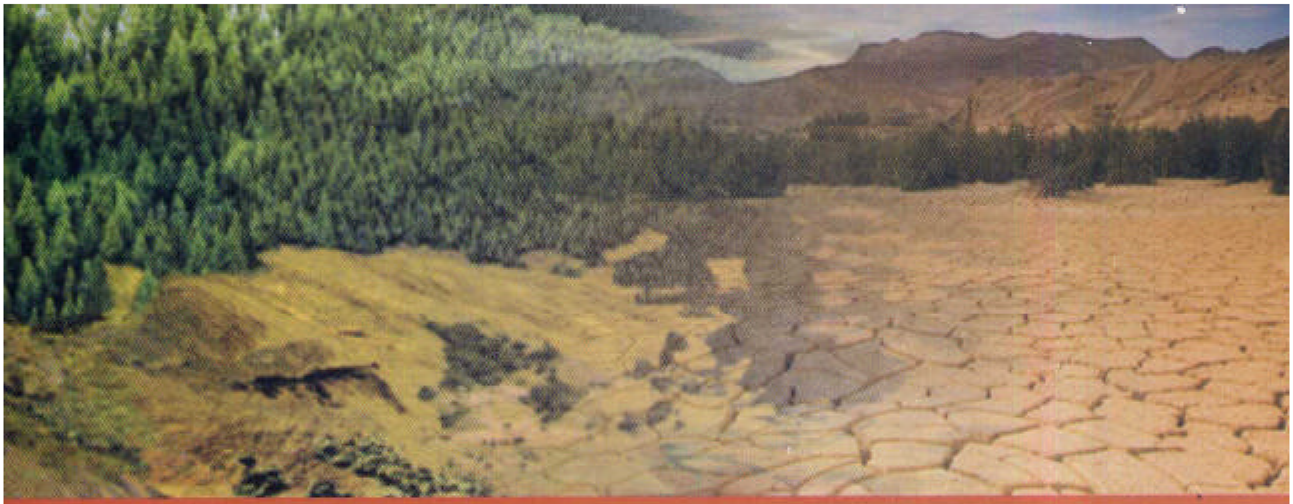
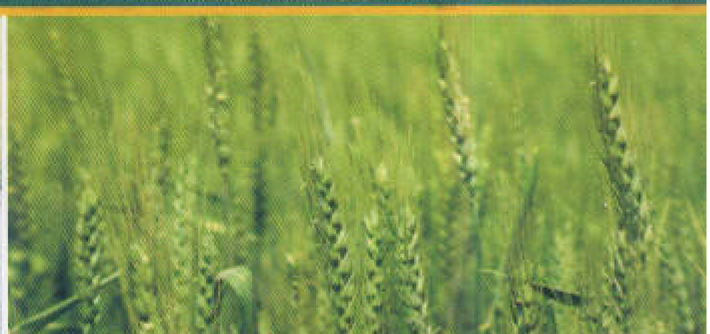


GLOBAL CLIMATE CHANGE AND INDIAN AGRICULTURE

Case Studies from the ICAR Network Project

EDITOR P.K. Aggarwal



भाकृअनुप
ICAR

Indian Council of Agricultural Research
New Delhi

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Foreword

AGRICULTURE an important sector of Indian economy, has nearly two-third population depending directly or indirectly on it for its livelihood. The rapid growth in food production during the last four decades has made us generally self-sufficient in food grain despite a large increase in population. In future, demand for food in our country is likely to increase considerably due to increasing income and population. The additional quantities will have to be produced from same or even shrinking land resource due to increasing competition for land and other resources by non-agricultural sector. Global climate change is, however, likely to exacerbate the current stresses and increase the vulnerability of food production and livelihoods of farming community. Some studies have projected that these changes could lead to a 10-40% loss in crop production by the end of this century. The increased climatic variability in future would further increase production variability.

