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Invited paper

Climate change adaptation strategies for agro-ecosystem – a review

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ABSTRACT

Agriculture the major economic and social activity in the globe. It is understood that agriculture is highly sensitive to climatic variability and likely to be affected most to predicted climate change. The fourth assessment report of Intergovernmental Panel on Climate Change (IPCC) has reconfirmed that the phenomenon of existence of climate change in recent decades is due to anthropogenic activities. It is also revealed the availability of wide array of adaptation options for agro-ecosystem to cope up with the impact of climate change. However, it is important to design more extensive adaptation strategies to reduce vulnerability of agriculture and rural poor to impacts of climate change. Climate change impacts and responses are presently observed as autonomous adaptation in the physical and ecological systems as well as in human adjustments to resource availability and risks at different spatial and trophic levels. But these strategies are not enough to reduce the current anthropogenic driven climate change, so there is a need to adopt the planned adaptation. This paper reviews the findings based on the series of studies carried across the globe on the potential adaptation strategies to alleviate the impact of climate change by improving the resilience of the agro-ecosystems. Adaptation strategies have to be in place to reduce vulnerability to climate change through developing consensus between industrialized countries and developing countries at global scale, whereas new public policies in place at national regional and local level is prudent to support adaptation research, insurances, incentives to farmers to adapt new technologies.

Key words: Climate change, impact, adaptation, Agro-ecosystem, livestock

Climate is usually defined as the average weather or more rigorously as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The climate change refers to a statistically significant variation in either the mean stage of the climate or in its variability, persisting for an extended period. Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC, 1995). Constant increase in greenhouse gases concentrations, since pre-industrial times, has led to positive radiative forcing of the climate, tending to warm the surface. The fourth assessment report of IPCC confirmed the rise in atmospheric temperature by 0.74^0C over the last 100 years due to global warming and projected a temperature increase of 1.8 to 4^0C by 2100. Global warming induces events such as frequent occurrence of warmest year, heavy intensity rainfall, flash flood, frost (Table 1), posing potential threat to ecosystems especially, agricultural production and productivity throughout the world (Cooper *et al.*,2009). Agricultural production is the most sensitive and vulnerable to climate change, as climate is the primary determinant of agricultural productivity (Watson *et al.* 1996). Crop productivity is projected to decrease for the increase of local temperature (1-2^0C) at lower latitudes, especially in seasonal dry and tropical regions of the world (IPCC, 2007). The rising atmospheric temperature and carbon dioxide along with rainfall uncertainties may influence future food security in developing countries due to its large population and limited resource. Climate change accompanied with an annual increase in climatic variability further jeopardizes the agricultural sector to face definite hardships and risks. Higher temperatures in tropics are likely to influence crop yields negatively while increasing the demand for already limited water supplies in many countries. Similarly, major epidemics of pests and diseases in agriculture are often correlated with the change in the weather factors. A shift in occurrence of pests or diseases complex, their distribution and relative severity with a shift in climatic change; a hitherto minor pest may take an epidemic form and poses a severe threat to the crop production.

On the other hand, non climatic stresses such as population, poverty, unequal access to resources etc., increase climate change vulnerability by reducing the adaptive capacity of the system. Considering the afore said facts, there is a need to exploring suitable adaptation strategies which make ecosystem more resilient to absorb larger shocks due to climate change. The adaptation strategies should be in place without sacrificing ecosystem services. Hence, adaptation strategies have to be designed to accommodate both climatic and non climatic stresses to sustain the resource base and agricultural productivity. In this review, an attempt has been made to highlight the already available technology in the world, which can be used as climate change adaptation strategies to make the agro-ecosystem more resilient and sustaining the agricultural and livestock production.

AGRICULTURE AND ADAPTATION TO CLIMATE CHANGE

An adaptation strategy is a set of actions that lead to a specific response to reduce the vulnerability of change, which includes information or resources required to enact the action as well as expected outcome. Adaptation to climate change can be defined as the range of actions taken in response to changes in local and regional climatic conditions (Smit *et al.*, 2000), which comprises of autonomous adaptation, i.e., actions taken by individual entity such as single farmer or local institutions and planned adaptation, i.e., climate-specific infrastructure development, regulations and incentives in place through regional, national and international policies. In the context of climate change, effective adaptation strategies are one that reduce the present climate change vulnerability as well as the impacts of climate change in future

Agriculture is the major land use enterprise across the globe. Currently 1.2–1.5 billion hectares are under arable farming, 3.5 billion hectares under grazing lands for livestock and 4 billion hectares of land under forest (Easterling *et al*. 2007). Agriculture is the major economic, social, and cultural activity, and agricultural production will have to continue its momentum to meet per capita food demand of projected growth in human population and in fact, have to doubling the current production (Tubiello *et al*. 2007). Agriculture remains highly sensitive to climatic variability, the dominant source of overall inter-annual variability where even small changes in drought frequency results in shortage in food production and causing permanent damage to the society. For example, the El Niño Southern Oscillation (ENSO) phenomenon and its associated cycles of droughts and flooding events in tropical regions during recent decades contributed 15 to 35% variation in global wheat, oilseeds and coarse grains production. Podesta *et al*., (1999) estimated higher anomalies for maize and sorghum yields during El Niño events and similarly, soybean yields were lower, while sunflower yields were higher during La Niña event. This situation explains the sensitivity of agricultural production to changing climate. Hence, it has become critical to identify and evaluate options for adapting to climate change (Howden *et al*. 2007).

