CLIMATE CHANGE-AGRICULTURE NEXUS: INDIAN SCENARIO

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ABSTRACT

Climate change impacts on agriculture are being witnessed all over the world but countries like India are more vulnerable in view of high population depending on agriculture and excessive pressure on natural resources. The agricultural sector represents 35% of India's Gross National Product (GNP) and as such plays a crucial role in the country's development. The impact of climate change on agriculture could result in problems with food security and may threaten the livelihood activities upon which much of the population depends. Climate change can affect crop yields (both positively and negatively), as well as the types of crops that can be grown in certain areas, by impacting agricultural inputs such as water for irrigation, amounts of solar radiation that affect plant growth, as well as the prevalence of pests.

Introduction

Climate Change is a serious global environmental concern. It is primarily caused by the building up of Green House Gases (GHG) in the atmosphere. The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land use change, while those of methane and nitrous oxide are primarily due to agriculture. Global Warming is a specific example of the broader term "Climate Change" and refers to the observed increase in the average temperature of the air near earth's surface and oceans in recent decades. Its effect particularly on developing countries is adverse as their capacity and resources to deal with the challenge is limited (MOEF, Annual Report, 2012-13, p. 349).

Agricultural sector is one of the sensitive areas which would be influenced by the projected global warming and associated climate change. In spite of the uncertainties about the precise magnitude of climate change on regional scales, an assessment of the possible impacts of changes in key climatic elements on our agricultural resources is important for formulating response strategies. Climate change may affect agricultural crops in four ways (Hulme, 1996). First, changes in temperature and precipitation will alter the distribution of agro-ecological zones. An increase of potential evapo-transpiration is likely to intensify drought stress, especially in the semi-arid tropics and subtropics. Second, carbon dioxide effects are expected to have a positive impact due to, greater water use efficiency and higher rate of photosynthesis. Third, water availability *(*or runoff*)* is another critical factor in determining the impact of climate change. A number of studies suggested that precipitation and the length of the growing season are critical in determining whether climate change positively or negatively affects agriculture. Fourth, agricultural losses can result from climatic variability and the increased frequency of extreme events such as droughts and floods or changes in precipitation and temperature variance. Higher frequency of droughts is likely to increase pressure on water supplies for numerous reasons ranging from plant transpiration to allocation.

Climate Modeling studies in India have indicated that the direct impacts of climate changes would be small on kharif crops but kharif agriculture will become vulnerable due to increased incidence of weather extremes such as changes in rainy days, rainfall intensity, duration and frequency of drought and floods, diurnal asymmetry of temperature, change in humidity, and pest incidence and virulence. Rabi crop production may become comparatively more vulnerable due to larger increase in temperature, asymmetry of day and night temperature and higher uncertainties in rainfall. The impacts of the climate change on Indian agriculture would be small in near future, but in long run the Indian agriculture may be seriously affected depending upon season, level of management, and magnitude of climate change (Shetty et al, 2013).

Night time temperatures above some threshold can have stronger negative impacts on rice yields compared to radiation and day time temperatures over India and other parts of south Asia (Peng *et al*, 2004). The recent studies highlight the importance of changing temperatures on the yields of major crops. The study by Kumar *et al*. (2011) suggested higher temperatures reduce the yields regardless of rainfall consistent with the findings by others. Notwithstanding the positive benefits that may occur in crop yields under increasing CO2 (Aggarwal and Mall, 2002), the substantial increase in temperatures could result in a net loss of productivity in the coming decades.

