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RESEARCH ARTICLE

Impact of climate change and farm management

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Abstract Climate change is all about increased temperature, altered precipitation regime and more recurrent frequency of extreme events. The global climate change resulted from anthropogenic activities. The major impact will be on the grain filling duration and incident radiation. The paradox is that areas that are currently most food-insecure will be most affected by climate change. Even a small change in climate may result in high social vulnerability. Since, climate change poses complex challenges like multiple abiotic stresses on crops and livestock, shortage of water, land degradation and affecting economies in addition to serious challenge to produce 40% more food, with limited land and water, using less energy. Due to climate change, the geographical shift of major field crops is likely to take place. Moreover, the useful insects are reducing which causes serious concerns to food and nutritional security. Furthermore, the excessive chemicals drained in water responsible for the development of dead zones due to which Marine Industries are bound further loss to the food and nutritional security for the ever increasing population. The biodiversity loss, climate change and the rising use of fertilizers are the major threat to our planet. The impact of climate change can be mitigated by suitable varieties and crop substitution, altering irrigation, water management practices the judicious use of fertilizers, manures and increased use of natural microbes that can fix nitrogen naturally. Similarly, the use of biofertilizers, biopesticides, biofungicides, and so on to reduce the chemical load and to sustain productivity. The conservation of natural resources (i.e., land and water) and better farm management practices will certainly help in not only enhancing production and productivity. Similarly, the integration of different components of the system, namely agriculture, livestock and agro/social forestry, will certainly be beneficial for the sustainability of the farms. Nevertheless, the practices of ecological agriculture, diversity farming, optimum levels of farm mechanization and reduction of post-harvest losses become the key component for maintaining factor productivity. The adoption of climate-resilient agriculture, change in crop calendar and new techniques like SRI, crop diversification and pollination management techniques will definitely reduce the yield gap at the farm level. The strengthening of weather forecasting system, credit facilities, linking to the market with better storage facilities and/or infrastructural development, and so on will be key factors to obtain the optimum price of the farm produce at the right time and the right place. The adaptation to climate change should include autonomous as well as planned measures. Therefore, suitable adjustment and improvements over the existing practices are required at different levels to mitigate the negative impact of climate change at the farm level.

Keywords Climate change, Extreme events, Biodiversity, Natural resources, Farm management

Introduction

If current greenhouse gas emission rates continue into the future, both agricultural and natural ecosystems will face enormous pressure. Past changes have resulted in about 0.6°C increases in global temperature over the past century. The projected global mean temperatures for those CO_2 stabilization scenarios are 0.4 - 1.1°C by 2025, 0.8 - 2.6°C by 2050 and 1.4 -5.8°C by 2100, which will be above the values of 1990. These changes in climate have remained unprecedented during the last 10,000 years (Reddy, 2008). According to the International Fund for Agricultural Development (IFAD), 75% of the world's 1.2 billion poor live and work in rural areas (IFAD, 2001). They are largely situated in the zone with tropical savannah agro-ecosystems and are characterized by considerable challenges: seasonal rainfall, intermittent dry spells, recurrent drought years, high evaporative demand and often inherently low-fertile soils

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vulnerable to erosion (Falkenmark and Rockstrom, 2004). There is widespread agreement on three points in particular: (a) all regions will become warmer; (b) soil moisture will decline with higher temperatures and evapotranspiration in the sub-tropics; and (c) sea level will rise globally with thermal expansion of the oceans and glacial melt. With glacial melting, the river systems are expected to experience higher seasonal flow and more flooding (Bellagio Meeting Statement, 2007). The realization of the potential beneficial effects of increased CO_2 in the field remains uncertain due primarily to potential, yet still undocumented, interactions with nutrients, water, weeds, pests and other stresses. If the climate change effects dominate, world crop yields are likely to be more negatively affected, as all scenarios project negative results (–9% to –22%), especially the A1 and A2 scenarios (-16% to -22%) (Parry *et al.*, 2004). More frequent extreme events may lower long-term yields by directly damaging crops at specific developmental stages, such as temperature thresholds during flowering, or by making the timing of field applications more difficult, thus reducing the efficiency of farm inputs (Porter and Semenov, 2005; Antle *et al.*, 2004).

The elements of modern agriculture were introduced in Western Europe and North America in the nineteenth century. Technological developments in this era included chemical fertilizers, mechanization, increased possibilities of irrigation and chemical control of pests and diseases. This coincided with a better understanding of genetics, which provided the basis for scientific plant breeding. These developments led to increasing possibilities to control the diversity of environmental and other conditions affecting plant growth (soil fertility, water requirement, pests and diseases), adapting the environment to the requirements of specific crops and to individual varieties. This represented the beginning of a dramatic change in agriculture. While previously crops and cropping systems were adapted to local and diverse environments, environments started to be adapted to the requirements of individual crops and even specific varieties, a process that continues even today (Hardon, 2004). Mechanization entailed a shift to mono-cropping, which was reasonable remuneration for those who could afford the requisite expanses. Unfortunately, such a strategy was more vulnerable to economic and climatic 'shocks' than the poly-cropping that it replaced (Uphoff, 2007). The world must produce 40% more food, with limited land and water, using less energy, fertilizer and pesticide by 2030 and at the same time reducing sharply the level of greenhouse gases emitted globally (Beddington, 2010). There is a need to develop new techniques that will keep agriculture both profitable for the farmer and make it sustainable for the future (Thuzar *et al.*, 2010). In the present study, the impact of climate change on agriculture and various strategies to mitigate the impact through farm management have been described.

Agriculture Situation and Food Security in Different Regions

Climate change affects agriculture and food production in complex ways. It affects food production directly through changes in agro-ecological conditions and indirectly by affecting growth and distribution of incomes (Schmidhuber and Tubiello, 2007). The six most widely grown crops in the world are wheat, rice, maize, soybeans, barley and sorghum. Production of these crops accounts for over 40% of the global cropland area, 55% of non-meat calories and over 70% of animal feed (FAO, 2006). Major impacts of climate change will be on rain-fed crops including pulses that account for nearly 60% of the cropland area. A temperature increase of 3-4°C could cause crop yields to decrease by 15-35% in Africa and west Asia and by 25–35% in the Middle East according to an FAO report released in March 2008 (FAO, 2008). In the recent past, Europe experienced a particularly extreme climate event during the summer of 2003, with temperatures up to 6°C above long-term means and precipitation deficits up to 300 mm. A record crop yield drop of 36% occurred in Italy for corn grown in the Po valley where extremely high temperatures prevailed (Ciais *et al.*, 2005).

Asian rice yields will decrease dramatically due to higher nighttime temperatures. A study by the International Rice Research Institute (IRRI) reports that rice yields are declining by 10% for each centigrade increase in nighttime temperatures (IRRI press release, 2004). Recent temperature changes have been particularly marked, such that the warming trend in the last 50 years has been 0.13°C per decade, nearly twice that of the preceding 100 years. The yield of wheat declined by 5–8% (Wheeler *et al.*, 1996) and by 10% (Mitchell *et al.*, 1993) per 1°C rise in mean seasonal temperature. Agriculture and food systems in the southern countries, especially in South Asia and Southern Africa, will be the first and most negatively affected. Extreme climate events (especially hotter, drier conditions in semi-arid regions) are likely to slash yields for maize, wheat, rice and other primary food crops. A temperature increase of 3–4°C could cause crop yields to fall by 15–35% in Africa and west Asia and by 25–35% in the Middle East according to an FAO report released in March 2008 (FAO, 2008). In Latin America, losses for rain-fed maize production will be far higher than for irrigated production; some models predict losses of up to 60% for Mexico, where around 2 million smallholder farmers depend on rain-fed maize cultivation (UNDP, 2007/2008). Today, nearly two-thirds of the world's undernourished live in the Asia/Pacific region, and a number of these countries are placed at "serious" or "alarming"

Table 1 Projected Climate Changes and Its Impact Various Crop Yield dynamics

S.N.	Climate-Related Changes	Likely Impact
1.	Warmer and fewer cold days and nights: warmer and more frequent hot days and nights over most land areas	Decreased yields in warmer and increased yields in colder regions: increased pest incidence
2.	Warm spells and heat waves increasing in frequency over most land areas	Reduced crop yields due to heat stress, adverse impact on health and productivity of livestock, increased danger of wild fires
3.	Increased frequency of heavy precipitation events over most areas	Damages of crops increased soil erosion: increased problem at time of cultivation due to water logging and so on
4.	Area affected by frequent drought will increase	Reduced crop yields from crop damage and failures, increased livestock deaths, accelerated land degradation/soil erosion, reduced arable land, migration
5.	Intense tropical cyclone activity increase	Damage to crops/trees/coastal ecology
6.	Increase in incidence of high sea level	Salinization of estuaries and freshwater systems, loss of arable land, increased migration

Source: Abrol (2009); IPCC (2007)

severity levels in the 2009 Global Hunger Index (vonGrebmer *et al.*, 2009). With the projected 15–50% loss in agricultural productivity by 2080 due to climate change (Nellemann *et al.*, 2009); the region faces severe threat of food insufficiency and hunger. The possible likely impact of climate change on farm productivity and ecosystems as indicated by Abrol (2009) is mentioned in Table 1.