Generally, agriculture is well adapted to mean or average environmental conditions, but it is highly susceptible to irregular and extreme events such as frequent droughts and floods or deviations from 'normal' growing season conditions (Reilly 1995; Smit *et al*. 1996; Risbey *et al*. 1999). Of course, long-term changes in mean conditions will have definite implications in agriculture. Hence, adaptation strategies aiming for climate change should also be considered in the context of annual climatic variability and extremes occurrence (Chiotti and Johnston 1995; Smithers and Smit 1997; IPCC 2001). Looking at the findings of adaptation studies in agriculture, the degree of benefits for adaptation are greater with moderate warming (<2°C) than with greater warming; and scenarios under increased rainfall than those with decreased rainfall (Howden *et al.*, 2007). The impacts of climate change on agriculture will hinge on seasonal and annual climatic variability. Reasonable adaptation strategies have to be evolved to cope with the climate change at the level of individual farmer or farm, community, village and watershed or at regional level.

Short term climate change adaptation strategies for agriculture

Short-term adaptation strategies are the efforts to optimize production without major system changes against the impact of climate change which are autonomous in nature. The short-term adjustment is considered as the first defence tool against climate change. Historically, farmers diversify the system including mixed cropping and livestock based agriculture besides changing crop varieties and adjusting planting time to adapt climatic stresses. Short-term adaptation strategies are mainly for implementing at micro level to address the local phenomenon, which includes simple decision making process in agriculture referring as no-cost technology and the use of low-cost inputs. Various soil, water and crop management strategies are discussed under short-term measures.

Land and water management strategies

Soil water conservation practices *per se* are considered as adaptation strategy to reduce the negative impacts of climate variability (Wani *et al.*, 2002; Rockstrom *et al.*, 2007, 2010) and climate change (Easterling 1996) aiming at improving *in-situ* soil water conservation. Soil water conservation is critical in regions where there is alteration in rainfall pattern, its distribution and intensity due to climate change. Conservation tillage is one of the land treatments recommended as adaptation strategy, which allows the previous season's crop residues on the soil surface with minimal disturbance of soil, thus retaining soil moisture by improving soil infiltration rate and reducing evaporation.

Watershed development activities are appropriate measures for enhancing local water availability for agriculture (Wani *et al.*, 2003). The most common *in-situ* interventions are contour and graded bunds and Broad bed and furrow (BBF), which reduce travel distance and minimize the velocity of generated runoff and allow more water to percolate into the fields. This practice created an opportunity to accumulate surface runoff along the contour line, and also protect soils from erosion. Locally constructed check dams and gully control structures on the streams (*ex-situ* practices) reduce peak discharge and harvest substantial amount of runoff, which increases groundwater recharge (Pathak *et al.* 2009). At the same time, these dams/gully control structures trap sediments which protect the river ecosystems further down-stream (Garg et al., communicated). Due to the non-linear relationship between evapotranspiration and yield in low yielding systems i.e. 2 t ha^{-1} for tropical grains (Rockström, 2003), a yield increase of moving from 1 t ha^{-1} to 2 t ha^{-1} does not necessarily have to entail a large upstream water appropriation, as the yield increase may be achieved by so-called vapour shift (from un-productive evaporation loss, to biomass productive transpiration). Available green water in soil profile or supplying supplemental irrigation from harvested runoff at storage structures (by watershed activities) can reduce crop failure especially at critical stages and also may increase crop production (Wani *et al.*, 2008).

Taha Ahmad and Nezar Husein (2007) demonstrated the results in terms of soil moisture content, number of seedlings m^{-2}, straw and grain yield of barley in conservation tillage systems compared to conventional and no tillage methods at Ramtha (Jordan). Moisture conservation practices (ridges and furrow + mulch) increased cluster bean yield (3.0 t/ha) significantly compared to flat bed method (2.4 t ha^{-1}) of cultivation as well as the moisture content at 10 days after rain in ridges and follows + mulch (24.2 and 25.1 per cent) as compared to flat bed method (21.4 and 22.1 per cent) at 0-15 and 16-30 cm soil depth respectively in arid regions of peninsular India receiving 450-600 mm of rainfall (Alloli *et al*.2008). Hulihalli and Patil (2006) found that compartmental bunding, tied ridges and furrows, broad bed and furrow produced significantly higher seed cotton yield compared to flat bed configuration. Similarly long term experiments in Vertisols showed that Broad Bed and Furrow (BBF) based system utilized 71% of the rainfall compared to flat bed (38%) based traditional system with average productivity of 5.3 t ha^{-1} with improved system as compare to 1.1 t ha^{-1} with farmers' management practices (Wani *et al* 2008).

Pathak *et al.*, 2006, 2007, 2009 have reported benefits of in-situ soil and water conservation measures on increased crop yields, reduced runoff, reduced soil loss and groundwater recharge enabling the farmers to overcome the adverse impact of drought. Broad bed and furrow is prudent in areas prone to waterlogging, as furrows (0.4-0.6% slope) in the system drains the excess water safely by reducing velocity. Kidane Georgis *et al*, (2001) concluded that there is significant increase of maize yield (an average of 22%) due to the tie ridge, which is effective in retaining rainwater at Zeway and Welechity of Ethiopia. Rice sowing was advanced three to four weeks than the transplanting technique with minimum tillage and direct seeding techniques (Kartaatmadja, *et al*., 2004). This strategy is highly efficient where there is a delay in the onset of monsoon, which further reduces the time and energy spent on nursery raising and main field preparation. Similarly Chuc et al., 2006 analyzed yield gap for major rainfed crops of Northern Vietnam and found vast potential of the rainfed areas which could be harnessed through large scale adoption of integrated genetic and natural resource management technologies. The main constraints for low yields of rainfed crops in northern Vietnam are undulating topography, poor soil fertility, drought and less adoption of improved soil, water, nutrient, crop and pest management practices leading to inefficient use of natural resources such as rainfall (Wani *et al.*, 2003). It is anticipated that climate change will reduce the length of growing period across the arid and semi-arid tropics and their geographical distribution, but this could in large part be mitigated by improved water management innovations and re-targeting / re-development of existing germplasm (Cooper *et al*., 2009).