One of the potential threats to agriculture is the impact of climate change in attaining sustainable development of agriculture coupled with food security. Climate change phenomenon is now a global reality. India is one of the most vulnerable countries to climate change that is affecting agricultural production. Forecasts are made by the Indian Council of Agricultural Research using crop simulation models incorporating future projections. Climate change is projected to reduce timely sown irrigated wheat production by about 6% by 2020. In the case of late sown wheat, the projected levels are alarmingly high, to the extent of 18%. Similarly, a 4% fall in the yield of irrigated rice crop and a 6% fall in rain-fed rice are foreseen by 2020 due to climate changes. The warming trend in India over the past 100 years is estimated at 0.60°C. The projected impacts are likely to further aggravate yield fluctuations of may crops with impact on food security. It requires a serious attention on adaptation and mitigation strategies to overcome the problems of climate change. Sustainable food security is further affected by persistent land degradation, land fragmentation, labour problem, overexploitation of natural resources, etc. We need to focus on sustainable production systems by strengthening the ecological foundations. This requires a holistic approach by considering technological, biophysical, socio-economic, political and environmental factors. Food security and environmental sustainability can be attained by improved land and water management, adopting eco-friendly technologies and initiating good agricultural practices in different agro-ecosystems. Further, strategic research and technology in agriculture and adoption of sustainable practices are necessary to meet current and future threats to food security (Shetty et al, 2013).

Impacts of Climate Change on Agriculture

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 photosynthate 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 snow melt, 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 (Pathak et al, 2012).

Table 1: Effect of high temperature and CO_2 on crop productivity

Crop	Effect of increased temperature ^0C (% reduction in yield)				CO_2 fert. effect (%)	Threshold temperature for net loss
	+1 ^0C	+2 ^0C	+3 ^0C	+4 ^0C	560 ppm	
Rice	5	10	15	20	15	3.0
Wheat	10	20	30	40	15	1.5
Chickpea	5	10	15	20	22	4.5
Groundnut	8	16	24	32	20	2.5
Green gram	6	12	18	24	20	3.0
Mustard	4	8	12	16	20	5.0
Potato	6	12	18	24	20	3.5

Source: Indian Agricultural Research Institute, New Delhi

Reduction in Crop Yield

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

The increased temperature would result in more water shortages and the demand for irrigation water would rise. Increase in air temperature will lead to more potential evapo-transpiration in the areas south of 40º N. Likewise; water shortage due to climate change would result in about 20% net decline in the rice yields in India (Pathak et al, 2012).

Irregularities in Onset of Monsoon, Drought, Flood and Cyclone

Indian agriculture is highly dependent on the onset, retreat and magnitude of monsoon precipitation, particularly in the rainfed areas of east, north-east and south India. Climate modelers and IPCC documents have projected possibilities of increasing variability in Asian Monsoon circulation in a warmer world. Despite expansion of area under irrigation, droughts, caused by inadequate and uneven distribution of rainfall, continue to be the most important climatic aberrations, which influence the agricultural production in India. The severity of a drought will be intensified in a warmer world. Intense and frequent flooding due to climate change would be a major problem in the Indian subcontinent (Pathak et al, 2012).

Adaptation and Mitigation Strategies

Successful adaptation to climate change requires long term investments in strategic research and new policy initiatives that mainstream climate change adaptation into development planning. As a first step we need to document all the indigenous practices farmers have been following over time for coping with climate change. Secondly we need to quantify the adaptation and mitigation potential of the existing best bet practices for different crop and livestock production systems in different agro-ecological regions of the country. Thirdly, a long term strategic research planning is required to evolve new tools and techniques including crop varieties and management practices that help in adaptation (Venkateshwarlu, 2010).

The Indian Council of Agricultural Research (ICAR) has initiated a Network Project on Climate Change (NPCC) in X Five Year Plan with 15 centres which has been expanded in the XI Plan covering 23 centres. The initial results of the project through crop modelling have helped in understanding the impacts of changes in rainfall and temperature regimes on important crops and livestock (Agarwal 2009). Currently the focus is on evolving cost effective adaptation strategies. More recently during 2010, ICAR has launched the National Initiative on Climate Resilient Agriculture (NICRA) as a comprehensive project covering strategic research, technology demonstration and capacity building. Targeted research on adaptation and mitigation is at nascent stage in India but based on knowledge already generated, some options for adaptation to climate variability induced effects like droughts, high temperatures, floods and sea water inundation can be suggested. These strategies fall into two broad categories viz., (a) crop based and (b) resource management based approaches.

