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A REVIEW :

Impact of climate change on agriculture

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BACKGROUND AND OBJECTIVES

Climate change and agriculture are interrelated processes, both of which take place on a global scale. Global warming is projected to have significant impacts on conditions affecting agriculture, including temperature, carbon dioxide, glacial run-off, precipitation and the interaction of these elements. These conditions determine the carrying capacity of the biosphere to produce enough food for the human population and domesticated animals. The overall effect of climate change on agriculture will depend on the balance of these effects. Assessment on the effect of climate change on agriculture might help to anticipate and adapt farming to maximize agricultural production.

At the same time, agriculture has been shown to produce significant effects on climate change, primarily through the production and release of greenhouse gases such as carbon dioxide, methane and nitrous oxide, but also by altering the Earth's land cover, which can change its ability to absorb or reflect heat and light, thus, contributing to radiative forcing. Land use change such as deforestation and desertification, together with use of fossil fuels, are the major anthropogenic sources of carbon dioxide; agriculture itself is the major contributor to increasing methane and nitrous oxide concentrations in Earth's atmosphere.

Impact of climate change on agriculture:

Despite technological advances, such as improved varieties, genetically modified organisms and irrigation systems, weather is still a key factor in agricultural productivity, as well as soil properties and natural communities. The effect of climate on agriculture is related to variabilities in local climates rather than in global climate patterns. The Earth's average surface temperature has increased by 1.5°F {0.83°C} since 1880. Consequently, agronomists consider any assessment has to be individually consider each local area.

On the other hand, agricultural trade has grown in recent years, and now provides significant amounts of food, on a national level to major importing countries, as well as comfortable income to exporting ones. The international aspect of trade and security in terms of food implies the need to consider the effects of climate change on a global scale.

Climatic change could affect agriculture in the following areas:

– *Productivity*, in terms of quantity and quality of crops

– *Agricultural practices*, through changes of water use (irrigation) and agricultural inputs such as herbicides, insecticides and fertilizers

– *Environmental effects*, in particular in relation of frequency and intensity of soil drainage (leading to nitrogen leaching), soil erosion, reduction of crop diversity

– *Rural space*, through the loss and gain of cultivated lands, land speculation, land renunciation and hydraulic amenities.

– *Adaptation*, organisms may become more or less competitive, as well as humans may develop urgency to develop more competitive organisms, such as flood resistant or salt resistant varieties of rice.

They are large uncertainties to uncover, particularly because there is lack of information on many specific local regions, and include the uncertainties on magnitude of climate change, the effects of technological changes on productivity, global food demands, and the numerous possibilities of adaptation.

Most agronomists believe that agricultural production will be mostly affected by the severity and pace of climate change, not so much by gradual trends in climate. If change is gradual, there may be enough time for biota adjustment. Rapid climate change, however, could harm agriculture in many countries, especially those that are already suffering from rather poor soil and climate conditions, because there is less time for optimum natural selection and adaption.

Impact of climate change on rain fed agriculture:

The vulnerability of Indian agriculture to climate change is well acknowledged. But, the impact has more on rain-fed agriculture, practiced mostly by small and marginal farmers. The crops that may be hit include pulses and oilseeds, among others. These are already in short supply and are consequently high-priced.

Nearly 80 million hectares, out of the country's net sown area of around 143 million hectares, lack irrigation facilities and, hence, rely wholly on rain water for crop growth. Over 85 per cent of the pulses and coarse cereals, more than 75 per cent of the oilseeds and nearly 65 per cent of cotton are produced from such lands. The crop yields are quiet low. The available records indicated that the predominantly rain-fed tracts experience three to four droughts every 10 years. Of these, two to three droughts are generally of moderate intensity and one is severe.

Most of the rain-fed lands, moreover, are in arid and semi-arid zones where annual rainfall is meagre and prolonged dry spells are quite usual even during the monsoon season. This makes crop cultivation highly risk-prone. If the quantum of rainfall in these areas drops further or its pattern undergoes any distinct, albeit unforeseeable, change in the coming years, which seems quite likely in view of climate change, crop productivity may dwindle further, adding to the woes of rain-fed farmers.

