Brainstorming Workshop on Climate Change, Soil Quality and Food Security

Proceedings & Recommendations

August 11, 2009
NASC Complex, Pusa Campus,
New Delhi-110012

taas
Progress Through Science

Trust for Advancement of Agricultural Sciences
Avenue II, Indian Agricultural Research Institute
New Delhi

Progress Through Science

TRUST FOR ADVANCEMENT OF AGRICULTURAL SCIENCES (TAAS)

GOAL

An accelerated movement for harnessing agricultural sciences for the welfare of people.

MISSION

To promote growth and advancement of agriculture through scientific interactions and partnerships.

OBJECTIVES

- To act as think tank on key policy issues relating to agricultural research for development (ARD).
- Organizing seminars and special lectures on emerging issues and new developments in agricultural sciences in different regions of India.
- Instituting national awards for the outstanding contributions to Indian agriculture by the scientists of Indian and other origin abroad.
- Facilitating partnerships with non-resident Indian agricultural scientists visiting India on short leave.

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Preamble

The Green Revolution of the 1960s and 1970s saved millions of people from starvation globally and is one of the major success stories of the 20th Century. In India, food grain production increased from 59 million tonnes (Mt) in 1955 to 231 Mt in 2008, while its population increased from 400 million to 1137 million during the same period. Thus, the per capita grain production remained above the population growth. Despite impressive gains in crop yields and increase in per capita food availability, there are greater challenges that lie ahead. The major challenges of agriculture in the 21st century include feeding the rapidly growing population in the background of shrinking natural resource base and increasing risks associated with climate change.

Global warming and associated climate changes are increasingly impacting agriculture in several ways which have serious implications for the national and global food security. At the same time, agriculture related activities contribute significantly to climate change through release of green house gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) and also by altering the land use pattern. Land use changes owing to deforestation and desertification, and use of fossil fuels are the major anthropogenic sources of carbon dioxide, while agriculture is the primary contributor of methane and nitrous oxide.

Asia currently accounts for about 26 per cent of global carbon dioxide (CO_2) emissions and its share of emissions is projected to increase to nearly 50 per cent by 2030. This raises a global concern calling for urgent measures to develop strategies to mitigate the threats to agriculture due to climate change and maintain the productive capacity of soil and water in the near future. The new measures would demand reorientation of agricultural research to comprehensively address these challenges and meet the Millennium Development Goals (MDGs) to reduce poverty, hunger, and malnutrition.

Keeping the above challenges in mind, a brainstorming workshop was organized by the Trust for Advancement of Agricultural Sciences (TAAS) for an in-depth discussion on food security and soil quality in the context of climate change. The main objective was to find a workable strategy for mitigation and adaptation to climate change and for this immediate implementation to ensure food security. The workshop was attended by a select group of leading agricultural experts from the national and international organizations; policy makers; scientists; and leaders of corporate sector, financial institutions, and organizations representing farming community and civil society.

Inaugural Session

The Inaugural Session was chaired by Dr. M.S. Swaminathan and co-chaired by Dr. R.S. Paroda. Dr. Paroda extended a warm welcome to Dr. Swaminathan and all the delegates. He highlighted the importance and objectives of the brainstorming workshop. He emphasized that major challenges before the world community in the twenty-first century are rapid increase in global population, degradation of agricultural land and other natural resources and emission of greenhouse gases in the atmosphere leading to climate change. He further mentioned that despite impressive gains in the past, Indian agriculture is facing enormous challenges. Achievement of the target growth of 4 percent per annum to meet the challenges of food security, arresting degradation of natural resources, and managing adverse impact of climate change are essential. He said that, in a true sense, Indian agriculture is currently at the cross-roads. It was also emphasized that there is a need to look forward and devise appropriate strategies and policies to address the present challenges, particularly climate change, soil quality and food security on a priority basis, and harness new growth opportunities. It was in this context that the present brainstorming workshop was organized with participation of key stakeholders under the chairmanship of Dr. M.S. Swaminathan.

Dr. M.S. Swaminathan, Chairman, M.S. Swaminathan Research Foundation and Member, Rajya Sabha, in his opening address, mentioned that the threat of food insecurity and vulnerability of poor and under-privileged people will be further intensified by the likely adverse impact of climate change on Indian agriculture. The climate change is a real threat which we are facing today and erratic monsoon behaviour this year is a clear example. Dr. Swaminathan stressed the need for the second Green Revolution, which will come through integrating plant genotypes and crop management practices for achieving food security while sustaining natural resources. In view of enormity of the present challenges, global community came forward to address these concerns through a series of deliberations. In this respect, the initiative taken by TAAS to hold this brainstorming workshop is indeed very timely.

Keynote Papers

Prof. Rattan Lal, a renowned expert on carbon sequestration and climate change and Director, Carbon Management and Sequestration Center, the Ohio State University, USA, presented his keynote paper on "Managing Soil Resilience for a Warming Climate and Decreasing Resources." Prof. Lal highlighted that achievements of Indian agriculture were among major global success stories during the second half of the 20th century. Food grain production in India increased from 59 to 231 million tonnes (Mt), while the population increased from 400 to 1137 million from 1955 to 2008 respectively. Thus, the per capita grain production exceeded the population growth. However, much greater challenges lay ahead as the population of India in 2050 will be 1750 million and the per capita availability of land will be 0.089 ha with projected freshwater supply of merely 1190 m^3/year. The problem is further exacerbated by the projected climate change, vulnerability of soil to degradation and desertification, urban encroachment and rapid industrialization. Yet, the food grain production must be doubled by 2050. The production of wheat must be increased from 78 Mt in 2008 to 109 Mt in 2020. The area under irrigation must be doubled from 57 Mha in 2000 to its maximum potential of 114 Mha by 2050. The use of fertilizers has also to be doubled from current 107 kg/ha to around 200 kg/ha. In addition, improving the use efficiency of fertilizer, water and other external inputs is extremely important.

Prof. Lal further stressed that India has adequate land and water resources, strong research base, highly trained professionals, and hardworking farmers. Therefore, the objective to meet future food demand, while improving quality of soil and water resources and adapting to changing climate is an achievable target. However, future gains in production would come from the use of improved soil-based systems in combination with elite germplasm. Therefore, we must focus on the following five strategies: (i) restoring degraded soils and ecosystems through increase in carbon (C) pools in soils and vegetation, trade C credits similar to other farm commodities and create another income stream for farmers, (ii) improving efficiency of the use of fertilizers, water, and other inputs, (iii) improving soil/ecosystems/social resilience, (iv) providing incentives to farmers for payments of ecosystem (environmental) services, and (v) adopting land-saving technologies. The strategy should be to learn and change, Prof. Lal emphasized. However, the key question was how can we expand the opportunities and facilitate human learning to strengthen soil/ecosystem and social resilience. The resilience was not just bouncing back but permanently retaining the ability to bounce back.

Therefore, land use and soil management systems must be such that it improves soil's buffering capacity against natural/anthropogenic perturbations through improvement in four distinct but related components of soil quality (e.g., physical, chemical, biological, and hydrological). Improvement and maintenance of soil quality is essential for enhancing soil's resilience which is essential for ensuring food security in a changing climate. Prof. Lal concluded that soil resources must never be taken for granted; these must be used, restored and even improved for security of the future generations.

Dr. J.S. Samra, Chief Executive Officer, National Rainfed Area Authority (NRAA), in his presentation on "Strategies for Managing Soils for Improved Productivity in the Rainfed Areas" emphasized that climate, soil, irrigation, improved inputs and technological interventions are the major drivers of food security, national integrity and sovereignty. He stressed that global warming and climatic change, their interaction with other resources, and impacts on people's livelihood and sustainability of ecosystems are the major concerns of researchers, planners, administrators and independent thinkers. High frequency and intensity of extreme weather events like uneven precipitation leading to droughts and floods, heat and cold waves, hailstorms, gales, cyclones/super cyclones, drought in the flood-prone and flood in drought-prone agro-ecological regions are some of the manifestations of global warming. The complex dynamics of climatic change and its interplay with natural resources and social capital provide opportunities as well as challenges. We need to convert the disadvantages into advantages. In this context, deficit rainfall in 2009 was quite unique requiring innovative and imaginative solutions. Dr. Samra highlighted some of the distinctive features of special monsoon of 2009 which should be the focus of policy initiatives. These are:

1. The monsoon arrives early in the southern parts of India but its advance to the north is delayed by about two weeks. Scanty rainfall in the otherwise high rainfall states of Jharkhand and Himachal Pradesh, under filling of major water reservoirs resulting in reduced generation of hydro-electric power and curtailed canal and ground water irrigation were major peculiarities of the monsoon.
2. High temperature and low humidity related animal diseases like Hyperthermia, Ephemeral fever have been reported from various parts of India. Reduced productivity of fodder and its deteriorated quality due to accumulation of hydrocyanic acids (HCN), nitrates, nitrites, lower concentration of essential elements and impaired digestibility are the other adverse impacts of drought.
3. Unlike food for work in the past, it is for the first time that the States have demanded electricity and subsidy on diesel which reiterates that ground water utilization is being looked upon for drought proofing. Additionally, there was a shortfall of about 6 million ha in the sown area of rice and about one million ha in groundnut.