The field techniques such as laser-levelling, chiselling compacted soils, stubble mulching, etc. may be used as strategy to improve water use efficiency in water scarce situations. Generally, a significant amount (10-25%) of irrigation water is lost during application at the farm due to poor management and uneven fields (Kahlown *et al.* 2000). Laser leveling of agricultural land is a recent resource-conservation technology, which involves altering the fields to create a constant slope of 0 to 0.2%, facilitating uniform water application and reduce deep percolation losses of water. Jat *et al.*, (2003) reported that the total water use in wheat and rice in laser leveled field was reduced to 49.5% and 31.7% respectively, compared to unleveled fields. The total water use of wheat crop was 3525 m^3 ha^{-1} in laser leveled fields while it was 5270 m^3 ha^{-1} in traditionally leveled fields. Similarly, total water use was 6950 m^3 ha^{-1} under precision land leveling in rice compared to 9150 m^3 ha^{-1} in traditional land leveling, resulting increased in water productivity of rice from 0.82 to 1.31 kg grain m^{-3} of water (Jat *et al.* 2005)

Zero tillage implies seeding a crop mechanically in undisturbed soil-covered plant residues, highly relevant in the regions for taking up post rainy season crop with residual moisture or supplemental irrigation. Rice-wheat is the predominant system in Indo-Gangetic plains (IGP), where sowing of wheat at appropriate time is important to utilize early residual moisture for seed germination and also avoid terminal drought due to rise in temperature. The reduced turn-around time was reported due to zero tillage, allowed advancement of wheat planting by 7–10 days in Haryana and by 8–25 days in Bihar (Gautam *et al.* 2002 and Nagarajan *et al*. 2002). Various *insitu* soil moisture conservation measures under rainfed system enhance moisture availability *per se* thus providing opportunity for the crops to utilize rainfall efficiently. These technologies could be an adaptation strategy in regions, where the quantity of rainfall and its distribution is likely to be altered due to climate change. Similarly, zero tillage is practical strategy in sequential cropping systems, where the length of growing period is likely to be reduced due to climate change. Levelling the field will definitely improve the irrigation use efficiency in water scarce environment. However, for small farm holders number of technical, social and institutional aspects need to be covered in depth.

Crop management practices

Crop management practices are one of the simple and affordable strategies to reduce the impact of climate change in agricultural production. One of the likely impacts of climate change is the high atmospheric temperature, for which post anthesis in annual crops is highly sensitive during their growth. The crop management practices include shift in date of sowing/planting (early or late), supplemental irrigation, and nutrient management and crop diversification to reduce the impacts of climate change.

Shift in sowing / planting date: Tubiello *et al*. (2002) carried out simulation studies under CCGS (Canadian Center Climate Model) scenarios for climate change adaptation for Fargo, ND, and Glasgow, MT and revealed that early planting of winter wheat and irrigated maize by 2 to 3 weeks predicted similar yields as current levels of production thus avoiding ill effects of high temperature during post anthesis period. Similarly, studies on dryland maize under early planting showed higher yields and decreased inter annual variability in yield levels. Early planting of potato by one month in Boise, ID also helped to reduce yield losses by 50% under climate change scenario compared to simulations without adaptation strategy. There are situation obtaining more crop yields under climate change scenarios than the current production levels for early planting. Donatelli *et al*., (2002) simulated sugar beet yields under climate change in north and central Italy with early sowing of 15 and 30 days, resulting 10% higher yields compared to current production in 2040 and 2090. Early sowing of sugar beet reduces water stress by providing drought avoidance in both 2040 and 2090. At the same time, a lessening of drought stress as a limiting factor to crop growth lead to improved crop response to CO_2 levels. The studies further simulated 24% higher yield than baseline production in sugar beet with additional irrigation. In Egypt, Abou Hadid *et al*, (2003) validated climate change scenarios of increasing temperature by + 1.5° C and + 3.6° C from current levels in wheat and revealed that delayed sowing of wheat by a month (December, 20) along with four irrigations reduced yield vulnerability by 3.8 % and 3.6 %, respectively. The modeling studies under the ECHAM4 (Max-Planck Institute for Meteorology) scenario revealed early sowing of soybean by a month as optimum sowing date at 2080s in Austria, than current sowing window. It is observed that the duration especially the grain-filling period of early sown soybean genotypes in 2080s are increased and coinciding with a period of ample water availability (Alexandrov *et al*, 2002). Parry *et al.,* (2005) analyzed the effects of adaptation strategies such as shifts in plating date, additional irrigation and change in crop variety alters cereal production under UKMO (United Kingdom Meteorological Office) scenarios. These adaptation strategies largely offset the negative climate change induced effects in developed countries, where cereal production increases by 4-14% over the reference case. However, developing countries benefit little from the adaptation (-9 to-12%) and average global cereal production is altered by 0 to 5% from the reference case. Similarly, climate warming in Western Australia allows earlier sowing of spring crops, which in turn matured earlier before reaching extreme temperatures in summer. Earlier planting in spring also increases the length of the growing season; thus allowing longer duration genotypes under earlier planting increases yield potential. However, on other hand, early planting with short-season cultivars in spring gives the best assurance of avoiding heat and water stresses (van Ittersum *et al*. 2003).

