Advances in Economics and Business Management (AEBM)
p-ISSN: 2394-1545; e-ISSN: 2394-1553; Volume 3, Issue 5; April-June, 2016, pp. 421-425

http://www.krishisanskriti.org/Publication.html

Impacts of Climate Change on Agriculture

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Abstract—*Global climatic changes can affect agriculture through their direct and indirect effects on the crops, soils, livestock and pests. An increase in atmospheric carbon dioxide level will have a fertilization effect on crops with C3 photosynthetic pathway and thus will promote their growth and productivity. The increase in temperature, depending upon the current ambient temperature, can reduce crop duration, increase crop respiration rates, alter photo-synthase partitioning to economic products, affect the survival and distribution of pest populations, hasten nutrient mineralization in soils, decrease fertilizer-use efficiencies, and increase evapo-transpiration rate. Indirectly, there may be considerable effects on land use due to snowmelt, availability of irrigation water, frequency, and intensity of inter- and intra-seasonal droughts and floods, soil organic matter transformations, soil erosion, changes in pest profiles, decline in arable areas due to submergence of coastal lands, and availability of energy. Equally important determinants of food supply are socio-economic environment, including government policies, capital availability, prices and returns, infrastructure, land reforms, and inter and intra-national trade that might be affected by the climatic change.*

1. INTRODUCTION

Rise in the mean temperature above a threshold level will cause a reduction in agricultural yields. A change in the minimum temperature is more crucial than a change in the maximum temperature. Grain yield of rice, for example, declined by 10% for each 1 °C increase in the growing season minimum temperature above 32 °C (Pathak et al., 2003). The climate change impact on the productivity of rice in Punjab (India) has shown that with all other climatic variables remaining constant, temperature increases of 1 °C, 2 °C and 3 °C, would reduce the grain yield of rice by 5.4%, 7.4% and 25.1%, respectively (Aggarwal et al., 2009b). Shortage of Water

2. SECTOR IMPACT

Crop • Increase in ambient CO2 concentration is beneficial since it leads to increased photosynthesis in several crops, especially those with C3 mechanism of photosynthesis such as wheat and rice, and decreased evaporative losses. Despite this, yields of major cereals crops, especially wheat are likely to be reduced due to decrease in grain filling duration, increased respiration, and / or reduction in rainfall/irrigation supplies.

- Increase in extreme weather events such as floods, droughts, cyclones and heat waves will adversely affect agricultural productivity.
- Reduction in yields in the rainfed areas due to changes in rainfall pattern during monsoon season and increased crop water demand.
- Incidence of cold waves and frost events may decrease in future due to global warming and it would lead to a decreased probability of yield loss associated with frost damage in northern India in crops such as mustard and vegetables.
- Quality of fruits, vegetables, tea, coffee, aromatic, and medicinal plants may be affected.
- Incidence of pest and diseases of crops to be altered because of more enhanced pathogen and vector development, rapid pathogen transmission and increased host susceptibility.
- Agricultural biodiversity is also threatened due to the decrease in rainfall and increase in temperature, sea level rise, and increased frequency and severity of droughts, cyclones and floods.

Water • Demand for irrigation water would increase with rise in temperature and evapo-transpiration rate. It may result in lowering of groundwater table at some places. Sector Impact

- The melting of glaciers in the Himalayas will increase water availability in the Ganges, Bhramaputra and their tributaries in the short-run, but in the long run, the availability of water will decrease considerably.
- A significant increase in runoff is projected in the wet season that, however, may not be very beneficial unless storage infrastructure is vastly expanded.

This additional water in the wet season, on the other hand, may lead to increase in frequency and duration of floods.

- The water balance in different parts of India will be disturbed and the quality of groundwater along the coastal track will be affected more due to intrusion of sea waters.

Soil • Organic matter content, which is already quite low in Indian soils, would become still lower. Quality of soil organic matter may be affected.

- The residues of crops under the elevated CO2 concentrations will have higher C:N ratio, and this may reduce their rate of decomposition and nutrient supply.
- Rise in soil temperature will increase N mineralization, but its availability may decrease due to increased gaseous losses through processes such as volatilization and denitrification.
- There may be a change in rainfall volume and frequency, and wind may alter the severity, frequency and extent of soil erosion.
- Rise in sea level may lead to salt-water ingression in the coastal lands, turning them less suitable for conventional agriculture.

Livestock • Climate change will affect fodder production and nutritional security of livestock. Increased temperature would enhance lignification of plant tissues, reducing the digestibility. Increased water scarcity would also decrease production of feed and fodder.