Impact of Climate Change on Economies

Ninety million people per year are affected by drought, 106 million people per year are affected by flooding and around 900 million ha of soil are affected by salinity (Bruins, 2009). The IPCC report indicated that an overall increase of 2°C in temperature and 7% in rainfall would lead to an almost 8% loss in farm-level net revenue. Auffhammer *et al.* (2006) described the role of brown clouds, known as ‘‘Atmospheric brown clouds’’ (ABC), over the Indian subcontinent. ABC-attributed harvest reductions alone are estimated to have grown from H≈4% during the 1970s to >10% during 1985–1998. Among a larger set of weather variables tested, June–September rainfall and October–November minimum temperatures were found to have significant influence on rice yield. As expected, higher rainfall ensured both larger areas to be cultivated and higher yield, whereas higher nighttime temperatures reduced yield (Peng *et al.*, 2004). Even a small change in climate may result in high social vulnerability, for at least two reasons: first, many crops rely on the regular return of monsoon rainfall (Krishna *et al.*, 2004), a system that has fluctuated widely in the past, and, second, the economic potential to adapt is very low for most Indian farmers (Luo and Lin, 1999). Recent warming (–0.44°C since 1930) has impacted crop yields through several mechanisms associated with direct temperature as well as changes in water availability (Peng *et al.*, 2004). In India, the effects of global warming are likely to be more severe, causing concern for food security. For every 2°C rise in temperature, the reduction in gross domestic product (GDP) is 5% and for the next 6°C it would be 15–16%. South Asia’s prime wheat-growing land – the vast Indo-Gangetic plain, which produces about 15% of the world’s wheat crop – will shrink by 51% by 2050 due to hotter, drier weather and diminished yields, a loss that will place at least 200 million people at greater risk of hunger (CGIAR, 2006). Although Stern (2007) projected that a 2°C increase in average temperatures would reduce world GDP by roughly 1%, the 2010 World Development Report of the World Bank (2009) focuses on developing countries and estimates that without offsetting innovations, climate change will ultimately cause a decrease in annual GDP of 4% in Africa and 5% in India (Lybbert and Sumner, 2010). Regional disparities around the global average impact are substantial. India and Africa are projected to see reductions of agricultural output by 30% or more (Cline, 2007). As temperatures rise and rainfall patterns change, additional losses of maize grain may approach 10 million tons/year, currently worth almost US$5 billion. In a global analysis of crop yields from 1981 to 2002, there was a negative response of wheat, maize and barley yields to rising temperature, costing an estimated $5 billion/year (Lobell and Field, 2007). Sixty-five countries in the south, mostly in Africa, risk losing 280 million tonnes of potential cereal production, valued at $56 billion, as a result of climate change (FAO, 2005). Latin America and Africa will see a 10% decline in maize productivity by 2055 – equivalent to crop losses worth US $2 billion/year (CGIAR, 2007).

Climate Change Effect on Geographical Crop Distribution

Abiotic stress is the primary cause of crop loss worldwide, reducing average yields for most major crop plants by more than 50% (Bray *et al.*, 2000). In drier areas, climate models predict increased evapotranspiration and lower soil moisture levels, resulting in some cultivated areas becoming unsuitable for cropping and some tropical grasslands becoming increasingly arid (IPCC, 2007). Climatic zones (and thus ecosystems and agricultural zones) could shift towards the poles by 150–550 km by 2100. Many ecosystems may decline or fragment and individual species may become extinct (Agrawal, 2011). In temperate latitudes, higher temperatures are expected to bring predominantly benefits to agriculture, the areas potentially suitable for cropping will expand, the length of the growing period will increase and crop yields may rise. These gains have to be set against an increased frequency of extreme events (Rosenweig *et al.*, 2002). Twenty-three crops are projected to suffer decreases in a suitable area, on average, while some 20 crops will gain suitable area. Overall, suitable area for crop cultivation is projected to increase. The biggest gains are in areas suitable for pearl millet (31%), sunflower (18%), common millet (16%), chick pea (15%) and soya bean (14%), although many of the gains in suitable areas occur in regions where these crops are currently not an integral component of food security (Lane and Jarvis, 2007). Land area suitable for pearl millet is projected to increase by over 10% in Europe and the Caribbean (Lane and Jarvis, 2007). By region, Europe is projected to experience the largest gain in suitable areas for cultivation (3.7%). Olesen and Grevsen (1993) predicted that, for field-grown vegetable crops in Europe; increasing temperature will generally be beneficial, permitting an expansion of production beyond the presently cultivated areas. Antarctica and North America will also gain suitable areas of 3.2% and 2.2%, respectively. Sub-Saharan Africa and the Caribbean are projected to suffer a decline in land area suitable for cultivation by –2.6% and –2.2%, respectively. Both models demonstrate a general trend of loss in the suitable area in the Sahel belt, parts of Southern Africa, India and northern Australia, and gains in the northern USA, Canada and most of Europe (Lane and Jarvis, 2007).

Eutrophication

It has been predicted that a doubling of food production between 2000 and 2050 could be associated with two to three times more eutrophication of marine and freshwater ecosystems, driven by increased levels of nitrogen and phosphorus. Agriculture has been cited as one factor behind the most recent high rate of species extinction, which for the past few hundred years has been as much as 1000 times the background rate (Beddington, 2010). Phosphorus is a commonly applied agricultural fertilizer. The major environmental consequence of phosphorus addition is eutrophication of surface waters, particularly freshwater lakes and streams (Carpenter *et al.*, 1998). Nitrogen is another factor that may limit crop yields. Nitrogen may become less available as the cost of fertilizer rises and the continued growth of eutrophic dead zones and nitrous oxide emissions lead to changes in the way fertilizer is used (Donner and Kucharik, 2008). For nitrogen, consequences include eutrophication of estuaries and coastal seas, loss of biodiversity and changes in species compositions in terrestrial and aquatic ecosystems, groundwater pollution with nitrate and nitrite, increases in the greenhouse gas N_2O, increases in NO*x* and resulting tropospheric smog and ozone, and acidification of soils and sensitive freshwaters (Tilman *et al.*, 2001). Eutrophication is the biggest pollution problem in most coastal waters (NRC, 2000b) and, with overfishing and aquaculture (Naylor *et al.*, 2000), is a major threat to marine biodiversity. Agricultural nutrient pollution has led to increased blooms of toxic algae in many coastal systems and to the large hypoxic (“dead”) zone in the Gulf of Mexico (Bouwman *et al.*, 1997; Downing *et al.*, 1999). In total, projected increases in nitrogen and phosphorus fertilization and irrigation would cause significant losses of biodiversity, as well as marked changes in the composition and functioning of both terrestrial and aquatic ecosystems (NRC, 2000a, b). Soil and water systems can continue to absorb higher levels of inorganic (i.e., reactive) nitrogen without serious ecological damage. Uphoff (2011) has described the rising use of nitrogen fertilizer as the third major threat to our planet, after biodiversity loss and climate change, referring to the impacts of reactive nitrogen on water quality and aquatic ecosystems.

Climate Change Effect on Different Component of Crop Production Crop Phenology

Abrol and Ingram (1996) emphasized that increased temperature would affect the crop calendar in tropical regions. In the tropics, however, global warming is likely to reduce the duration of the effective growing season, particularly where more than one crop per year is grown. Sustained temperature increases over the season will change the duration of the crop (Roberts and Summerfield, 1987), whereas short episodes of high temperature at critical stages of crop development can impact yield independent of any substantial changes in mean temperature (McKeown *et al.*, 2005). Record high daytime and nighttime temperatures over most of the summer growing season reduced grain-filling development of key crops such as maize, fruit trees and vineyards, accelerated crop ripening and maturity by 10–20 days and resulted in reduced soil moisture and increased water consumption in agriculture (Easterling *et al.*, 2007).