The world community is intensively discussing means to arrest the emissions growth of greenhouse gases and reduce the impacts of climate change. Recently approved Bali Action Plan calls for cooperative action by all countries for meeting these challenges for enhanced action on mitigation and adaptation by nationally appropriate commitments and actions, technology development and transfer, and provision of financial investments and resource to support these. Irrespective of the outcome of the international negotiations on climatic change, agriculture has to become more com-petitive, efficient, profitable, and develop mechanisms to reduce its vulnerability. Evolving scientific, technological, economic and political solutions to address these challenges would be in the interest of Indian farming as well as global environment. We need to know from the Indian scientific community how much is likely to be the impact on agriculture. Which crops, commodities, regions and communities are more vulnerable? What do we need to do increase our adaptive capacity and ensure sufficient food production? Can agriculture help us in mitigating emissions of greenhouse gases?

To address these issues, Indian Council of Agricultural Research set up a Network Project on 'Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change' in 2004 and provided liberal funding support to the researchers. Since then, the Network partners have assessed the likely impacts on climate change on several crops, soils, pests, water, fish, and livestock. They have also assessed the magnitude of emissions of greenhouse gases from Indian agriculture and have evaluated the potential of various mitigation strategies. This book provides glimpses of major achievements of the work done on various themes. I wish to complement the Natural Resource Management Division of the ICAR; Dr P.K. Aggarwal, Network Coordinator; and all Institutions and scientists associated with the project for their excellent work. We hope the knowledge base in this book would help our stakeholders to better address the challenge of global climate change in agriculture sector.

(Mangala Rai)
Secretary (DARE) and Director-General (ICAR)

Executive Summary

1. THE Indian Council of Agricultural Research launched a National Network Project on 'Impacts, Adaptation and Vulnerability of Indian Agriculture to Climate Change' to assess the vulnerability of Indian agro-ecosystems to global warming, and analyze adaptation and mitigation strategies in 2004. The network has focused initially on a comprehensive understanding of the impacts of global changes on different sectors of agricultural production viz. food crops, plantation crops, horticultural crops, fish, livestock, agroforestry, soil, water, market and policy. The Network Project collaborated with 15 institutes during the Xth Plan. This report provides a summary of the major research findings of the project during the first phase, 2004-07.
2. A simulation study was conducted to assess the magnitude of impact of climate change on wheat production in India. Results indicated that if we adapt, a 1°C increase in mean temperature, associated with CO_2 increase, would not cause any significant loss to wheat production in India. Simple adaptation strategies viz., change in planting date and varieties can reduce the extent of loss caused by high temperatures. The benefits of such simple adaptation strategies, however, gradually decrease as temperatures increase to 5°C. In the absence of adaptation and CO_2 fertilization benefits, a 1°C increase in temperature alone could lead to a decrease of 6 million tonnes of wheat production. This loss is likely to increases to 27.5 million tonnes at 5°C increase in mean temperature. Increase in CO_2 to 450 ppm is likely to reduce these losses by 4 to 5 million tonnes at all temperatures. It was estimated that we could lose 3.9 million tonnes of wheat due to climate change by 2020, 11.7 million tonnes by 2050 and 23.5 million tonnes of wheat by 2080 (results for the A2 scenario of HadCM3 model). Implementing adaptation strategies may, however, be difficult considering that wheat cannot be planted earlier in most of the Indo-Gangetic plains because of late availability of fields after rice harvest.
3. Yield gap in wheat, at an aggregated level in the country, has decreased from 3.4 tonnes/ha in 1960s to 2.07 tonnes/ha in 2000 due to technology development and its adoption on a large-scale. Bridging the yield gap is an important strategy for increasing food production in the future. Research have showed that climate change is, likely to reduce this gap since both potential yields and current yields are likely to reduce with time even after considering technological growth in management. Relatively potential yields are likely to decrease much more than the current yields leading to a reduction in yield gap. Considering the slow process of bridging yield gap and the costs involved in creating appropriate environment for this, it can be concluded that global warming will constrain the progress in increasing wheat production in future unless some new technologies are evolved.
4. Climatic change is likely to reduce cereal yields significantly in TamilNadu. A simulation study showed *kharif* rice more vulnerable to climate change than maize

and sorghum. The mean reduction in rice production was 6.7, 15.1 and 28.2 % by 2020, 2050 and 2080, respectively. For the same time periods, reductions in maize and sorghum yields were 3.0, 9.3 and 18.3%, and 4.5, 11.2 and 18.7%, respectively, if no new management interventions are made.

