena which need social attendance in the form of improved and sustainable agricultural practices and could help agriculture contribute less to the changing climate. This chapter will focus on numerous strategies that could be adapted to assess and cope with the negative impacts of changing climate on agriculture.

Keywords
Climate change · Climate-smart agriculture · Adaptation · Mitigation · Food security

12.1 Introduction

Climate change has emerged as a real threat to agriculture, food security and livelihood of millions of people around the globe (IPCC 2014). Major components of climate affect the actual and future projected crop yields. Some of these components determine yield potential (CO_2 concentrations, temperature and radiation), some limit these yields by the extent of their availability (nutrients and water) and others reduce it by their presence in the form of biotic (diseases, weeds and pests) and abiotic (e.g., waterlogging, salinity and ozone) stresses (Neumann et al. 2010; van Ittersum et al. 2013) Almost every climatic factor has dramatically changed in its intensity over the past few decades. Global temperature has increased by 0.74 °C over 1880–2012 and is expected to increase more by 0.2 °C per decade with a final increase of 2–4 °C by the end of the twenty-first century (IPCC 2007). CO_2 concentration has risen to 391 ppm in 2011, 40% above that of the pre-industrial era (IPCC 2014) and, presently, the CO_2 concentration is 410 ppm. Climate change has its severe effect on water availability, and it is estimated that nearly 20 million hectare (mha) area will be water-scarce by 2025 (Bouman et al. 2007). Among other abiotic stresses indirectly caused or amplified by climate change are salinity and air pollution. With changing climate, extreme weather events may increase in intensity, frequency, duration and timing. Climate change may affect agriculture directly through increased CO_2 levels or indirectly by changes in the patterns of solar radiations and the subsequent heat. Sea level rise may inundate coastal lands. Air pollution will block solar radiation thwarting crop outputs (Tang et al. 2013). Drought and floods may increase in severity. Pest and weed incidences may escalate. Precipitation in many high latitude and equatorial pacific regions may increase while midlatitude subtropical regions may become drier (IPCC 2014).

12.2 Contribution of Agriculture to Climate Change

The N_2O, CH_4 and CO_2 concentrations were 270 ppb, 722 ppb and 280 ppm, respectively in 1750 A.D. These values rose to 324 ppb, 1803 ppb and 391 ppm, respectively, by 2011 (IPCC 2014). It has been confirmed that these values are higher than at any time in the last 65,000 years (Long et al. 2015). Between 1961 and 2005, food production increased to 4.8 from 1.8 billion tons per annum while cropland increased to 1208 from 960 m ha. Average crop yield increased to 3.96 tons per ha from 1.84 tons per ha during this period. Agriculture now contributes significantly to climate change as greenhouse gas emissions due to many current farming practices. Some authors put it at 19–29% of the total greenhouse gas emissions (Vermeulen et al. 2012) with significant variability worldwide. If land-use change is also considered, agriculture is responsible for the generation of 30% of greenhouse gas production (FAO 2012). Most of this contribution is in the form of direct emissions from agriculture systems as CH_4 and N_2O emissions or indirectly in the form of energy consumption driven by agriculture (CO_2) (Vermeulen et al. 2012). By 2030, greenhouse gas emissions are predicted to rise almost 40 per cent (Smith et al. 2008).

12.3 Effect of Climate Change on Agricultural Productivity

Climate change is projected to have both negative and positive effects on agriculture systems around the world with negative impacts overweighing the positive ones (Müller 2013). Climate change may negatively impact agriculture by affecting farming structure and planning, destroying agro-climatic resources incurring agro-meteorological and biological disasters and reduction in crop growth and yields (Cohn et al. 2016). Several studies have indicated that agriculture production could be adversely affected by rising temperatures (Aggarwal 2009), changes in precipitation patterns (Prasanna 2014) and variations in the intensity and frequency of extreme climatic events such as droughts and floods (Singh et al. 2017). Studies report that "the daily minimum night time temperature increased at a faster rate than daily maximum temperature in the last century" and the differential effects of increase in day and night temperatures were observed on the growth, development and yield of rice (Venkatramanan and Singh 2009a) and wheat (Venkatramanan and

Singh 2009b). This study of increases in day and night temperatures on rice and wheat is significant as the rice–wheat system drives food security in South Asia and China. The frequency and severity of floods and droughts will be increased in the coming decades, posing risks for both croppers and livestock keepers (Thornton and Gerber 2010). The risk has been further increased by climate change and weather variability. Climate change will have more impact on crop productivity in the lower altitudes (Stocker 2014).

Climate-driven diseases caused an estimated 16% reduction globally for unprotected crops (Oerke 2006). Climate change–induced yield reduction is 1–5% over the last 30 years (Porter et al. 2014). A greater impact is projected to be on cereal crops. Climate change has negatively affected maize and wheat crop yields in many regions on a global average (Knox et al. 2012) but the effect on rice and soybean is small (IPCC 2014). Wheat and maize yields have already been reduced by 5.5% and 3.8%, respectively, since 1980 (Lobell et al. 2008). Climate change is predicted to reduce crop yields by 20% in south Asia and Sub-Saharan Africa with 30% and 40% risk of crop failure for wheat and maize, respectively (Lobell et al. 2008; Thornton and Gerber 2010). The anticipated impacts of climate change on cereal crop yields in different parts of the world are estimated to be −20% for wheat, −35% for rice, −60% for maize, −50% for sorghum and −13% for barley depending on the projected year, location and future climate scenarios (Porter et al. 2014).

12.4 Effect on Food Security

World food production is expected to increase by 70 million annually (Popp et al. 2013) with the projection that the world's population will be up by two billions by 2050 (FAO 2013). The world crop area increased by only 12% over the last 50 years (1969–2009) while the population doubled, causing per capita crop land globally to fall to 0.25 ha from 0.44 ha. World demand for food has been estimated to increase by 60% by 2020 (FAO 2012). This has led to the fact that for now more than a billion people are going to bed hungry every day. Moreover, agriculture employs 1.3 billion small holders and landless workers who are likely to be severely affected by climate change. World edible crop production is under risk due to the production of biofuel crops, decrease in chemical inputs for mitigation purposes and installation of solar farms on arable lands. Increase in demand always ends up with price hike. Almost 20% of local food prices in 51 countries were affected by domestic weather variability between 2008 and 2012 (Brown and Kshirsagar 2015). The adverse effects of climate change have more severely affected the poor people in developing countries, resulting in retarded economic growth and undermining poverty alleviation (Brown and Kshirsagar 2015). In wealthier nations, the problem has a different face. In addition to increase in global population and subsequent increase in food demand, the food consumption patterns are also changing. People are getting wealthy, and they are now consuming more food and meat, hence, increasing competition for energy, land, water and other inputs in food production.

12.5 Benefits of Climate Change to Agriculture

Increase in atmospheric CO_2 concentration may boost production for various crops (Franzaring et al. 2008; Miglietta et al. 1998; Qaderi et al. 2006). Increase in CO_2 concentration might be beneficial for plant productivity with significant biomass increase for C3 plants. Other potential benefits include decreased stomatal conductance and oxidative stress, higher abiotic stress tolerance, increased root growth and high water-use efficiency (Lopes et al. 2016). For instance, Amthor (2001) compiled and compared 50 studies on the impact of increased CO_2 concentration on wheat and found that doubling of CO_2 concentration to 700 from 350 ppm enhanced wheat yield by 31%, subject to ample supply of nutrients and water. However, findings of yield enhancement in free air CO_2 enrichment are fewer compared to enclosure studies (Long et al. 2016). These findings reflect the output produced in control conditions and do not necessarily translate for productivity in agricultural ecosystems. CO_2 concentration increase will be accompanied by increased global warming. A modest warming trend (1–4 °C) may cancel out the beneficial effects of increased CO_2 levels on plant productivity (Lopes et al. 2016).

12.6 The Way Forward

Farmers across the globe, with many of them not yet realizing the climate change threat, may face difficulties adopting suitable practices in a real climate change scenario. Currently, the existing farmland too is reducing as we lose more land to salinity, waterlogging and, above all, erosion. The whole system needs a complete rethinking of food systems. Meeting world food demand needs to be met while saving the planet. It is getting increased production from existing farmland in such a way that it has little impact on the environment and which do not undermine our capacity to produce more food in future (Garnett et al. 2013). The solution lies in two concepts, namely, sustainable intensification and climate-smart agriculture. Although the two terminologies refer to two different approaches, climate-smart agriculture is the key to achieve the goal of sustainable intensification.