According to Indian Council of Agricultural Research (ICAR), medium-term climate change predictions have projected the likely reduction in crop yields due to climate change at between 4.5 and 9 per cent by 2039. The long run predictions paint a scarier picture with the crop yields anticipated to fall by 25 per or more by 2099. This will have a detrimental effect on farmers' income and purchasing power. Some meteorological sub-divisions have shown significant decrease in seasonal rainfall though some others have recorded an uptrend in precipitation as well. Since rain-fed crops, like coarse grains, pulses and oilseeds are grown mostly during the *Kharif* season, these are impacted by both low as well as excess rainfall.

Climate change is also reflected in the increasingly fluctuating weather cycle with unpredictable cold waves, heat waves, floods and exceptionally heavy single-day downpours. The most noticeable of such events in recent years included the country-wide drought in 2002, the heat wave in Andhra Pradesh in May 2003, extremely cold winters in 2002 and 2003, and prolonged dry spell in July 2004 and January 2005 in the north, unusual floods in the Rajasthan desert in 2005, drought in the north-east in 2006, abnormal temperature in January and February in 2007, and 23 per cent rainfall deficiency in the 2009 monsoon season. All these events took a heavy toll on crop output.

Impact of climate change on rice cultivation:

Climate change may have a positive impact on rice production in some areas. For example, a global temperature rise might allow more rice production to occur in the Northern regions of countries such as China, or growing two rice crops where, until now, only one can be grown per year. Yet, the vast majority of climate change impacts and the overall impact of climate change on rice are likely to be negative. An International Food Policy Research Institute (IFPRI) study forecasts a 15% decrease in irrigated rice yields in developing countries and a 12% increase in rice prices as a result of climate change by 2050. Another study reports that the variety IR8, well-known in the 1960s as the "miracle rice" can no longer produce 10 tons per hectare if grown in today's environment. An increase in night-time temperature was reported to be one of the many factors that likely caused a 15 per cent drop in yield of IR8.

Sea-level rises :

Recent predictions suggest that, as a consequence of melting polar ice shields and glaciers and rising temperatures, seawater levels may rise on average by about 1 m by the end of the 21st century. Rice is grown in vast low-lying deltas and coastal areas in Asia predicted to experience the impact of sea-level rises - making rice one of the crops most vulnerable to climate change. For example, in Vietnam, more than 50% of rice production is grown in the Mekong River delta - all of which would be affected by sea-level rises. Predicting the precise effect of sea-level rises on rice production in these areas is complicated because the effect goes beyond the basic sea-level rise itself. The entire hydrology of the delta would be affected, including changes in sediment discharge and shoreline gradients.

In Vietnam, the Mekong Delta alone yields 54% of the national rice production with the Red River Delta adding another 17% (data for 2005 from IRRI, 2008). Production growth in the Mekong Delta has driven the steadily increasing rice production in Vietnam over the last decades. The Mekong Delta contributes to the vast share of rice exports in Vietnam, which accounts for 4.7 million t of rice every year, making it the second largest exporter worldwide (IRRI, 2008). Thus, any shortfall in rice production in this area because of climate change would not only affect the economy and food security in Vietnam but also have effect on the international rice market. However, a rising sea level may deteriorate rice production in a sizable portion of the highly productive rice land in the deltas (Wassmann *et al.,* 2004).

Flooding :

Rice is unique in that it can thrive in wet conditions where other crops fail. Uncontrolled flooding is a problem, however, because rice cannot survive if submerged under water for long periods of time. Flooding caused by sea-level rises in coastal areas and the predicted increased intensity of tropical storms with climate change will likely hinder rice production. At present, about 20 million hectares of the world's rice-growing area is at risk of occasionally being flooded to submergence level, particularly in major rice-producing countries such as India and Bangladesh. Major flooding events are likely to increase in frequency with the attack of climate change and rice-growing areas, currently not exposed to flooding, will experience floods.

