Climate change and agriculture: Adaptation and mitigation stategies

Article *in* Indian Journal of Agronomy · June 2009

2 authors:

Bandi Venkateswarlu
Vasant Rao Naik Maratwada Krishi Vidya Peeth , Parbhani , India

Arun K. Shanker
Central Research Institute for Dryland Agriculture, India

Indian Journal of Agronomy **54**(2): 226–230 (June 2009)

Climate change and agriculture: Adaptation and mitigation stategies

B. VENKATESWARLU AND ARUN K. SHANKER

Central Research Institute for Dryland Agriculture, Santosh Nagar, Hyderabad, Andhra Pradesh 500 059

ABSTRACT

Changes in climate can be expected to have significant impacts on crop yields through changes in temperature and water availability. The purpose of mitigation and adaptation measures is therefore to attempt a gradual reversal of the effects caused by climate change and sustain development. There are several mitigation and adaptation practices that can be effectively put to use to overcome the effects of climate change with desirable results. These methods fall into the broad categories of under crop/cropping system-based technologies, resource conservation-based technologies and socio-economic and policy interventions. These measures are discussed to suggest effective strategies among them to combat climate change with specific reference to India.

Key words: Agroforestry, Carbon, Food insecurity, Intercropping, Pollutants, Rainfed farming, Rice fields, Zero tillage

Climate change is a complex alteration of climate, subtle and continuous, yet extremely important through its consequences on vegetation of various types that thrived under constant or relatively unchanged climates. The effects of climate change have reached such an extent that irreversible changes in the functioning of the planet are feared. Some of the main effects of climate change with specific reference to agriculture and food production especially during the last decade are: increased occurrence of storms and floods; increased incidence and severity of droughts and forest fires; steady spreading out of frost-free intervals and potential growing season; increased frequency of diseases and insect pest attacks; and vanishing habitats of plants and animals.

Apparently, these modifications of previously stable climates imply an obvious warming trend and a growing climatic variability impacting the exiting ecosystem. It is important for the international scientific community to use all accessible knowledge to stop or reverse this trend to the maximum extent possible. There have been various attempts and viable measures in the past to bring down atmospheric greenhouse gases (GHGs) to slow down climate change (Boer *et al.*, 2000). However, if the warming trend continues at its current pace, these may soon prove inadequate. The early impacts of climate change already are being felt worldwide. Future impacts will affect a broad array of human and natural systems, with consequences for human health, food and fiber production, water supplies, and many other areas vital to economic and social well being. While certain impacts may in the nearer term prove beneficial to some, in the long-term, the effects will be largely detrimental.

Carbon dioxide emissions from agriculture are small; but other important GHGs are emitted from agriculture. Agriculture accounts for about 60% of all nitrous oxide, mainly from fertilizer use and about 50% of methane mainly from natural and cultivated wetlands and enteric fermentation. Methane and nitrous oxide emissions are projected to further increase from 35 to 60% by 2030, driven by growing nitrogen fertilizer use and increased livestock production in response to growing food demand.

Changes in climate can be expected to have significant impacts upon crop yields through changes in both temperature and moisture. As climate patterns shift, changes in the distribution of plant diseases and pests may also have adverse effects on agriculture. At the same time, agriculture proved to be one of the most adaptable human activities to varied climate conditions (Mendelsohn *et al.*, 2001). Many investments are relatively short-term and crops and cultivars can be quickly changed to suit new conditions. For these reasons, agriculture at the global level can probably adapt to a moderate amount of global warming up to 2.5^{O}C above current levels, assuming no dramatic change in climate variability. Crops in low latitudes (tropical and sub-tropical) are more often close to their limits of heat tolerance, while growing conditions are likely to improve in higher latitudes (temperate), where agriculture might gain in competitive advantage. As in other sectors, adaptive capacity is likely to be a major factor in determining the relative distribution of adverse impacts.