Proposed strategy to combat these adverse impacts should comprise the following:

1. Shortfall in production of rice, groundnut and forages due to deficit in rainfall can be compensated by intensification of production in areas receiving normal rainfall. Also, intensification of boro rice, winter maize, rabi/summer sorghum and groundnut in less risky areas should be undertaken.
2. Rescheduling of canal irrigation, uninterrupted supply of electricity for ground water utilization, and adoption of water saving technologies like laser land levelling, micro-irrigations (sprinklers, drip system and fertigation), and direct-seeded rice need special emphasis as well as policy support for their adoption.
3. Rice residue being burnt in north-west India should be used effectively for *in-situ* recycling under no-till system as well as may be bailed, densified and fortified to set up fodder banks.

Dr. I.P. Abrol, Director, Centre for Advancement of Sustainable Agriculture (CASA) presented an insight into the natural resource management scenario while presenting his paper on "Conservation Agriculture – Addressing Emerging Soil Health, Climate Change and Food Security Concerns." He indicated that the Indian agriculture is facing multiple challenges and this fact is no longer questioned. However, nature, magnitude and complexity of the challenges which needed to be confronted have been deliberated over the past 2-3 years at the highest level (National Development Council, Planning Commission and Report of the Commission on Farmers) and are now well understood in a broad manner. These challenges are (i) stagnating productivity growth, (ii) widespread land and water degradation and diversion to other uses, (iii) increasing production and income disparities in rainfed agriculture and small farmers, and (iv) climate change.

As a follow-up, a number of initiatives have been taken by the Government of India to infuse resources to overcome the immediate crisis (*Rashtriya Krishi Vikas Yojana*, National Agricultural Innovation Project, National Food Security Mission, National Rainfed Area Authority). It was, however, clearly recognized by the Planning Commission that the most critical factor limiting the growth related to 'technology fatigue' and that India's Agricultural Research and Education System must undergo transformation in ways which enable it to respond more effectively to the pressing problems. Dr. Abrol stressed that there was a need for a paradigm shift to transform from present 'commodity centric' to 'farmer centric' (farming) system-based research in finding solutions of the pressing problems. We need to have a clear strategy that assigns definite responsibilities to various research organizations based on prioritized research agenda (adaptive, applied, strategic/basic research). There should be mechanisms which permit large scale testing, refinement, and adaptation of technologies developed in a disciplinary mode before they are ready for wider adoption. This is necessary to strengthen research-extension-farmer continuum involving all stakeholders.

Emphasizing the importance of Conservation Agriculture (CA), Dr. Abrol mentioned that it is a concept which has evolved as a response to concerns of sustainability of agriculture globally. This concept called for translating three basic principles into region/ location specific technologies and practices as a way to address farmers' problems. The three principles are: (a) developing and promoting a system of raising crops that involve minimum soil disturbance (e.g., zero-tillage), (b) keeping soil surface covered by adopting practices such as leaving crop residues on soil surface, growing cover crops etc., and (c) promoting diversified crop sequencing through crop rotations, intercropping, agro-forestry etc. Sufficient scientific evidence has accumulated to show that practices based on these principles, when adopted in an integrated way, in the context of watershed development over a period of time contribute to (i) sustained productivity increases, (ii) reversing processes of land and water degradation, (iii) improving soil health and quality, (iv) enhancing biodiversity, (v) enhancing capacity to mitigate GHGs and cope with climate change, and (vi) strengthened ecological foundation for sustained agricultural development.

Dr. Abrol further stressed that CA provided an entry point for much needed change for integrating farmers' knowledge and experience in developing and refining technologies, establishing seamless research-farmer-extension linkages, ensuring institutional and policy change for technology generation and adoption. CA has made good progress globally and adopted over 108 million hectares mainly concentrated in South and North America having serious problems of land degradation. In India, a good beginning has been made through the efforts of the Rice-Wheat Consortium. Now it should be mainstreamed in the national research and development agenda through putting in place a strong 'CA Adaptive Research and Policy Program' for priority production systems and ensure appropriate linkages of regional stations with the main campus of SAUs and ICAR institutes on the one hand and field agencies on the other. The CA programs would also need greater socio-economic and policy research (monitoring, assessment), understanding of local resource endowments and dependence of local people on them, farm machinery development, participatory farming system research, and collaboration with the best of institutions globally. In his concluding remarks, Dr. Abrol stressed that capacity of India's Agricultural Research and Education System to provide knowledge base for new generation technologies depends critically on the system's ability to undergo transformation in tune with the new challenges.

Dr. P.K. Aggarwal, National Professor, Indian Agricultural Research Institute, presented his paper concerning implications of global climate change on Indian agriculture. In his presentation entitled "Adaptation to climate change and improving soil health," he highlighted that climatic risks are common in Indian Agriculture as 66 percent of arable land in the country is rainfed where drought is a common phenomenon. During the past 130 years, we had experienced 26 droughts including severe droughts of 1987 and 2002. Irrigation which is considered to be drought proofing measure is also dependent on monsoon. The other weather aberrations as a consequence of climate change are frequent floods in eastern India, frost in north-western India, cyclones in eastern coast and frequent heat stress. While quantifying the losses due to climatic risks in recent times, severe drought of 2002 led to the loss of 29 Mt food grain production, whereas cold wave of January 2003 resulted in poor fruiting in mango, papaya, banana, brinjal, tomato and poor yield of potato, winter maize, and boro rice. Similarly, heat wave of March 2004 resulted in the loss of 4 Mt of wheat and significant losses in mustard, peas, linseed, vegetables and fruits. This indicates that the climatic risks associated with global warming are increasing.

Cereal productivity is expected to decrease by 10-40% by 2100. An increase of 1°C in temperature might reduce annual wheat production by 4-5 Mt unless we adapt to the changing climate. The projected increase in temperature and change in other climatic conditions will result in greater instability in food production and threaten the national food security and livelihood of farmers. Production of enough food for meeting increasing demand without degrading the environment is a challenging task, especially when natural resources are shrinking and global climate is changing. This would require increased adaptation and mitigation research, capacity building, changes in policies, regional cooperation, and pooling of the global resources. Simple adaptations such as change in planting dates and crop varieties could help in reducing impacts of climate change to some extent. Additional strategies will entail developing appropriate technologies and building capacity of framers to cope with climate risks. The elements of both adaptation and mitigation strategies were highlighted as follows:

1. Assisting farmers in coping with current climatic risks through providing weather related information, including early warning, crop insurance, pest surveillance and community partnership in food, forage and seed banks.
2. Intensify food production systems and bridge yield gaps for higher crop productivity. This will require promotion of technologies like integrated pest management (IPM), integrated nutrient management (INM), supply of quality inputs and farmers' trainings. Plant breeding efforts for adaption to climate change should be intensified.

3. Improving land and water management in view of glacier melting and increased rainfall variability and promotion of resource conservation technologies (RCTs) with adequate incentive for their adoption.
4. Sequestering carbon in soils by soil restoration, addition of organic manures and minimal tillage. Improved management of livestock diet, efficiency of energy use in agricultural machinery, and higher use of wind and solar power should be encouraged.
5. Enabling policies and regional cooperation for securing finances and technologies for adaptation and building capacity in global climate change assessments, including evaluating biophysical and economic potential of various adaptation strategies.