Irrigation and nutrient management: Increase in atmospheric CO_2 concentration due to climate change would benefit C_3 plants rather than C_4 plants. Crops (C_3) grown under elevated CO_2 levels showed greater photosynthetic rate and leaf area resulting in higher plant biomass than those grown under ambient CO_2 levels due to reduced oxygenase activity of Rubisco enzyme (Pal *et al.*, 2005) and higher number of stomata in the leaves (Chowdhury *et al.* 2005). The growth response of plants under elevated CO_2 is directly influenced by water and nutrient availability in the soil (Stitt and Krapp, 1999, Cambell and Sage, 2002). It is also projected that vigorous growth of crops under elevated CO_2 level demands more nitrogen, however Uprety and Mahalaxmi (2000) reported reduction of nitrogen content in Brassica. Low percentage of nitrogen is due to the dilution effect of higher nitrogen use efficiency under elevated CO_2

Table 1: Principal conclusions of the IPCC fourth assessment report (IPPC, 2007)

Climate change impact and direction of trend	Probability of trend [a]		Agriculture, Forestry and Ecosystem
	Recent decades	Future	
Warmer and fever cold days and nights Warmer and more frequent hot days and nights over most land areas	Very likely	Virtually certain	Increased yield in cold environments; decreased yield in warm environments; increased insect outbreaks
Frequency of warm spells/heat waves increases over most land areas	Likely	Very likely	Reduce yield in warmer region due to heat stress and increased risk of wild fires
Frequency of heavy precipitation events increases over most land areas	Likely	Very likely	Damage to crops; soil erosion, inability to cultivate land due to water logging soil
Areas affected by drought increases in many regions	Likely	Likely	Land degradation; lower yields/crop damage and failure; increased livestock death
Intense tropical cyclone activity increases in some regions	Likely	Likely	Damage to crops; windthrow (uprooting) of trees; damage to coral reefs
Increased events of sea level rise (excluding tsunamis)[b]	Likely	Likely [c]	Salinization of irrigation water, estuaries, fresh water ecosystems

concentration (high biomass per unit of nitrogen). They were also observed the higher photosynthetic rate in mustard for the addition of more nitrogen under elevated CO_2, thus producing additional carbohydrates utilized for the development of sinks.

Agustin Giménez (2006) reported that adaptive measures including optimal planting dates and increased nitrogen rates under elevated CO_2 concentration, would result in higher maize yields by 14%, 23% and 31% for 2020, 2050 and 2080 respectively under SRES (Special Report on Emission Scenarios)A_2 and 11%, 15% and 21% under SRES B_2 respectively, over the same period. The corresponding soybean yields were: 35%, 52% and 63% for 2020, 2050 and 2080 under SRES A_2 and 24%, 38% and 47% under SRES B_2 respectively . However, the supplementary irrigation strongly reverted the situation increasing soybean yields between 30% (A_2 2080) and 43% (A_2 2020).

Climate change enhances the nitrogen losses through leaching (higher rainfall) or gaseous losses (rise in temperature) in the field and however, it is projected to enhance nitrogen use efficiency under elevated levels of CO_2. The vigorous growth of crops under elevated CO_2 level demands more nitrogen application than the present level of use in agriculture. Nutrient management will need to be adapted not only to suit the modified growth and yield of crops, but also changes in the turn-over of nutrients in soils including gains and losses. It may thus be necessary to look soil nitrogen mineralization rates and the decomposition of organic manures while designing fertilizer program, as these processes are likely to be altered due to climate change. There is a range of nutrient management options to improve nutrient use efficiency especially nitrogen, through the use of crop nitrogen assessment tools such as leaf color chart, chlorophyll meters, canopy reflectance through remote sensing and adjusting timing and rate of nitrogen fertilizer accordingly. Characterization of soil fertility in different states of India (Andhra Pradesh, Madhya Prades, Karnataka, Rajasthan, Gujarat, Haryana and Tamil Nadu) shows deficiency of several secondary and micro-nutrients like S, Zn, and B, apart from nitrogen and Phosphorus (Rao *et al.*, 2009) in a larger percentage of farmers' field. The extent of macro and micro nutrients deficiency was found as high as 100% suggesting an urgent need for applying soil test based-balance nutrients diet. Various integrated nutrient management options such as organic manure such as Gliricidia, vermicompost, FYM, along with micro-nutrients and chemical fertilizer together with soil and water conservation measures certainly can help in increasing crop productivity and income under current and future climatic situations (Rao *et al.*, 2009).

Table 2 : Selected case studies on climate change adaptation strategies in agro-eco system