The purpose of mitigation and adaptation measures is therefore to attempt a gradual reversal of the effects caused by climate change and sustain development under the inescapable effects of climate change. Here is it important to note and understand the subtle difference between mitigation and adaptation. Mitigation and adaptation are related to the temporal and spatial scales on which they are effective. The benefits of mitigation activities carried out today will be evidenced in several decades because of the long residence time of greenhouse gases in the atmosphere, whereas the effects of adaptation measures should be apparent immediately or in the near future (Kumar and Parikh, 2001). Besides, mitigation has global in addition to local benefits, whereas adaptation typically takes place on a local or regional scale.

Vulnerability to food security has (difficult phase in) grown global. Global and local food security vulnerability patterns will be modified by climate change. Small-scale rainfed farming systems, pastoralist systems, inland and coastal fishing and aquaculture communities and forest-based systems are particularly vulnerable to climate change. It is imperative to improve preparedness to future and uncertain impacts through preventive and planned adaptation and innovation, technical adaptation measures range from change in production systems like adjusting planting or fishing dates, rotations, multiple cropping/species diversification, crop-livestock pisciculture systems, agroforestry investing in soil, water and biodiversity conservation and development by building soil biomass, restoring degraded lands, rehabilitating rangelands, harvesting and recycling water, planting trees, developing adapted cultivars and breeds, protecting aquatic ecosystems to maintain long-term productivity. Adaptation measures also take account of establishing disaster risk management plans and risk transfer mechanisms, such as crop insurance and diversified livelihood systems (Reilly and John, 1996). Mitigation options include carbon sequestration in agriculture and forestry. Mitigation of climate change is a global responsibility. Agriculture, forestry, fisheries/aquaculture provide in principle, a significant potential for greenhouse gases mitigation. The IPCC estimates that the global technical mitigation potential for agriculture will be between 5,500 and 6,000 Mt CO_2-equivalent per year by 2030, 89% of which are assumed to be from carbon sequestration in soils. The potential benefits of carbon sequestration are: (i) Mitigation is done when CO_2 is removed from the atmosphere; ii) Adaptation is achieved when higher organic matter levels in soil increase agroecosystem resilience and iii) Income generation and livelihood is sustained when improved soil fertility leads to better yields.

New scope is foreseen in increasing carbon sinks in soil and in above- and below-ground biomass, and thus contributing to soil carbon sequestration under the post-2012 climate change regime by organic agriculture and conservation agriculture.

Adaptation and mitigation through improved technologies

The twin pillars under mitigation and adaptation are strategies (i) mitigation and adaptation through novel technologies in crop production and management under projected climate change scenario and (ii) sound governmental policy and political will to overcome the projected ill effects of climate change in agriculture.

The first is by successful manipulation of the direct effects of climate change on grain crops, viz. reduction in duration, embryo abortion, spikelet sterility, effects on grain number and grain size, anthesis interval etc. The strategy involved here is the efficient use of conventional breeding and molecular/ mutation breeding by the use of biotechnological tools including marker assisted selection, whole genome expression analysis and its subsequent elucidation and gene finding by bioinformatics. The indirect effects, viz. decline in water resources, increased pests and disease incidence, loss of soil organic carbon should be tackled by conservation and efficient use of water, integrated pest management and conservation farming.

Crop/cropping system based technologies

These will be mainly centered on promoting the cultivation of crops and varieties that fit into new cropping systems and seasons, development of varieties with changed duration that can overwinter the transient effects of change, release of varieties for high temperature, drought and submergence tolerance, evolving varieties which respond positively in growth and yield to high CO_2. Besides varieties with high fertilizer and radiation use efficiency and also novel crops and varieties that can tolerate coastal salinity and salt water inundation are needed.