5. Ricardian analysis based on land values is often used to analyze the vulnerability of climate change, since this considers efficient adaptations practised by farmers to climate/weather changes in the past. This analysis also indicated negative impact on the area and productivity of major crops in Tamilnadu due to past changes in rainfall and temperature. The analysis further suggests a reduction in both area and yields of major crops by 3.5 to 12.5% in Tamil Nadu due to climate change by 2050. Consequently, overall production is likely to decrease between 9 and 22%. The overall impacts are however, likely to be somewhat smaller due to non-consideration of CO_2 fertilization effect in the Ricardian analysis.
6. A dynamic coconut simulation was developed, calibrated and validated in the diverse agro-environments of the country to assess the impact of climate change. Simulation experiments based on this showed that coconut yields are likely to increase by 4%, 10%, and 20% by 2020, 2050 and 2080, respectively due to a positive impact of climate change in the western coast areas Kerala, Maharashtra,Tamil Nadu and Karnataka and negative impacts in the eastern coast areas Andhra Pradesh, Orissa, Gujarat, Tamil Nadu and Karnataka. The eastern coast is already much warmer and in future likely to experience increased temperature with global warming than the western coast. The results may vary, if future irrigation availability decreases particularly in currently irrigated areas, viz. in Tamil Nadu and Karnataka.
7. Free-air CO_2 enrichment Free air CO_2 enrichment (FACE) in open fields is a relatively expensive but appropriate methodology that is being used at some places in the developed countries to understand the response of plant to higher CO_2 in field environments. Two such Free air CO_2 enrichment rings were indigenously established at a cost Rs 2 million (50,000 US $). This included the computer control system and logging system. The running cost of the system was almost Rs.1,500/day (40$/day), and this was largely related to CO_2 consumption. The data on CO_2 levels recorded in these rings during the crop-growing period in *kharif* and rabi indicate their satisfactory performance.
8. Studies using Free-air CO_2 enrichment rings (FACE) as well as Open Top Chambers indicate that increase in CO_2 is likely to enhance the growth and yields of several field crops in future. The increase in yield at 550 ppm was 9 to 15% in mungbean, soybean and chickpea (FACE studies), 24% in tomato, 26% in onion, and 35% in castor. These enhancements were largely due to increase in number of storage organs. This indicates that the response to CO_2 is smaller than in Open Top Chambers.
9. The availability of viable pollen, sufficient numbers of germinating pollen grains and successful growth of pollen tube to the ovule are of fundamental importance for grain formation. Our field experiments showed that high temperature around flowering reduced fertility of the pollen grains as well as pollen germination on stigma in both rice and wheat crop. These effects were relatively more pronounced in basmati cultivars of rice. *Durum* wheat cultivars were more sensitive to temperature increase relative to *aestivum* cultivars.