- Major impacts on vector-borne diseases will be through expansion of vector populations in the cooler areas. Changes in rainfall pattern may also influence expansion of vectors during wetter years, leading to large outbreaks of diseases.
- Global warming would increase water, shelter, and energy requirement of livestock for meeting the projected milk demands.
- Climate change is likely to aggravate the heat stress in dairy animals, adversely affecting their reproductive performance.

Fishery • Increasing temperature of sea and river water is likely to affect breeding, migration and harvests of fishes.

- Impacts of increased temperature and tropical cyclonic activity would affect the capture, production and marketing costs of the marine fish.
- Coral bleaching is likely to increase due to higher sea surface temperature. Source: Aggarwal et al. (2009a)

3. RISE IN SEA LEVEL

In South, South East and East Asia about 10% of the regional rice production, which is enough to feed 200 million people, is from the areas that are susceptible to 1 m rise in the sea level. Direct loss of land combined with less favorable hydraulic conditions may reduce rice yields by 4% if no adaptation measures are taken, endangering the food security of at least of 75 million people. Saltwater intrusion and soil salinization are other concerns for agricultural productivity.

4. DECLINE IN SOIL FERTILITY

Soil temperature affects the rates of organic matter decomposition and release of nutrients. At high temperatures, though nutrient availability will increase in the short-term, in the long-run organic matter content will diminish, resulting in a decline in soil fertility.

5. LOSS OF BIODIVERSITY

Species of animals and plants are estimated to disappear at a rate which would be about 100-times faster than the historical record, largely as a result of human activities. A detailed assessment of the 394 species of primates from South America to Indonesia has indicated that 29% are in danger of disappearing due to hunting, habitat loss and climate change.

6. PESTS, WEEDS, AND DISEASES

As temperature increases, the insect-pests will become more abundant through a number of inter-related processes, including range extensions and phonological changes, as well as increased rates of population development, growth, migration and over-wintering. The climate change is likely to alter the balance between insect pests, their natural enemies and their hosts. The rise in temperature will favour insect development and winter survival. Rising atmospheric carbon dioxide concentrations may lead to a decline in food quality for plant-feeding insects, as a result of reduced foliar nitrogen levels. The epidemiology of plant diseases will be altered. The prediction of disease outbreaks will be more difficult in periods of rapidly changing climate and unstable weather. Environmental instability and increased incidence of extreme weather may reduce the effectiveness of pesticides on targeted pests or result in more injury to non-target organisms. Mitigation Strategies to Climate Change

The strategies for mitigating methane emission from rice cultivation could be alteration in water management, particularly promoting mid-season aeration by short-term drainage; improving organic matter management by promoting aerobic degradation through composting or incorporating it into soil during off-season drained period; use of rice cultivars with few unproductive tillers, high root oxidative activity and high harvest index; and application of fermented manures like biogas slurry in place of unfermented farmyard manure (Pathak and Wassmann, 2007). Methane emission from ruminants can be reduced by altering the feed composition, either to reduce the percentage which is converted into methane or to improve the milk and meat yield.

The most efficient management practice to reduce nitrous oxide emission is site-specific, efficient nutrient management

(Pathak, 2010). The emission could also be reduced by nitrification inhibitors such as nitrapyrin and dicyandiamide (DCD). There are some plant-derived organics such as neem oil, neem cake and karanja seed extract which can also act as nitrification inhibitors.

7. ADAPTATION STRATEGIES TO CLIMATE CHANGE

To deal with the impact of climate change, the potential adaptation strategies are: developing cultivars tolerant to heat and salinity stress and resistant to flood and drought, modifying crop management practices, improving water management, adopting new farm techniques such as resource conserving technologies (RCTs), crop diversification, improving pest management, better weather forecasting and crop insurance and harnessing the indigenous technical knowledge of farmers. Some of these strategies are discussed below. Developing Climate-ready Crops Development of new crop varieties with higher yield potential and resistance to multiple stresses (drought, flood, salinity) will be the key to maintain yield stability. Improvement in germ plasm of important crops for heat-stress tolerance should be one of the targets of breeding programme. Similarly, it is essential to develop tolerance to multiple abiotic stresses as they occur in nature. The abiotic stress tolerance mechanisms are quantitative traits in plants. Germ plasm with greater oxidative stress tolerance may be exploited as oxidative stress tolerance is one example where plant's defense mechanism targets several abiotic stresses. Similar to the research efforts on conversion of rice from C3 to C4 crop, steps should be taken for improvement in radiation-use efficiency of other crops as well.