Agricultural biodiversity and crop germplasm exploration for favorable traits is an important area that needs to be tapped to the fullest extent. Seeds, plants and plant parts exhibiting tolerance to temperature, water and other atmospheric stresses caused by climate change needs to collected and conserved to aid crop breeding research. A thorough revisit and re-evaluation of all the wild relatives, land races, extant varieties, modern varieties and breeding stocks could help in unraveling previously unknown or ignored traits than could prove more useful in the present scenario. Genetic resources could well prove to be the most important cost effective basic raw material which will allow agriculture to adapt to climate change. In India, considerable progress has been made in the genetic dissection of flowering time, inflorescence architecture, temperature, and drought tolerance in certain model plant systems and by comparative genomics in crop plants. CRIDA, Hyderabad has come out with a transformed *Sorghum bicolor* L. Moench cv. SPV462 with the mtlD gene encoding for mannitol -1- phosphate dehydrogenase from *E.coli* with an aim to enhance tolerance to water deficit and NaCl stresses (Maheswari *et al*., 2006). Germination potential of these transgenic seeds was several folds higher when challenged with salt and water stresses. In addition, they have remarkably robust root system in terms of root biomass and length. Strategies for genetic enhancement of heat tolerant genotypes especially in pulses by identifying and validating markers for high temperature tolerance coupled with yield potential is one of the key technological advances that can prove to be a significant strategy for adapting to climate change. An additional strategy is to take advantage of faster growth under higher temperatures, the new varieties, especially of the *rabi* cropping season should have characteristics of early flowering (photo- and temperature-insensitivity, but development-related onset of flowering) and early maturity and high produce.

Improved and novel agronomic and crop production practices like adjustment of planting dates to minimize the effect of high temperature increase-induced spikelet sterility can be used to reduce yield instability, by avoiding flowering to coincide with the hottest period (Gadgil, 1995) . Adaptation measures to reduce the negative effects of increased climatic variability as normally experienced in arid and semi-arid tropics may include changing the cropping calendar to take advantage of the wet period and to avoid extreme weather events during the growing season. Crop varieties that are resistant to lodging may withstand strong winds during the sensitive stage of crop growth. In addition, improved crop management through crop rotations and intercropping, integrated pest management, supplemented with agroforestry and afforestation schemes will be an important component in strategic adaptation to climate change in India. In grazing lands, pasture improvement is essential to combat impeding changes through planned grazing processes, enclosures for recovery, or enrichment planting.

Intercropping is an efficient strategy that can be followed with desirable outcome in the present climate change scenario. Grain-legume intercrops have many potential benefits such as stable yields, better use of resources, weeds, pest and disease reductions, increased protein content of cereals, reduced N leaching as compared to sole cropping systems. Establishment of seed banks are of crucial importance in highly variable and unpredictable environments. This facility will provide a practical means to re-establish crops obliterated by major disasters and extreme climate events. This will also help in plant community dynamics, as differential plant germination strategies to buffer against inter-annual variability in growing conditions.

The promotion of scientific agroforestry forms a key component in the war against climate change. Agroforestry systems buffer farmers against climate variability, and reduce atmospheric loads of greenhouse gases. Agroforestry can both sequester carbon and produce a range of economic, environmental, and socio-economic benefits. For example, trees in agroforestry systems improve soil fertility through control of erosion, maintenance of soil organic matter and physical properties, increased N accretion, extraction of nutrients from deep soil horizons, and promotion of more closed nutrient cycling.

Resource conservation-based technologies

The key resource conservation-based technologies are *in situ* moisture conservation, rainwater harvesting and recycling, efficient use of irrigation water, conservation agriculture, energy efficiency in crop production and irrigation and use of poor quality water. The suggested strategies are: characterization of bio-physical and socio-economic resources utilizing GIS and remote sensing; integrated watershed development; developing strategies for improving rainwater use efficiency through rainwater harvesting, storage, and reuse; contingency crop planning to minimize loss of production during drought/flood years (Kapoor, 2006). Zero tillage (ZT) has effectively reduced the demand for water in rice-wheat cropping systems in more than 1 million ha of area in the Indo-Gangetic Plains. With ZT technology, farmers can realize higher yields and reduce production costs. In addition, ZT has a direct mitigation effect as it converts the green house gases like CO_2 into O_2 in the atmosphere and carbon, and enriches soil organic matter. Bed-planting is widely adopted in the Indo-Gangetic Plains, proved to be a successful conservation technology. The main advantages are: increased water use efficiency, reduced water logging, better access for inter-row cultivation, weed control and banding of fertilizers, better stand establishment, less crop lodging and reduced seed rates.