Dr. H.S. Gupta, Director, Indian Agricultural Research Institute (IARI) made a presentation on "Genetic Enhancement of Crops for Adaptation to Climate Change and Abiotic Stresses." His paper provided an insight on genetic improvement strategies including conventional and modern molecular breeding. Dr. Gupta emphasized the following main issues:

1. Rising temperature and CO_2 levels are reducing crop yields due to increased transpiration and respiration losses, increasing insect-pest damage, and shifting the crop calendar.
2. Genetic enhancement of crops should be re-oriented to address the concerns of stagnant productivity growth of major crops in the country due to multiple abiotic stresses and mitigation and adaptation to climate change. Varieties need to be bred for enhanced input use efficiency, fragile ecosystems like drought and water logging conditions. Marker assisted breeding, tilling/ecotilling and exploiting alien genes from wild species for better adaptation should also be pursued.
3. Understanding plant physiological processes for developing genotypes for stress environments. Plant phenotypic traits like canopy temperature depression (CTD) and membrane injury index could be the reliable measures to adapt to increasing temperature and reduced moisture.
4. The earlier identified genes for drought (hardy gene), submergence (sub-1), salinity (ots A and B) need to be transferred to the existing varieties for better adaptation to fragile environments.
5. Wheat genotypes like HD 2802, PBW 892, PBN 142, WH 730 have been developed to withstand terminal heat and various area specific varieties have been released like Raj 3765 for North West Plains, DBW 14 for North East Plains and PBW 373 for North East and West Plains. Similarly several rice varieties adaptive to different climatic conditions have been released.

6. Most pulses in India were suffering from abiotic stresses which led to 15-30 percent yield loss. Therefore, transformation is required using DREB gene for incorporating tolerance for drought, salinity and cold.
7. Maize in India suffered from drought stress at flowering and water-logging in early vegetative stage and these stresses are going to increase during the coming decades due to emerging climatic risks. Therefore, strategies are needed to use most elite germplasm for breeding program at hot spots, promote markers assisted recurrent selection, develop transgenics, introduce elite DT lines from CIMMYT, and support allele mining and QTLs mapping for component traits.

Dr. Gupta concluded by saying that there was a need for strong research and policy support as the cost of adaptation and mitigation was likely to be high, but on the contrary, the cost of inaction would be even much higher.

Dr. R.S. Paroda in his presentation on "Imperatives of Global Climate Change for Agricultural Research in Asia-Pacific" highlighted that Asia is the home for more than half of the world population and occupies only one-third of global land. Rapid increase in population and economy implies higher demand for food in the region which would be 30-50 percent more by 2020 than the current demand. Producing this food from same or even less land and inferior quality of other natural resources is a challenge before scientific community. This challenge will be further compounded by the need for keeping pace with changing environmental and climatic scenario and rising cost of inputs in most of the countries in the Asia-Pacific region.

Highlighting the impact of climate change on agriculture, Dr. Paroda mentioned that changing climatic scenario was projected to impinge on sustainable development of most developing countries of Asia as it compounded the pressures on natural resources and environment which in turn were associated with rapid urbanisation, industrialisation, and economic development. The impact of climate change on agriculture is now real, and without adequate adaptation and mitigation strategies, food insecurity and loss of livelihood are likely to be witnessed in Asia in near future, Dr. Paroda added.

Increase in the emission of green house gases (GHGs) has resulted in global warming by 0.74°C between 1906 and 2005. It has been further projected that increase in temperature by the end of this century is likely to be in the range 2 to 4.5°C. It is expected that future tropical cyclones would become more intense, with larger peak wind speeds and heavier precipitation. Himalayan glaciers and snow cover are projected to shrink. It is also very likely that hot extremes, heat waves, and heavy precipitation events would continue and become more frequent. Increase in the amount of precipitation is expected more in high-latitudes, whereas reduction is likely in most sub-tropical regions. At the same time, sea level is expected to rise between 0.18 to 0.59 meters by the end of this century. Freshwater availability in Central, South, East and Southeast Asia particularly in large river basins is expected to decrease due to climate change which could adversely affect more than a billion people by the 2050.

Climatic changes are affecting agriculture through their direct and indirect effects on crops, soils, livestock and pests, which in turn affect global food security. There are likely to be negative effects on livestock productivity due to increased heat stress, lower pasture productivity, and increased risks due to animal diseases. Increase in sea surface temperature and acidification will also lead to changes in the distribution of marine species as well as their production.

Dr. Paroda highlighted that APAARI has been instrumental in promoting regional cooperation for agricultural research in the Asia-Pacific region and it has organized series of expert consultations on emerging issues *vis-à-vis* agricultural research and development (ARD) concerns in the Asia-Pacific region. In this endeavour, 'food crisis' and 'climate change' were identified as major themes during the expert consultation on "Research Need Assessment" organized by APAARI in 2006. Accordingly, the issue of climate change and its imperatives for agricultural research in the Asia-Pacific region was deliberated in an International Symposium jointly organized by APAARI and JIRCAS in November 2008 at Tsukuba (Japan) and the participants were from NARS, CGIAR, IARCs, GFAR, ACIAR, JIRCAS, ARIs, universities and regional fora. "The Tsukuba Declaration on Adapting Agriculture to Climate Change" spelled out research priorities for adaption of agriculture to climate change. The recommendations of this declaration have been widely distributed among the key stakeholders.

Discussion

It was broadly agreed that the Indian agriculture is at the crossroads. It has to find ways to feed the growing population while being environmentally, socially and economically sustainable. In India, past achievements in agriculture are significant but some of the current farming practices are posing new threats to the future of agriculture. India, a natural resource rich country, having strong research base and highly trained professionals, needs to focus on developing and deploying technologies to improve use efficiency of water, fertilizers, labour and energy for improving soil, ecosystems, and social resilience, restoring degraded agro-ecosystems, and create alternate sources of income for farmers through various means including carbon trading. Natural resources should not be taken for granted but need to be improved and restored for future generations.

The major adaptation and mitigation strategies for climate change should include conservation agriculture, developing elite germplasm for abiotic (drought, flood, temperature, salinity etc.) stress-tolerance, local refinement of technologies, dissemination of weather linked value-added advisory services, integration of indigenous/traditional knowledge with modern science for adaptation to climate change, and developing social security net for risk management such as crop insurance, seed banks etc. Some policy measures to support agriculture currently somehow act as disincentives. Important among these are subsidization of electricity leading to uncontrolled groundwater depletion, and almost free water leading to excessive use for irrigation, imbalanced use of fertilizers, lack of incentives to conserve common resources like pastures and watersheds, lack of incentives to conserve *in-situ* agro-biodiversity, non focus on conservation agriculture, etc. In the short term, this means that farmers switching from modern intensive agriculture to resource-conserving agriculture can rarely do so without incurring additional transition cost. In the long term, it means that sustainable agriculture may not be able to spread widely beyond those of some sporadic/localized successes. Therefore, there is need for harmonizing policy, technologies and farm practices for promoting sustainable production systems, especially in the context of climate change. Since there is greater diversity of production systems, natural resource endowments and dependence of the poor on natural resources for their livelihood, a diversified approach suiting to the specific local conditions and combining traditional knowledge with the modern technologies has to be encouraged. Climate change being a global challenge, it will be worthwhile taking advantage of the available world wide knowledge and resources to address specific local problems. However, the main action must be around the implementation of national policy on climate change, already in place, with due diligence. All on-going efforts should now form an integral part of the overall sustainable agricultural development strategy aiming at both national food and nutrition security. This would need a well coordinated inter-departmental/inter-ministerial approach, while ensuring involvement of all stakeholders.

Recommendations

The following specific recommendations emerged out of this brainstorming workshop:

1. Per capita availability of land in India is likely to decrease substantially (around 0.09 ha by 2050) with the current growth in population. This coupled with the challenge of rising food demand necessitates an urgent need to **double** the resource allocation for agricultural R&D to focus on increased irrigated area, improved efficiency of water and fertilizer use, and improvement in the health of our degraded land. Immediate action on these R&D aspects is needed to address the emerging threats in the context of climate change and food security.