Submergence is increasingly becoming a major production constraint, affecting about 10–15 million ha of rice fields in South and Southeast Asia and causing yield losses of upto US$1 billion every year (Dey and Upadhyaya, 1996), a clear upward trend over recent years (Bates *et al.,* 2008). Conventional rice varieties can tolerate complete submergence only for a few days. A few tolerant rice varieties, however, were already identified in the 1970s (Vergara and Mazaredo, 1975) and have been used as donors of tolerance by breeders.

Water scarcity :

Rice requires ample water to grow. Rainless days for a week in upland rice-growing areas and for about two weeks in shallow lowland rice-growing areas can significantly reduce rice yields. Average yield reduction in rainfed, drought-prone areas has ranged from 17 to 40% in severe drought years, leading to production losses and food scarcity. With the onset of climate change, the intensity and frequency of droughts are predicted to increase in rainfed rice-growing areas and droughts could extend further into water-short irrigated areas.

Drought regularly occurs on 23 million ha of rice land in Asia (Pandey *et al.,* 2007). Severe droughts in recent years, such as those seen in 2002-03 in India and in 2004 in Thailand, had a great impact on rice production and thus, food security in these countries (Pandey *et al.,* 2007). Drought stress is highly damaging during the reproductive stage, specifically during flowering, but even drought in other stages or drought of milder intensity can also lead to big losses (Liu *et al.,* 2006). The current projections of climate change scenarios include a strong likelihood of a shift in precipitation patterns in many regions, exacerbating an almost universal trend for less water availability of the agricultural sector stemming from competition by other sectors (Bates *et al.,* 2008).

Increased carbon dioxide levels and higher temperatures :

Increases in both carbon dioxide levels and temperature will also affect rice production. Higher carbon dioxide levels typically increase biomass production, but not necessarily yield. Higher temperatures can decrease rice yields as they can make rice flowers sterile, meaning no grain is produced. Higher respiration losses linked to higher temperatures also make rice less productive. The different predictions for elevated temperature, carbon dioxide levels, changes in humidity, and the interactions of these factors make forecasting future rice yields under these conditions challenging. IRRI research indicates that a rise in night time temperature by 1 degree Celsius may reduce rice yields by about 10%.

The predicted 2–4 °C increment in temperature by the end of the 21st Century poses a threat to rice production. The impact of high temperatures at night is more devastating than day-time or mean daily temperatures. Booting and flowering are the stages most sensitive to high temperature, which may sometimes lead to complete sterility. Humidity also plays a vital role in increasing the spikelet sterility at increased temperature (Shah *et al.*, 2011).

Higher temperatures affect rice yields through two fundamentally different processes: (1) gradual changes in metabolism and phenology and (2) spikelet sterility caused by temperatures (heat waves) beyond certain temperature/humidity thres holds. Rice is grown in many regions where current temperatures during grain filling are only slightly below the critical limits for spikelet sterility (Wassmann *et al.*, 2009). The dry-season crop is potentially at risk in many regions in Asia, but, as of now, variety selection and flooding of fields (which reduces heat stress at the canopy level) usually keep the incidence of heat-induced sterility low. However, it seems justifiable to assume that progressing climate change will soon cause heat-induced losses and thus necessitate varietal improvement in terms of heat tolerance.

Extremely high temperatures during vegetative growth reduce tiller number and plant height and negatively affect panicle and pollen development, thereby decreasing rice yield potential (Yoshida, 1981). High temperature is of particular importance during flowering, which typically occurs at mid-morning. Exposure to high temperatures (*i.e.*, >35 °C) can greatly reduce pollen viability and cause irreversible yield loss because of spikelet sterility (Matsui *et al.*, 2000).

The simulated yield reduction from a 1 ºC rise in mean daily temperature was about 5–7% for major crops, including rice (Brown and Rosenberg, 1997 and Matthews *et al.*, 1997). The yield reduction is mostly associated with the decrease in grain formation, shortening of growth duration and increase in maintenance respiration. Peng *et al.* (2004) reported that annual average night time temperature increased at a rate of 0.04 ºC per year from 1979 to 2003 at IRRI. The increase in night time temperature was three times greater than the increase in daytime temperature over the same period. More importantly, rice yield decreased by 10% for each 1ºC increase in growing-season night time temperature in the dry season. Ziska and Manalo (1996) suggested that higher night time temperatures could also increase the susceptibility of rice to sterility with a subsequent reduction in seed set and grain yield, but the possible mechanism for this remains unknown.