Kudo *et al.* (2004) reported that high temperatures can change a plant's phenology – the annual timing of bud break, flowering, seed production and other things linked to seasonal climate change. It can also alter the number, size and orientation of the leaves and it might change the depth of plant roots. High temperatures are likely to shorten the growing cycle of many crop species and, during some developmental stages, such as the reproductive phase, most crops are only able to tolerate narrow temperature changes, which, if exceeded, can reduce seed set and thus yield (Porter, 2005). Indeterminate crops (peanut, cowpea, pea, canola, *Brassica napus* L. and dry bean) undergo floral initiation over a longer period of time and floral development and events coinciding during nonstress or lower stress periods can compensate for inhibited development during the periods of higher stress (Prasad *et al.*, 2008).

Phenology is a sensitive biosphere indicator of climate change (Walther *et al.*, 2002). Plant phenology has been reported to advance by 2–3 days in spring and delayed by 0.3–1.6 days in autumn per decade (Parmesan and Yohe, 2003; Root *et al.*, 2003). In Germany, the phenology of 78 agri-horticultural events between 1951 and 2004 was, on average, 1.1–1.3 days earlier per decade (Estrella *et al.*, 2007). Chmielewski *et al.* (2004) found that in Germany, for the period 1961–1990, the beginning of the growing season advanced by 2.3 days per decade, following increases in mean annual air temperature of 0.36°C per decade. Over the same period, warmer temperatures advanced the beginning of stem elongation in rye by 2.9 days per decade, the beginning of cherry tree blossom by 2 days per decade and the beginning of apple tree blossom by 2.2 days per decade. Because the flowering and fruiting phenology of plants is very sensitive to environmental cues such as temperature, moisture and photoperiod (Rathcke and Lacey, 1985), phenological differences in reproductive events among species over the growing season may reduce competition by spreading primary resource use over different temporal pools (Henry *et al.*, 2001). Differential changes in phenology and growth between species in response to climate change could lead to new patterns of species coexistence during reproduction, potentially affecting competitive interactions and, ultimately, the species composition of the community (Chuine and Beaubien, 2001; Post *et al.*, 2001).

Effect of Climate Change on Pest Population Dynamics and Emergence of New Pests

According to FAO data, the current annual loss worldwide due to pathogens is estimated at US$85 billion and to insect at US$45 billion (Bruins, 2009). Climate change can affect pathogen and pest dynamics in multiple ways. For airborne pathogen and pest organisms, higher temperatures may lead to faster disease cycles (Bouma, 2008). Price (2002) estimated that globally there are 360,000 insect species, which mainly survive on plant material. Pimentel (2009) estimates that globally 70,000 pest species, including 9,000 insect and mites, 50,000 plant pathogens and 8,000 species of weed exist. About 10% of these 70,000 are considered major pests. Invasions by pests and pathogens have a huge impact on agriculture. Temperature is the single most important factor affecting insect ecology, epidemiology and distribution, whereas plant pathogens will be highly responsive to humidity and rainfall, as well as temperature (Coakley *et al.*, 1999). The relative importance of mean and extremes of temperature varies geographically. It has been estimated that with a 2°C temperature increase, insects might experience one to five additional lifecycles per season (Yamamura and Kiritani, 1998). In general, higher temperatures increase the rate of development with less time between generations. Warmer winters will increase survival and possibly increased insect populations in the subsequent growing season (Gutierrez, 2000).

Porter *et al.* (1991) studied the effects of temperature upon insects, including limitation of geographical range, over-wintering, population growth rates, number of generations per annum, crop pest synchronization, dispersal and migration. The temperature increases associated with climatic changes could impact crop insect pest populations in several complex ways like (a) extension of geographical range; (b) increased over-wintering; (c) changes in population growth rate; (d) increased number of generations; (e) extension of development season; (f) changes in crop pest synchrony; (g) changes in interspecific interactions; (h) increased risks of invasions by migrant pests; and (i) introduction of alternative hosts and over-hosts (Babu, 2011). Temperature may change gender ratios of some pest species such as thrips potentially affecting reproduction rates. Lower winter mortality of insects due to warmer winter temperatures could be important in increasing the insect population (Harrington *et al.*, 2001). Higher average temperature might result in some crops being able to be grown in regions further north – it is likely that at least some of the insect pests of those crops will follow the expanded crop areas. Insect species diversity per area tends to decrease with higher latitude and altitude (Gaston and Williams, 1996; Andrew and Hughes, 2005).

Climate Change Effect on Disease Development

Temperature, rainfall, humidity, radiation or dew can affect the growth and spread of fungi and bacteria (Patterson *et al.*, 1999). Other important factors influencing plant diseases are air pollution, particularly ozone and UV-B radiation (Manning and von Tiedemann, 1995) as well as nutrient (especially nitrogen) availability (Thompson *et al.*, 1993). Elevated CO_2 may increase C_3 plant canopy size and density, resulting in a greater biomass with a much higher microclimate relative humidity. This is likely to promote plant diseases such as rusts, powdery mildews, leaf spots and blights (Manning and von Tiedemann, 1995). Research on rice leaf blast and rice sheath blight in the temperate climes of Japan showed that elevated CO_2 increased the potential risks for infection from leaf blast and epidemics of sheath blight (Neumeister, 2010). Climate conditions also influence post-harvest pest damage. Beneficial and harmful insects, microbes and other organisms in the environment will also be responding to changes in CO_2 and climate (Goho, 2004). Host plants such as wheat and oats become more susceptible to rust diseases with increased temperature; however, some forage species become more resistant to fungi with increased temperature (Coakley *et al.*, 1999). In 1999, a new strain of wheat stem rust appeared in eastern Africa that is able to overcome the resistance of many of the world's most widely sown wheat varieties. Increase in temperature accompanied by changing vapour pressure deficits (VPDs) that result in altered RH in the canopy region of the crop enables the creation of conditions favourable for the insect–pest and disease causing pathogens to parasitize on the crop at a frequency and intensity higher than normal. An example of such a scenario is the epidemic-like situation of yellow rust severity on wheat variety PBW343 in Punjab in February 2009 and unprecedented infestation by brown plant hopper on rice varieties in Kharif 2008 in Punjab and Haryana. Such an adaptation by a race of yellow rust was never noticed at such temperature situations before. Such consequences are unpredictable and likely to occur with many other pathogens and pests (Gupta, 2009).

Climate Change Effect on C_3/C_4 Crops and Crop Weed Interactions

According to FAO data, the current annual loss worldwide to weeds is a staggering US$95 billion. Of this, around US$70 billion is lost in developing countries, which is equivalent to a loss of 380 million tonnes of wheat (Bruins, 2009). The effect of climate change varies on different crop species, while some will have more pronounced effects compared with others. C_4 plants account for a small fraction of the total number of plant species (fewer than 1,000 out of 250,000; Elmore and Paul, 1983). According to Holm *et al.* (1977), 14 of the world's worst weeds are C_4 plants, whereas around 76% of the harvested crop area in 2000 was grown with C_3 crops (Monfreda *et al.*, 2008). Optimal temperatures for growth in C_4 plants are generally higher than optimal temperatures for C_3 plants (Flint and Patterson, 1983), but with higher CO_2 the optimum temperature of many C_3 plants also increases (Bunce and Ziska, 2000). The benefit of elevated CO_2 under sufficient water condition will lead to higher C_3 weed competitiveness in C_4 crops (Neumeister, 2010). However, C_4 crops might outcompete better growing C_3 weeds in drought situations, and at higher temperatures utilizing mycorrhiza (Tang *et al.*, 2009). Although both C_3 crops and C_3 weeds benefit from elevated CO_2, it seems that the magnitude varies. Since all C_4 plants (weeds and crops) have the same photosynthesis path, they may react to changes in the same ecosystem in a similar manner.

Temperature and precipitation changes in future decades will also modify, and potentially limit, direct CO_2 effects on plants (IPCC, 2007). The benefit of elevated CO_2 under sufficient water condition will lead to higher C_3 weed competitiveness in C_4 crops. Ziska (2003) observed that most C_3 weeds benefit more than C_3 crop species from elevated CO_2. Many weeds respond more positively to increasing CO_2 than most cash crops, particularly C_3- "invasive" weeds that reproduce by vegetative means (roots, stolons, etc.) (Ziska and George, 2004). Although many weed species have the C_4 photosynthetic pathway, and therefore show a smaller response to atmospheric CO_2 relative to C_3 crops, in most agronomic situations crops are in competition with a mix of both C_3 and C_4 weeds. For all weed/crop competition studies where the photosynthetic pathway is the same, weed growth is favoured as CO_2 is increased (Ziska and Runion, 2006). On average across several species and under unstressed conditions, crop yields are expected to increase in the range of 10–20% for C_3 crops and 0–10% for C_4 crops (Ainsworth *et al.*, 2004; Gifford, 2004). The CO_2–temperature interactions are recognized as a key factor determining plant damage from pests in future decades; CO_2–precipitation interactions will be likewise important (Zvereva and Kozlov, 2006). Increases in the concentration of atmospheric CO_2 will likely stimulate the growth of weeds. Some weeds respond more positively to increasing CO_2 than most cash crops, particularly C_3-"invasive" weeds that reproduce by vegetative means (Ziska and George, 2004).