2. Increasing weather aberrations and consequent risks are likely to impact adversely on Indian agriculture. Severity of these risks will get compounded with climate change or especially in terms of increasing temperature, erratic rainfall and rising sea level. It is estimated that cereal productivity may decrease anywhere between 10 and 40 per cent by 2100 if no corrective measures are taken in time. Hence, adaptation to climate change must receive high priority by all stakeholders.
3. Achievement of the Millennium Development Goals (MDGs) in the event of climate change is likely to become more difficult, especially in South Asia where high incidence of poverty and malnourishment is rampant. In such a scenario, the achievement of MDGs would obviously require global/regional research partnerships, and sharing of information and experiences. In this context, organizations such as Asia-Pacific Association of Agricultural Research Institutions (APAARI), Global Forum on Agricultural Research (GFAR), international CG centers, Food and Agriculture Organization (FAO) and some advance research institutions (ARIs) like Japan International Research Center for Agricultural Sciences (JIRCAS) have to play an effective role in bringing all stakeholders together for research partnerships and capacity building.
4. To cope with climate change, the strategy should mainly entail adaptation to changing environment (new genotypes), and efficient use of resources (land, water, energy) as well as weather management services. Additionally, the long term mitigation strategy should aim at neutralising the factors such as green house gases (GHGs) causing climate change.
5. Adaptation and mitigation strategies would require strong R&D back up as well as proper financial and policy support. Diversity of agricultural systems, experiences of Green Revolution and new innovations are the keys to understand the processes that would accelerate both adaptation and mitigation. Mostly, these strategies should evolve around new plant type, appropriate land use planning, and efficient management of crops as well as available natural resources (biodiversity, land, water, energy, etc.).
6. Crop improvement through traditional plant breeding, and biotechnology tools, should target better tolerance in crops to drought, heat, salinity, floods, etc. This could be done through breeding for earliness, adaptability to fragile ecosystems, improved plant architecture, and tolerance to pest dynamics. The strategy should also aim at the exploitation of alien genes as well as new genes for gene pyramiding, converting C_3 into C_4 plants, building multiple resistance to both biotic and abiotic stresses, etc.
7. Rainfed agriculture occupies nearly two-thirds of our agricultural land where water is the most scarce resource. Hence, increasing water use efficiency through

measures such as sprinkler irrigation, drip irrigation, use of plastic mulch and water harvesting (through bunding around small farm holdings) becomes an essential part of the proposed adaptation strategy. It is estimated that nearly 11-37 per cent runoff can be utilized by simple means like field bunding and land levelling, to successfully raise one crop in almost 25 million ha of rainfed area. However, this will require proper technical backstopping through a responsive and efficient extension system, involving both public and private institutions, particularly NGOs active in rural areas.

8. The role of R&D, especially in conserving natural resources like land and water, assumes significance for adoption of a strategy aimed at mitigation and adaptation to climate change. Conservation agriculture ensuring minimum disturbance of soil, increased vegetative cover, and diversification of crop sequences which has a lot of potential. However, adoption of new innovations would require proper policy, funding and institutional support.
9. Improvement in soil fertility and productive capacity of ecosystem should evolve around the increasing carbon pools both in soil and vegetation. Trading of carbon, similar to other farm commodities prevalent in developed countries, can create another stream of income for farmers. However, special incentives to small and resource poor farmers for adopting resource conserving technologies/ environmental services need to be provided since these initiatives are in overall national interest. For this, we need to pursue the strategy of learning through change that will improve our soil and ecosystem, and bring in resilience in agriculture.
10. Soil carbon sequestration is an effective strategy to improve soil health and raise crop yields. Somehow, available soil organic carbon (SOC), in most uplands in India, is only around 0.2-0.5 per cent, which is much below the threshold level (around 1.1 per cent). Application of soil amendments such as crop residues and animal manure can enhance SOC pool significantly in rainfed areas, and hence be promoted. Burning of wheat and rice straw should be stopped/banned and farmers should be encouraged to adopt organic recycling to improve soil health and raise crop productivity.
11. The Agricultural Research and Education System must be reoriented to respond effectively to the emerging challenges of natural resource degradation, and climate change. As stated before, there is an urgent need to **double** the agricultural R&D allocation to meet the new challenges being faced by Indian agriculture. The policy mismatch for different sectors of agriculture should also be looked in while making future R&D allocations.

Invited Papers

Managing Soil Resilience for a Warming Climate and Decreasing Resources

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Abstract

Food grain production in India increased from 59 million tonnes (Mt) in 1955 to 231 Mt in 2008, while its population increased from 400 million to 1137 million. Thus, the per capita grain production kept ahead of the population growth. However, even greater challenges lie ahead because the population of India may stabilize by 2100 at 1850 million under low growth scenario and 2200 million under high growth scenario. By 2050, with projected population of 1750 million, the per capita availability will be 0.089 ha of cropland and 1190 m^3/yr of the freshwater supply. The problem will be further exacerbated by the projected climate change, vulnerability of soil to degradation and desertification, urban encroachment and rapid industrialization. Yet, the food grain production must be doubled by 2050, the production of wheat increased from 7.8 Mt in 2008 to 109 Mt in 2020, and even more beyond 2020. Therefore, the cropland area under irrigation must be doubled (from 57 Mha in 2000 to 114 Mha by 2050) to its maximum potential, and the use of fertilizer also doubled from 107 kg/ha in 2006 to 200 kg/ha. In addition, improving the use efficiency of these two essential inputs is extremely important. The strategy is to restore degraded soils and ecosystems through increase in the terrestrial C pools comprising soils and vegetation, trade C credits by commoditization of the terrestrial C, and create another income stream for farmers. The key question is how can we implement ways to expand human opportunity, and facilitate human learning to strengthen soil/ecosystem/social resilience? The resilience is not just bouncing back but permanently retaining the ability to bounce back. The strategy is to learn and change at the grass root levels through education of the younger generation, and creating and strengthening channels of communication between scientists on the one hand and policy makers, land managers/farmers, and public at large on the other.

Key words: Food Security, Green Revolution, Soil Resilience, Soil Management, Sustainable Agriculture, Climate Change

Introduction

Achievements of Indian agriculture during the second half of the 21st century are among major global success stories. The net sown cropland area increased by 19%, from 118.8 million hectares (Mha) in 1950 to 141.2 Mha in 2000 (Table 1), and the area under food grains by merely 7% from 116 MHa in 1960 to 124 Mha in 2008 (Table 2). Yet the production of food grains (cereals and pulses) increased by a factor of 3.4 from 68.7 million tonnes (Mt) in 1955 to 231 Mt in 2008 (Table 3). Agronomic production between 1955 and 2008 increased by a factor of 3.3 for rice and 9.0 for wheat (Table 3).

Table 1. Land use in India (Economics Survey Reports).

	Land Use	Area (10^6 ha)					
		1950	**1960**	**1970**	**1980**	**1990**	**2000**
1.	Forests	40.5	54.1	63.9	67.5	67.8	69.3
2.	Non-agricultural	9.4	14.8	16.5	19.7	21.1	23.0
3.	Barren Land	38.2	35.9	28.2	20.0	19.4	19.4
4.	Culturable Wasteland	22.9	19.2	17.5	16.7	15.0	13.8
5.	Permanent Pasture	6.7	14.0	13.3	12.0	11.4	11.0
6.	Miscellaneous Tree Crops & Groves	19.8	4.5	4.3	3.6	3.8	3.6
7.	Fallow	28.1	22.8	19.9	24.8	23.4	24.9
8.	Net Area Sown	118.8	133.2	140.3	140.0	143.0	141.2
9.	Area Sown More Than One	13.1	19.6	25.5	32.6	42.7	48.5
10.	Gross Cropped Area	131.9	152.8	165.8	172.6	185.7	189.7

Geographical Area = 328.7 Mha

The quantum jump in production was caused by increase in crop yields per hectare by vertical expansion through agricultural intensification. Between 1960 and 2008, grain yields per hectare increased by a factor of 2.15 for rice, 3.30 for wheat, 2.49 for maize and 2.61 for all food grains (Table 4). Despite the population increase from 363 million in 1950 to 1137 million in 2007, the per capita availability of food grain kept ahead of the population growth. The per capita availability of food grains peaked in 1990, with increase from 395 g/person/day in 1950 to 476 g/person/day in 1990 followed by a decrease to 443 g/person/day in 2007 (Table 5). This agrarian

Table 2. Gross Area Under Major Crops in India (10^6 ha) (Economic Survey, 2008-09).