IRRI crop modeler John Sheehy determined that, as a general rule, for every 75 ppm increase in CO_2 concentration, rice yields will increase by 0.5 ton per hectare, but yield will decrease by 0.6 ton per hectare for every 1 °C increase in temperature. However, nobody

Table 1 : Rice crop response to variations in temperature

		Yield and yield attributes						
Climate scenarios	Temperature change	Crop duration (Days)	Grain yield (kg ha^{-1})	Grains (m^{-2})	Grains (Ear^{-1})	Max (LAI)	Biomass (kg ha^{-1})	Straw (kg ha^{-1})
		(% deviation over norma scenario)						
Extreme warm	+2.0ºC	-3.3	-8.4	-8.4	-12.4	-3.9	-7.4	-6.4
Greater warm	+1.5ºC	-2.6	-8.2	-8.2	-8.3	-3.9	-6.5	-4.7
Moderate warm	+1.0ºC	-2.0	-4.9	-4.9	-6.1	-2.4	-3.6	-2.2
Slight warm	+0.5ºC	-1.3	-3.2	-3.2	-2.4	-1.1	-1.3	-0.7
Normal weather	Normal	153	6136	18846	494	6.2	10220	4943

(Mathauda *et al.*, 2000)

has studied the interactions between CO_2 and temperature under controlled, realistic field conditions. The technology to do this is now available, and, if funding can be found, IRRI hopes to develop an experimental system in which both CO_2 and temperature can be controlled in rice fields.

Pests, diseases and weeds :

Surveys in hundreds of farmers' fields over the last 10 years shown that rice diseases and pests are strongly influenced by climate change. Water shortages, irregular rainfall patterns and related water stresses increase the intensity of some diseases, including brown spot and blast. On the other hand, new environmental conditions and shifts in production practices that farmers may adopt to cope with climate change could lead to reductions of diseases such as sheath blight or insects such as whorl maggots or cutworms. As such, new crop health dynamics are emerging. Weed infestation and rice-weed competition are predicted to increase and will represent a major challenge for sustainable rice production. Also, extreme weather events have recently led to dramatic rodent population outbreaks in Asia due to unseasonal and asynchronous cropping.

Climate change and soil erosion :

The warmer atmospheric temperatures observed over the past decades are expected to lead to a more vigorous hydrological cycle, including more extreme rainfall events. As a result, erosion and soil degradation is more likely to occur. Soil fertility would also be affected by global warming. However, because the ratio of carbon to nitrogen is a constant, a doubling of carbon is likely to imply a higher storage of nitrogen in soils as nitrates, thus providing higher fertilizing elements for plants, providing better yields. The average needs for nitrogen could decrease, and give the opportunity of changing often costly fertilisation strategies. Due to the extremes of climate that would result, the increase in precipitations would probably result in greater risks of erosion, whilst at the same time providing soil with better hydration, according to the intensity of the rain.

Adaptation and mitigation strategies :

Developing rice varieties adapted to climate change:

Comprehensive rice research and breeding programme at IRRI to make rice more tolerant of submergence, drought, heat and salinity - all conditions predicted to increase in frequency and severity with climate change. A recent major advance in this area has been the release of IRRI's submergence-tolerant rice that can still produce good yields, even after two weeks under water conditions that would devastate most other types of rice. Varieties with improved drought and salinity tolerance have also been released.

International Rice Genebank - the most comprehensive collection of rice genetic diversity in the world with more than 109,000 different types of rice - as a source of rice genes associated with traits that help rice cope with climate change. Modern science is finding beneficial genes from this diversity and incorporating them into high-yielding rice varieties more accurately and faster than ever before. Genetic diversity outside of rice can also be used to improve the properties of rice through genetic modification.

IRRI is making progress towards developing "C_4" rice - rice with a supercharged photosynthesis mechanism that is much better at using sunlight to convert carbon dioxide and water into grain. C_4 rice could yield upto 50% more grain than currently possible from existing rice varieties. Importantly, in relation to climate change, it would be vastly more water and nutrient efficient.