Region	Crop	Analysis tool	Adaptation method	Scenario	Climate change impact	Response of target system to adaptation	Reference
World	Cereals	IBSANAT (UKMO)	Shift in planting date, additional irrigation and change in crop varieties	2060	-12% change in yield in developing countries and -2 to +10% Change yield in developed countries than baseline (3286 mt in 2060)	-6 to-4 % change in yield in developing countries and +2 to +12% Change in yield in developed countries than baseline (3286 mt)	Parry *et al*., 2005
Fargo, ND and Glasgow, MT	Winter wheat	DSSAT (CCGS & HCGS)	2-3 weeks of early planting	2090	-18 to -39 % change in wheat yield from the current levels (4.5 – 5.5 t/ha)	Getting similar winter wheat yield as obtained at current levels	Tubiello *et al*., 2002
North-eastern Austria	Winter wheat	DSSAT (GISS & GFDL)	New cultivar, shorter period than Perlo	2020, 2050 & 2080	2 to 8% reduction in yield from the baseline (5.5 to 7.7 t/ha)	4-10 % increase in yield from the baseline	Alexandrov *et al*., 2002
Egypt	Wheat	Regression model	Delayed sowing by one month	Increasing temp. by 1.5 ^{0}C & 3.6 ^{0}C	14.95% and 35.87% reduction in yield from current (5.9 to 6.1 t/ha)	Reducing the impact by 3.8%& 3.6% respectively	Abou Hadid *et al*., 2003
Argentina,Brazil and Uruguay	Maize	DSSAT (HadCM3)	Supplement irrigation	2020& 2080	Yield decreased by 12% from the current	Yield increased by 43&30% (SRES A2),	Agustin Gimenez, 2006
Argentina Brazil and Uruguay	Maize	DSSAT (CERES HadCM3)	Optimum planting date & more Nitrogen	2020, 2050 & 2080	Reduction of yield by 4.3, 11.4 &17.6 % (SRES A2) and 3.4, 8.7 &12% (SRES B2)	Yield increasing by 3.4, 4.6 & 8.5% (SRES A2), 3, 3.5 & 5.2% (SRES B2) from the impact	Agustin Gimenez, 2006
Austria	Soybean	CERES & CROPGRO (ECHAM4)	Early sowing by one month	2080	8 to 10% reduction in yield from the baseline (4100 kg/ha)	10-12% increase in yield from the base line	Alexandrov *et al*., 2002
Argentina Brazil and Uruguay	Soybean (Irrigated)	DSSAT (HadCM3)	Optimizing planting & more Nitrogen	2020, 2050 & 2080	Yield change by -0.3, -0.5&-14.6% & +0.6, -1 &-1.6% (SRES A2 & SRESB2 Respectively)	Yield increasing by 17.7, 31.7 &35.6%(SRES A2), 17.3, 25.2 &31.2% (SRES B2)	Agustin Gimenez, 2006
North-eastern Austria	Soybean	DSSAT (GISS & GFDL)	Cultivar, slightly longer than Apache	2020, 2050 & 2080	8 to 10% reduction in yield from the baseline (4100 kg/ha)	Increasing the soybean by 5% in a warmer climate	Alexandrov *et al*., 2002
Boise, ID	Potato	DSSAT (CGM, CCGS & HCGS)	1 month early planting than current planting date	2090	30 to 40% reduction in potato yield from baseline production (40-50t/ha)	50% yield loss recovery from Climate change impact	Tubiello *et al*., 2002
Northern and Central Italy	Sugar- beet	CGM	15 & 30 days of early sowing	2040 & 2090	+2 to +5 % & -5 to15% change in yield at 2040 &2090 from the baseline(7-10.8 t/ha)	10 % increasing yield than base line consistently.	Donatelli *et al*., 2002
Northern and Central Italy	Sugar- beet	CGM	Additional irrigation	2040 & 2090	+2 to +5 % & -5 to15% change in yield at 2040 &2090 from the baseline(7-10.8 t/ha)	Approximately +13 to +24% increasing yield than base line	Donatelli *et al*., 2002
Great Plains, USA	Livestock Swine,	GCM CGCMI & UKMO	Installation of sheds or sprinkler in feedlots or evaporative cooling of barns	2020, 2050 & 2080	9.1 to 24.3% reduction in slaughter weight	reducing the effect of temperature rise	Frank *et al*, 2001

Soil organic matter is the key element for the resilience of the soil against the direct effects of the climate change, excess of water (higher intensity rainfall) and lack of water (extended drought periods). Soil organic matter improves and stabilizes the soil structure so that the soils can absorb higher amounts of water without causing surface run off, which could cause soil erosion and flooding in further downstream. Soil organic matter also improves the water holding capacity of the soil for during extended drought. Hence, introducing suitable production systems and land management practices such as: zero or reduced tillage systems that avoid or reduce soil disturbance; use of legume crops; planting of hedgerows (*Sesbania spp, Glyricidia sepium, Calliandra calothrysus*); afforestation of farmland, aiming to improve soil organic matter may be the prime strategy to reduce the impacts of climate change in agriculture. For example, long term experiments in ICRISAT watershed show that by adapting appropriate cropping sequence and watershed practices increased soil organic carbon about 7.3 t C ha^{-1} over the 24-year period rater than getting declining trend as of ordinary farmers' practices. Overall, the improved system shows increased rainwater use efficiency (65% versus 40%), reduced runoff from 220 mm to 91 mm and soil loss from 6.64 t ha^{-1} to 1.5 t ha^{-1} along with increased crop productivity (Wani *et al.*, 2007). It is found that sorghum/ pigeonpea intercropping system sequestered 34% more organic carbon than sole sorghum system (Wani *et al.*, 2003).

Diversification of rainfed systems with high-value legumes such as groundnut, soybean, pigeonpea, greengram, not only improves systems' sustainability in the fragile rainfed ecosystems but also contributes significantly in protecting the environment. Rehabilitation of degraded lands with *Pongamia Pinnata* and income from the sale of carbon units and oil can benefit the poor. These good case studies in the SAT areas demonstrate – irrefutably – that developing C markets and biofuel initiatives can be harnessed to benefit the poor and reduce poverty, while maintaining environmental quality (Wani *et al.*, 2007; Bhattacharyya *et al.*, 2009; Rao *et al.*, 2009). IPCC in its latest assessment reported that soil carbon sequestration in farmland and wasteland holds the greatest potential for mitigation of global green house gas emissions. But with changing current climate pattern and rising temperature, there are high chances to have more soil degradation and carbon depletion in Indian conditions until appropriate management programs like waste land reclamation, watershed development and natural resources rehabilitation program run effectively from local to regional and national scale.

Pests management: Global warming in general alters the incidence of weeds, insect pests and diseases in plants and animals. A variety of field, microcosm and laboratory studies concluded that insect population increases with rising temperatures. Hence, the temperature is the major factor that directly affects insect development, reproduction and survival. Although the behavior of individual insect may vary to global climatic change (rise in temperature), the impact of global warming on plant – insect interaction has been predicted to increase the intensity of herbivore pressure on plants (Cannon, 1998 and Bale *et al*., 2002). Boomiraj (2008) revealed that the temperature increased from 17 to 21°C during the month of February, resulting in increased aphid population, which is serious pest in Indian mustard (*Brasssica juncea*). Normally, temperature prevailing during the last week of January to third week of February, determines the build up aphid population Indian mustard. Further temperature increase due to climate change during this period, might favor the population build up and more over, if the flowering stage of Indian mustard coincides with period of increased temperature, then crop will be more susceptible to aphids. Early sowing of crop during October 1st week (15 days early than normal sown crop) is considered as one of the option to avoid aphid infestation during flowering stage. One of the other consequences of growing number of pests and diseases could lead to higher and even unsafe levels of pesticides resulting in residue and veterinary drugs in local food supplies. Integrated Pest Management (IPM) systems (deals with complex interactions between crops, pests, beneficial insects and indigenous knowledge in pest control) may play important role in climate change as adaptation strategy, as it considers the economic threshold of pests and environmental factors in the pest management program (Bindi and Howden, 2004).