Improvement in water-use and nitrogen-use efficiencies is being attempted since long. These efforts assume more relevance in the climate change scenarios as water resources for agriculture are likely to dwindle in future. Nitrogen-use efficiency may be reduced under the climate change scenarios because of high temperatures and heavy precipitation events causing volatilization and leaching losses. Apart from this, for exploiting the beneficial effects of elevated CO2 concentrations, crop demand for nitrogen is likely to increase. Thus, it is important to improve the root efficiency for mining the water and absorption of nutrients.

Exploitation of genetic engineering for 'gene pyramiding' has become essential to pool all the desirable traits in one plant to get the 'ideal plant type' which may also be 'adverse climate-tolerant' genotype.

Farmers need to be provided with cultivars with a broad genetic base. Their adaptation process could be strengthened with availability of new varieties having tolerance to drought, heat and salinity and thus, minimize the risks of climatic aberrations. Similarly, development of varieties is required to offset the emerging problems of shortening of growing season and other vagaries of production environment. Farmers could better stabilize their production system with basket of technological options.

8. CROP DIVERSIFICATION

Diversification of crop and livestock varieties, including replacement of plant types, cultivars, hybrids, and animal breeds with new varieties intended for higher drought or heat tolerance, are being advocated as having the potential to increase productivity in the face of temperature and moisture stresses. Diversity in the seed genetic structure and composition has been recognized as an effective defense against disease and pest outbreak and climatic hazards. Moreover, demand for high-value food commodities, such as fruits, vegetables, dairy, meat, eggs and fish is increasing because of growing income and urbanization. This is reducing the demand for traditional rice and wheat. Diversification from rice-wheat towards high-value commodities will increase income and result in reduced water and fertilizer use. However, there is a need to quantify the impacts of crop diversification on income, employment, soil health, water use and greenhouse gas emissions. A significant limitation of diversification is that it is costly in terms of the income opportunities that farmers forego, i.e., switching of crop can be expensive, making crop diversification typically less profitable than specialization. Moreover, traditions can often be difficult to overcome and will dictate local practices.

9. CHANGES IN LAND-USE MANAGEMENT PRACTICES

Changing land-use practices such as the location of crop and livestock production, rotating or shifting production between crops and livestock, shifting production away from marginal areas, altering the intensity of fertilizer and pesticide application as well as capital and labour inputs can help reduce risks from climate change in farm production. Adjusting the cropping sequence, including changing the timing of sowing, planting, spraying, and harvesting, to take advantage of the changing duration of growing seasons and associated heat and moisture levels is another option. Altering the time at which fields are sowed or planted can also help farmers regulate the length of the growing season to better suit the changed environment. Farmer adaptation can also involve changing the timing of irrigation or use of other inputs such as fertilizers.

10. ADJUSTING CROPPING SEASON

Adjustment of planting dates to minimize the effect of temperature increase induced spikelet sterility can be used to reduce yield instability, by avoiding having the flowering period to coincide with the hottest period. Adaptation measures to reduce the negative effects of increased climatic variability as normally experienced in arid and semi-arid tropics may include changing of the cropping calendar to take advantage of the wet period and to avoid extreme weather events (e.g., typhoons and storms) during the growing season. Cropping systems may have to be changed to include growing of suitable cultivars (to counteract compression of crop development), increasing crop intensities (i.e., the number of successive crop produced per unit area per year) or planting different types of crops. Farmers will have to adapt to changing hydrological regimes by changing crops.

11. EFFICIENT USE OF RESOURCES

The resource-conserving technologies (RCTs) encompass practices that enhance resource- or input-use efficiency and provide immediate, identifiable and demonstrable economic benefits such as reduction in production costs; savings in water, fuel and labor requirements; and timely establishment of crops, resulting in improved yields. Yields of wheat in heat- and water-stressed environments can be raised significantly by adopting RCTs, which minimize unfavorable environmental impacts, especially in small and medium-scale farms. Resource conserving practices like zero-tillage (ZT) can allow farmers to sow wheat sooner after rice harvest, so the crop heads and fills the grain before the onset of pre-monsoon hot weather. As the average temperatures in the region rise, early sowing will become even more important for wheat. Field results have shown that the RCTs are increasingly being adopted by farmers in the rice-wheat belt of the Indo-Gangetic Plains because of several advantages of labour saving, water saving, and early planting of wheat. The RCTs in rice-wheat system also have pronounced effects on mitigation of greenhouse gas emission and adaptation to climate change (Pathak et al. 2009). These approaches of crop management should be coupled with the measures of crop improvement for wider adaptation to climate change.