12.7 Climate-Smart Agriculture

Climate-smart agriculture (CSA), a relatively new concept that lies at the interface between science and policymaking, was proposed by FAO in 2010 at The Hague Conference on Agriculture, Food Security and Climate Change (FAO 2013). Two processes developed parallel soon after the Hague Conference. On one hand, the process of policymaking was initiated which resulted in the making of a "global alliance for climate smart agriculture" in 2014 and on the other hand, a scientific processes was started in the form of worldwide conferences on CSA (Saj et al.

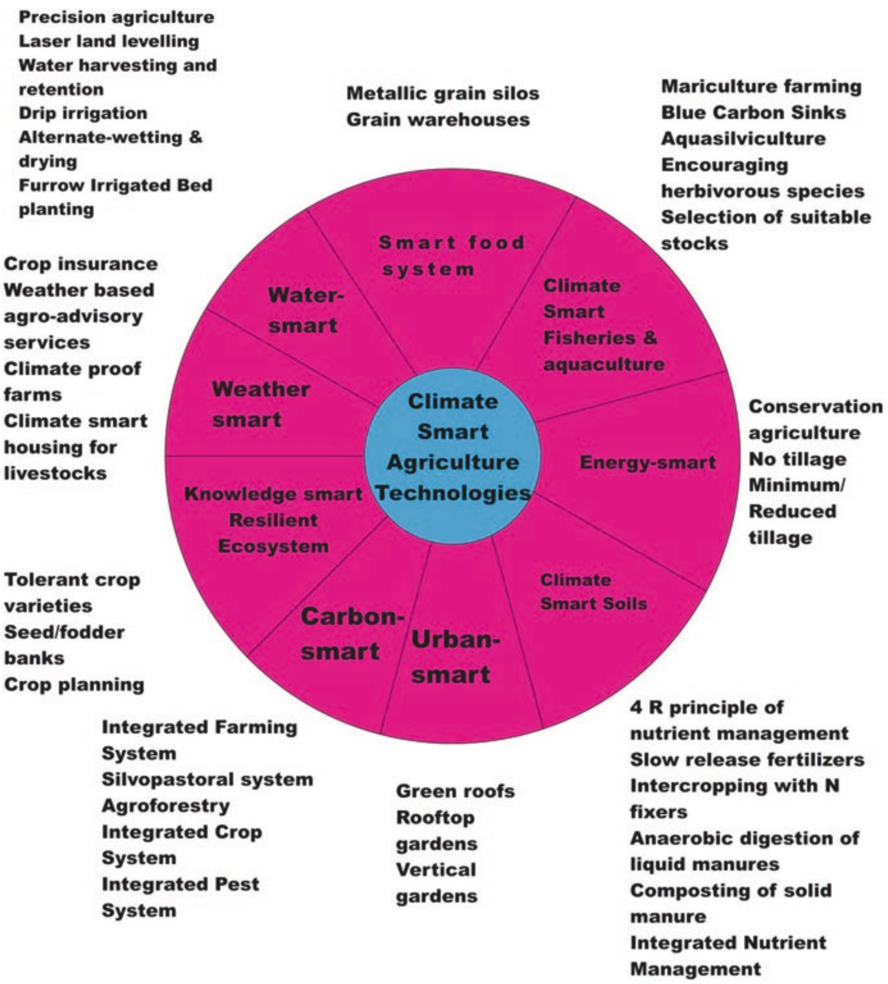

Fig. 12.1 Climate-smart agriculture technologies. (Source: Venkatramanan and Shah 2019)

2017). Climate-smart agriculture can be clearly defined by three objectives. Firstly, increasing agricultural productivity for enhanced food security; secondly, increasing the adaptive capacity of the food production system to a changing climate; and thirdly, reducing greenhouse gas emissions from current and intensification practices. To achieve the triple objectives of climate-smart agriculture, there is a dire need of innovative climate-smart agriculture technologies (Fig. 12.1), which aid in conserving agricultural resources, achieving food security and tapping the mitigation potential of the agriculture system.

12.7.1 Adaptation

Adaptation means adjustment to the expected or actual impact of climate. Adaptation includes agronomic management for soil, water, nutrients, pest- and weed-adjusting cropping system and distribution (Bonzanigo et al. 2016; Rippke et al. 2016), conservation agriculture (Powlson et al. 2014), plant breeding and biotechnology (Abberton et al. 2016), strengthening infrastructure construction and enhancing disaster prevention.

Negative impacts of climate change can be ameliorated through adaptation strategies that could range from minor changes in production practices to transformative reforms in production policies. The adaptive capacity may be built in such a way that farmers, farmers' service providers and institutions respond effectively to long-term climate variability. The adaptation strategies are diverse. The main components are efficient soil, water and plant nutrient management which could be achieved by improved irrigation systems and on-farm water management, breeding and making access to crop varieties that are resistant to drought, heat, salinity, flooding conditions and other climate-related threats, building the capacity of institutions to enhance actions, disseminate knowledge and pave the way for efficient policy reforms. Actions vary around the globe with clear differences between poor and rich countries due to differences in adaptive capacities.

12.7.2 Mitigation

In a changing climate context, two challenges, meeting global food demand and reducing the amount of greenhouse gases emitted per unit of food production, go parallel. With increasing population, going back to organic farming and still meeting the world food demand is seemingly impossible; however still, achieving lower N_2O and CH_4 emissions per unit of output is the major objective of CSA. All practices that could reduce the emissions of these gases can be termed climate change mitigation strategies. Mitigation also includes soil friendly practices to control the rate of land loss to drought, salinity, and waterlogging and soil erosion. However, keeping in mind the need for producing more, getting more out of existing farmland without damaging the environment, is the main component of climate change mitigation. Mitigation may also include a practice of not doing anything in the form of reducing land cover changes, especially wetlands and carbon-rich forests (Wollenberg et al. 2011).

12.8 Adaptation Strategies

Climate change adaptation includes "initiatives and measures to reduce the vulnerability of human and natural systems facing actual or expected impacts of climate change" (IPCC 2007). Adaptation takes into account the implementation of a range of strategies that include introduced and local biotechnology, hard technologies (equipment, machinery and tools), soft technologies (knowledge, awareness raising and capacity building) and organizational technologies (resource user organization and institution building). Climate change adaptation practices can be adopted in almost every field in agriculture with more focus on saving and harvesting water, managing soil for water and nutrient conservation, nutrient management, crop production practices and improved livestock management.

12.8.1 Water Management Practices

Water management practices for climate change mainly focus on saving water or coping drought stress and ways of harvesting water from natural sources.

12.8.1.1 Sprinkler Irrigation

Sprinkler irrigation improves water-use efficiency and contributes to food production in a changing climate characterized by heat and drought stresses. It works well under limited water supply. It also performs better in high temperatures by supplying colder water and also reduces the risk of crop freezing due to low temperatures (Hodgkinson and Smith 2018).

12.8.1.2 Drip Irrigation System

Drip irrigation system is used to ensure a constant supply of water through pipes and valves to the root of plants. It has the most efficient water supply (90%) compared to sprinkler (75%) and flood irrigation (60%). Drip irrigation works well in arid and semi-arid areas. It has not only high water-supply efficiency but also nutrients can be supplied through this system, reducing risks of leaching or volatilization (Nigussie et al. 2018).

12.8.1.3 Fog Harvesters

Fog harvesters are simple and low-cost collection systems that are an alternative source of fresh water for agricultural irrigation and domestic use in dry regions. Fog harvester works best in coastal areas with long fog periods and mountainous regions whose height range from 400 m to 1200 m (UNEP 1997).

12.8.1.4 Rainwater Harvesters

Rainwater harvesters range from small water tanks to large reservoirs and dams in areas with no surface water, where groundwater is too deep to draw or where drinking and irrigation water are too salty or acidic (Pillay and Kalu 2012).

12.8.2 Soil Management Practices

Climate change already has and is projected to affect soil negatively through increase in CO_2, changes in vegetative cover, sea level rise, changes in temperature and rainfall patterns and human activities. The climatic origin of these problems is not fully certain but still some soil management practices are found helpful (Brinkman and Sombroek 1996).

12.8.2.1 Terrace Farming

Terrace is a levelled surface used for farming in slope regions in areas where soil and climatic conditions are conducive to erosion. Benefits of terraces include control in water and wind erosion, increase in soil moisture retention and improvement in general agricultural conditions. Besides controlling erosion and retaining moisture in a changing climate, terraces also capture heat during daytime and release it at night-time, hence, protecting crops against frost (Mars 2005).

12.8.2.2 Conservation Tillage

Conservation tillage refers to soil management practices that allows establishment of crops in previous crops residues. Soil is minimally disturbed. This helps in slowing down the water movement and hence controls soil erosion. Conservation tillage is widely practiced in Latin America and has huge potential to be introduced to Europe, Asia and Africa (Derpsch 1999). Indeed, the conservation tillage that includes minimum/reduced tillage is "energy-smart technology" as it conserves not only the soil ecosystem, but also energy by minimizing soil disturbance (Venkatramanan and Shah 2019).