Mitigating the Effect of Climate Change through Farm Management

Drought- and heat-tolerant crops will play an increasingly important part in adapting to changes in the climatic variation and to the long-term underlying trends towards hotter and probably drier production environments. As a rough rule of thumb, it has been estimated that 25% of losses due to drought can be eliminated by genetic improvement in drought tolerance, and a further 25% by application of water-conserving, agronomic practices, leaving the remaining 50% that can only be met by irrigation (Edmeades, 2010). Various measures to mitigate the negative impact of climate change and farm management in response to the same are described in the sections that follow:

Conservation Agriculture and Integrated Farming

Conservation agriculture (CA) constitutes an integrative approach to address multiple challenges facing the agriculture and environmental sectors – enhancing productivity in the face of acute and widespread problems of resource degradation (soil erosion, declining water availability and quality, declining diversity) and increasingly stressed ecosystems and climate change. It is apparent that CA-based practices when adopted in an integrated manner and over a period of time hold a significant potential to mitigate GHG emissions and at the same time offer opportunities as an adaptive strategy to cope up with climate change-related challenges increasingly facing the agricultural sector (Abrol, 2009). CA results in social and economic benefits gained from combining production and protecting the environment, including reduced input and labour costs, which are greater than those resulting from production alone. CA employs all modern technologies that enhance the quality and ecological integrity of the soil, but the application of these is tempered with traditional knowledge of soil husbandry gained from generations of successful farmers. About 47% of the 95 million ha of zero tillage is practiced in South America, 39% in North America, 9% in Australia and 3.9% in Europe, Asia and Africa (Dumanski *et al.*, 2006). In a review of 286 projects in 57 countries, farmers were found to have increased agricultural productivity by an average of 79%, by adopting “resource-conserving” or ecological agriculture (Pretty *et al.*, 2006). A variety of resource-conserving technologies and practices can be used, such as integrated pest management (IPM), integrated nutrient management (INM), conservation tillage, agroforestry, water harvesting in dry land areas and livestock and aquaculture integration into farming systems. These practices not only increased yields but also reduced adverse effects on the environment and contributed to important environmental goods and services (e.g., climate change mitigation), as evidenced by increased water use efficiency and carbon sequestration and reduced pesticide use (Ching, 2009).

In parts of Africa, there is a system of planting trees alongside crops –called agroforestry – that might include shade coffee and cacao, or leguminous trees. The trees send their roots considerably deeper than the crops, allowing them to survive a drought that might damage the grain crop. The tree roots will also pump water into the upper soil layers where crops can tap it. Trees improve the soil, their roots create spaces for water flow and their leaves decompose into compost. Farmers in central Kenya are using a mix of coffee, macadamia nuts and cereals that results in as many as three marketable crops in a good year. Of course, in any one year, the monoculture will yield more money, but farmers need to work on many years. It will be important to devise more resilient agricultural production systems that can absorb and survive more variability (Halweil, 2005). Some crops are more ‘resource-conserving’ than others. Manioc (*Manihot esculenta Crantz*) is prized for its ability to produce viable yields even under marginal conditions of water and nutrient availability. In resource-poor environments, maintaining yield requires resource-conserving traits and some of these, such as chemical defence, has been retained, and possibly even enhanced (McKey and Beckerman, 1993).

Ecological Agriculture

In developing countries, where irrigation facilities are not available and agriculture depends mainly on rainfall, low-input practices are opted. In such subsistence conditions, agriculture is organic by default. Some areas can be converted into organic agriculture by adopting certification standards and cultural norms to obtain optimum price of the organic produce. The most critical aspect of ecological/organic farming is the protection of crops from insects, pests and other diseases. To accomplish this, a multi-prong approach was used, which includes the use of biopesticides, biofertilizers, herbal and plant-based preparations, pheromones, animal dung and urine-based products along with the use of resistant crops. Badgley *et al.* (2007) examined a global dataset of 293 examples and estimated the average yield ratio (organic: nonorganic) of different food categories for the developed and developing world. For most of the food categories examined, it was found that the average yield ratio was slightly less than 1.0 for studies in the developed world, but more than 1.0 for studies carried out in developing countries. On average, in developed countries, organic systems produce 92% of the yield produced by conventional agriculture. In developing countries, however, organic systems produce 80% more than conventional farms. The comparative analysis of fuel- and fertilizer-based modern agriculture and organic agriculture made by LaSalle and Hepperly (2008) is shown in Table 2.

Diversity Farming

Diversity farming is the single most important modern technology to achieve food security in a changing climate. The diversity provides a natural insurance policy against major ecosystem changes, be it in the wild or in agriculture (Diaz *et al.*, 2006). It is now predicted that genetic diversity will be most crucial in highly variable environments and those under rapid human-induced climate change (Hajjar *et al.*, 2008, Hughes *et al.*, 2008). In a unique cooperation project among Chinese scientists and farmers in Yunnan during 1998-1999, researchers observed the effect of diversity on the severity of rice blast, the major disease of rice (Zhu *et al.*, 2000). They demonstrated, on a large scale, that simple agronomic measures such as mixing varieties

Table 2 Main element of regenerative organic farming (carbon focused) and commercial agriculture (commodity focused)

Carbon focused	Commodity focused
Improves crop biodiversity – Rewarding all farmers, regardless of crops and acreage, for carbon stored will stimulate a variety of crops, rather than traditional commodity crops. Crop rotations also allow soil to replenish itself.	**Limits crops** – Limiting financial incentives to commodity crops – corn, soybeans, wheat, rice, cotton – directs farmers to choose the same small number of crops. Growing single crops each year also depletes nutrients from the soil.
Rewards "green" practices – Regenerative methods reduce greenhouse gas emissions, avoid waterway pollution, limit erosion and improve soil health.	**Environmentally harmful** – Petroleum-based inputs release greenhouse gases, leach nitrogen and phosphorus into the water and deplete naturally occurring soil nutrients, making it more dependent on chemical fertilizers.
Economically independent – By creating an integrated system that does not depend on artificial inputs tied to historically increasing petroleum prices, farmers are more economically independent.	**Petroleum-industry dependent** – Farmers' profits are tied to increases in petroleum-based fertilizer and pesticide prices, creating a cycle of dependency
Long-term strategic land use – More perennial crops, including pasture and trees, focused on land stewardship to create a holistic farm plan.	**Short-term field focus** – Annual crops (tilled and non-tilled) are the main focus on a year-to-year basis.
Reduces Erosion – More acres covered with growing crops for more months of the year reduce the risk of soil erosion.	**Erosion prone** – Current systems that leave fields fallow for large portions of the year are much more vulnerable to soil loss.
Energy saving – Energy saving reduces or eliminates petroleum-dependent chemical fertilizer and pesticide inputs. Integrated systems reduce the need for artificial inputs with high-energy costs.	**High energy use** – It continues and increases use of petroleum-dependent chemical fertilizer and pesticide inputs that take a great deal of energy to produce and transport.
Spurs independent, entrepreneurial seed production – It increases demand for a broader range of crop seeds with carbon benefits, spurring new growth in regional and entrepreneurial seed companies that are often independent of input producers.	**Generates dependence on monopolistic seed and input companies** – It continues the concentration of seed production focused on high-input varieties that trap farmers into a cycle of dependency with a few large companies producing a small variety of crops.
Opens marketplace – It creates non-traditional opportunities to enter commercial markets, meeting surging demand for local and regional production in the Midwest and the East; Also allows more diverse farmers into the market.	**Discourages new farmers and innovative crop production** – Commodity programs include strong disincentives that discourage commodity crop farmers from diversifying.