Crop based strategies

Crop based approaches include growing crops and varieties that fit into changed rainfall and seasons, development of varieties with changed duration that can over winter the transient effects of change, development of varieties for heat stress, drought and submergence of tolerance: evolving varieties which respond positively in terms of growth and yield under high CO_2. In addition, varieties with high fertilizer and radiation use efficiently and also novel crops and varieties that can tolerate coastal salinity and sea water inundation are needed. Intercropping is a time tested practice to cope with climate variability and climate change if one crop fails due to floods or droughts second crop gives some minimum assured returns for livelihood security. Germplasm of wild relatives and local land races could prove valuable source of climate ready traits. We need to revisit the germplasm collected so far which has tolerance to heat and cold stress but not made use in the past due to low yield potential. A detailed account of crop based approaches is beyond the scope of this paper. Susheel Kumar (2006) provides a succinct account of breeding objectives under climate change in India.

Strategies based on resource conservation and management

There are large number of options in soil, water and nutrient management technologies which contribute to both adaptation and mitigation. Much of the research done in rainfed agriculture in India relates to conservation of soil and rain water and drought proofing which is an ideal strategy for adaptation to climate change (Venkasteswarlu et al. 2009). Important technologies include in situ moisture conservation, rainwater harvesting and recycling, efficient use of irrigation water, conservation agriculture, energy efficiency in agriculture and use of poor quality water. Watershed management is now considered an accepted strategy for development of rainfed agriculture. Watershed approach has many elements which help both in adaptation and mitigation. For example, soil and water conservation works, farm ponds, check dams etc. moderate the runoff and minimize floods during high intensity rainfall. The plantation of multi-purpose trees in degraded lands helps in carbon sequestration. The carbon and soil management practices can be tailored for both adaptation and mitigation at the landscape level. Some of the most important adaptation and mitigation approaches with high potential are described below:

Rainwater conservation and harvesting

These are based on in situ and ex-situ conservation of rainwater for recycling to rainfed crops. The arresting of soil loss contributes to reduced carbon loss. Lal (2004) estimates that if water and wind erosion are arrested, it can contribute to 3 to 4.6 Tg per year of carbon in India. Increased ground water utilization and pumping water from deep tube wells is the largest contributor to GHG emissions in agriculture. If surface storage of rainwater in dug out ponds is encouraged and low lift pumps are used to lift that water for supplemental irrigation, it can reduce dependence on ground water. Sharma et al estimated that about 28 m ha of rainfed area in eastern and central states has the maximum potential to generate runoff of 114 billion cubic meters which can be used to provide supplemental irrigation in about 25 m ha of rainfed area. For storing such quantum of rainwater about 50 million farm ponds are required. This is one of the most important strategies not only to control runoff and soil loss but also contribute to climate change mitigation. Conjunctive use of surface and ground water is an important strategy to mitigate climate change. Innovative approaches in ground water sharing can also contribute to equitable distribution of water and reduced energy use in pumping.

Soil carbon sequestration

Soil carbon sequestration is yet another strategy towards mitigation of climate change. Although, tropical regions have limitation of sequestering carbon in soil due to high temperatures, adoption of appropriate management practices helps in sequestering reasonable quantities of carbon in some cropping systems particularly in high rainfall regions. The potential of cropping systems can be divided into that of soil carbon sequestration and sequestration in to vegetation. Tree based systems can sequester substantial quantities of carbon in to biomass in a short period. Total potential of soil C sequestration in India is 39 to 49 Tg per year (Lal, 2004). This is inclusive of the potential of the restoration of degraded soils and ecosystem which is estimated at 7 to 10 TgC per year (Table 2). The potential of adoption of recommended package of practice on agricultural soils 6 to 7 Tg per year. In addition, there is also a potential of soil inorganic carbon sequestration estimated at 21.8 to 25.6 TgC per year. Long term manorial trials conducted in arid regions of Andhra Pradesh (at Anantapur) under rainfed conditions indicate that the rate of carbon sequestration in groundnut production system varied from 0.08 to 0.45 T per ha per year with different nutrient management systems (Srinivasarao et al. 2009). Under semi arid conditions in alfisol region of Karnataka, the rate of carbon sequestration was 0.04 to 0.38 t per ha per year in finger millet system under diverse management practices. Under rabi sorghum production system in versitol region of Maharashtra (semi arid) the sequestration rate ranged from 0.1 to 0.29 t per ha per year with different integrated management options. In soybean production system in black soils of Madhya Pradesh (semi arid) the potential rate of carbon sequestration is up to 0.33 t per ha per year in top 20 cm soil depth.