12.8.2.3 Integrated Nutrient Management

Although chemical fertilizers have helped attaining higher yields amid rapidly increasing population, they have environmental costs. On the other hand, organic farming has very less productivity potential and is expected to eventually fail if tried to practice globally in the context of current food demand. An integrated approach towards the combined use of chemical and organic fertilizer has great adaptation capacity. The organic part of integrated nutrient management has the potential to minimize many risks posed by climate variability such as increased pests and diseases, erosion and others. Root growth in the presence of organic matter is high and, hence, can cope with drought stress. Moreover, organic matter–containing soils have high water-holding capacity.

12.8.3 Biotechnology

Climate change is sudden and current crops and varieties at hand are mostly susceptible to it. In such a scenario, the need for crop diversification has increased manifold.

12.8.3.1 Breeding New Varieties

Breeding new varieties that are resistant to different kinds of climatic stresses such as heat, drought, salinity and pests is a promising adaptation strategy (Mottaleb et al. 2017). Resistant varieties are proposed to experience and incur minimum losses under unfavourable conditions in a changing climate. Besides high yields and resistance, varieties can also be bred for improved nutritional status, providing benefits to animals and humans alike.

12.8.3.2 Crop Diversification

It refers to the introduction of new crops to an agricultural system to increase biodiversity and gain economic return. It also helps farmers identify crop species that can thrive best in the environmental conditions of a particular locality. This minimizes the risk of total crop failure in case of sudden climate change or in times of disaster. Natural biodiversity is increased, and the ability of agroecosystem to severe stresses is strengthened.

12.8.3.3 Genetic Engineering

Conventional breeding has been proved promising in developing pest- and disease-resistant varieties along with increased yield performance. However, this process is slow and is limited to the exploitation of the existing genetic variation between crops and their nearest relatives. Biotechnology and genetic engineering are rather quick responses to this problem. The first generation of genetically modified plants was introduced in 1996 and produced genetically modified maize, soybean and cotton that had tremendous resistance to pests and tolerance to herbicides. Promising results have also been shown in transgenic canola, alfalfa, squash and papaya. Genetic modification has been limited to pest and herbicide resistance and to date no genetically modified drought- and heat-tolerant variety has been released. However, some of the related problems are being addressed, for example, transgenic rice with the introduction of HRD gene has improved its water-use efficiency and the ratio of biomass produced to the water consumed has been increased, mainly because of enhanced photosynthetic capacity and reduced respiration (Karaba et al. 2007).

12.8.4 Seed and Grain Storage

Secured seed and grain storage is among the major challenges faced by resource-poor farmers in developing countries (Wambugu et al. 2009). Seeds must be stored against biological damage by insects, rodents and microorganisms, chemical damage by acidity and physical damage due to poor post-harvest management. Recent advancement in technology has ensured safety in post-harvest operations, improved storage conditions, helped attain safe moisture levels and provided safety against insects and rodents. However, poor economic conditions in underdeveloped countries have prevented farmers of those countries to benefit from the technology. Efficient seed and grain storage ensures food security of both animals and humans in case of prolonged drought or other natural disasters. In fact, seed and grain storage conditions and reserves of food and other agricultural inputs have been used as indicators of the adaptive capacity of nations (CARE 2010).

12.8.5 Cropping System Management

Much of the productive and ecological resilience to climate change comes from managing crops and livestock diversity which help farmers maintain their agricultural productivity.

12.8.5.1 Mixed Farming

Mixed farming is composed of several practices that involve the cycling of inputs and outputs within the farms or between several farms. Forage or fodder crops are fed to livestock and in return animal excreta is used as fertilizer for the crops. Intercropping and crop rotation are also included in mixed farming wherein legumes benefit grain crops by their supply of nitrogen. Another example of mixed cropping is combined chicken–fish farming where chicken waste serves as fish feed. Mixed farming has greater adaptive capacity in a changing climate because of the diversification of crops under uncertain weather conditions. Failure of one crop can easily be compensated by another crop. Moreover, livestock is a valuable asset and in fact a walking bank that could be sold in case of crop failure due to prolonged drought or flooding.

12.8.5.2 Agroforestry

It is an integrated approach towards farming in a world of changing climate. In this system, trees and non-tree crops are sown either together at same time, in rotation or in separate plots. Materials from both crops and trees benefit one another. Agroforestry has great adaptive capacity. Trees can withstand severe climatic conditions in the form of drought and winds. Their deep-rooted nature helps them explore water and nutrients from deep grounds and bring them up. They have higher evaporation rates and hence keep the soil aerated (Martin and Sherman 1998). Trees also significantly reduce erosion. A combination of leguminous shrubs and Napier grass in contour hedgerows was reported to reduce erosion by 70% on 10% inclination slope in central Kenya (Mutegi et al. 2008).

12.8.6 Priming

Priming is the technique of pre-exposure of plants to an eliciting factor, enabling plants to cope with later stress events. It is a cost-effective strategy that improves plant tolerance to stress. In plants pre-primed with abiotic stresses, beneficial microbes or pathogens showed stronger responses against biotic and abiotic stresses as compared to non-primed plants in the same generation (Conrath et al. 2015). Various priming mechanisms induce the regulation of primary metabolism, chromatin modification, increase in levels of pattern recognition receptors and accumulation of nitrogen-activated protein kinase (Balmer et al. 2015; Conrath et al. 2015).

12.8.6.1 Priming for Heat Tolerance

Heat tolerance depends on the ability of plants to perceive the stimulus as well as biochemical and physiological adjustments (Hasanuzzaman et al. 2013). It has been found that thermopriming has successfully induced tolerance in plant species to heat that recurred in the later growth stages of plants. In wheat, when day/night temperature was increased by 8 °C as compared to control in 7 and 9 leaf stages for 2 days, enhanced heat tolerance of wheat at anthesis was observed. Primed plants showed higher photosynthetic capacity, higher activity of peroxides and glutathione reductase in mitochondria and superoxide dismutase in chloroplast. This increased activity of hormones resulted in lower damage caused to cell membrane which was indicated by lower content of malondialdehyde in the chloroplasts and mitochondria of wheat leaf. Also more starch was found in the grain of primed plants (Wang et al. 2014).

12.8.6.2 Priming for Cold Stress Tolerance

Cold stress has been found to damage plant cell membrane. Cold stress enhances the overproduction and ability of reactive oxygen species (ROS) to damage cell membrane. Cold priming enhances the activity of ROS-scavenging enzymes and hence checks their negative activity (Thomashow 1999). Exposure of plants to cold temperature before anthesis is known to reduce the effects of cold stress. This could be attributed to the accumulation of metabolites such as proline, sucrose and other osmolytes induced due to cold priming (Iba 2002). Cold priming with 10 °C (5 °C lower than the ambient temperature) for 7 days at tillering could alleviate the negative effects of cold stress at jointing stage. This can be attributed to the upregulation of genes encoding ARX, SOD and GR in chloroplast and mitochondria induced by priming. All these activities help protecting photosynthetic apparatus by protecting cell membrane (Li et al. 2014).

12.8.6.3 Priming for Drought Stress Tolerance

Many researchers have found drought priming effective against drought stress at later growth stages (Selote and Khanna-Chopra 2010; Wang et al. 2015). Selote and Khanna-Chopra (2010) exposed wheat seedlings (21 days old) to mild drought stress for 9 days and then well-watered them for 2 days. They found that the wheat plants performed excellent during a subsequent 11-day severe drought. They attributed this tolerance to the activation of enzymes and non-enzyme processes in the ascorbate glutathione cycle, maintaining plant water status through maintenance of turgor potential and redox homeostasis. Wang et al. (2015) got enhanced wheat yield due to enhanced photosynthetic activity and improved ROS-scavenging capacity in comparison with non-primed plants.

12.8.6.4 Priming for Waterlogging Stress

Waterlogging stress can be ameliorated by the formation of aerenchyma, which facilitates oxygen diffusion from air to root tips (Colmer and Voesenek 2009). Li et al. (2011) exposed wheat at 7–9 leaf stage and heading stage to waterlogged conditions and found enhanced tolerance to waterlogging at grain-filling stage. They also found higher chlorophyll content, improved photosynthetic activity and enhanced light use efficiency in waterlogged primed plants. Wang et al. (2016) conducted proteome profile on wheat plants primed for a week and found the induction of proteins related to energy production, protein storage and destination and stress defence.

12.8.7 Pest Control Adaptations

Several practices are promoted for pest control through natural predator strategies.