Changes in rainfall, temperature and relative humidity readily contaminate foods like groundnuts, wheat, maize, rice and coffee with fungi, which produce potentially fatal aflatoxin due to *Aspergillus sp*. There is need to strengthen national plant and animal health services as a top priority by focusing on modeling, population ecology and epidemiology to reduce the climate change impact.

Crops or cultivar substitution

Diversification of crop allows farmers to contend with annual climatic variability to reduce the risk in crop production. Change from monoculture, which is highly vulnerable to climate change and pest and diseases, to more diversified agricultural production systems helps to alleviate the impact of climate change. Use of high productive and disease and pest tolerant hybrids or cultivars is one of the options to cope with changing climate.

Introduction of suitable crops in the system replacing traditional crops is likely an adaptive strategy to match the changing scenarios. Crops with high inter-annual variability in production may be substituted with crops having higher or lower productivity but more stable yields. Heat tolerant crops perform well in dry weather conditions even if they have similar water requirements, for example, sorghum is more tolerant than maize under dry weather conditions (Bindi and Howden, 2004). Results of on-farm trials indicate that substitution of winter wheat with winter maize or boro rice were found suitable for adapting climate change in the eastern Gangetic Plains of India, Nepal and Bangladesh. The productivity of winter wheat is estimated on average of 2.5 to 3.5 t ha^{-1}, whereas yield of winter maize is above 6.5 t ha^{-1} in eastern Gangetic plains (Gupta *et al.* 2002). Lorenzoni *et al*. (2001) found that partial substitution of heat and drought tolerant crops such as maize, sunflower, linseed etc. are the best option instead of root crops to reduce the climate change impact in eastern England during 2050's due to the availability of less water and rise in temperature.

Similarly, Alexandrov *et al*, (2002) concluded that winter wheat cultivars with a shorter vegetative period than the Perlo cultivar; soybean cultivar with slightly longer duration than current cultivar Apache would be beneficial for wheat and soybean productivity in north-eastern Austria under expected climate change. Tubiello *et al.* (2002) reported that in the Great Plains, changing new winter wheat cultivar requiring less vernalization and longer grain filling periods would be the better adaptation method to reduce the climate change impact scenarios projected by CCGS (Canadian Centre Climate Model scenario)model. International Crop Research Institute for the Semi Arid Tropics (ICRISAT) identified crop cultivars that are adapted to heat and high soil temperatures based on the photoperiod-sensitive flowering, genetic variation for transpiration efficiency, short duration varieties that escape terminal drought, and high yielding disease resistant varieties, for e.g. in chick pea ICCV96029 (super early 75-80 days), ICCV2 (extra early 85-90 days) and KAK 2 (early 90-95 days) in post rainy season in peninsular India (ICRISAT, 2008). As well as short-duration groundnut variety ICGV 91114 have good levels of drought tolerance, and are already replacing more susceptible older varieties.

Legumes are likely to be an important candidate in the coping strategies against the climate change because of its multiple environment friendly services. Legumes has hallmark trait of fixing atmospheric nitrogen in their root nodules in symbiotic relation with rhizobia bacteria referred as "Biological Nitrogen Fixation" (BNF) resulted in resource conservation by saving the investment in nitrogen inorganic fertilizers. In other words, legumes requires minimum fossil energy for production because of its less requirement of nitrogen fertilizer, where it is reported that green pea requires 25 – 50% less energy compared to non legumes due to BNF (Bumb and Baanante, 1996). It is evident from the study which revealed that the cultivation of a legume saves approximately 0.2 t of fuel ha^{-1} corresponding to the production of 600 kg of CO_2 ha^{-1}.

Generally, legumes are short in duration with less water requirement, makes them to fit into either as intercrop or sequential crop in the system. Legumes also have great promise in improving soil fertility in the cropping system. A comprehensive study on rice + wheat sequential cropping showed that significant improvement in organic carbon and total nitrogen was observed in the soil after 5 years of cropping when one of the cereal component in the system was replaced with legume (Singh *et al.,* 1996). So we can utilize these already existing methods against climate change, which are site specific and there is need to identify the potential adaptation methods location wise by employing crop simulation models.

Long-term climate change adaptation strategies for agriculture

The major structural changes such as changes in land use pattern, development of drought and heat resistant varieties, infrastructure enhancement for improving irrigation use efficiency and farming system change are brought under long-term adaptations strategies for reducing the impact of climate change.

Change in land use

The change in allocation of cultivable land for different crops under different season may reduce the adversity of climate. Studies reported by Parry *et al.* (1988) for Central Europe showed an "optimal land use" under climate change scenarios which increased the area cultivated with winter wheat, maize and vegetables, while the allocation for spring wheat, barley and potato will be decreased. Such land use pattern may be used to stabilize production against climate change. Market forces are also likely to significantly influence such changes. Watershed Management Programme implemented in rainfed areas of India benefited directly by bringing more area under irrigation, high value crops and rehabilitation of degraded lands, which in turn resulted multiplier benefits, such as enhanced production and its sustainability, resource conservation, ground water recharge, drought proofing, employment generation and social equity (Dhyani *et al*. 1997; Joshi *et al.*, 2005, 2008; and Wani *et al*., 2002, 2008, 2009).