Source: LaSalle and Hepperly (2008).

reduced rice blast severity by 94% and increased yield by 89% and reported that disease-susceptible rice varieties planted with resistant varieties had an 89% greater yield than when they were grown in a monoculture. Mixed varieties of rice produced more grain per hectare than their corresponding monocultures in all cases. Moreover, the fungicidal sprays were no longer applied by the end of the two-year programme. The practice expanded to more than 40,000 ha in 2000, and now includes some varieties that were formerly locally extinct (Zhu *et al.*, 2003). This is especially remarkable as the yield gains were in addition to the already high average yields in the region, at nearly 10 tonnes/ha among the highest in the world (Zhu *et al.*, 2000). This shows that greater rice diversity indicates lower rates of plant disease and greater yields while conserving genetic diversity, all at minimal cost for farmers and the environment (Cotter and Tirado, 2008). Nevertheless, in Italy, a high level of genetic diversity within wheat fields on non-irrigated farms reduces risk of crop failure during dry conditions. A scenario where rainfall declines by 20%, the wheat yield would fall sharply, but with diversity, yield is increased by 2% (Di Falco and Chavas, 2006, 2008). Similarly, agronomists in the United States compared corn yields between fields planted as monocultures and those with various levels of intercropping in Michigan over 3 years. They found the yields in fields with the highest diversity (three crops, plus three cover crops) were over 100% higher than in continuous monocultures. Crop diversity improved soil fertility, reducing the need to use chemical inputs while maintaining high yields (Smith *et al.*, 2008).

Genetic diversity within a field provides not only a buffer against losses caused by environmental change, pests and diseases but also the resilience needed for reliable and stable long-term food production (Diaz *et al.*, 2006). In addition to enhancing food security and climate resilience, diversity in the field also delivers important ecosystem services. Variety mixtures that are tolerant to drought and flood not only increase productivity but also prevent soil erosion and desertification, increase soil organic matter and help stabilize slopes (Hajjar *et al*., 2008). Benefits for farmers include reducing the need for costly pesticides, receiving price premiums for valued traditional varieties and improving their dietary diversity and health (Hajjar *et al*., 2008). Many traditional farmers plant diverse crops not only to maximize productivity in a given year but also to decrease the chances of crop failure in a bad year (Altieri, 1990). Species diversity also reduces the probability of outbreaks by 'pest' species by diluting the availability of their hosts. This decreases host-specific diseases, plant-feeding nematodes (Wasilewaska, 1995) and consumption of preferred plant species (Bertness and Leonard, 1997). In soils, microbial diversity decreases fungal diseases owing to competition and interference among microbes (Nitta, 1991).

Resilient of Crop/Varieties/Traits

If farming communities are to adapt successfully to climate change, they need crop varieties with greater tolerance to stresses such as drought and heat. One important adaptation strategy for farmers is to switch from highly vulnerable to less-vulnerable crops (Lobell *et al.*, 2008). Different varieties of crop plants may also occupy different positions along the resource conservation/acquisition continuum. For example in manioc, 'sweet' varieties with non-toxic roots may have higher yields than bitter varieties in rich soils, or if herbivores and pathogens are absent, whereas 'bitter' varieties with toxic roots produce higher yields than sweet varieties in poor soils (McKey and Beckerman, 1993; Wilson, 2008), especially if potential pests are abundant. Ecological strategies show variation even among bitter manioc varieties: 'fraca' varieties characterized by rapid production are adapted to richer alluvial and terra preta soils, whereas 'forte' varieties, slower to produce but more resistant, are adapted to the poorest soils (Fraser and Clement, 2008). There are crop varieties of moth bean (legume) that can mature in 65 days and are ideally suited for semi-arid and arid regions. Duration of the varieties in soybean has been reduced from 120 days to 85 days, pearl millet from 130 to 70 days and so on (Samra, 2009).

Porter *et al.* (2007) predict that if global temperatures do not increase more than 4°C over the next century, arable agricultural production can probably adapt to changes in mean global temperature using breeding, selection and management. Adapting crop varieties to local ecological conditions will reduce risk due to climate change; however, varieties improved for cultivation in one region could be adopted for cultivation elsewhere, where they would face the same abiotic and biotic stresses. Rice varieties that were initially bred for resistance to chilling temperatures in Nepal, for example, were successfully adopted in Bangladesh (Sthapit and Wilson, 1992). South Asia and Southern Africa are two regions that, without sufficient adaptation measures, will likely suffer negative impacts on several crops that are important to large food-insecure human populations (Lobell *et al.*, 2008). In some regions, such as the semi-arid Sahel region of Africa, resource availability to crops varies dramatically among years. In at least two crops of this region, pearl millet (*Pennisetum glaucum* [L.] R. Br.) and sorghum's (*Sorghum bicolor* [L.] Moench) continued gene flow with wild relatives (Mariac *et al.*, 2006; Barnaud *et al.*, 2009) generate variation that may help farmers adapt to such unpredictability. The impact of climate change on the major cereal crops wheat, rice and maize, representing a wide range of agroclimatic zones and management options, results in the benefits of adaptation that vary with crop (wheat vs. rice vs. maize) and with temperature and rainfall changes. The benefits for rice and maize are lesser than those for wheat, with a 10% yield benefit compared with yields when no adaptation is used (Easterling *et al.*, 2007).

In addition to increasing productivity generally, several new varieties and traits offer farmers greater flexibility in adapting to climate change, including traits that confer tolerance to drought and heat, tolerance to salinity (e.g., due to rising sea levels in coastal areas) and early maturation to shorten the growing season and reduce farmers' exposure to risk of extreme weather events. In many places, new traits and varieties for the crops farmers have traditionally cultivated will confer sufficient scope for adaptation. In other places, shifting to a totally different mix of crops will be required to cope with dramatic changes in rainfall or temperature, and cropping systems will fundamentally change as a result. Crops, varieties and traits that are resistant to pests and diseases will improve producers' ability to adapt to climate change. To the extent that these varieties reduce the need for pesticides, they also reduce carbon emissions by decreasing pesticide demand as well as the number of in-field applications.

Management of Resources

Exploiting the full potential of rain-fed agriculture will require investment in water-harvesting technologies, crop breeding and extension services, as well as good access to markets, credit and supplies. Water-harvesting and conservation techniques are particularly promising for the semi-arid tropics of Asia and Africa, where agricultural growth has been less than 1% in recent years. The management of precious resources is described to maintain sustainability at the farm level in the sections that follow.

Land and Water Management

Land management for food production is a fundamental human activity. Of the H≈14 billion ha of ice-free land on earth, H≈10% are used for crop cultivation, whereas an additional 25% of land is used for pasture. Although irrigated land is only 17% of the total arable land, irrigated crops supply a significant portion of total production (H≈40% in the case of cereals) consuming >2,500 billion m^3 water, or 75% of the total freshwater resources consumed annually. Total land and total prime land would remain virtually unchanged at the current levels of 2,600 million and 2,000 million ha, respectively. However, there are more pronounced regional shifts, with a considerable increase in suitable cropland at higher latitudes (developed countries: +160 million ha) and a corresponding decline of potential cropland at lower latitudes (developing countries: –110 million ha) (Rosengrant and Sarah, 2003). Around 1,600 million ha of land are currently cultivated for crops (FAO, 2008a). The FAO estimates that, ignoring impacts on biodiversity and the carbon cycle, about 2,400 million ha of land globally would be at least moderately suitable for wheat, rice and grain maize cultivation, which is around 18% of the total world land area (FAO/IIASA, 2000). Other studies have variously suggested between 50 and 1,600 million ha of land to be suitable for agricultural expansion (Delft, 2008). Future population and economic growth will require a doubling of current food production, including an increase from 2 billion to >4 billion tonnes of grains annually. Considering that current growth trends in crop yields continue into the future, increased supply may, in fact, be achieved without significantly increasing the current arable land. Some land expansion will take place in developing countries, most of it in sub-Saharan Africa and Latin America, whereas crop yields will continue to increase; for instance, cereal yields in developing countries are projected to increase from 2.7 tonne/ha today to 3.8 tonne/ha in 2050 (Tubiello *et al.*, 2007).