12.8.7.1 Reduced Tillage

Reduced tillage retains soil moisture and protects against drought (VandenBygaart 2016). It also causes a significant reduction in GHG. Conservation tillage residues also help against drought and soil erosion (Henneron et al. 2015). In the context of combating pests, reduced tillage increases ground predators (spiders and staphylinids) in maize and soybean (Crowder et al. 2010). Conservation tillage in wheat provides habitat for natural predators (Rivers et al. 2016).

12.8.7.2 Intercropping

Intercropping helps agriculture by improving yields, increasing water-use efficiency and reducing erosion (Hassanali et al. 2008). It repels insects through several ways, firstly by releasing volatiles, secondly by masking volatiles released by other crop plants and lastly by providing alternative food in the form of less important intercropped crops (Lopes et al. 2016). More than 30,000 farmers in east Africa have adapted a push–pull strategy in which, for instance, maize is intercropped with legumes with Sudan, Napiers or molasses grasses at borders. This can pull or push insects (Khan et al. 2011).

12.8.7.3 Cover Cropping

Cover cropping reduces moisture loss, erosion and reduces greenhouse gas emission from otherwise fallow land. Cover crops offer habitat to predator insects, thus increasing natural predator population. More than 39 parasitoids and 2 predator species were attracted by buckwheat in Florida (Campbell et al. 2016).

12.8.7.4 Organic Farming

Organic fertilizers such as the use of compost and manures can boost beneficial insects while suppressing others. Significantly higher predator population of beneficial insects was observed in manure-applied plots in alfalfa during maize–alfalfa rotation. The possible reason for this might be the more diverse soil biome due to lack of chemicals (Garratt et al. 2011).

12.8.7.5 Biochar

Biochar has been found to reduce greenhouse gas emissions from carbon-depleted acidic soils (Dickie et al. 2014). Fecundity and development rates of rice brown plant hopper have been reported to decrease with application of biochar (Hou et al. 2015).

12.8.8 Genetic Engineering for Adaptation

Novel genetic and epigenetic variation through transportation activation and differential methylation can be induced in plants through exposing them to stressful environments (Cavrak et al. 2014). These epigenetic changes are considered drivers of climate change mitigation and arise more frequently than genetic mutation (Becker et al. 2011). However, these changes are challenged by instability and impersistence across generations which are critical for the implementation of breeding programmes. Selection under optimal conditions prevents realization of full genetic potential of the crop while selection under stressful conditions may help plants uncover their genetic potential (Des Marais et al. 2014).

12.8.8.1 Root Architecture Manipulation

Manipulation of root architecture can make plants able to cope with multiple stresses such as water deficit and nutrient deficiency. This can be exemplified by Deeper Rooting 1 (DRO1) locus in rice. It enables rice root system to become more vertical and go deeper improving drought tolerance and enhanced nitrogen acquisition (Uga et al. 2013). Overexpression of Cytokinin catabolic enzyme CKX resulting in root specific cytokinin degradation has also reported to increase drought tolerance and accumulation of micro- and macronutrients both in tobacco and Arabidopsis. Expression of botanical RNA Chaperon CspB in maize has shown higher yield under drought conditions (Werner et al. 2010).

12.8.8.2 Stomatal Function Regulation

Regulation of stomatal functions to achieve low canopy temperature is also a target for optimal crop performance in multiple stresses including drought and heat stress as well as resistance against stomatal invading pathogens (Lawson and Blatt 2014). Higher transpiration rate can prove detrimental leading to moisture loss especially in drought conditions. In this case, stomatal closure is preferred; however stomatal closure can amplify heat stress (Blum 2015). Engineering ABA receptors to non-agonist chemical receptors can contribute to field scale manipulation of stomatal functions (Park et al. 2015).

12.8.8.3 Increasing Photosynthetic Efficiency

This process through genetic engineering might unlock a great set of unrealized crop potential and maximize positive impact of increasing CO_2 levels (Long et al. 2016). Engineering a Rubisco protein with higher carboxylase catalytic activity has been reported to increase the net photosynthetic efficiency (Lin et al. 2014).

12.8.8.4 Enhancing Fertilization

Floral fertility and sustained fruit set is of crucial importance to plant productivity under stressful conditions. Ear-specific expression of trehalose-6-phosphate phosphatase has shown to increase yield and kernel set in maize under drought conditions (Nuccio et al. 2015).

12.8.8.5 Enhancing Nutrient Status

Optimal nutritional status is of crucial importance to getting higher yields under stressful conditions. Certain genes are involved in the facilitation of uptake, transport and assimilation of nutrients. Examples are the Phosphate Efflux Transporter (PH1) and the NRT1 and NRT2 transporter family which are reported to mediate nitrogen uptake in crops (Hu et al. 2015; Schroeder et al. 2013).

12.8.8.6 Resistance to Pathogens

Building pest resistance is quite simple in comparison to abiotic stresses. Deployment of *mlo* mutants can be exemplified which has successfully shown to induce resistance against powdery mildew in various crops (Appiano et al. 2015). The first generations of commercial transgenic insect-resistant and herbicide-tolerant crops have been highly successful. They have been cultivated on more than a billion hectares while the second generation of many abiotic stress tolerant crops is struggling to make its way into the market (Klümper and Qaim 2014). The complex nature of these stresses and plant response pathways seems to pose a challenge to the spread of this generation.

12.8.8.7 Domestication of Extremophiles

Extremophiles have evolved and reproduced in severe stress environments such as drought, salinity and others. Adoption and domestication of extremophiles seem to be a feasible strategy in developing agriculture in stressful environments. They can be further improved through the use of modern genetic tools and knowledge of domestication events of other crops. Novel genes/alleles can be taken from extremophiles and used in other crops to make them tolerant too. Some extremophile species are given in this regard. *Miscanthus* spp. is a C4 plant that could be used as a biofuel and feed plant. Similarly, *Halophyte Salicornia* could be used as a vegetable and oilseed crop (Ventura and Sagi 2013), Opuntia as a fruit of high nutritive quality (Castellar et al. 2012) and *Chenopodium quinoa* as a cereal (Adolf et al. 2013).

12.8.9 Livestock Management as an Adaptation Measure

Livestock management generally takes into account disease management for susceptible livestock assets and breeding-resistant and more productive animals.

12.8.9.1 Disease Management

Climate change has led to the expansion of vector-borne diseases into cooler climates of both higher altitudes and temperate regions. Changes in rainfall pattern have also led to the expansion of vectors during the wetter parts of the year and hence resulted in larger outbreaks. Appropriate livestock management is hence required so that livestock keepers could benefit from the increasing demand in the face of changing climate. Livestock diseases can be reduced through controlled breeding, quarantining sick animals and controlling entry into the farm lots, improvement of the existing and development of new drugs such as antibiotics and vaccines, development of new diagnostic tools and vector control techniques.

Disease management constitutes two key components, that is, prevention and control. Prevention of diseases can be achieved by several measures, such as care during animal purchase, hygiene in water and food supply, vaccination schedule, observation for signs of diseases, careful disposal of dead animals and watching the movement of animals. Control measures include timely report of diseases, specimen submission and last but not the least, drug administration.

12.8.9.2 Selective Breeding

The genetic makeup of farm animals strongly influences the fitness and determines the tolerance of animals to extreme climate conditions such as heat and drought stress and, above all, diseases. Adaptation of animals includes animals' performance under poor nutritional conditions due to these stresses and diseases brought about by these stresses. Major breeding traits associated with climate adaptation include reliance on low quality feed, thermal tolerance, high disease resistance, kid survival rate, animal morphology and good body condition (Hoffmann 2008). Selective breeding enables animals to become more stress tolerant as well as produce and reproduce more. Three approaches are usually followed in selective breeding. *Outclassing* involves mating animals that are unrelated for at least four to six generations. *Line breeding* involves mating with half-brothers, half-sisters and cousins, etc., while *inbreeding* involves mating of directly related animals. Among all these methods, outclassing is the best method with outstanding results such as increased milk production, reproductive ability and kids' survivability. Selective breeding reduces the risk of losing animals to harsh weather and changing climate conditions and enables farmers to get maximum productivity.

12.9 Climate Change Mitigation Strategies

The agriculture sector plays a vital role in GHG mitigation by sinking 10% of GHG emissions. Agriculture reduces global GHG emissions by approximately 10% from reducing N_2O emissions, 42% by carbon offsets through biofuel production, 32% by absorbing CO_2 emissions and 15% by reducing methane emissions (IPCC 2007). Emission mitigation strategies are generally grouped as (1) reducing emissions from agriculture, (2) enhancing sinks for the sequestration of CO_2 and (3) avoiding emissions through prevention of land-use change and by using replacement products.

12.9.1 Crop Production

12.9.1.1 Improved Varieties

Improved varieties help in producing more biomass from lesser piece of land which could otherwise come from forests if productivity was lower or crops were disease susceptible. Genetically modified (GM) crops with Bt resistance are examples of this. It has been estimated that GM crops conserved 14,200 M kg of CO_2 in 2007 which is equivalent to removing 6 million cars from the circulation (Brookes and Barfoot 2012). However, GM technology has received stiff opposition from the consumers.