Lorenzoni *et al*. (2001) carried out climate change simulation study to find the suitable land use in NALMI (Norfolk Arable Land Management Initiative) using UKCIP 98 (United Kingdom Climate Impact Programme) and HadCM2 (Hadley climate model) scenarios and concluded that cover crops should be maintained on the field during the winter months to arrest soil erosion due to possible heavier and higher (13%) rainfall. The paper further elaborated that the severity of soil erosion increases as the possible climate change impact, if current land use under pastures replaced with scenario of other heat tolerant crops like maize, linseed and sunflower. Hence, shift or disturbance of current land use pattern in future as an adaptation strategy is critical in regions where it is projected for more and intensive rainfall due to climate change

Heat and drought tolerant crop varieties

Introduction of heat and drought tolerant crop varieties through crop improvement using conventional breeding and biotechnology techniques are prudent to adapt and improve production in changing climate (Sushil Kumar, 2006). Genetic resources in germ-plasm banks may be screened to find out sources of resistance to changing diseases and insects, as well as to heat and water stress environment. Breeding efforts need to address multiple stress environments-droughts, floods, heat, pest load-imposed by changing global climate. There is a need for better understanding of wild relatives, land races, and their distributions, sensitivity of wild and cultivated species, and genetic material currently in the gene banks to climatic variables, creating trait based collection strategies, and establishing pre-breeding as a public good for providing a suitable response to challenges of global climate change (Aggarwal, 2008). For example, crop varieties with higher harvest index help to maintain irrigation efficiency under conditions of reduced water supplies or enhanced demands. Genetic manipulation offer the possibility of developing "designer-cultivars" to adapt to both biotic and abiotic stresses (heat, water, pest and disease, etc.) enhanced by climate change (Goodman *et al*. 1987). Similarly, species which are not used previously for agricultural purposes may be identified and others already identified may be introduced into farming systems. To cope up with the adverse effects of global warming, Central Potato Research Institute (CPRI), Shimla, has developed a new variety of potato having more heat resistance in India. The variety *'Kufri Surya'* can resist over four degree Celsius heat. A night temperature up to 18 degrees is ideal for cultivation of the ordinary potato variety, but Kufri Surya could endure heat up to 22 degrees (Minhas *et al*, 2006). The development and adoption of better temperature adapted varieties, together with improved management practices, could results in the almost complete mitigation of the negative impact of temperature increases (Cooper *et al*, 2009).

Introducing improved/short duration crop varieties

Introducing short duration, early maturing crop variety is helpful in reducing crop failure particularly in semi arid/ arid rainfed areas where moisture is only available to a certain period in monsoon. A major shift of chickpea area (about 2.5 m ha) from northern India (cooler, long-season environments) to southern India (warmer, short-season environments) is found during the past four decades (http://www.icrisat.org/crop-chickpea.htm). This shift in cropping pattern is because of the adoption of fusarium wilt resistant, short-duration varieties is a good example of adaption strategy. During the past 10 years (1996/97 to 2005/06), the chickpea area in southern state of Andhra Pradesh has increased 3.7 times (from 106,000 ha to 394,000 ha), yield has increased 1.9 times (853 to 1596 kg ha^{-1}) and the production has increased 7-times (90,000 t to 629,000 t). Similarly ICRISAT-bred chickpea cultivars covered 82% of chickpea area in Myanmar during 2005-06. Adoption of improved cultivars has led to increase in area and productivity of chickpea. During the past decade (1995-96 to 2005-06), the chickpea area in Myanmar increased by 23.5% (from 166,000 to 205,000 ha), production has increased 2.6 times (from 92,000 t to 239,000 t) and yields have almost doubled (from 588 to 1171 kg ha^{-1}). Similarly it has been rapidly adapted in other African countries like Ethiopia, Tanzania, Sudan and Kenya as well.

Extra-short and short-duration pigeonpea varieties fit well in various cropping systems, providing greater crop diversity. One good example has been the adoption of ICPL 88039 (extra-short duration variety) in pigeonpea-wheat rotation in the rice-wheat cropping system in North-west India (Dahiya *et al.*, 2001). It is also found promise in rice fallows at lower latitudes (http://www.icrisat.org/crop-pigeonpea.htm).

CLIMATE CHANGE ADAPTATION STRATEGIES FOR LIVESTOCK MANAGEMENT

Potential direct and indirect impacts of climate change on livestock production have not been thoroughly explored. However, there are studies using projected global change models, to show that changes in climate would directly lead to reductions milk production and conception rates in dairy cows and significant reductions in growth rates of swine during the summer season (Hahn *et al.*, 1992 and Klinedinst *et al.*, 1993). There are chances of increased spread of existing vector-borne diseases and macro parasites of animals as well as the emergence and spread of new diseases due to direct effects of climate change (higher temperatures and changes in rainfall patterns). Increasing water scarcity in the future due to climate change, will not only influence livestock drinking water sources, but it also affect the productivity of livestock feed production systems.

Frank *et al*., (2001) projected reduction in milk production is because of reduction in Voluntary Food Intake (VFI) by cows due to rise in temperature. They also showed that beef producers potentially have to face up to 16% longer feeding periods to get slaughter weight and reduction in swine potential production by 24.3% due to temperature gradient simulated under CGCMI (Canadian Global Coupled Model Version I) and HadCM3 scenarios. Generally, temperature-induced reductions in livestock productivity may be reduced through installation of shades or sprinklers in feedlots or evaporative cooling of barns. Similarly, provision of natural shades (low cost) may be possible strategy for rural settings to reduce the heat stress in livestock population.