Increasing Water and Fertilizer Use Efficiency

In the midst of increasing urban and environmental demands on water, agriculture must improve water use efficiency generally. The IPCC projects that changes in water quantity and quality due to climate change are expected to affect food availability, stability, access and utilization (OECD-FAO, 2009). Where crops are grown near their maximum temperature tolerance and where dry land, non-irrigated agriculture predominates, the challenge of climate change could be overwhelming, especially on the livelihoods of subsistence farmers and pastoral people, who are weakly coupled to markets (Parry, 2007). With hotter temperatures and changing precipitation patterns, controlling water supplies and improving irrigation access and efficiency will become increasingly important. Doll (2002) estimated an increase of net crop irrigation requirements (i.e., net of transpiration losses) of +5% to +8% globally by 2070, with larger regional signals, e.g., +15% in Southeast Asia. Climate changes will burden currently irrigated areas and may even outstrip current irrigation capacity due to general water shortages, but farmers with no access to irrigation are clearly most vulnerable to precipitation volatility. Africa only irrigates 6% (13.6 million ha) of its arable land in contrast to 20% worldwide. In places with limited access to irrigation, well-timed 'deficit irrigation' can make a substantial difference in productivity. With dwindling water supplies, such deficit irrigation techniques will become increasingly important. In non-irrigated areas, water conservation and water-harvesting techniques may be farmers' only alternative to abandoning cultivation agriculture all together. Adopting such practices may not be technology intensive, but will almost certainly require investments in capacity building and agricultural extension (Lybbert and Sumner, 2010).

Nitrogen use efficiency, defined as the amount of crop produced per unit of input, has steadily improved in the United States since the 1980s (Frink *et al.*, 1999); however, it is declining in developing countries. More precise nitrogen applications and genetic improvements in crops are likely to sustain improvements in nitrogen-use efficiency, although there is a limit to how far nitrogen application can be reduced. While several measures are required to reverse the trend and make agriculture an effective instrument of development in the region (FAO, Oct. 2009), improving agriculture productivity and nutritional quality of food in an environmentally sustainable manner through application of appropriate technologies is an important solution (Karihallo and Perera, 2010). Since a substantial proportion of the GHGs produced by agriculture is attributable to the production and application of nitrogen fertilizer alone (Stern, 2007), breakthroughs in nitrogen use efficiency could substantially mitigate emissions in agriculture.

Farm Management

The impact of climate change on the production of various crops varies markedly depending mainly on the region, growing season, the crops and their temperature thresholds. Cereals, oilseed and protein crops depend on temperature and, in many cases, day length, to reach maturity. Temperature increase may reduce the duration of the growing period of the crops and, in the absence of compensatory management responses, reduce yields (Porter and Gawith 1999; Tubiello *et al.*, 2000) and change the area of cultivation by rendering unsuitable some currently cultivated areas and rendering suitable others not currently cultivated (Lane and Jarvis, 2007). Cropping rotations, integrated pest management, soil conservation and fallow techniques are all examples of management practices that contribute to stability of farm production and income (Rosenzweig and Tubiello, 2007). The approach used to mitigate risks associated with seasonal climate variability focuses primarily on techniques such as shifting planting dates, changing crop varieties and cultural practices (Fraisse *et al.*, 2009). Often integrated combinations of technologies/practices serve farmers' needs. For instance, integrated water management through genetic drought resistance and agronomic practices will reduce drought risk (Erenstein, 2010).

Adaptation to weather conditions has always been part of farm management and, to some extent; adaptation to climate change follows the same principles as adaptation to short-term oscillations. Adaptation of agronomic techniques and farm strategies is already happening. In the coming decades, however, the magnitude of climatic changes may exceed the adaptation capacity of many farmers. Existing agroecological conditions and the experience in dealing with changing conditions influence farmers' adaptive capacity. The combination of changes in the agricultural production potential in different world regions and increased incidence of extreme events could lead to greater variability of production, contributing to increased volatility of prices and changes in trade flows. Constant evolution of crop patterns, farm management practices and land use are observed across the European Union, partly in response to climatic variation. Such farm-level adaptations aim at increasing productivity and dealing with existing climatic conditions, and draw on farmers' current knowledge and experience. Over the next decades, adaptation may need to go beyond mere adjustments of current practice **(**CSWD, 2009**)**. The main drivers of agricultural responses to climate change are biophysical effects and socioeconomic factors. Crop production is affected biophysically by meteorological variables, including rising temperatures, changing precipitation regimes and increased atmospheric CO_2 levels. In most cases, the SRES scenarios exerted a slight to moderate (0% to –5%) negative impact on simulated world crop yields, even with beneficial direct effects of CO_2 and farm-level adaptations taken into account (Parry *et al.*, 2004).

Farm Mechanization

Farm mechanization level mainly depends on the size of operational holding, land topography, cropping pattern, credit availability and closeness to market, which in turn control the cropping intensity and productivity of the region. For example, in India, there are large variations in farm power availability varying from 0.6 KW/ha in Orissa to 3.5 KW/ha in Punjab. Application of farm mechanization is useful to manage timely operations related to crop raising and post-harvest operations. A delay of one week in the sowing of wheat has been shown to bring down the yield by as much as 400–500 kg/ha in experiments carried out in Punjab. Similar conclusions have been drawn for other crops as well. It is also known that the farm operations such as weeding, irrigation, harvesting and threshing need to be carried out timely to avoid losses due to shattering, quality and deterioration, resulting in improved income from the sale of produce. In India, improved agricultural tools and equipment are estimated to contribute to food and agricultural production by reducing costs associated with seeds (15–20%), fertilizers (15–20%), time (20–30%) and labour (20–30%) and also by increasing cropping intensity (5–20%) and productivity (10–15%) (Pandey, 2011).

Reduction in Post-Harvest Losses

Post-harvest losses represent one of the single greatest sources of inefficiencies in food production worldwide and therefore one of the best opportunities for effectively improving crop productivity. These losses, which are due to poorly timed or executed harvesting, exposure to rain, humidity and heat, contamination by microorganisms and a host of other sources of damage and deterioration, often receive far less attention than they deserve. Half or more of the total harvest of some crops can be lost post-harvest. Investments in improved harvesting, processing, storage, distribution and logistics technology and necessary training investments can pay off as well as improved crop yields in terms of gains to consumers and the climate. As climates become hotter and precipitation more erratic, the potential for post-harvest losses may increase and thus improved transport and storage become even more important (Lybbert and Sumner, 2010).

Adaptation

"Ecosystems to adapt naturally to climate change" ensure that "food production is not threatened" and enable "economic development to proceed in a sustainable manner" (Smith *et al.*, 2009). Adaptation to future changes may require an attention to stability and resilience of production, rather than to improving its absolute levels. Adaptation is a key factor that will shape the future severity of climate change impacts on food production (Easterling *et al.*, 2007). The development and adoption of better 'temperature-adapted' varieties, together with improved management practices, could result in the almost complete mitigation of the negative impact of temperature increases. Adaptation to climate change is not just about seeds – it is about farming systems. Farmers can adapt to changing climate by shifting planting dates, choosing varieties with different growth durations, changing crop rotations, diversifying crops, using new irrigation systems, and so on. Farmers cultivate early- and late-maturing varieties of the same crops to increase the period of food availability and to spread out the amount of labour required at harvest time (ETC group, 2008). Climate change is likely to make matters worse, with increases in rainfall variability in the semi-arid tropics (SAT) being predicted (Cooper *et al.*, 2009). The SAT are defined as regions where the average LGP is between 75 and 180 days, and the mean monthly temperature of all months, corrected to sea level, is greater than 18°C, with daily mean temperatures during the growing period being greater than 20°C (TAC, 1992). Increasing temperatures enhance the rate of crop development and result in corresponding declines in crop yield in pigeon pea, sorghum, pearl millet, groundnut and maize (Cooper *et al.*, 2009). For wheat, maize and barley, negative yield impacts for the 1980s and 1990–2002 indicate that recent climate trends have, unless addressed through adaptation measures, suppressed global yield progress for these three crops (Lobell and Field, 2007). If each additional ppm of CO_2 results in ~0.1% yield increase for C_3 crops (Long *et al.*, 2006), then the ~35 ppm increase since 1981 corresponds to a roughly 3.5% yield increase, about the same as the 3% decrease in wheat yield due to climate trends over this period. Thus, the effects of CO_2 and climate trends have likely largely cancelled each other over the past two decades, with a small net effect on yields. This conclusion, although tempered by the substantial uncertainty in yield response to CO_2, challenges model assessments that suggest global CO_2 benefits will exceed temperature-related losses up to ~2°C warming (IPCC, 2001).

In the light of the impact that increased temperature has in reducing time (days) to maturity and subsequent lower crop yields, in a warmer world, there will be a need to re-deploy germplasm that would, under current climatic condition, be considered to be too long a maturity type for any given location. For example, in a warmer world, a currently defined ‘medium-duration type’ will become a ‘short-duration type’ (Cooper *et al.*, 2009). Even in temperate regions, farmers will need to adapt to changing temperature and rainfall patterns, and the increased likelihood of extreme events such as floods and droughts. The impact of changing temperatures on the range of pests and diseases is uncertain, but this too cannot be ignored (Diffenbaugh *et al.*, 2008). The likely impact of climatic change on agriculture and possible adaptive strategies as suggested by Abrol (2009) is provided in Table 3.