12.9.1.2 Cover Crops

Cover crops such as rye and clover offer tremendous GHG mitigation potential by sequestering carbon, leaving residues and least reliance on chemical inputs. They also provide nitrogen to the subsequent crops, hence reducing nitrogen input and resultantly N_2O emissions. In an old study, cover crops were found to sequester carbon at the rate of 0.28–2.60 Mg ha^{-1} $year^{-1}$ (Lal 1998).

12.9.2 Nutrient Management

The efficient use of nitrogenous fertilizers offers mitigation of GHG emissions in two ways: by reducing N_2O emissions through efficient use and by reducing CO_2 emissions due to reduction in the manufacturing of chemical fertilizers.

12.9.2.1 Nitrification Inhibitors

The use of nitrification inhibitors such as S-benzylisothiouronium fluroate (SBT fluroate) and S-benzylisothiouronium butanoate (SBT butanoate) can lead to reduction in N_2O emissions by 4–5% and global warming potential of urea by 8–19% (Bhatia et al. 2010).

12.9.2.2 Slow-Release Fertilizers

Chemical modification and changing the size of fertilizer granules can lead to the slow release of fertilizer, greatly benefiting crop yield and reducing N_2O emissions. Chances of nutrient losses and N_2O emissions due to leaching and volatilization are greatly reduced due to slow-release fertilizers. Combined with zero tillage, there has been great reduction (19%) in global warming potential (Bhatia et al. 2010).

12.9.2.3 Type of Fertilizer

It has been found that ammonia-based fertilizers result in higher N_2O emissions as compared to nitrate fertilizers (Bouman et al. 2007). The relative magnitude and total emissions from different fertilizers are given as follows: more N_2O emissions were recorded from anhydrous ammonia, followed by urea and ammonium sulphate while least emissions were recorded from calcium ammonium nitrate (Tenuta and EG Beauchamp 2003).

12.9.2.4 Fertilizer Application Time

Nitrogen application requirement is lower at the beginning of plant growth, higher at vegetative growth and again reduces at maturity. Huge applications at the beginning and at maturity are a total loss and results in higher N_2O emissions (Hultgreen and Leduc 2003). N application immediately after rainfall and irrigation increases N-use efficiency and reduces N_2O emissions. In this case, N loss through leaching and volatilization is reduced.

12.9.2.5 Fertilizer Placement

The placement of N fertilizers near the zone of active root uptake results in greater N-use efficiency, hence reducing N_2O emissions (CAST 2004).

12.9.2.6 Fertilizer Application Rate

Lower application rates of N also result in lower N_2O emissions (Drury et al. 2008). Help could be sought from organic sources of nitrogen to make sure crop nutrient requirements are met.

12.9.2.7 Mycorrhiza

Mycorrhizal fungi reduce plants' reliance on nitrogenous and other fertilizers, hence reducing fertilizer input and resulting N_2O emissions. The resulting plant biomass offers increased residues with great potential of C sequestration. Glomalin is a glycoprotein produced by mycorrhizal fungi that contains several soil-improving properties, including enhanced carbon sequestration (Subramanian et al. 2009).

12.9.3 Soil Management for Mitigation

Soil acts a great sink for greenhouse gases. Minimal disturbance of soil to reduce the possible release of greenhouse gases along with massive burial of carbon in the soil is most accurately termed as the only way to save the planet.

12.9.3.1 Conservation Tillage

Conservation tillage has a significant role in reducing the release of GHG emissions from soil. It has been found that tillage stimulates microbial decomposition of soil organic matter which increases the release of CO_2 to the atmosphere. Conservation tillage conserves soil, water and crop residues. Agriculture-driven CO_2 emissions are also reduced due to less use of fossil fuels from agricultural operations. Examples of conservation tillage are strip tillage, ridge till and mulch till farming (MDA 2011).

12.9.3.2 Biochar Application

Biochar, a pyrolysed biomass of wood or other agricultural biomass, has been found to have great potential for carbon sequestration. It has several soil-improving properties such as porous structure which increases the soils' carbon sequestration capacity, enhanced water-holding capacity, nitrogen-use efficiency and microbial activity. All these properties have been found to greatly affect plant nutrient use efficiency and subsequent reduction of N_2O emissions (Lehmann 2007).

12.9.3.3 Enhancing Microflora in the Soil

Microbes can help plants maintain their health through several ways such as tolerance to abiotic (such as salts) and biotic (such as pathogens) stresses and increase plant efficiency of resources such as N uptake. Several reports have demonstrated reduction of N emissions and leaching as well as carbon emissions from the soil with use of mutualistic microorganisms and reduced reliance on agrochemicals (Dobermann and Cassman 2002; Bakker et al. 2012).

12.9.4 Biofuels

The agriculture sector has recently started to contribute to the production of solid, liquid and gaseous biofuels which substitute fossil fuels for energy delivery. Several crops such as sugarcane, corn, sorghum, soybean, oil palm, switch grass as well as crop residues, bioengineered algae, Miscanthus and Jatropha have been recently known to produce biofuels. Biofuel production spans over three generations. The first-generation biofuel crops consisting of sugarcane and maize have been highly successful. The second-generation cellulosic ethanol crops (e.g., Miscanthus) are gaining ground while the third-generation of biofuels, where micro-algae is grown on water and CO_2, are being tested to produce biofuels with research in its infancy (Harvey et al. 2014).

12.9.5 Agroforestry

Forests are important carbon sinks. Though land-use change is not encouraged, afforestation and making judicious use of variable land via occupying land through crops and trees are appreciable in the mitigation process. Trees have a greater capacity for terrestrial carbon sequestration and in the soil through root growth and incorporation of organic matter (Martin and Sherman 1998).

12.9.6 Management in Rice Production Systems

Rice cultivation is responsible for 10–16% GHG emissions. Proper nutrient management (such as use of nitrification inhibitors) to reduce N_2O and residue management to control CO_2 emissions are vital for the mitigation process. Burning rice residues is responsible for the worst CO_2 emissions worldwide and often results in the creation of smog which creates widespread health issues. Dry land zero tillage is the best strategy in this regard. Certain irrigation measures such as midseason drainage (removal of water for about 7 days towards the end of tillering), alternate wetting and drying and direct seeded rice are also found helpful in reducing methane emissions. Direct seeding of pre-germinated rice has a shorter flooding period and hence leads to lesser methane emissions. Corton et al. (2000) noticed 16–54% while Wassmann et al. (2000) observed 16–92% reduction in methane emissions with direct seeded rice. Electron acceptors such as ferrihydrite, when added to paddy soil, stimulate microbial population which slows the activity of methanogens and hence reduces methane emissions. Breeding and introducing rice cultivars with greater mitigation potential are of utmost importance in meeting the mitigation goals. Rice cultivars with small root systems, high root oxidative capacity, more productive tillers and high harvest index have been found to have greater mitigation potential.

12.9.7 Livestock Management for Mitigating GHG Emissions

The livestock sector is mainly responsible for the generation and emission of CH_4 in the environment. In 2005, it was responsible for two-third of total agricultural methane emissions and over one-third of global methane emissions. CH_4 mitigation option for livestock sector falls into the following categories:

1. Improved feeding practices of generally low-quality feed with an aim to increase its utilization as product output and less feed is converted into methane as well as using other feed additives such as oils, oilseeds and others, hence improving the pasture quality with regard to CH4 emissions. Feeding quality and practices are improved through several ways ranging from adding additives to increasing the amount of concentrates in the forages.
2. Animal breeding and management aimed to increase animal productivity per unit of output. Total emissions can be substantially reduced by reducing the number of animals and increasing the productivity per unit of output.

12.9.7.1 Straw Ammonisation

In this practice, low-value forage, such as rice straw, corn stalks and wheat straw, is ammoniated in a cement ammonization pond or water tank. Adding urea, ammonium bicarbonate and liquid ammonia completely degrades the lignin part while the nutrients are enhanced. Rumen microorganisms easily digest it (Shankar et al. 2015).

12.9.7.2 Straw Silage

It is a type of forage prepared through the fermentation of forage grass, fresh green fodder, vines and other materials by lactobacillus in an air-proof (anaerobic conditions) silage container. In this method, raw materials are converted into organic acids (mainly lactic acid). Due to airtight conditions with no microbial activities after completion of fermentation, it remains unchanged for a longer period of time (Shankar et al. 2015). These methods improve the digestibility of forage and reduce the methanogenesis process. In China, the amount of straw processed through ammonization in 2009 was about 92 million tons, accounting for 44% of the total amount of forage (MOA 2010).