In coastal salinity, the *Doruvu/Kottai* technology for managing seawater intrusion in coastal areas was practised effectively in Andhra Pradesh and Tamil Nadu in India. This mainly involves digging of deep (upto 6 m) open wells, which allows horizontal flow of underground water enabled in to the well through pipes. This technology helps in increased fresh water storage in comparatively lesser area giving more water to pump and irrigate crops.

System of Rice Intensification (SRI) has key benefits under the present climate situation. This technology primarily consists of keeping the rice fields moist rather than continuously saturated, thereby minimizing anaerobic conditions, and improving root growth and diversity of aerobic soil organisms; rice plants are spaced optimally to permit more growth of roots and canopy and to keep all leaves photosynthetically active; and rice seedlings are transplanted when young with two leaves, quickly, shallow and carefully, to avoid trauma to roots and to minimize transplant shock. SRI offers a potential strategy to counter climate related risk because it uses less water. The resistance of SRI plants to lodging caused by wind and/or rain, given their larger root systems and stronger stalks, is a useful trait for extreme floods. SRI method reduce the agronomic and economic risks that farmers face with the advent of climate change.

Integrated Nutrient Management (INM) and Site-Specific Nutrient Management (SSNM) also have the potential to mitigate effects of climate change. Demonstrated benefits of these technologies are; increased rice yields and thereby increased net CO_2 assimilation, 30-40% increase in nitrogen use efficiency. This offers important prospect for decreasing greenhouse gas emissions linked with N fertilizer use in rice systems. It is critical to note here that higher CO_2 concentrations in future will result in temperature stress for many rice production systems, but will also offer a chance to obtain higher yield levels in environments where temperatures are not reaching critical levels. This effect can only be tapped under sufficient integrated and site directed nutrient supply particularly nitrogen (N). Phosphorus (P) deficiency, for example, not only decreases yield, but also triggers high root exudation and increases CH_4 emissions. Judicious fertilizer application, a principal component of SSNM approach, thus has 2-fold benefit *i.e.* reducing GHG emissions; at the same time improving yields under high CO_2 levels. One of the key emerging technologies to reduce GHG emissions from paddy fields is the use of zymogenic bacteria, acetic acid and hydrogen-producers, methanogens, CH_4 oxidizers, and nitrifiers and denitrifiers in rice paddies which help in maintain the soil redox potential in a range where both N_2O and CH_4 emissions are low (Hou et al., 2000). The application of 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. Use of neem-coated urea is another simple and cost effective technology which can be practised in the entire South Asia by small farmers. Promotion of integrated farming systems for marginal and small farmers will also be a viable and effective alternative in combating climate change. Multiple-enterprise agriculture wherein crop, livestock, poultry, fish farming and trees in a single unit of land will minimize risk.

Policy interventions

Apart from the use of technological advances to combat climate change related impacts on crop production, there has to be sound policy framework and strong political will on the part of the government to effectively battle climate change. A sound policy framework should address the issues of redesigning social sector with focus on vulnerable areas/ populations, introduction of new credit instruments with deferred repayment, liabilities during extreme weather events, and weather insurance as a major vehicle to transfer risk. Governmental initiatives should be undertaken to identify and prioritize adaptation options in key sectors, viz. storm warning systems, water storage and diversion, health planning and infrastructure needs. Focus on integrating national development policies into a sustainable development framework that complements adaptation should accompany technological adaptation methods. Emphasis should also be given on tapping financial resources to strengthen adaptation efforts within countries. Besides the role of local institutions in strengthening capacities e.g. SHGs, banks and agricultural credit societies should be promoted. Role of community institutions and the role of private sector in relation to agriculture should be a matter of policy concern. There should be political will to implement economic diversification in spreading diverse livelihood strategies, migrations and financial mechanisms (Schneider *et al.*, 2007). Policy initiatives in relation to access to banking, micro-credit/insurance services before, during and after a disaster event, access to communication and information services is imperative in the envisaged climate change scenario.