Year	Rice	Wheat	Cereals	Pulses	Food Grains
1960	34.1	12.9	92.0	23.6	115.6
1970	37.6	18.2	101.8	22.6	124.3
1980	40.1	22.3	104.2	22.5	126.7
1990	42.7	24.2	103.2	24.7	127.8
2000	45.2	25.7	100.7	21.1	121.0
2005	43.7	26.5	99.2	22.4	121.6
2008	45.6	27.7	100.8	23.0	123.8

Table 3. Production of Food Grains in India (10^6 Tonnes) (Economic Survey 2008-09).

Year	Rice	Wheat	Cereals	Pulses	Food Grains
1955	26.9	8.6	54.5	14.2	68.7
1960	34.6	11.0	69.3	12.7	82.0
1970	42.2	23.8	96.6	11.8	108.4
1980	53.6	36.3	119.0	10.6	129.6
1990	74.3	55.1	162.1	14.3	176.4
2000	89.7	76.4	185.7	11.0	196.7
2005	91.8	69.4	195.2	13.4	208.6
2008	99.4	77.6	216.0	14.8	229.9

miracle, called The Green Revolution, saved hundreds of million of people from starvation, and proved utterly wrong the doomistic prophesies of those who expressed apprehensions, pointed fingers and had strong misgivings.

Table 4. Crop Yield in India (kg/ha) (Economic Survey, 2008-09).

Year	Rice	Wheat	Maize	Pulses	Oilseeds	Cereals	Food Grains
1960	1013	851	926	539	507	753	710
1970	1123	1307	1279	524	579	949	872
1980	1336	1603	1159	473	532	1142	1023
1990	1740	2281	1518	578	771	1571	1380
2000	1901	2708	1822	544	810	1844	1626
2005	2102	2619	1938	598	1004	1968	1715
2008	2177	2806	2302	617	1016	2140	1857

Table 5. Per Capita Food Availability in India (Economic Survey, 2008-2009).

Year	Population (millions)	Food Grain Availability (g/person/day)		
		Cereals	Pulses	Total
1950	363	334	61	395
1960	433	384	66	450
1970	539	463	52	455
1975	-	366	40	406
1980	675	380	31	411
1985	-	416	38	454
1990	833	435	41	476
2000	1015	423	32	455
2005	-	391	32	423
2007	1137	407	36	443

Despite impressive gains in crop yields and increase in per capita food supply during the second half of the 21st century, even the greater challenges lie ahead. The population of India may increase from 1029 million in 2001 to 1751 million by 2051 and 1853 by 2101 by the low growth scenario. The population may surge to 1824 million by 2051 and 2181 million by 2101 by the high growth scenario (Table 6). With rising aspiration in standards of living along with possible change in dietary habits towards more animal-based food, the demand on agricultural production will increase drastically by 2050 and even beyond. Therefore, the objective of this article is to conceptualize basic principles and identify strategies of sustainable management of soils and the natural resources to meet the growing demands for food production in India.

The Green Revolution Technology

The Green Revolution of the 1960s and 1970s was essentially a need-based technology, and comprised growing input-responsive varieties on irrigated land with application of fertilizers and other chemicals. For example, the net cropland area under irrigation was 24.9 Mha in 1962, 26.9 Mha in 1967, 31.6 Mha in 1972, 33.7 Mha in 1975, 35.2 Mha in 1977, 40.5 Mha in 1982, 41.8 Mha in 1985, 42.6 Mha in 1987, 47.4 Mha in 1996, and 57.2 Mha in 2000 (FAO, 2009). Because of double cropping, such as that in the wheat-rice belt, the gross irrigated area increased from 22.6 Mha to 76.3 Mha, along with increased in cropping intensity from 110% in 1950 to 134% in 2000 (Table 7).

Table 6. Projected population of India (Population Reference Bureau, 2007).

Year	Population (10^6)	
	Scenario A	Scenario B
2001	1029	1029
2011	1204	1201
2021	1380	1370
2031	1546	1523
2041	1695	1651
2051	1824	1751
2061	1931	1822
2071	2019	1865
2081	2087	1881
2091	2141	1876
2101	2181	1853

Population in 1947 = 350

Table 7. Gross and Net Irrigated Cropland Area in India (10^6 ha).

Year	Gross Irrigated	Net Irrigated	Cropping Intensity (%)
1950	22.6	20.9	110.1
1960	28.0	24.7	114.7
1970	38.2	31.1	118.2
1980	49.8	38.7	123.3
1990	62.5	47.8	129.9
2000	76.3	57.2	134.3

Maximum irrigation potential = 113.5 Mha

There was a drastic increase in the percent irrigated area under most food grain crops (especially wheat) between 1970 and 2000 (Table 8).

Similar to the increase in area under irrigation there was a progressive increase in the use of chemical fertilizers. Indeed, there is a long history of fertilizer manufacture in India, going back to 1906 (Table 9).

Production of $(NH_4)_2SO_4$ and NH_4Cl was started in 1959. Fertilizer production expanded considerably during the 1960s (Table 9). Between 1950 and 2007, the use of N fertilizer increased from 0.055 Mt to 14.42 Mt by a factor of 262, that of P from

Table 8. Percent Irrigated Area Under Different Crops (Economic Survey 2008-09).

Year	Rice	Maize	Wheat	Pulses	Oil Seeds
1970	38.4	15.9	54.3	8.8	7.4
1980	40.7	20.1	70.0	9.0	14.5
1990	45.5	19.7	81.1	10.5	22.9
2000	55.1	21.8	88.4	12.6	22.5
2003	52.9	19.2	89.6	13.8	25.1
2004	55.2	20.8	89.9	14.1	27.2
2005	56.5	22.2	90.0	14.6	28.3
2006	56.7	21.5	90.2	15.4	28.6

Table 9. Chronology of fertilizer manufacture in India (FAO, 2005).

Year	Fertilizer Product	# of Units
1906	Single Super Phosphate	65
1933	Ammonium Sulphate	10
1959	Ammonium Sulphate Nitrate	Discontinued
1959	Urea	29
1959	Ammonium Chloride	1
1960	Ammonium Phosphate	3
1961	Calcium Ammonium Nitrate	3
1965	Nitrophosphate	3
1967	Diammonium Phosphate	11
1968	Triple Super Phosphate	Discontinued
1968	Urea Ammonium Phosphate	2
1968	NPK Complex Fertilizers	6

0.004 Mt to 2.43 Mt by a factor of 608, and that of K from 0.005 Mt to 2.19 Mt by a factor of 438. Total fertilizer use increased from 0.064 Mt in 1950 to 19.03 Mt in 2007, by a factor of 298 (Table 10).

Similar to the increase in total fertilizer, total use of plant nutrients (N, P, K) per unit of gross cropped area (GPA) also increased. The GPA, both irrigated and rainfed, increased from 133 Mha in 1950 to 192.8 Mha in 2007, an increase of 45%. Between 1950 and 2007, the use of fertilizers per unit of GPA increased from 0.44

Table 10. Use of N, P, K nutrient fertilizers in India (Recalculated from Fertilizer Association of India, 2008).

Year	Fertilizer Consumption (10^3 Tonnes)			
	N	P	K	Total
1950	55.0	3.9	5.0	63.9
1955	107.5	5.7	8.6	121.7
1960	249.8	26.6	23.2	299.6
1965	737.8	109.4	94.8	942.0
1970	1798.0	245.6	249.5	2293.1
1975	2456.9	279.3	264.9	3001.1
1980	4068.7	581.8	561.3	5211.8
1985	5660.8	882.3	670.7	7213.8
1990	7997.2	1417.2	1102.2	10,516.6
1995	9822.8	1274.9	959.3	12,057.0
2000	10,920.2	1854.4	1301.0	14,075.6
2005	12,723.3	2289.6	2003.0	17,015.9
2007	14,419.1	2426.5	2188.1	19,033.7

kg/ha to 74.79 kg/ha of N by a factor of 170, 0.02 kg/ha to 12.58 kg/ha of P by a factor of 629, 0.01 kg/ha to 11.35 kg/ha of K by a factor of 1135, and 0.47 kg/ha to 98.72 kg/ha of total fertilizer by a factor of 210 (Table 11). There was a linear increase in crop yield with increase in the percentage of cropland area under irrigation (Fig. 1), and the rate of fertilizer application per hectare (Fig. 2). Thus, crop yields increased with increase in input. In other words, growth in food grain production was more due to vertical expansion caused by increase in crop yield per unit area than to horizontal expansion in the area under cultivation for different crops (Table 12).