12.9.7.3 Increasing the Amount of Concentrates in Feed

An animal's diet normally consists of forage and concentrates. Forage provides the fibre necessary for energy generation, sustaining microbial flora and adding milk with fat while concentrates mainly provide fats, protein, vitamins and minerals. The ratio of concentrate to forage significantly affects the growth performance, health conditions and methane emissions. A diet with more fibre forage than concentrates has a high number of methanogens, enhanced methanogenesis, and hence increased methane emissions and vice versa. So the ration of concentrates must be higher than that of fibre (Demeyer and Henderickx 1967).

12.9.8 Human Diet Adjustment

Human diet greatly affects GHG emissions. It is commonly perceived that supply affects demand. Increasing demand of animal protein results in more GHG emissions as compared to plant protein. Mutton and beef have particularly high emissions (Davis et al. 2010). Therefore, dietary change holds a large theoretical potential towards mitigating the adverse effects of GHG emissions which is obvious from several studies (Berners-Lee et al. 2012; Green et al. 2015). Consumer preferences play a vital role in the practical implementation of dietary mitigation. Dietary mitigation is limited by very few researches. Policy intervention such as consumption taxes differentiated by emission levels might help.

12.10 Conclusions

Climate change has emerged as a major threat to planet Earth as a whole and to agriculture in particular. Severe biotic and abiotic stresses have brought life on Earth to the brink of extinction. While these lines are being written, a recent speech of Sir David Attenborough is going through my mind in which he termed climate change as the greatest threat to life in thousands of years. He said "if we don't take action now, the collapse of civilization and the extinction of much of the natural world is on the horizon". Luckily this is not the first call for action. The threat has been realized and humanity has started to take action to save itself and the Nature. While much can be done by governments and industrialists, farmers also have to do their share of work. They need to do three things: produce more, adapt to the change that has already happened and reduce the share of agriculture in climate change, that is, mitigate it. All these practices together make the collective practice of climate-smart agriculture. The world is already producing more, but still, much of it goes to waste and billions still go to bed hungry. Producing more has consequences and makes agriculture to contribute significantly to greenhouse gas emissions and, hence, to climate change. On the other hand, it is agriculture that mitigates this change by absorbing much of CO_2, a greenhouse gas. But CO_2 is not alone, there are other gasses produced by agriculture such as N_2O and CH_4 which are far more powerful in their magnitude to warm the planet. It is thus of vital importance to reduce the agriculture-oriented emissions of these gasses. Adaptation to the current level of these gasses is needed to sustain the population through meeting the food demand. While collective actions are needed for adaptation, this chapter provides with ample adaptation strategies that could be adopted by individual farmers. These include a number of water management practices such as water-saving irrigation methods and water-harvesting techniques, soil management practices in highly vulnerable mountainous and plain soils, nutrient management practices, biotechnological and genetic engineering methods for developing stress-tolerant varieties, farming systems to produce more and diverse food as well as safe and efficient storage of the produced food and seeds. Breeding of livestock for stress and disease resistance is also of vital importance while considering adaptation strategies. Among mitigation strategies, which focus on reducing the emissions from agriculture sector, include breeding less-emitting crops with higher water- and nutrient-use efficiencies, nutrient management to reduce loss as emissions, efficient irrigation, making use of microorganisms to reduce reliance on agrochemicals, agroforestry, use of biofuels and efficient management of rice and livestock management systems to reduce methane emissions. At this point, I would recall a part of Sir David's speech in which he expressed his and his race's willingness to make sacrifices in their daily lives. Human dietary behaviour must change: Consuming food that require fewer emissions to produce and not letting food go to waste.

References

Abberton M et al (2016) Global agricultural intensification during climate change: a role for genomics. Plant Biotechnol J 14:1095–1098

Adolf VI, Jacobsen S-E, Shabala S (2013) Salt tolerance mechanisms in quinoa (Chenopodium quinoa Willd.). Environ Exp Bot 92:43–54

Aggarwal P (2009) Global climate change and Indian agriculture: case studies from the ICAR network project. Indian Council of Agricultural Research. New Delhi:148

Amthor JS (2001) Effects of atmospheric CO_2 concentration on wheat yield: review of results from experiments using various approaches to control CO_2 concentration. Field Crop Res 73:1–34

Appiano M et al (2015) Identification of candidate MLO powdery mildew susceptibility genes in cultivated Solanaceae and functional characterization of tobacco NtMLO1. Transgenic Res 24:847–858

Bakker MG, Manter DK, Sheflin AM, Weir TL, Vivanco JM (2012) Harnessing the rhizosphere microbiome through plant breeding and agricultural management. Plant Soil 360:1–13

Balmer A, Pastor V, Gamir J, Flors V, Mauch-Mani B (2015) The 'prime-ome': towards a holistic approach to priming. Trends Plant Sci 20:443–452

Becker C, Hagmann J, Müller J, Koenig D, Stegle O, Borgwardt K, Weigel D (2011) Spontaneous epigenetic variation in the Arabidopsis thaliana methylome. Nature 480:245

Berners-Lee M, Hoolohan C, Cammack H, Hewitt C (2012) The relative greenhouse gas impacts of realistic dietary choices. Energy Policy 43:184–190

Bhatia A, Sasmal S, Jain N, Pathak H, Kumar R, Singh A (2010) Mitigating nitrous oxide emission from soil under conventional and no-tillage in wheat using nitrification inhibitors. Agric Ecosyst Environ 136:247–253

Blum A (2015) Towards a conceptual ABA ideotype in plant breeding for water limited environments. Funct Plant Biol 42:502–513

Bonzanigo L, Bojovic D, Maziotis A, Giupponi C (2016) Agricultural policy informed by farmers' adaptation experience to climate change in Veneto, Italy. Reg Environ Chang 16:245–258

Bouman BAM, Lampayan RM, Tuong TP (2007) Water management in irrigated rice: coping with water scarcity. International Rice Research Institute, Los Banos, p 54

Brinkman R, Sombroek WG (1996) The effects of global change on soil conditions in relation to plant growth and food production. In: Bazzaz F, Sombroek WG (eds) Global climate change and agricultural production: direct and indirect effects of changing hydrological, pedological and plant physiological processes. Wiley, West Sussex, pp 49–63

Brookes G, Barfoot P (2012) GM crops: global socio-economic and environmental impacts 1996–2010 PG Economics Ltd http://www.pgeconomics.co.uk/page/33/global-impact-2012. Accessed 31 Jan 2013

Brown ME, Kshirsagar V (2015) Weather and international price shocks on food prices in the developing world. Glob Environ Chang 35:31–40

Campbell JW, Irvin A, Irvin H, Stanley-Stahr C, Ellis JD (2016) Insect visitors to flowering buckwheat, Fagopyrum esculentum (Polygonales: Polygonaceae), in North-Central Florida. Fla Entomol 99:264–268

CARE (2010) Toolkit for integrating climate change adaptation into development projects – digital toolkit – version 1.0 CARE international, with technical input by the International Institute for Sustainable Development (IISD), July 2010

CAST (2004) Council for agricultural science and technology (CAST). Climate change and greenhouse gas mitigation: challenges and opportunities for agriculture. Paustian K, Babcock B (Cochairs) report 141

Castellar M, Solano F, Obón J (2012) Betacyanin and other antioxidants production during growth of Opuntia stricta (Haw.) fruits. Plant Foods Hum Nutr 67:337–343

Cavrak VV, Lettner N, Jamge S, Kosarewicz A, Bayer LM, Mittelsten SO (2014) How a retrotransposon exploits the plant's heat stress response for its activation. PLoS Genet 10:e1004115. https://doi.org/10.1371/journal.pgen.1004115

Cohn AS, VanWey LK, Spera SA, Mustard JF (2016) Cropping frequency and area response to climate variability can exceed yield response. Nat Clim Chang 6:601

Colmer T, Voesenek L (2009) Flooding tolerance: suites of plant traits in variable environments. Funct Plant Biol 36:665–681

Conrath U, Beckers GJ, Langenbach CJ, Jaskiewicz MR (2015) Priming for enhanced defense. Annu Rev Phytopathol 53:97–119

Corton T et al (2000) Methane emission from irrigated and intensively managed rice fields in Central Luzon (Philippines). Nutr Cycl Agroecosyst 58:37–53

Crowder DW, Northfield TD, Strand MR, Snyder WE (2010) Organic agriculture promotes evenness and natural pest control. Nature 466:109

Davis J, Sonesson U, Baumgartner DU, Nemecek T (2010) Environmental impact of four meals with different protein sources: case studies in Spain and Sweden. Food Res Int 43:1874–1884

Demeyer D, Henderickx H (1967) The effect of C18 unsaturated fatty acids on methane production in vitro by mixed rumen bacteria. Biochim Biophys Acta (BBA)-Lipids Lipid Metab 137:484–497