Climate change simulation studies showed that grazing time of livestock should be extended by at least six hours by 2020, and even longer in 2050 and 2080 in Mangolia. However, it is impossible to extend the grazing time of by 6-8 hours, for which it is suggested to modifying the grazing schedule of livestock from mid-day hours to early morning or late evening hours as adaptation measure to spend extended time on the grazing during summer (Punsalmaa Batima, 2006)

Pastoral and agro-pastoral systems, livestock are key assets for poor communities who reside in arid and semi arid ecosystems, providing multiple economic, social, and risk management functions. Pastoral and agro-pastoral systems already become less productive or degraded due to the pressure of excessive stocking density. HadCM3 and CSIROMk2 scenarios predict less pasture productivity in the forest steppe and steppe regions in 2020 and 2080. Pasture productivity would be reversed by introducing drought tolerant and more productive species along with *insitu* soil water conservation measures. In this context, reduction (less number but more productive animals) and composition (between small and large ruminants) of livestock may be also one of the options looking at the nature of feed availability. Seo and Mendelssohn (2006) suggested to change the livestock composition for farmers in Africa, to move away from rearing cattle to goats and sheep by using AOGCMs (Atmospheric Oceanic General Circulation Models), CCC (Canadian Climate Center), PCM (Parallel Climate Model) and CCSR (Center for Climate System Research) scenarios. Similarly, if the Himalayas turn warmer, the yak could be restricted to higher altitudes where there is less availability of grass and fodder and hence local communities will have seek other species for production.

Adaptations for improving the economic sustainability

Table 3: Scientific basis for selected climate change adaptation studies

Country/Regions	Crop	climate change Scenarios	Proposed adaptation Strategies	Impact of adaptation strategies
Egypt	Wheat	Rise in temperature up to 3.6^{0}C	Delay sowing with supplemental irrigation	For early maturing to avoid terminal drought
North eastern Austria	Winter wheat	Temperature rises	Cultivar with short vegetative period than current variety	Increasing the grain filling period i.e. post flowering stage to improve the yield
Great Plains, USA	Wheat and maize	Rising temperature	Heat tolerant variety with less vernalization period	Less vegetative period and increased reproductive period especially duration of grain filling
Argentina, Brazil, Uruguay	Maize	Increasing rainfall during March – April months, which is the harvest time for maize under current dates of sowing	Advance planting than current	It will contribute longer vegetative period, which would increase the grain number to increase the yield
Boise ID	Potato	Temperature rise	Pre-ponding the planting by one month than current practice	To favor the tuber initiation, which requires cold weather
Austria	Soybean	Rise in temperature	30 days early sowing than current date of sowing	Effective utilization of soil water accumulated during the winter period in order to avoid drought impact in spring
North and Central Italy	Sugar beet	Temperature rise with increased water stress	15-30 days early sowing than current with supplemental irrigation	Lessening of drought stress lead to improved crop responses to increased level of CO_2

of livestock production may be focused on the feed availability to livestock during annual production cycles like agro forestry, bund planting with perennial fodder trees, value addition of animal feeds. The best strategy for driving climate change impact in livestock management would be identifying and strengthening local breeds which are adapted to local climatic stress and feed sources or improving local genetics through cross breeding with heat and disease tolerant breeds. Adaptation measures for increased livestock productivity would be to increase livestock weight or livestock bio-capacity by improving supplementary feed due to decreased VFI and grazing time.

CROP LIVESTOCK INTEGRATION

Crop livestock integration always has inherited larger resilience to changes in the environment, as there are more options for the buffering and change (Bindi and Howden, 2004) compared to the specialized farms such as either livestock based or arable crop production. It is believed that income generated outside of cropping is crucial for livelihoods of poor people and recognized as livestock and low dependency on external inputs as factors to reduce the climatic vulnerability (Block and Webb, 2001). It is often argued that the poorest smallholders would benefit the most from integrating livestock with crops in the risky environment through the insurance function of livestock and recycling of farm yard manure for maintaining soil productivity. Crop-livestock mixed systems, intensification may occur through the introduction of animal traction, use of animal manure, fodder production and stall feeding, which creates opportunities for further integration due to increased production of crop residues that may be fed to livestock, and manure that may be used for cropping. Rufino (2008) studied crop livestock integration in western parts of Kenya and revealed that the absolute quantity of nitrogen recycled about 1-6, 4-17 and 7-18 kg nitrogen y^{-1} for poor, medium and wealthier farmers respectively and however, it is revealed that there is still significant scope for recycling more nitrogen by capping nitrogen losses during the collection and storing of manures.

The economic conditions are also favoring crop livestock integration due to market prospects scenario for livestock-based commodities. The integrated crop-livestock production system has been resilient, flexible and responsive to economic fluctuations and technical innovation, but must evolve further to meet the certainty of further change and the challenges of sustainable production. Some case studies and scientific base for afore said adaptation strategies are shown in the Table 2 and 3.

SUMMARY AND CONCLUSION

Climate change phenomenon is an imminent based on the IPCC assessment reports and evidences of case occurring around the globe. There is varying scenarios projected that the impact of climate change is likely going to alter global temperature, rainfall pattern and more frequency of extreme events like drought and floods. In this context, all living things have autonomous adaptation for the naturally occurring gradual change in climate events. However, there is need to evolve planned adaptation strategies for individual species to overcome the impact of anthropogenic driven climate change. There are adaptation strategies evolved during the course of time in agriculture to cope with drought, flooding, high and low temperature and other abiotic as well as biotic factors which hold still good to use against the impact of climate change. The effective adaptation strategies to coping with climate change may include *in-situ* soil and water conservation, rainwater harvesting and storage for using as supplemental irrigation to bridge the gap for water during dry spells, watershed management which provides multiple benefits, crop diversification and diversification of livelihood options. Other technologies such as use of legumes through crop rotations and intercropping, minimum tillage, zero tillage; mulching; use of organic manures; suitable cropping system; shift in planting; early maturing varieties; high tillering cultivars and optimal root traits for mid-season drought; early maturing traits for terminal drought; heat tolerance traits; water harvesting and run off control for early drought; crop residue management and large number of seedling per planting hill; along with better soil water and nutrient management to promote positive effect of increased CO_2 level. These adaptation strategies are complex phenomena, which require social capital, efficient institutional networks and extension system. Climate change adaptation needs to be linked closely to evolving policies in order to achieve win–win solutions at multiple scales. It is also critical to modify government policies on crop insurance programs to cover farm-level risk to climate-related yield losses and to provide incentives for the stakeholders adopting climate change adaptation strategies.

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