10. Field experiments in Temperature Gradient Tunnels and by varying dates of sowing were done to quantify the effects of increase in temperature on growth and yield of rice, wheat, potato, greengram, soybean, and chickpea. An increase of temperature from 1 to 4 ^{0}C reduced the grain yield of rice (0 to 49%), potato (5 to 40%), greengram (13 to 30%) and soybean (11-36%). The linear decrease per ^{o}C temperature increase was 14%, 9.5%, 8.8%, 7.3%, and 7.2% in rice, potato, soybean, wheat, and greengram, respectively. Chickpea, however, registered a 7 to 25% increase in seed yield by an increase in temperature up to 3^{o}C, but was reduced by 13% at 4^{o}C increase in temperature. Rice showed no significant change in yield upto an increase of 1^{o}C temperature.
11. A significant decrease has been observed in average productivity of apples in Kullu and Shimla districts of Himachal Pradesh in recent times. A key reason for this could be a trend of inadequate chilling in recent decades, crucial for good apple yields. Cumulative chill units of coldest months have declined by 9.1 to 19.0 units per year in last two decades in different districts of Himachal Pradesh. As a consequence, there has been a shift of apple belt to higher elevations of Lahaul- Spitti and upper reaches of Kinnaur district of Himachal Pradesh.
12. Increase in temperatures during grain development phase of rice and wheat affect their grain quality. High temperatures reduced 1000-grain weight and amylose content and adversely affected important quality traits viz. grain elongation and aroma in basmati cultivars. In wheat, high temperatures reduced both 1000- grain weight and hecto-litre weight, and increased grain protein content. The impact was more pronounced on bread wheat than durum wheat cultivars.
13. A mechanistic population dynamics simulation model was developed and validated for rice gundhi bug, *Leptocorisa acuta,* based on the concept of thermal constants for assessing the impact of climate change on population dynamics. Considering the impact of global warming on development period as well as survival of the bug, the model showed that a 1^{o}C rise in daily average temperature of Delhi would not affect the gundhi bug population but further increase would cause appreciable decline in it.
14. The increase in atmospheric CO_2 concentration in future causes a dilution of critical nutrients in crop foliage resulting in increased herbivory. This was evident in Tobacco caterpillar, *Spodoptera litura,* who consumed 39% more castor foliage under elevated CO_2 conditions than control treatments. Final larval dry weights were also more in high CO_2 fed leaves. A larva fed with castor foliage grown under elevated CO_2 conditions developed slower and the larval duration of *Spodoptera litura* as well as castor semilooper, *Achaea janata*, was increased by 2 days. Dilution of critical nutrients in crop foliage caused the insects to feed slowly and more quantity and thus the rate of development was increased.
15. Monthly rainfall data of 1200 stations for 1871-2004 spread across the country for the rainfed areas were analyzed to determine climatic trends. Significant negative trends in annual rainfall were observed in the eastern parts of Madhya Pradesh, Chhattisgarh, parts of Bihar, Uttar Pradesh, parts of north-west and north-east India and a small patch in Tamil Nadu. Significant increase in rainfall was noticed in Jammu and Kashmir and in some parts of southern peninsula. The variability in rainfall appears to be increasing**.** There is also an increasing trend of temperature in most places.

16. Increase in temperature could result in higher mineralization and CO_2 emissions from the soil. Experimental studies on soil warming indicated that small incremental increase in temperature results in high carbon dioxide emissions in low carbon soil when compared with medium and high carbon soil, thereby making low carbon soil more vulnerable to warming. Furthermore, the greater availability of nutrients because of increased mineralization of soil organic matter led to increased abundance of gram-positive bacteria. This shift in microbial community may be important in soil organic matter dynamics.
17. Simulation modeling of water balance using HadCM3 and PRECIS scenarios indicated a likely increase in seasonal as well as annual streamflow. An increase of 26, 28, and 53% in annual streamflow was projected by 2080 under HadCM3 A2a, HadCM3 B2a and PRECIS scenarios, respectively. Even though all the scenarios indicated likely increase in annual streamflow in the Brahmani basin, a decrease in streamflow is projected during the winter and summer (June) in most of the cases. This has implications for *rabi* crops as well as for meeting the peak water demands during the summer. Greater increase in magnitude of streamflow during the monsoon could also lead to flooding and waterlogging. This indicated need for development of different adaptations strategies for winter and summer crops, including improved water management interventions.
18. Management of runoff and soil loss is important for crop management. A simulation study conducted to quantify the impact of climatic variability on runoff and soil erosion in different agro-climatic regions of India revealed that the runoff and soil loss are expected to increase significantly throughout India due to global climate change.
19. Sea surface temperature (SST) in the Indian seas may increase by about 3.0^{o}C by 2100. This is likely to affect fish breeding, migration, and harvests. The relationship of oil sardine distribution, a coastal, pelagic schooling fish, forming massive fisheries in India, with sea surface temperature was examined using data of annual oil sardine catch along each maritime state for 1961-2005. Considering the catch as a surrogate of distribution, it was found that the oil sardine has extended with time its northern and eastern boundaries of distribution. Oil-sardine fishery did not exist before 1976 in the northern latitudes and along the east coast. With a gradual slow warming of warming of sea surface, the oil sardine was able to find temperature of its preference in the waters of northern latitudes and eastern longitudes, thereby extending its distributional boundaries. It is expected that the distribution may extend further to Gujarat and West Bengal coasts in the coming years assuming that other fishery related physical and biological parameters will not vary considerably. However, if the sea surface temperature in the southern latitudes increases beyond the physiological optimum of the fish, it is possible that the population may be driven away from the southern latitudes, which will reduce the catches along the south-west and south-east coasts in the future.
20. The threadfin breams- *Nemipterus japonicus* and *N. mesoprion*- are distributed along the entire Indian coast at depths ranging from 10 to 100 m. Data on the spawning season of these fishes off the Chennai coast from 1981 to 2004 showed a good correlation between sea surface temperature and spawning activity. The occurrence of spawners linearly decreased with increasing temperature between