Derpsch R (1999) Keynote: frontiers in conservation tillage and advances in conservation practice. In: Stott DE, Mohtar RH, Steinhart GC (eds) Sustaining the global farm. Selected papers from the 10th International Soil Conservation Organisation meeting held May, pp 24–29

Des Marais DL, Auchincloss LC, Sukamtoh E, McKay JK, Logan T, Richards JH, Juenger TE (2014) Variation in MPK12 affects water use efficiency in Arabidopsis and reveals a pleiotropic link between guard cell size and ABA response proceedings of the National Academy of Sciences 111:2836–2841

Dickie A, Streck C, Roe S, Zurek M, Haupt F, Dolginow A (2014) Strategies for mitigating climate change in agriculture: recommendations for philanthropy–executive summary. Climate focus and California environmental associates, prepared with the support of the climate and land use alliance

Dobermann A, Cassman K (2002) Plant nutrient management for enhanced productivity in intensive grain production systems of the United States and Asia. Plant Soil 247:153–175

Drury C, Yang X, Reynolds W, McLaughlin N (2008) Nitrous oxide and carbon dioxide emissions from monoculture and rotational cropping of corn, soybean and winter wheat. Can J Soil Sci 88:163–174

FAO (2012) Crop prospects and food situation (no. 3, October 2012). http://www.fao.org/docrep/016/al992e/al992e00

FAO (2013) Climate-smart agriculture sourcebook executive summary. Food and Agriculture Organization of the United Nations, Rome, p 570

Franzaring J, Högy P, Fangmeier A (2008) Effects of free-air CO_2 enrichment on the growth of summer oilseed rape (Brassica napus cv. Campino). Agric Ecosyst Environ 128:127–134

Garnett T et al (2013) Sustainable intensification in agriculture: premises and policies. Science 341:33–34

Garratt M, Wright D, Leather S (2011) The effects of farming system and fertilisers on pests and natural enemies: a synthesis of current research. Agric Ecosyst Environ 141:261–270

Green R et al (2015) The potential to reduce greenhouse gas emissions in the UK through healthy and realistic dietary change. Clim Chang 129:253–265

Harvey CA et al (2014) Climate-smart landscapes: opportunities and challenges for integrating adaptation and mitigation in tropical agriculture. Conserv Lett 7:77–90

Hasanuzzaman M, Nahar K, Alam M, Roychowdhury R, Fujita M (2013) Physiological, biochemical, and molecular mechanisms of heat stress tolerance in plants. Int J Mol Sci 14:9643–9684

Hassanali A, Herren H, Khan ZR, Pickett JA, Woodcock CM (2008) Integrated pest management: the push–pull approach for controlling insect pests and weeds of cereals, and its potential for other agricultural systems including animal husbandry. Philos Trans R Soc London B Biol Sci 363:611–621

Henneron L et al (2015) Fourteen years of evidence for positive effects of conservation agriculture and organic farming on soil life. Agron Sustain Dev 35:169–181

Hodgkinson JH, Smith MH (2018) Climate change and sustainability as drivers for the next mining and metals boom: the need for climate-smart mining and recycling. Resour Policy. https://doi.org/10.1016/j.resourpol.2018.05.016

Hoffmann I (2008) Livestock genetic diversity and climate change adaptation. Livestock and Global Change conference proceeding. May 2008, Tunisia

Hou X, Meng L, Li L, Pan G, Li B (2015) Biochar amendment to soils impairs developmental and reproductive performances of a major rice pest Nilaparvata lugens (Homopera: Delphacidae). J Appl Entomol 139:727–733

Hu B et al (2015) Variation in NRT1. 1B contributes to nitrate-use divergence between rice subspecies. Nat Genet 47:834

Hultgreen G, Leduc P (2003) The effect of nitrogen fertilizer placement, formulation, timing, and rate on greenhouse gas emissions and agronomic performance. Saskatchewan Department of Agriculture and Food. Final report project no.5300G, ADF#19990028. Regina, Saskatchewan, Canada

Iba K (2002) Acclimative response to temperature stress in higher plants: approaches of gene engineering for temperature tolerance. Annu Rev Plant Biol 53:225–245

IPCC (2007) Technical summary. In: Parry ML, Canziani OF, Palutikof JP et al (eds) Climate change 2007. Impacts, adaptation, and vulnerability. Contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

IPCC (2014) Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. In: Field CB, Barros VR, Dokken DJ et al (eds) Contribution of Working Group II to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

Karaba A et al (2007) Improvement of water use efficiency in rice by expression of HARDY, an Arabidopsis drought and salt tolerance gene. Proc Natl Acad Sci 104:15270–15275

Khan Z, Midega C, Pittchar J, Pickett J, Bruce T (2011) Push—pull technology: a conservation agriculture approach for integrated management of insect pests, weeds and soil health in Africa: UK government's foresight food and farming futures project. Int J Agric Sustain 9:162–170

Klümper W, Qaim M (2014) A meta-analysis of the impacts of genetically modified crops. PLoS One 9:e111629

Knox J, Hess T, Daccache A, Wheeler T (2012) Climate change impacts on crop productivity in Africa and South Asia. Environ Res Lett 7:034032

Lal R (1998) Soil erosion impact on agronomic productivity and environment quality. Crit Rev Plant Sci 17:319–464

Lawson T, Blatt MR (2014) Stomatal size, speed, and responsiveness impact on photosynthesis and water use efficiency. Plant Physiol 164:1556–1570

Lehmann J (2007) A handful of carbon. Nature 447:143

Li C, Jiang D, Wollenweber B, Li Y, Dai T, Cao W (2011) Waterlogging pretreatment during vegetative growth improves tolerance to waterlogging after anthesis in wheat. Plant Sci 180:672–678

Li X, Cai J, Liu F, Dai T, Cao W, Jiang D (2014) Cold priming drives the sub-cellular antioxidant systems to protect photosynthetic electron transport against subsequent low temperature stress in winter wheat. Plant Physiol Biochem 82:34–43

Lin MT, Occhialini A, Andralojc PJ, Parry MA, Hanson MR (2014) A faster Rubisco with potential to increase photosynthesis in crops. Nature 513:547

Lobell DB, Burke MB, Tebaldi C, Mastrandrea MD, Falcon WP, Naylor RL (2008) Prioritizing climate change adaptation needs for food security in 2030. Science 319:607–610

Long SP, Marshall-Colon A, Zhu X-G (2015) Meeting the global food demand of the future by engineering crop photosynthesis and yield potential. Cell 161:56–66

Long TB, Blok V, Coninx I (2016) Barriers to the adoption and diffusion of technological innovations for climate-smart agriculture in Europe: evidence from the Netherlands, France, Switzerland and Italy. J Clean Prod 112:9–21. https://doi.org/10.1016/j.jclepro.2015.06.044

Lopes T, Hatt S, Xu Q, Chen J, Liu Y, Francis F (2016) Wheat (Triticum aestivum L.)-based intercropping systems for biological pest control. Pest Manag Sci 72:2193–2202

Mars R (2005) The basics of permaculture design. Chelsea Green Publishing, Hartford

Martin FW, Sherman S (1998) Agroforestry principles. ECHO

MDA (2011) Conservation practices, Minnesota conservation funding guide, Minnesota Department of Agriculture. Available at: http://www.mda.state.mn.us/protecting/conservation/practices/constillage.aspx

Miglietta F, Magliulo V, Bindi M, Cerio L, Vaccari F, Loduca V, Peressotti A (1998) Free air CO_2 enrichment of potato (Solanum tuberosum L.): development, growth and yield. Glob Chang Biol 4:163–172

MOA, Ministry of Agriculture, Science and Education Department (2010) National survey and evaluation report of crop straw resources (in Chinese)

Mottaleb KA, Rejesus RM, Murty M, Mohanty S, Li T (2017) Benefits of the development and dissemination of climate-smart rice: ex ante impact assessment of drought-tolerant rice in South Asia. Mitig Adapt Strateg Glob Chang 22:879–901

Müller C (2013) African lessons on climate change risks for agriculture. Annu Rev Nutr 33:395–411

Mutegi JK, Mugendi DN, Verchot LV, Kung'u JB (2008) Combining Napier grass with leguminous shrubs in contour hedgerows controls soil erosion without competing with crops. Agrofor Syst 74:37–49

Neumann K, Verburg PH, Stehfest E, Müller C (2010) The yield gap of global grain production: a spatial analysis. Agric Syst 103:316–326

Nigussie Y, van der Werf E, Zhu X, Simane B, van Ierland EC (2018) Evaluation of climate change adaptation alternatives for smallholder farmers in the Upper Blue-Nile Basin. Ecol Econ 151:142–150. https://doi.org/10.1016/j.ecolecon.2018.05.006