Management strategies to cope with climate change :

Suitable management strategies to help rice cope with the effects of climate change such as establishment and development of efficient irrigation infrastructure coupled with water-saving techniques, can help make the best use of limited water. Modified cropping patterns, improved nutrient supply and nutrient management strategies adjusted to available water resources, land levelling and soil improvement may all help rice in times of drought. The challenge of food security, worsened by the complexity of climate change, could be effectively addressed through farm based methods namely 'smart water management and planting practices', but they need large investments and require immediate attention (Gujja and Thiyagarajan, 2010).

In the case of flooding, proper seed and seedbed management practices, direct seeding and optimal fertilizer use can help to have taller, healthier, less flood-susceptible plants that also recover better after flood exposure. Growing rice in the dry season, when floods are unlikely to occur, is also an option with potential in many regions.Salinity can be managed by improving water harvesting, water management and appropriate choice of cropping patterns. Infrastructure can also be developed to improve drainage and yet restrict intrusion of saline water, thereby reducing the impact of salinity.

IRRI is preparing for possible shifts in the impacts of different pests by developing more ecology-based pest management approaches to reduce pest damage. These strategies seek to maximize rice productivity by using pest-resistant varieties, gaining a smarter understanding of pest dynamics and developing more diverse ecosystems to keep pests at acceptable levels with minimum use of pesticides.

Impact of rice cultivation on climate change :

Although rice production is predicted to be affected by climate change, rice farming can also contribute to climate change. In spite of its fairly minor contribution on a global scale, rice production is a substantial source of greenhouse gases (Methane and nitrous oxide) at the national scale in many Asian countries. Methane (CH_4) and nitrous oxide (N_2O) are two important greenhouse gases and lead to chemical changes in the atmosphere. Although, atmospheric loading of N_2O is lower than CH_4 globally, the former is a 310 times more potent greenhouse gas than CO_2 on a 100-year time-scale while CH_4 is only 21 times more potent. During 1990–1999, CH_4 and N_2O concentrations have increased 0.007 and 0.0008 ppb yr–1, respectively.

Methane emission :

Yan *et al*. (2009) recently estimated the methane emissions from global rice fields based on the Tier 1 method described in the 2006 IPCC guidelines (IPCC, 2007) with country-specific statistical data regarding rice harvest areas and expert estimates of relevant agricultural rice production and global climate change: scope for adaptation and mitigation activities. The estimated global emissions for 2000 were 25.4 Tg year–1, which is at the lower end of earlier estimates and close to the total emissions summarized by individual national communications. These results are in line with other assessments of methane source strengths from rice fields. According to the latest summary by the IPCC (Denman *et al.*, 2007), rice fields emit 31–112 Tg of CH_4 per year, about 12–26% of the anthropogenic methane sources, or about 9–19% of the global methane emissions (base year: 1983-2001).

Nitrous oxide emission :

According to the latest IPCC summary (Denman *et al.*, 2007), arable lands emit about 2.8 Tg N of N_2O per year, about 42% of the anthropogenic N_2O sources, or about 16% of the global N_2O emissions, but rice fields have not been distinguished from upland fields. Early studies found N_2O emissions from rice fields to be negligible. However, later studies suggest that rice cultivation is an important anthropogenic source not only of atmospheric methane but also of N_2O (Cai *et al.*, 1997).

Mitigation of methane and nitrous oxide from rice fields :

Combining water-saving and nutrient management technologies can maintain yields and reduce greenhouse gas emissions from rice fields, while simultaneously reducing costs and conserving valuable inputs. And smart management of rice residues and reducing the cooking time of rice can also help reduce the impact of rice on climate change.

Reducing methane emissions:

Rice is often grown in flooded fields under anaerobic soil conditions that release methane as organic matter decomposes in the soil. Methane is a greenhouse gas

Table 2 : Methane gas emissions from rice fields in selected countries

	Total amount of emitted CH_4 (Gg CH_4)	Contribution of rice methane to total methane emission (%)	Contribution of rice methane to total greenhouse gases emission (%)
USA in 2005	328	1.3	0.1
Italy in 2005	70	3.7	0.3
Japan in 2004	274	24.0	0.4
China in 1994	10182	30.0	5.9
India in 2006	6600	35.0	9.8

Source: leip, Boochi (2007)

that is about 25 times more potent than carbon dioxide. Methane accounts for about 20% of the enhanced greenhouse effect and rice contributes about 10% of this.