The increase in energy-based inputs (e.g., fertilizer, irrigation) are also reflected in the total and per capita emissions from fossil fuel combustion in India (Table 13).

Despite the rapid increase in fossil fuel consumption, per capita CO_2 emission in India in 2008 was only 5% of that of the U.S., 10% of that of Japan, 30% of that of China and 25% of that of the world average (Table 14). Total coal reserves in India are 192 billion tonnes, which implies increase in emissions through fossil fuel combustion during the next several decades.

Table 11. Rate of Application of N, P, K fertilizers per unit of gross cropped area (Recalculated from FAI, 2008).

Year	Gross Cropped Area (Mha)	NPK Use (Kg/ha) N	P	K	Total
1950	133.2	0.44	0.02	0.01	0.47
1955	147.3	0.73	0.04	0.06	0.83
1960	152.8	1.39	0.15	0.16	1.70
1965	155.3	3.70	0.37	0.42	4.49
1970	165.8	8.92	41.43	1.19	11.54
1975	171.3	12.54	1.20	1.34	15.09
1980	172.6	21.31	3.09	3.00	27.40
1985	178.46	31.72	4.95	3.76	40.43
1990	185.74	43.06	7.63	5.93	56.62
1995	187.47	52.40	6.80	5.12	64.32
2000	185.37	58.91	10.01	7.02	75.94
2005	192.80	66.00	11.87	10.39	88.26
2007	192.80	74.79	12.58	11.35	98.72

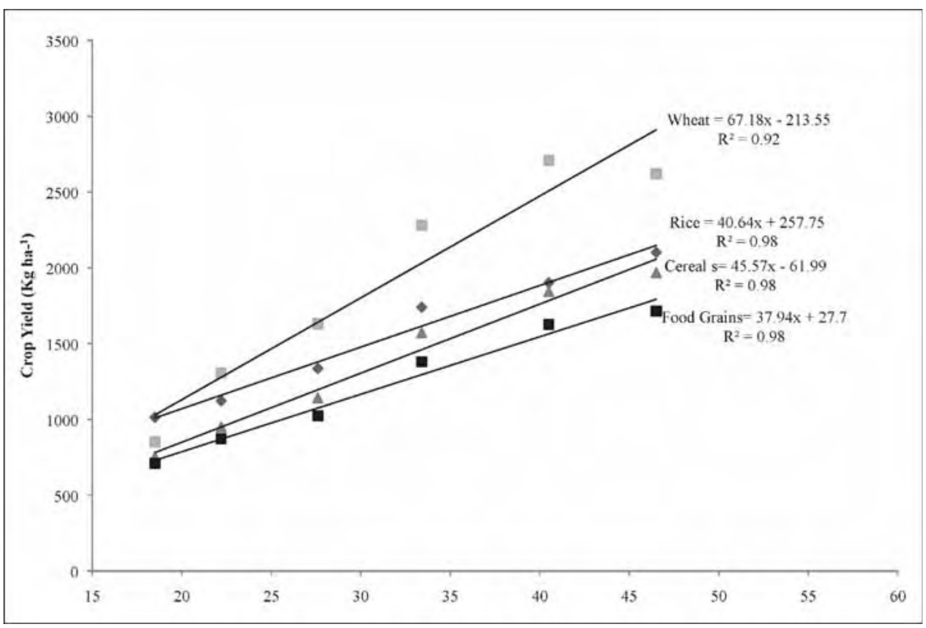

Fig. 1. Relationship between the total cropland area under irrigation and dthe increase in yield of different crops.

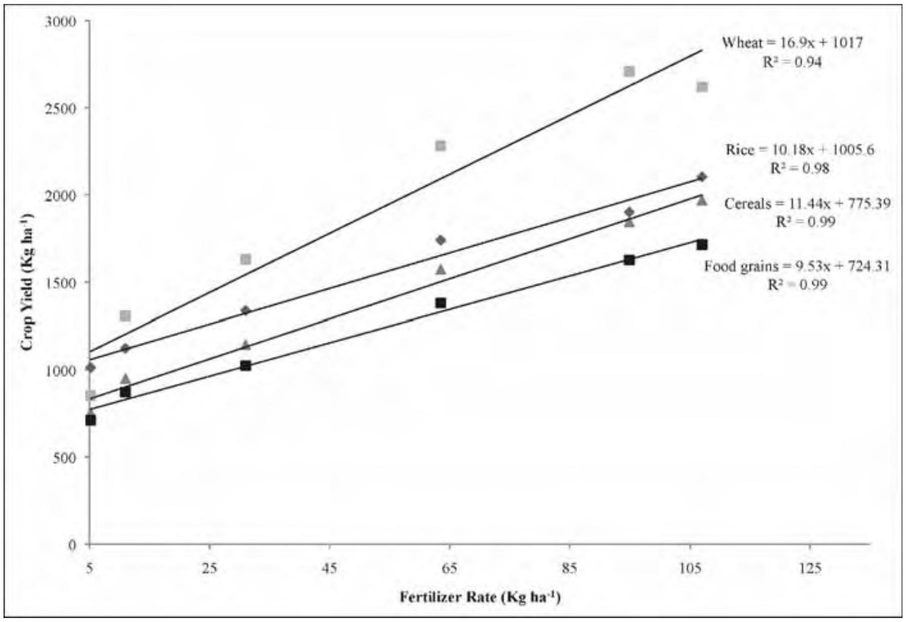

Fig. 2. Relationship between the rate of fertilizer use and yield of different crops.

Table 12. Growth Rate In Crop Production (%/yr) (Economic Survey, 2008-09).

Crop	Parameter	1980-90	1990-2000	2000-2008
Rice	Area	0.4	0.7	-0.1
	Production	3.6	2.0	1.9
	Yield	3.2	1.3	2.0
Wheat	Area	0.5	1.7	1.3
	Production	3.6	3.6	1.4
	Yield	3.1	1.8	0.1
Pulses	Area	-0.1	-0.6	1.9
	Production	1.5	0.6	3.4
	Yield	1.6	1.9	1.7
Oil Seeds	Area	2.5	0.2	3.4
	Production	5.4	1.4	7.2
	Yield	2.5	1.4	3.7

1981 = 100

Table 13. Fossil fuel emissions of C in India (Calculated from Marland *et al.*, 2007).

Year	Total Emissions (10^6 Mg C/yr)	Per Capita Emissions (Mg C/person/yr)
1860	0.19	-
1880	0.56	-
1900	3.56	-
1920	10.80	-
1940	15.75	-
1947	17.34	-
1950	18.17	0.05
1960	32.89	0.07
1970	53.22	0.10
1980	95.07	0.14
1990	188.34	0.23
2000	323.64	0.32
2006	411.91	0.37

Table 14. Per Capita CO_2 Emissions In India and Other Countries in 2008-09.

Country	Per Capita CO^2 Emissions (tonnes/person/yr)	Relative
USA	20.01	19.62
Russia	11.71	11.48
Japan	9.87	9.68
EU	9.40	9.22
China	3.60	3.52
India	1.02	1
World Average	4.25	4.17

Total coal reserves in India = 192 billion tons

Availability and the state of soils and natural resources in india

Alas! most of the gain in agricultural production has been nullified by the increase in population. The data summary in Table 15 show that in comparison with 1950 the per capita availability of food grains merely increased by 7% in year 2005. Further, any future gains in agronomic production must occur from the soil and water resources already committed to cropland use. Per capita arable land area has declined from 0.492 ha in 1950 to 0.20 ha by 1990 (Table 16).

Table 15. Agricultural statistics between 1950 and 2000 and the net gains in per capita food production (FAO State, various years).