April and September and increased positively from October to March. It appears that sea surface temperature between 28^{o} C and 29^{o} C may be the optimum and when this is exceeded, the fish are adapted to shift the spawning activity to seasons when the temperature is around the preferred optima.

21. Coral reefs are the most diverse marine habitat, which support an estimated 1 million species globally. They are highly sensitive to climatic influences and are among the most sensitive of all ecosystems to temperature changes, exhibiting the phenomenon known as coral bleaching when stressed by higher than normal sea temperatures. To understand the effect of elevated temperatures, the large scale (50 km) sea surface temperature coral bleaching hotspot anomaly image was used as a forecasting tool for potential bleaching conditions. Results indicated reef-building corals are likely to disappear as dominant organisms on coral reefs between 2020 and 2040 and the reefs are likely to become remnant between 2030 and 2040 in the Lakshadweep region and between 2050 and 2060 in the Andaman and Nicobar regions. These projections on coral reef vulnerability have taken into consideration only the warming of seawater. Projected increase in the acidity of seawater associated with global warming might dissolve the calcium carbonate in the exoskeleton of the reefs leading to accelerated impacts.
22. Recent hydrological changes in the flow pattern of river Ganga related to changes in the climatic patterns have been a major factor resulting in erratic breeding and decline in fish spawn availability. The average fish landing in the Ganga river system has declined from 85.2 tonnes during 1959 to 62.5 tonnes during 2004. There is also a perceptible shift in geographic distribution of the fishes of river Ganga. The warm water fish species viz., *Glossogobius giuris, Puntius ticto, Xenentodon cancila, Mystus vittatus,* earlier available only in the middle stretch of river Ganga, are now available in the colder stretch of the river around Haridwar due to increase in river water temperatures in recent periods. In the middle and lower Ganga 60 genera of phytoplankton were recorded during 1959, which declined to 44 only by 1996. The Zooplankton number during the same period diminished from 38 to 26.
23. In recent years the phenomenon of maturing and spawning of Indian Major Carps has been observed as early as March in West Bengal. Its breeding season has also extended from 110 to 120 days (Pre-1980-85) to 160-170 days (2000-2005). As a result it has been possible to breed these fishes biannually at an interval ranging from 30 to 60 days. A prime factor influencing this trend is elevated temperature, which stimulates the endocrine glands of fish and helps in the maturation of the gonads.
24. Milk is an important component of food that is significantly increasing in demand. Increased heat stress associated with global climate change may, however, cause distress to dairy animals and possibly impact milk production. Temperature-Humidity Index was used to relate animal stress with productivity of milk of buffaloes, crossbred, and local cows. These studies indicated that India loses 1.8 million tonnes of milk production at present due to climatic stresses in different parts of the country. Global warming will further negatively impact milk production by 1.6 million tonnes by 2020 and more than 15 million tones by 2050. High producing crossbred cows and buffaloes will be impacted more than indigenous cattle. Northern India is likely to experience greater impact of global

warming on milk production of both cattle and buffaloes in future.