Site specific nutrient management

Integrated Nutrient Management and Site-Specific Nutrient Management (SSNM) is another approach with potential to mitigate effects of climate change. Demonstrated benefits of these technologies are; increased rice yield and thereby increased CO_2 net assimilation and 30-40% increase in nitrogen use efficiency. This offers important prospects for decreasing GHG emissions linked with N fertilizer use in rice systems. It is critical to note here that higher CO_2 concentration in the future will result in temperature stress for many rice production systems, but will also offer a chance to obtain higher yield levels in environment where temperatures are not reaching critical levels. This effect can only be tapped under integrated and site directed nutrient supply, particularly N. Phosphorus (P) deficiency, for example, not only decreases yields, but also triggers high root exudation and increases CH_4 emissions. Judicious fertilizer application, a principal component of SSNM approach, thus has twofold benefit, i.e. reducing greenhouse gas emissions; at the same time improving yields under high CO_2 levels. The application of a urease inhibitor, hydroquinone (HQ), and a nitrification inhibitor, dicyandiamide (DCD) together with urea also is an effective technology for reducing N_2O and CH_4 from paddy fields. Very little information is available on the potential of SSNM in reducing GHG emissions in rainfed crops.

Conservation agriculture (CA)

In irrigated areas, zero tillage (ZT) in particular has effectively reduced the demand for water in rice-wheat cropping system of Indo-Gangetic plains and is now considered as a viable option to combat climate change. ZT has some mitigation effect in terms of enhancing soil carbon, reducing energy requirement and improving water and nutrient use efficiency but actual potential has to be quantified from long term experiments. The scope of CA in rainfed agriculture has been reviewed by Singh and Venkateswarlu (2009). While reduced tillage is possible in few production systems in high rainfall regions in eastern and northern India, non-availability of crop residue for surface application is a major constraint, particularly in peninsular and western India where it is mainly used as fodder.

Bio-mass energy and waste recycling

A large amount of energy is used in cultivation and processing of crops like sugarcane, food grains, vegetables and fruits, which can be recovered by utilizing residues for energy production. This can be a major strategy of climate change mitigation by avoiding burning of fossil fuels and recycling crop residues. The integration of biomass-fuelled gasifiers and coal-fired energy generation would be advantageous in terms of improved flexibility in response to fluctuations in biomass availability with lower investment costs. Waste-to-energy plants offer twin benefits of environmentally sound waste management and disposal, as well as the generation of clean energy.

Livestock production has been an integral part of agriculture in India. Livestock provides an excellent recycling arrangement for most of crop residue. Most by products of cereals, pulses and oilseeds are useful as feed and fodder for livestock while that of other crops like cotton, maize, pigeonpea, cator and sunflower and sugarcane are used as low calorie fuel of burnt to ashes or left in open to decompose over time. Ideally such residue is incorporated into soil to enhance physical properties of the soil and its water holding capacity. Lack of availability of proper chipping and soil incorporation equipment is one of the major reasons for the colossal wastage of agricultural biomass in India. Increased cost of labour and transport is another reason for lack of interest in utilizing the biomass. This is one area where little or no effort has gone in despite availability of opportunities for reasons such as aggregation, transport and investment in residue processing facilities. Many technologies like briquetting, anaerobic digestion vermin-composting and bio-char etc. exist, but they have not been commercially exploited. This area is gradually receiving attention now as a means to producing clean energy by substituting forest biomass for domestic needs. Modest investments in decentralized facilities for anaerobic digestion of agricultural residue through vermin-composting and biogas generation can meet the needs of energy deficit rural areas and simultaneously contribute to climate change mitigation.