Parameter	1950	2000	Factor Increase
Population (10^6) 363	1015	2.8	
Urban Population (10^6)	63	289	4.6
Fossil Fuel Emissions (10^6 Mg)	18	324	18.0
Irrigated Area (Mha)21	57	2.7	
N Fertilizer (10^6 Mg)0.055	14.42	25.5	
P Fertilizer (10^6 Mg)0.004	2.43	608	
K Fertilizer (10^6 Mg)0.005	2.19	438	
Cereal Production (10^6 Mg)	50	186	3.7
Food Grains (10^6 Mg)	69	197	2.6
Per Capita Grains (g/person/day)	395	423 (455)	1.07 (1.15)

Total food insecure people = 230 million

Table 16. Per capita arable land area in India (Engleman and Le Roy, 1995, Economic Survey, 2008-09).

Year	Arable Land Area (ha/person)
1950	0.429
1960	0.36
1990	0.20
2025	0.12
2050	0.095
2100	0.089

In consideration of the projected increase in population for the medium growth scenario, the per capita arable land area will be 0.12 ha in 2025, 0.095 ha in 2050 and 0.089 ha in 2100. By the time the population stabilizes around 2100, all basic necessities (food, feed, fiber, fuel) will have to be met from the meager per capita arable land area of <0.1 ha. Similarly, there will also be decline in per capita availability of renewable fresh water resources. Per capita availability of fresh water declined from 5,831 m^3/yr in 1950 to 2,244 m^3/yr in 1995, simply because of increase in population. With the scenario of medium projection of population growth, per capita available fresh water supply will decline to 1,456 m^3/yr by 2025, 1,190 m^3/yr by 2050 and 1124 m^3/yr by 2100 (Table 17).

Table 17. Per capita water availability in India (Modified from Gardner-Outlaw and Engelman, 1997).

Year	Per Capita Availability (m^3)
1950	5831
1995	2244
2025	1456
2050	1190
2100	1124

Rapid depletion of the aquifer underlying the Indo-Gangetic Plains (Kerr, 2009; Rodell et al., 2009) is a major global concern. Rodell et al. (2009) estimated that ground water is being depleted at a mean rate of 4.0 ± 1.0 cm/yr equivalent height of water (17.7 ± 4.5 km^3/yr) over the Indian states of Rajisthan, Haryana, Punjab including Delhi. During the period of August 2002 to October 2008, Rodell et al. (2009) estimated that the ground water depletion in these states was equivalent to a net loss of 109 km^3 of water. However, per capita availability of arable land and that of the fresh water supply are also reduced by soil degradation (erosion, salinization) and pollution and eutrophication of water, both are severe problems in India. Although credible data on the extent and severity of soil erosion by water and wind are scanty, the problem is severe in India (Table 18), especially in the Himalayan region (Shivalic hills) on Vertisols in central India and Alfisols in Southern India.

Technological option for enhancing agronomic productivity

Assuming that agronomic production must be maintained at the peak level of 476 g/person/day (Table 5), and making provision for 25% increase to account for possible change in dietary preferences, the desired per capita production must be 600 g/person/day (550 g cereals and 50 g pulses). Therefore, food demand for India with population growth scenario A and B shown in (Table 19) indicates the future increase required in the production. In comparison with total food grain production of 196.7 Mt/yr in 2000, demand under population scenario A will increase by 22% by 2011, 40% by 2021, 58% by 2031, and 86% by 2051. Increase in the food demand by population scenario B will be by 22% by 2011, 40% by 2021, 56% by

Table 18. Soil Degradation in India.

	Process	Area Affected (10^6 Ha)	
		Economic Survey (1998-99)	**FAO (1994)**
1.	Water and Wind Erosion	141.3	43.6
2.	Waterloggeda	8.5	-
3.	Fertility Decline	-	29.4
4.	Alkali Soil	3.6	-
5.	Acid Soil	4.5	-
6.	Saline Soil	5.5	7.0
7.	Ravine and Gullies	4.0	-
8.	Shifting Cultivation	4.9	-
9.	Riverine and Torrents	2.7	
	Total Degraded	175.0	45.0
	Total Land Area	328.7	-
	% Degraded	53.2	13.7

2031, and 68% by 2051 (Table 19). The production of wheat must be increased from 77.6 Mt in 2008 to 109 Mt in 2020 (Nagarajan, 2005), at the rate of 2.6 Mt/yr or an increase in grain yield of 100 kg/ha/yr. The adverse impact of soil degradation on agronomic production will be exacerbated by unprecedented season heat because of the climate change (Lal et al., 1998; Aggarwal et al., 2002; Attri and Rathore, 2003; Mall et al., 2004; Battisti and Naylon, 2009; Wassman, et al., 2009). Even though the potentially irrigable land area is 114 Mha, double the presently irrigable land area, scarcity of good quality irrigation water may be a principle constraint in realizing the potential. Stagnating and even the declining productivity of the rice-wheat system, whose causes and consequences have been widely studied (Dawe et al., 2000; Mohanty et al., 2007; Aulakh et al., 2001, Manna et al., 2006), is a principal concern which must be addressed. Yet its productivity may be even more adversely impacted by the rapid melting of the Himalayan glaciers (Wassman et al., 2009) and rapid depletion of the ground water (Rodell et al., 2009).

Plateauing of yield of wheat in Punjab and Haryana is also associated with the fatigue in input application because there is a need for breaking the genetic barrier (Kalra et al., 2007). Wheat production may be adversely affected by the abrupt temperature rise in March during the grain filling stage, shortage of irrigation water, decline in soil quality caused by depletion of the soil organic matter (SOM) content, and increase in soil salinity. Sinha and Swaminathan (1991) demonstrated the

Table 19. Estimated food grain demand (106 Mg/yr) in India (Calculated from Table 6 with food demand of 600 g/person/day (cereals 550 g, pulses 50 g).

Year	Population Scenario A			Population Scenario B		
	Cereals	Pulses	Total	Cereals	Pulses	Total
2000	185.7	11.0	196.7	-	-	-
2011	220	22	240	219	21	240
2021	252	25	277	250	25	275
2031	282	28	310	278	28	306
2041	309	31	340	301	30	331
2051	333	33	366	320	32	362
2061	352	35	387	333	33	366
2071	368	37	405	340	34	374
2081	381	38	419	343	34	378
2091	391	39	430	342	34	376
2101	398	40	438	338	34	372

Based on per capita need of 0.1825 Mg/yr of cereals and 0.01825 Mg/yr of pulses.

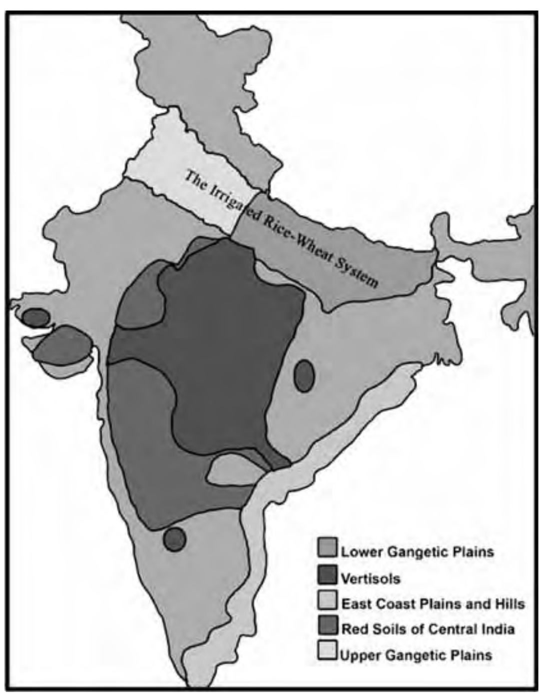

Fig. 3. The rice-wheat belt in the Indo-Gangetic Plains, red soils, and eastern coastal belt for intensive agricultural development.

impact of temperature on wheat by relating grain yield to the latitude. Grain yield of wheat was 1.6 Mg/ha at Coimbatore (11° N), 3.5 Mg/ha at Junegarh (21° N), 4.3 Mg/ha at Delhi (28° N) and 5.0 Mg/ha at Ludhiana (31° N). The adverse impacts of water shortage and groundwater depletion on wheat yield may be partly off-set by the CO_2-fertilization effect (Lal et al., 1998). Yet, the adverse effect of increase in temperature will be a severe constraint which cannot be ignored. For example, increase in temperature by 4° C may decrease the yield of wheat by 4% (Amgain et al., 2006). Further, lowering the rainfall to zero, for each day after 96 days after sowing (DAS) to until watering may reduce wheat yield by 18% (Amgain et al., 2006). Direct seeding, in the stubbles and mulch of rice straw by conservation tillage/no-till, may sustain yield of wheat in the Indo-Gangetic Plains of Northwestern India (Fig. 3). There are both short-term and long-term strategies of increased crop production. The short-term adaptation measures for wheat include possible changes in sowing date, genotype selection, improved and balanced application of plant nutrients (Nagarajan, 2005).