Nuccio ML et al (2015) Expression of trehalose-6-phosphate phosphatase in maize ears improves yield in well-watered and drought conditions. Nat Biotechnol 33:862

Oerke EC (2006) Crop losses to pests. J Agric Sci 144:31–43

Park SY, Peterson FC, Mosquna A, Yao J, Volkman BF, Cutler SR (2015) Agrochemical control of plant water use using engineered abscisic acid receptors. Nature 520:545–548

Pillay V, Kalu A (2012) A sustainable and robust membrane water treatment unit for potable water production in remote rural areas. In: Accra, Ghana 4th international appropriate technology conference, 2012

Popp A, Rose S, Calvin K, Van Vuuren D, Dietrich J, Wise M, Stehfest E, Humpenöder F, Kyle P, Van Vliet J, Bauer N, Lotze-Campen H, Klein D, Kriegler E (2013) Land-use transition for bioenergy and climate stabilization: model comparison of drivers, impacts and interactions with other land use based mitigation options. Clim Chang 123:495–509. https://doi.org/10.1007/s10584-013-0926-x

Porter JR, Xie L, Challinor AJ, Cochrane K, Howden SM, Iqbal MM, Lobell DB, Travasso MI (2014) Food security and food production systems. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge/New York, pp 485–533

Powlson DS, Stirling CM, Jat M, Gerard BG, Palm CA, Sanchez PA, Cassman KG (2014) Limited potential of no-till agriculture for climate change mitigation. Nat Clim Chang 4:678

Prasanna V (2014) Impact of monsoon rainfall on the total foodgrain yield over India. J Earth Syst Sci 123:1129–1145

Qaderi MM, Kurepin LV, Reid DM (2006) Growth and physiological responses of canola (Brassica napus) to three components of global climate change: temperature, carbon dioxide and drought. Physiol Plant 128:710–721

Rippke U, Ramirez-Villegas J, Jarvis A, Vermeulen S, Parker L, Mer F, Diekkrüger B, Challinor A, Howden M (2016) Timescales of transformational climate change adaptation in sub-Saharan African agriculture. Nat Clim Chang 6:605–609. https://doi.org/10.1038/nclimate2947

Rivers A, Barbercheck M, Govaerts B, Verhulst N (2016) Conservation agriculture affects arthropod community composition in a rainfed maize–wheat system in Central Mexico. Appl Soil Ecol 100:81–90

Saj S, Torquebiau E, Hainzelin E, Pages J, Maraux F (2017) The way forward: an agroecological perspective for climate-smart agriculture. Agric Ecosyst Environ 250:20–24

Schroeder J, Delhaize E, Frommer W, Guerinot M, Harrison M, Herrera-Estrella L, Horie T, Kochian L, Munns R, Nishizawa N, Tsay Y, Sanders D (2013) Using membrane transporters to improve crops for sustainable food production. Nature 497:60–66. https://doi.org/10.1038/nature11909

Selote DS, Khanna-Chopra R (2010) Antioxidant response of wheat roots to drought acclimation. Protoplasma 245:153–163

Shankar M, Prasanna Kumar M, Thimmegowda M, Shivaramu H (2015) Climate change-research, mitigation and adaptive opportunities for Indian Agriculture History 1:386–390

Singh P, Boote KJ, Kadiyala MDM, Nedumaran S, Gupta SK, Srinivas K, Bantilan MCS (2017) An assessment of yield gains under climate change due to genetic modification of pearl millet. Sci Total Environ 601-602:1226–1237. https://doi.org/10.1016/j.scitotenv.2017.06.002

Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B, Sirotenko O, Howden M, McAllister T, Pan G, Romanenkov V, Schneider U, Towprayoon S, Wattenbach M, Smith J (2008) Greenhouse gas mitigation in agriculture. Philos Trans R Soc B Biol Sci 363:789–813. https://doi.org/10.1098/rstb.2007.2184

Stocker T (2014) Climate change 2013: the physical science basis: Working Group I contribution to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

Subramanian K, Tenshia V, Jayalakshmi K, Ramach V (2009) Role of arbuscular mycorrhizal fungus (*Glomus intraradices*) (fungus aided) in zinc nutrition of maize. J Agric Biotechnol Sustain Dev 1:029–038

Tang H, Takigawa M, Liu G, Zhu J, Kobayashi K (2013) A projection of ozone-induced wheat production loss in China and India for the years 2000 and 2020 with exposure-based and flux-based approaches. Glob Chang Biol 19:2739–2752

Tenuta EG, Beauchamp M (2003) Nitrous oxide production from granular nitrogen fertilizers applied to a silt loam soil. Can J Soil Sci 83:521–532

Thomashow MF (1999) Plant cold acclimation: freezing tolerance genes and regulatory mechanisms. Annu Rev Plant Biol 50:571–599

Thornton PK, Gerber PJ (2010) Climate change and the growth of the livestock sector in developing countries. Mitig Adapt Strateg Glob Chang 15:169–184

Uga Y, Sugimoto K, Ogawa S, Rane J, Ishitani M, Hara N, Kitomi Y, Inukai Y, Ono K, Kanno N, Inoue H, Takehisa H, Motoyama R, Nagamura Y, Wu J, Matsumoto T, Takai T, Okuno K, Yano M (2013) Control of root system architecture by DEEPER ROOTING 1 increases rice yield under drought conditions. Nat Genet 45:1097–1102. https://doi.org/10.1038/ng.2725

UNEP (1997) Sourcebook of alternative technologies for freshwater augmentation in some countries in Asia. UNEP, Unit of Sustainable Development and Environment General Secretariat, Organization of American States, Washington, DC.

van Ittersum MK, Cassman KG, Grassini P, Wolf J, Tittonell P, Hochman Z (2013) Yield gap analysis with local to global relevance—a review. Field Crop Res 143:4–17

VandenBygaart A (2016) The myth that no-till can mitigate global climate change. Agric Ecosyst Environ 216:98–99. https://doi.org/10.1016/j.agee.2015.09.013

Venkatramanan V, Shah S (2019) Climate smart agriculture technologies for environmental management: the intersection of sustainability, resilience, wellbeing and development. In: Shah S et al (eds) Sustainable green technologies for environmental management. Springer, Singapore, pp 29–51. https://doi.org/10.1007/978-981-13-2772-8_2

Venkatramanan V, Singh SD (2009a) Differential effects of day and night temperature on the growth of rice crop. Pusa Agric Sci 32:57–62

Venkatramanan V, Singh SD (2009b) Differential effects of day and night temperature on the growth of wheat crop. Ann Agric Res 30(1&2):49–52

Ventura Y, Sagi M (2013) Halophyte crop cultivation: the case for Salicornia and Sarcocornia. Environ Exp Bot 92:144–153

Vermeulen S et al (2012) Climate change, agriculture and food security: a global partnership to link research and action for low-income agricultural producers and consumers. Curr Opin Environ Sustain 4:128–133. https://doi.org/10.1016/j.cosust.2011.12.004

Wambugu P, Mathenge P, Auma E, Van Rheenen H (2009) Efficacy of traditional maize (Zea mays L.) seed storage methods in Western Kenya. Afr J Food Agric Nutr Dev 9:1110–1128

Wang X, Cai J, Liu F, Dai T, Cao W, Wollenweber B, Jiang D (2014) Multiple heat priming enhances thermo-tolerance to a later high temperature stress via improving subcellular antioxidant activities in wheat seedlings. Plant Physiol Biochem 74:185–192

Wang X, Vignjevic M, Liu F, Jacobsen S, Jiang D, Wollenweber B (2015) Drought priming at vegetative growth stages improves tolerance to drought and heat stresses occurring during grain filling in spring wheat. Plant Growth Regul 75:677–687

Wang X, Huang M, Zhou Q, Cai J, Dai T, Cao W, Jiang D (2016) Physiological and proteomic mechanisms of waterlogging priming improves tolerance to waterlogging stress in wheat (Triticum aestivum L.). Environ Exp Bot 132:175–182

Wassmann R, Lantin R, Neue H, Buendia L, Corton T, Lu Y (2000) Characterization of methane emissions from rice fields in Asia. III. Mitigation options and future research needs. Nutr Cycl Agroecosyst 58:23–36

Werner T, Nehnevajova E, Köllmer I, Novák O, Strnad M, Krämer U, Schmülling T (2010) Root-specific reduction of cytokinin causes enhanced root growth, drought tolerance, and leaf mineral enrichment in Arabidopsis and tobacco. Plant Cell 22:3905–3920

Wollenberg EK, Campbell BM, Holmgren P, Seymour F, Sibanda LM, Braun JV (2011) Actions needed to halt deforestation and promote climate-smart agriculture, CCAFS policy brief 4. CCAFS, Copenhagen