Biomass based biogas production

There is renewed interest in the use of anaerobic digestion processes for efficient management and conversion of cattle dung and other agro-industrial wastes (livestock, paper and pulp, brewery and distillery) into clean renewable energy and organic fertilizer source. The biogas captured could not only mitigate the potential local and global pollution but could either be combusted for electricity generation using combined heat and power generator in large to medium enterprises or used for cooking and lighting for small households. A 2 m^3 digester can generate up to 4.93 t CO_2 per year of certified emission reduction (CER). Animal wastes are generally used as feedstock in biogas plants. But, the availability of these substrates is one of the major problems hindering the successful operation of biogas digesters. Khandelwal (1990) reported that the availability of cattle wastes could support only 12-30 million family-size biogas plants against the requirement of 100 million plants. A significant portion of 70-88 million biogas plants can be run with fresh / dry biomass residues. Of the available, 150 tonnes of biomass, a fifth would be sufficient to meet this demand.

Biochar

When biomass is exposed to moderate temperatures, between about 400 and 500*C (a kind of low temperature, pyrolysis), under complete or partial exclusion of oxygen, biomass undergoes exothermic processes and releases a multitude of gases in addition to heat along with biochar (Czernik and Bridgewater 2004). Pyrolysis produces biochar, a carbon rich, fine grained, porous substance and solid by product, similar in its appearance to charcoal, which when returned to soil, produces a range of environmental benefits, such as enhanced soil carbon sequestration and soil fertility improvement (lehmann 2007). Both heat and gases can be captured to produce energy carriers such as electricity, hydrogen or bio-oil which can be used as a fuel for various purposes in the process of manufacturing biochar. In addition to energy, certain valuable co-products, including wood preservative, food flavouring, adhesives etc. can be obtained (Czernik and Bridgewater 2004).

This is a novel approach to sequester carbon in terrestrial ecosystems which has several associated products in the process of its manufacture and also the end products. In India, it has been projected that about 309 m t of biochar could be produced annually, the application of which might offset about 50% of carbon emission (292 TgC per year) from fossil fuel (Lal 2005) rice, wheat cropping system in the Indo-Gangetic plains of India produces substantial quantities of crop residues and if these residues can be pyrolysed, 50% of the carbon in biomass is returned to the soil as biochar, increasing soil fertility and crop yields, while sequestering carbon. Addition of biochar to soil has also been associated with enhanced nutrient use efficiency, water holding capacity and microbial activity. At CRIDA, research on biochar use in rainfed crops has been initiated. Biochar from castor, cotton and maize stalks was produced by using a portable kiln and used as an amendment for pigeon pea during Kharif 2010. The crop growth was significantly superior in biochar applied plots from all three sources (Venkatesh 2010)

Agro-forestry

Agro-forestry systems like agri-silvi-culture, silvipasture and agri-horticulture offer both adaptation and mitigation opportunities. Agro-forestry systems buffer farmers against climate variability, and reduce atmospheric loads of green house gases. Agro-forestry can both sequester carbon and produce a range of economic, environmental and socio-economic benefits; the extent of sequestration can be up to 10 t per hectare per year in short rotation Eucalyptus, leucaena plantations.

Conclusion

One of the potential threats to agriculture is the impact of climate change in attaining sustainable development of agriculture coupled with food security. Climate change phenomenon is now a global reality. India is one of the most vulnerable countries to climate change that is affecting agricultural production. Forecasts are made by the Indian Council of Agricultural Research using crop simulation models incorporating future projections. Climate change is projected to reduce timely sown irrigated wheat production by about 6% by 2020. In the case of late sown wheat, the projected levels are alarmingly high, to the extent of 18%. Similarly, a 4% fall in the yield of irrigated rice crop and a 6% fall in rain-fed rice are foreseen by 2020 due to climate changes. The warming trend in India over the past 100 years is estimated at 0.60°C. The projected impacts are likely to further aggravate yield fluctuations of may crops with impact on food security. It requires a serious attention on adaptation and mitigation strategies to overcome the problems of climate change. Going forward, India must work toward achieving a sustainable agricultural system. However, many challenges exist in trying to achieve this goal. The degradation and scarcity of natural resources, pollution resulting from agricultural production, food loss and waste, and food safety, both in terms of production and post-harvest handling, are critical issues that must be addressed in order to achieve sustainable agricultural growth in India.

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