25. A rise of 2 to 6 °C due to global warming will negatively impact growth, puberty and maturity of crossbreds and buffaloes. Time required for attaining puberty of crossbreds and buffaloes will increase by 1 to 2 weeks due to their higher sensitivity to temperature than indigenous cattle. It will negatively impact oestrus expression, duration and conception of buffaloes.
26. Inventory of greenhouse gases emissions from rice and wheat production systems was developed for India using a simulation model, soil databases, acreage of crops, inputs used, and management environment. It indicated higher emissions in intensely cultivated regions of Indo-Gangetic plains, coastal Andhra Pradesh and Orissa. No-tillage mitigated emissions to a limited extent in upland cropping system. Simulated annual emission from 42.2 million ha of rice fields of India were 2.07, 0.19 and 72.90 Tg (1 Tg = 10^{12} g) of CH_4-C, N_2O-N and CO_2-C, respectively. The global warming potential of the Indian rice fields was 13.7 Tg CO_2 equivalents (316.6 if direct CO_2 emissions are also included). Annual emissions from the 27.4 million ha of wheat fields were estimated at 17.10 Gg of N_2O-N, with a GWP of 127 Tg CO_2 equivalent (164 if direct CO_2 emissions are also included).
27. An inventory of methane (CH_4) emission from enteric fermentation from livestock was developed using the revised 1996 Inter-Governmental Panel on Climate Change guidelines. India specific emission factors for ruminant livestock have been calculated based on IPCC tier2 recommended net energy equations for cattle and buffaloes. The total emission of methane from the entire Indian livestock is estimated to be 9.37Tg for 2003. Earlier studies showed this value vary from 7.26 to 10.4Tg. Buffaloes and Indigenous cattle contributed 40% each to this estimate.
28. Two new nitrification inhibitors S-Benzylisothiouronium butanoate and S-Benzylisothiouronium furoate were found to be effective in reducing emission of nitrous oxides from fertilized soil by 8.9 to 13.5% in conventional tillage and from 15.6 to 19.6% in zero tillage plots.
29. Annual C sequestration in above-ground biomass of coconut varied from 15 to 35 Mg. ha^{-1}. $year^{-1}$ depending on cultivar, agro-climatic zone, soil type and management; Annually sequestered carbon stocked in to stem in the range of 0. 3 to 2.3 Mg. ha^{-1}. $year^{-1}$. Standing C stocks in 16-year-old coconut cultivars in different agro-climatic zones varied from 15 to 60 Mg. ha^{-1}. $year^{-1}$; Annual C sequestration by coconut plantation is higher in red sandy loam soils and lowest in littoral sandy soils.
30. Agroforestry has maximum carbon sequestration potential in subtropical climate and the least in dry temperate. Its carbon sequestration potential decreased with the increase in altitudinal gradient from 468 m asl to 2100 m asl. Agri-silviculture and agri- horti-silviculture were considered to be the most suitable agroforestry systems for carbon sequestration in subtropical climate type whereas agri-horticulture was most suitable in temperate climates.
31. Various mitigation options viz., improving nutrition of animals through feed additives, and strategic supplementation and dietary manipulation are commercially available for increasing rumen efficiency and thereby decreasing methane emissions from enteric fermentation. An *ex-ante* assessment of economic

viability of selected methane mitigation options indicated that for crossbred cows and buffaloes, the decrease in loss of dietary energy as methane (CH_4) owing to adoption of methane mitigation option has the potential to increase the milk productivity. The incremental returns on account of increased milk production more than compensates for the additional cost of mitigation. If carbon-trading benefits are reaped from methane mitigation in dairy sector, the potential economic gains can be further enhanced.

P K Aggarwal
Technical Editor

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