IRRI's research shows that growing rice in flooded fields has proven to be a highly sustainable practice where soil health can be maintained. Irrigated rice fields have been an integral part of rice production in Asia for centuries and they are responsible for 75% of global rice production. Water-saving technologies such as alternate wetting and drying reduce the amount of time rice fields are flooded and can reduce the production of methane by about 60-90%. IRRI is promoting alternate wetting and drying as an alternative management practice.

Reducing nitrous oxide emissions :

Practices such as alternate wetting and drying that reduce methane emissions can, however, increase the production of nitrous oxide, another greenhouse gas, which is 300 times more potent than carbon dioxide. The presence of excess nitrogen in the soil, combined with 'unsaturated' fields, produces nitrous oxide. To mitigate the production of nitrous oxide, water-saving technologies must be accompanied by good nutrient management. Reducing fertilizer wastage - hence the amount of excess nitrogen in the soil reduces nitrous oxide emissions. IRRI helps farmers manage their nutrients through tools such as the Nutrient Manager, an online resource to help determine if fertilizer applications are necessary, what nutrients are needed, and what application time is optimal.

Rice residues :

After rice is harvested and dehusked, rice straw and rice husk residues remain. These residues are commonly incorporated back into the soil or burned. When incorporated, methane is produced as decomposition occurs under waterlogged conditions; when burned, methane and soot develop and contribute to climate change.

Charring - or partly burning - rice residues and adding the obtained black carbon or "biochar" to paddy fields instead of incorporating untreated harvest residues may reduce field methane emissions by as much as 80%. In addition, the black carbon is highly stable - meaning the carbon can be effectively stored in the ground for potentially hundreds or thousands of years. As an added bonus, black carbon can improve the fertility of degraded soils.

Biochar can be the byproduct of bioenergy production from rice residues, which adds the additional advantage of energy generation. For rice husk, the respective technologies are already advanced, but little is known on the use of straw. IRRI is looking at ways to overcome the practical challenges in collecting and charring rice residues at the farm or village level to help farmers take advantage of this technology.

Rice cooking time :

Everyday, millions of households cook rice and in so doing consume energy, which usually results in the emission of greenhouse gases. The cooking time of rice is determined by the temperature at which the crystalline structures of the starch begin to melt - the gelatinization temperature. Rice with low gelatinization temperature takes a short time to cook and rice with high gelatinization temperature takes longer.

IRRI is exploring whether a recently discovered gene that affects gelatinization temperature could allow rice varieties with lower gelatinization temperature to be bred. If achieved, this could decrease average rice cooking time by upto four minutes.

A decrease in four minutes of cooking time for each time rice is cooked worldwide could save more than 10,000 years of cooking time everyday, resulting in massive global energy savings and reduced emissions of greenhouse.

Current research on climate change :

– Plant breeding to improve the resilience of rice to stresses such as drought, submergence, salinity, and higher temperatures.

– Crop physiology and genetics to understand how climate change could damage rice plants and develop adaptation strategies for them.

– Social science and geographic information systems (mapping) to identify what the vulnerabilities are to climate change of an area and create adaptation measures for rice production systems.

– Soil and water management to assess the impacts of carbon, nitrogen, greenhouse gas emissions and water under different patterns of land-uses.

–Agro-meteorology to detect climatic trends.

– Systems analysis and crop modeling to develop scenarios for greenhouse gas production and emission of rice production systems.

Future research needs :

· Precision in climate change prediction with higher resolution on spatial and temporal scales;

– Linking of predictions with agricultural production systems to suggest suitable options for sustaining agricultural production;

– Preparation of a database on climate change impacts on agriculture;

– Evaluation of the impacts of climate change in selected locations; and

– Development of models for pest population dynamics.

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