Adoption of New Strategies, Technologies and Education

System of Rice Intensification (SRI) represents a paradigm shift for the agricultural sector, from an external input-dependent approach, revolving around genetic improvements or modifications, to more of an ecological perspective and strategy. By 2011, the number of countries where SRI methods have been validated has reached 42. SRI has been shown to work in tropical, subtropical and temperate environments and across dry, sub-humid and humid moisture climates. The impacts of SRI management have been reviewed by various studies and a number of advantages have been recorded, e.g. it increases yield (50–100%), water saving (25–50%), cost of production reduced (10–20%), resistance to biotic stresses (pests and diseases), abiotic stresses (drought, storms, heat spells, cold snaps) and higher milling outturn (10–15%). Evidence from SRI experience over the past decade suggests that making certain changes in crop management can greatly enhance the productivity of available land, labour, water, nutrient and capital. It is noteworthy that the principles and practices of SRI are now being adapted to a variety of other field crops such as wheat, sugarcane, millet, maize and even some legumes and vegetables (Uphoff, 2011).

Use of biofertilizers: Natural fixation of nitrogen should be encouraged with the use of microorganisms. Similarly, blue green algae (BGA) and *Azolla* have been found effective in certain rice-growing areas. Biofertilizers are associated with the liberation of growth substances, which promote germination and plant growth. In case of phosphorus, several phosphorus-solubilizing bacteria are known to mobilize the significant quantities of soil phosphates that would otherwise not be available to the plant; however, their effectiveness is

Table 3 Adaptation Strategies to Cope with Climate Change

Likely impact on agriculture	Possible adaptive strategy
Greater vulnerability of production systems through:	
• Direct impact increased temperature	• Promote agro-biodiversity (plant and animal) including agroforestry that can import greater resilience to changing environmental conditions and stresses
• Indirect impacts on water availability resulting from increased incidence of draughts and higher-intensity rains	• Develop and promote adoption of draught-resistant/flood and salinity-resistant crops, and livestock breeds with greater ability to withstand stressed environments
	• Develop, adopt and promote soil, crop and water management practices aimed at efficient use of water available from water resources in a watershed; to enhance use efficiency of nutrients Develop and promote practices for improved livestock nutrition and management to cope with stress

Source: Abrol (2009).

variable and not predictable. However, unlike mineral fertilizer, use of the biofertilizer is crop and location specific due to competition with native soil microbes, poor aeration, increased temperature, soil moisture, acidity, salinity and alkalinity, presence of toxic elements, and so on. It also requires careful handling and storage.

Use of FYM, compost/biocompost, vermicompost/ biofertilizers, biopesticides/biofungicides, and so on: The substitution of fertilizer nitrogen requirement to 50% by FYM has produced yield levels nearly similar to those obtained with complete fertilization. The application of FYM not only increases the nitrogen use efficiency of urea but also increases the fertility status of the soil. FYM and vermicompost are helpful to recoup the soil health. Use of vermicompost can help combat the ill effects of chemical fertilizers to the soil health (Ranwa and Singh, 1999). Vermicomposting reduces the C: N ratio substantially over normal composting. A part of nutrient demand of crops should be made available through FYM, compost, green manure and biofertilizers. For effective nutrient management, the use of biofertilizers, enriched biocompost, multi microbial combination of biofertilizers and biofungicides (microbial consortia of nitrogen fixation, phosphorus solubilizing, biofungicides) and growth enhancers (amino acids, micronutrients, sea-weed extracts, growth promoters, growth hormones, etc.) and agrowaste decomposer and enriched biocompost should be encouraged. Biological control has emerged as an alternative choice to mitigate the side-effects of the chemical intensive approach. This method basically comprises live sources for the management of plant problems. These living entities are diverse, ranging from microorganisms (viruses, bacteria, fungi, bacterial agents, etc.) to plants (neem, turmeric, garlic, etc.), which in one form or the other helps in reducing the population of pests; in addition, botanical extracts and combinations should be encouraged (Mehta, 2009).

Pretty *et al.* (2006), for example, showed how education influences pesticide use. The researchers investigated 61 Integrated Pest Management (IPM) projects in 21 developing countries. In five projects, pesticide use was declined by 93.3% (±6.7%), but yields declined only by 4.2% (±5%); in 47 projects, pesticide use declined by 70.8% (±3.9) and yields increased by 41.6% (±10.5). In 10 projects, mainly zero-tillage and conservation agriculture projects, pesticide use as well as yields increased. In those IPM projects, where pesticide use was considerably reduced, pests, weeds and diseases did not simply disappear, but the management changed from a pesticide-based to a knowledge-based system, making many pesticide applications redundant.

Crop Diversification

Joshi *et al.* (2003) defined that the diversification as an adjustment of farm enterprise patterns to increase farm incomes, or to reduce income vulnerability, and accordingly, diversification here means (i) a larger mix of diverse and complementary activities within agriculture; (ii) a movement of resources from low-value agriculture to high-value agriculture; and (iii) a shift of resources from farm to nonfarm activities. Such changes to traditional forms of agriculture can be pathways out of poverty because they contribute to increasing rural incomes and employment opportunities.

Even if adaptation does not imply an entirely new mix of crops, many producers will benefit from new crops and varieties as they diversify their production portfolios as a means of stabilizing their revenue or local production of basic foods in the face of more volatile conditions. In India, maize is grown round the year for different purposes. Single cross hybrids (SCHs) can offer solution to lowering the water table, rising temperature, vagaries of monsoon, weed menace, and so on. Owing to scarcity of water and delayed monsoon rice seedling becoming overage, farmers have shifted from rice to maize. In West Bengal, farmers are producing maize SCH seed instead of rice during the Rabi season due to shortage of water in February–March. Income of West Bengal farmers increased three times than rice cultivation and also facilitated advancing the sowing of jute in maize standing crop (Dass, 2010). Crop diversification must also include under-utilized species that offer natural tolerance to environmental stresses such as heat, drought, cold, and so on.

However, climate risks are only one aspect influencing farmers' decisions, which involve many other socioeconomic and market considerations. Diversifying farm activities and income sources with fundamental changes in farm structures and, in some cases, additional investments – may become necessary.

Employment Opportunities through High-Value Agri-horticultural Crops

The horticulture sector can contribute to poverty reduction by providing employment and wages to labourers. Diversification of agriculture can affect both the structure and the level of employment. The production of horticultural products offers opportunities for poverty alleviation because it is usually more labour intensive than the production of staple crops. Often, it requires twice as much, sometimes up to four times as much labour than the production of cereal crops. Horticultural production can be made highly profitable, increase employment opportunities and bring about increasing commercialization of the rural sector. The first Millennium Development Goal, to eradicate extreme poverty and hunger in particular, depends on raising the productivity of agriculture (von Braun *et al.*, 2004). Fruit and vegetable production is usually lucrative compared with staple crops. Horticultural produce has high value-add and income generation potential, and due to a relative lack of economics of scale (compared to grain production and livestock), their production is attractive, especially for small farmers. The production of fruit and vegetables has a comparative advantage, particularly under conditions where arable land is scarce, labour abundant and markets accessible. In India, horticultural products account for approximately 10% of the total agri-exports and more than 19% of the labour force (Gajanana and Hegde, 2009).

Greater employment opportunities result in greater incomes for poor households. Labour demands also arise in the post-harvest sector, since sorting, grading, cleaning, packing and transports are all labour-intensive activities (Weinberger and Genova, 2005). In Africa, Asia and Latin America, high-value crop exports are women-oriented industries, with women dominating most aspects of production and processing. The relative profitability of horticultural crops compared to cereals has been shown to be a determining factor for crop diversification into horticultural production in India (Joshi *et al.*, 2003). Vegetable production is most profitable compared to rice production in terms of cropping days, since the growing period of vegetables is usually less than rice. For instance, in Bangladesh, farmers on average sell 96% of their vegetable products but only 19% of their cereal output. The average number of labour days per hectare for production of cereals and vegetables in selected countries is given in Table 4.