Some of the key policy initiatives, to be considered, are: (i) mainstreaming adaptations by considering impacts in all major development initiatives. (ii) facilitate greater adoption of scientific and economic pricing policies, especially for water, land, energy and other natural resources. (iii) consider financial incentives and package for improved land management and explore CDM benefits for mitigation strategies and (iv) establish "Green Research Fund" for strengthening research on adaption, mitigation and impact assessment.

It is concluded that even though climate change in India is a reality and impending negative consequences are predicted, a more certain assessment of impacts and vulnerabilities and a comprehensive understanding of adaptation options across the full range of warming scenarios, sectors and regions would go a long way in preparing the nation for climate change.

The following researchable issues are identified for future:

(i) Breeding for improved crop varieties with specific reference to growth and flowering phenology, photo sensitivity/insensitivity, stability in response to inputs viz., lodging resistant, optimum tillering, harvest index etc.

(ii) Evolving efficient water and soil management practices in addition to identification of crops and varieties with high water use efficiency, dry matter conversion ratio, positive response to temperature extremes and elevated CO_2.

(iii) Identifying new intercropping and novel farming system combinations including livestock and fisheries, which can withstand predicted climate change situations and can be economically viable.

(iv) Identifying cost effective methods for reducing greenhouse gas emission from rice paddies and also from cropping systems with livestock components.

(v) Promoting conservation agriculture practices especially in water harvesting, nutrient, pest and disease management.

REFERENCES

Boer, G., Flato, G. and Ramsden, D. 2000. A transient climate change simulation with greenhouse gas and aerosol forcing: projected climate for the 21st century. *Climate Dynamics* **16**: 427–450.

Gadgil, D. 1995. Climate change and agriculture: An Indian perspective. *Current Science* **69**(8): 649–659.

Kapoor, A. 2006. Mitigating natural disasters through preparedness measures. Proceedings of the International Conference on Adaptation to Climate Variability and Change, 5-7 January 2006, New Delhi, organized by Institute for Social and Environmental Transition and Winrock International India. 184 pp.

Kumar, K.S.K. and Parikh, J. 2001. Indian agriculture and climate sensitivity. *Global Environmental Change* **11**(2): 147–154.

Maheswari, M., Varalaxmi,Y., Vijayalashmi, A., Yadav, S.K. Sharmila P., Venkateswarlu, B., Pardha Saradhi, P. 2006. 'Metabolic engineering for abiotic stress tolerance in soghum using mtlD gene'. Paper presented in the International Symposium on Frontiers in Genetics and Biotechnology- Retrospect and Prospect at Osmania University, Hyderabad, January 8-9 2006.

Mendelsohn, Robert., Dinar, Ariel. and Sanghi, Apurva. 2001. The Effect of Development on the Climate Sensitivity of Agriculture. *Environment and Development Economics* **6**: 85–101.

Reilly, Y. and John. 1996. Agriculture in a Changing Climate: Impacts and (Eds.) Adaptations" in Watson, Robert, Manufu Zinyowera, Richard Moss, and David Dokken. Climate Change 1995: Impacts, Adaptations, and Mitigation of Climate Change: Scientific- Technical Analyses Cambridge University Press: Cambridge pp.427–468.

Rosenzweig, Cynthia. and Parry, Martin. 1994. Potential Impact of Climate Change on World Food Supply. *Nature* **367**: 133–138.

Tol, Richard. 2002. Estimates of the damage costs of climate change. Part 1: benchmark estimates. *Environmental and Resource Economics* **21**: 47–73.

Schneider, S.H., Semenov, S., Patwardhan, A., Burton, I., Magadza, C.H.D., Oppenheimer, M., Pittock, A.B., Rahman, A., Smith, J.B., Suarez, A. and Yamin, F. 2007. Assessing key vulnerabilities and the risk from climate change. Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.). In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York, pp. 779–810.