Soil and water management is highly critical for adaptation to climate change with higher temperatures and changing precipitation patterns, water will further become a scarce resource. Serious attempts towards water conservation, water harvesting improvement in irrigation accessibility, and water-use efficiency will become essential for crop production and livelihood management. Farmers have to be trained and motivated for adopting on-farm water conservation techniques, micro-irrigation systems for better water-use efficiency, selection of appropriate crops, etc. Principles of increasing water infiltration with improvement in soil aggregation, decreasing runoff with use of contours, ridges, vegetative hedges, etc. and reducing soil evaporation with use of crop residues mulch could be employed for better management of soil-water. Relocation of Crops in Alternative Areas.

Climate change in terms of increased temperature, CO2 level, droughts and floods would affect production of crops. But, the impact will be different across crops and regions. There is a need to identify the crops and regions that are more sensitive to climate changes/variability and relocate them in more suitable areas. For example, it is apprehended that increased temperature would affect the quality of crops, particularly important aromatic crops such as basmati rice and tea. Alternative areas that would become suitable for such crops from quality point of view need to be identified and assessed for their suitability.

12. HARNESSING INDIGENOUS TECHNICAL KNOWLEDGE OF FARMERS

Farmers in South Asia, often poor and marginal, are experimenting with the climatic variability for centuries. There is a wealth of knowledge on the range of measures that can help in developing technologies to overcome climate vulnerabilities. There is a need to harness that knowledge and fine-tune them to suit the modern needs. Traditional ecological knowledge of people developed and carried which have stood the test of time could provide insights and viable options for adaptive measures. Anthropological and sociological studies have highlighted the importance of community based resource management and social learning to enhance their capacity to adapt to the impacts of future climate change.

During the course of their habitation, the indigenous people of Himalayan terrain region through experience, experimentation and accumulated knowledge, have devised ways of reducing their vulnerability to natural hazards. Studies have shown that their understanding was fairly evolved in the matters of earthquake, landslide, and drought and they have devised efficient ways of mitigating the effect of natural or climatic changes.

13. IMPROVED PEST MANAGEMENT

Changes in temperature and variability in rainfall would affect incidence of pests and disease and virulence of major crops. It is because climate change will potentially affect the pest/weed-host relationship by affecting the pest/weed population, the host population and the pest/weed-host interactions.

Some of the potential adaptation strategies could be: (i) developing cultivars resistance to pests and diseases; (ii) adoption of integrated pest management with more emphasis on biological control and changes in cultural practices, (iii) pest forecasting using recent tools such as simulation modeling, and (iv) developing alternative production techniques and crops, as well as locations, that are resistant to infestations and other risks. Management of pests and diseases with use of resistant varieties and breeds; alternative natural pesticides; bacterial and viral pesticides; pheromones for disrupting pest reproduction, etc. could be adopted for sustainability of agricultural production process. Bio-agents have a crucial role in pest management, hence practices to promote natural enemies like release of predators and parasites; improving the habitat for natural enemies; facilitating beetle banks and flowering strips; crop rotation and multiple cropping should be integrated in pest management practices. Reduction in use of pesticides will also help in reducing carbon emissions.

14. BETTER WEATHER FORECASTING AND CROP INSURANCE SCHEMES

Weather forecasting and early warning systems will be very useful in minimizing risks of climatic adversaries. Information and communication technologies (ICT) could greatly help the researchers and administrators in developing contingency plans. Effective crop insurance schemes should be evolved to help the farmers in reducing the risk of crop failure due to these events. Both formal and informal, as well as private and public, insurance programs need to be put in place to help reduce income losses as a result of climate-related impacts. However, information is needed to frame out policies that encourage effective insurance opportunities. Micro-finance has been a success among rural poor, including women. Low-cost access to financial services could be a boon for vulnerable farmers. Growing network of mobile telephony could further speed up SMS-based banking services and help the farmers in having better integration with financial institutions.

However, compared to micro-finance, micro-insurance innovations and availability is limited. There is a need to develop sustainable insurance system, while the rural poor are to be educated about availing such opportunities. Conclusions

Climatic changes and increasing climatic variability are likely to aggravate the problems of future food security by exerting pressure on agriculture. However, there are lot of uncertainties about the assessment of impact, adaptation and mitigation of climate change in agriculture. It is mainly because the methodology followed for such assessments is not standardized and sometimes is inaccurate and imprecise. Researchers follow different methodologies and arrive at contrasting results making it still more difficult to reach a logical conclusion and develop policy actions. There is a need to develop and apply a standard methodology across the board for various studies related to climate change and agriculture.

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