Table 4 Average number of labour days per hectare for production of cereals and vegetables in Asia

Country	Cereals	Vegetables
Cambodia	81	437
Laos	101	227
South Vietnam	111	297
North Vietnam	216	468
Philippines	93	185
Bangladesh	133	338
India	80	124

Source: Weinberger and Lumpkin (2007)

In India, the villagers of a peri-urban village diversified from agricultural crops to horticultural crops in a period of 10 years. Altering the cropping pattern, on the one hand, helped the growers to improve their income and diffuse risk and, on the other hand, provided more alternatives of food items to the consumers. Engaging in diversified crop cultivation ensured full-time employment for all the family members in the village. Diversification had stopped the migrational tendencies in addition to ensuring food and nutritional security along with environmental enrichment (Ponnusamy *et al.*, 2005). Small farmers are adopting high-value crop diversification more compared with medium and large farmers. The small farmers are more affected by crop failures and fluctuations of net return. They are also more vulnerable to distress as they do not have enough financial support. The resource-constrained farmers are averse to diversifying, particularly if the high-value crop in question is perishable in nature, risky and whose price is subject to high degree of fluctuations (Sen and Raju, 2006).

Pollination Management

Millennium Ecosystem Assessment (MEA) in 2005 assessed that out of the 24 ecosystem services, 15 are considered to be seriously degraded. Climate change may potentially be one of the most severe threats to pollinator biodiversity (Kerr, 2001). The consequences of pollinator declines are likely to impact the production and costs of vitamin-rich crops such as fruits and vegetables, leading to increasingly unbalanced diets and health problems. To manage farm, such as soil, water and nutrients, pollination is also a limiting factor in crop productivity. The declining agricultural productivity can be attributed to a number of factors but crop failures due to inadequate pollination, caused by several factors, the most important of which include the lack of adequate number of pollinators as a result of decline in pollinator populations and diversity due to several factors such as decline in wilderness and loss of habitat. Approximately 80% of all flowering plant species are specialized for pollination by animals, mostly insects. In canola seed production in northern Canada, fields near uncultivated areas produce greater yields due to greater pollination services from a more diverse and abundant wild bee community. Resilience is built in agro-ecosystems through biodiversity. Different pollinators become most active at different times of the day or under different weather conditions, and even between years the most abundant and effective pollinators of a crop may shift from one pollinator to another (Kremen *et al.*, 2002). The “insurance” provided by a diversity of pollinators ensures that there are effective pollinators not just for current conditions, but for future conditions as well. Morandin and Winston (2006) reported that farmers could maximize profits by retiring up to 30% of the field area from production, to receive higher yields on the remaining 70%. Well-pollinated crops can be of noticeably better quality, and consumers and markets are sensitive to quality considerations: in Canada, good pollination in apple orchards resulted in about one extra seed per apple, which produced larger and more symmetrical apples. These improved apples were estimated to provide marginal returns of about 5-6%, or about Can. $250/ha compared with orchards with insufficient pollination (Kevan, 1997). In Himachal Pradesh and the north-western Indian

Himalayas, where honeybees are being used for apple pollination, some farmers keep their own honeybee colonies while others rent them. The fees for renting bee colonies either *Apis cerana* or *A. mellifera* is Indian rupees 800 (US$ 16) per colony for two weeks. This includes Rs. 500 (US$10) as refundable security deposit and Rs. 300 (US$6) per colony per two weeks of rent. *Apis mellifera* is the main bee species made available to farmers from government institution and private beekeepers for pollination purpose (Partap, 1998).

Estimates of increased seed set due to pollinators have been made in different parts of the world; assured pollination has been variously responsible for increases in seed yield of 22–100% (radish), 100–300% (cabbage), 100–125% (turnip), 91–135% (carrot) and 350–9000% (onion). Furthermore, the yield response was due to animal pollination (bees, birds and bats), which affect 35% of the world's crop production, increasing outputs of 87 of the leading food crops worldwide (FAO, 2009). Bee pollination also improves the yield and quality of other vegetable crops such as asparagus, carrots, onion, turnips and several other crops (Deodikar and Suryanarayana, 1977). In the northeast Himalayan region, honeybee pollination does not only increase fruit set in rapeseed mustard and sunflower but also increases the oil contents in these oilseed crops (Singh *et al.*, 2000).

Reduction in Yield Gap

The average cereal yield varies in the different regions of the world; it was reported to be 5.5 tonne/ha in developed countries, 4.5 tonne/ha in East Asia and Pacific region, 3.3 tonne/ha in Latin America and Caribbean regions, 2.5 tonne/ha in South Asia and just 1.2 tonne/ha in sub-Saharan African region (Lybbert and Sumner, 2010). Given that average global yields of wheat are less than 3 metric tonne/ha and given there are many areas with yields as high as 10 metric tonne/ha, the majority of land cropped to wheat delivers yields below 3 metric tonne/ha. Therefore, by virtue of the much larger areas of low-yielding land globally, low-yielding environments offer the greatest opportunity for substantial increases in global food production. Increasing yield by 1 metric tonne/ha in a low-yielding area produces a much higher relative increase than does the same increase in high-yielding environments. This increase can be achieved by considering major limitations on yield in poor environments (termed "yield stability"); for example, by protecting plants and yield from factors such as salinity and heat or drought periods (Tester and Langridge, 2010). A list of various biophysical and socioeconomic factors responsible for yield losses in farmers' field as summarized by Lobell *et al.* (2009) is given in Table 5.

The many irrigated cropping systems have yields that have plateaued at 80% of yield potential. This implies that yield gains in these regions will be small in the near future, and yields may even decline if yield potential is reduced because of climate change. Many rain-fed cropping systems, in contrast, appear to have relatively large yield gaps that could be closed with existing technologies but persist largely for economic reasons. Increasing average yields above 80% of yield potential appears possible but only with technologies that either substantially reduces the uncertainties farmers face in assessing soil and climatic conditions or dynamically respond to changes in these conditions (e.g., sensor-based nutrient and water management). Although these tools are more often discussed because of their ability to reduce costs and environmental impacts, their role in improving future crop yields may be just as important (Lobell *et al.*, 2009).

Table 5 Common factors that contribute to yield losses in farmers' fields

Biophysical factors	Socioeconomic factors
Nutrient deficiencies and imbalances (nitrogen, phosphorus, potassium, zinc and other essential nutrients)	Profit maximization
Water stress	Risk aversion
Flooding	Inability to secure credit
Suboptimal planting (timing or density)	Limited time devoted to activities
Soil problems (salinity, alkalinity, acidity, iron, aluminium or boron toxicities, compaction, and others)	Lack of knowledge on best practices
Weed pressures	-
Insect damage	-
Diseases (head, stem, foliar, root)	-
Lodging (from wind, rain, snow or hail)[a]	-
Inferior seed quality	

Note: One goal of yield gap analysis is to quantify the percentage of total losses attributable to each factor.

[a] The crop fell over because the stems broke or because it became too top heavy.

Source: Lobell *et al.* (2009)

The impact of temperature increases alone on the yields under current low-input agricultural practice is likely to be relatively small as other factors will continue to provide the overriding constraints to crop growth and yield. Significant reductions in rainfall amounts, however, would modify this conclusion (Cooper *et al.*, 2009).

Strengthening of Weather Forecasting System

As farmers face with changes in climate due to more variability in weather, history becomes a less reliable guide in helping make production decisions. Under these conditions, there is greater payoff to improvements to forecasts of weather events and inter-seasonal weather probabilities. Farmers with prior knowledge of such events can respond by planting more appropriate crops or varieties (say barley rather than maize if a dry year is expected). Such improved forecasts would also affect planting even in regions unaffected by the weather events in response to price expectations and opportunities for trade. Thus, major innovations in response to climate variability will take the form of improved information through global monitoring and forecasting (Hallstrom and Sumner, 2000). These improved interpolations could lead to improved short-term forecasts, which could be disseminated via SMS using rapidly spreading cell-phone networks. Lastly, better and more timely information can also help forecast impending 'slow onset' weather events such as drought more effectively, thereby improving response times and adaptation (Lybbert and Sumner, 2010).

Forecasting climate change is imperfect, complex, important and often controversial. Stemming from these two primary dimensions of climate change (higher averages and more volatility) are melting glaciers and ice caps, rising sea levels and more frequent and more severe extreme weather events. For agriculturally important agroecological zones, higher-level forecasting of daily weather extremes (frosts, the intensity and form of precipitation, extreme temperature, etc.) is crucial but even more demanding (Lybbert and Sumner, 2010). The detrimental effects of climate crisis are not just a matter of geographic vulnerability but also depend on a region's ability to pay for adaptation measures. For poor countries, there is no climate safety net. Even the most basic resources are scarce. Africa currently has one meteorological station for every 25,460 km^2 – one-eighth the minimum level recommended by the World Meteorological Organization. In contrast, the Netherlands has one weather station for every 716 km^2 (ETC, 2008).

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