Decrease in rice yield by as much as 20% to 34% by climate change (+4° C) may be caused by high temperature-induced sterility in rice and the water shortage (Lal et al., 1998; Amgain et al., 2006). Acute water shortage combined with the thermal stress would adversely affect rice yield even under the elevated CO2 conditions. Potential of increasing rice yield is higher in eastern India, where rice is grown on 63% of the total area. (Kar and Kumar, 2009) (Fig. 3). As much as 79% of the rice in eastern India is grown under rainfed conditions, and no crop is grown during the post-rainy season. Thus, conserving soil moisture and growing a crop during the post-rainy season is important for enhancing production. This can be achieved by mulch farming and conservation tillage. Some genetic recommendations of improving agronomic production through adoption of innovative technologies are outlined in Table 20. Rather than growing the conventional low land rice under flood irrigation, the strategy is to grow aerobic rice with sprinkler irrigation (Kreye et al., 2009; Bouman et al., 2007).

Table 20. Some innovative technologies for improving agronomic production in India.

Technological Innovation
1. Normalized Difference Vegetation Index (NDVI), AVHRR, Remote sensing, etc, to predict drought stress
2. Biofertilizers (Azospirillum and Vesicular abuscular mycorrhiza-VAM)
3. Moisture conservation (mulch farming)
4. Enhancing water productivity for the rice-hweat system
5. Post-rain season crop in eastern India
6. Soil C sequestration & tracking C credits

(i) Irrigated Agriculture: With regard to the rice-wheat system, improving efficiency of the irrigation is extremely important, from 36% in 1993-94 to 60% in 2050. An increase in efficiency by 10% equals adding another 14 Mha of gross irrigated area in India. The excessive use of groundwater must be avoided by improving the use efficiency and reducing the losses The benchmark for expressing crop yield is reciprocal of the water use efficiency (WuE^{-1}), which is the amount of H_2O required to produce a unit of crop yield (or the transpiration ratio). Average crop yield under rainfed condition is 2.6 to 2.8 Mg/ha for wheat, rice and maize. Grain yield of wheat can be increased to 4.5 Mg/ha or by 60%, that of rice to 8.2 Mg/ha or by 220%, and that of maize to 10.8 Mg/ha or by 320% (Table 21). Remote sensing techniques can be used to assess the current and feasible areas under irrigation (Thenksbail et al., 2009).

Table 21. Actual vs. maximum yield potential of irrigated agriculture in India (Molden, 2007).

Crop	Actual Yield 2000	Maximum Potential Yield	Relative Increase
	----------	Mg/ha	----------
Wheat	2.8	4.5	1.6
Rice	2.6	8.2	3.2
Maize	2.6	10.8	4.2

(ii) Dryland Farming: Rainfed agriculture is practiced on nearly two-thirds of the cropland area in India. It accounts for about half of the total production. As many as 300 million people depend on dryland farming in India, and depend on low and variable production governed by the vagaries of climate. Crop yields in irrigated land are 78% higher than those under dryland farming. Soil moisture stress is the major constraint (Biggs et al., 2008), and is responsible for low yields and low-input or extensive farming prevalent in the rainfed agroecosystems. There is a large yield gap between on-station and on-farm yield, and about 1000 kg/ha for millet and 1500 kg/ha for sorghum. Crop yields under dryland farming can be increased by: (i) improving quality of soils on sloping land, and in soils with thin top layer and root-restrictive horizon at shallow depths, enhancing low nutrient reserves and plant-available water capacity, and moderating soil temperatures in the root zone of soils which are prone to supra-optimal soil temperatures, (ii) growing modern varieties adaptable to biotic and abiotic stresses, and (iii) improving institutional support such as market, credits, and extension support. The average yield of cereals under rainfed condition is about 1.6 Mg/ha. The yields of rainfed cereals can be increased from 1.6 to 2.7 Mg/ha for wheat (+70%), 1.6 to 3.5 Mg/ha for rice (+120%), and 1.6 to 6.9 Mg/ha for maize (+33%).

Soybeans are grown on Vertisols in central India (Fig. 4). Grain yield of soybeans have increased from 816 kg/ha in 1972 to 1235 kg/ha in 2007 (+51%). Yet, these soybean yields are only 44% compared with those in Brazil of 2813 kg/ha and in USA of 2807 kg/ha (Table 22).

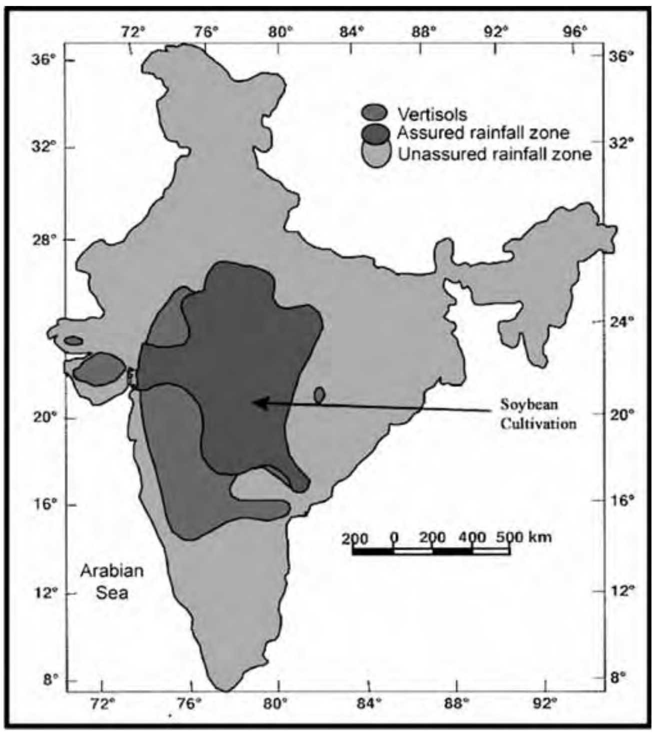

Fig. 4. Distribution of Vertisols, where soybeans are grown, in central India.

Low soybean yields are attributed to supra-optimal soil temperatures, poor crop stand because of low germination, frequent drought stress and ineffective rhizobium culture. Soybean yields in the future may also be constrained by the projected climate change (Lal et al., 1999). Agronomic practices to adapt to climate change and reduce the adverse impacts include delaying the sowing date and planting in December in the second season (Mall et al., 2004). At present investments to improve soil moisture regime on private lands seem most effective for Vertisols located downstream, and those farms with access to irrigation (Bouma and Scott, 2006).

Table 22. Soybean Yield in India (FAO, 2009).

	Yield (kg/ha)		
Year	**India**	**Brazil**	**USA**
1972	816	1612	1870
1975	981	1699	1942
1980	728	1551	1776
1985	764	1800	2292
1990	1015	1732	2292
1995	1012	2200	2376
2000	822	2400	2561
2005	1073	2223	2891
2007	1235	2813	2807

(iii) ***Soil Carbon Sequestration and Mulch Farming:*** Most upland soils in India have a low SOC concentration, often as low as 0.2% even in the surface layer. The low SOC concentration in most soils in India is below the threshold level of 1.1% for optimal soil processes. The general problem of low SOC concentration is exacerbated by the extractive farming practices whereby crop residues are removed as cattle feed, and animal dung is used as household cooking fuel. While fuel wood is commonly used, cattle manure and crop residues are also extensively used as household fuel (Tables 5, 23 and 24). Traditional biofuels have strong impact on local and regional climate through emission of black carbon.

Therefore application of soil amendments, including crop residues and animal manure, can enhance SOC pool and improve crop yields (Katyal et al., 2001). Venkateswarlu et al. (2007) reported that application of biomass under rainfed conditions improved SOC concentration by 24% than fallowing over a 10-year period. In Punjab, Ghuman and Sur (2001) and Gajri et al. (2007) also observed increase in Soc concentration by application of crop residues as mulch and animal dung as manure in coarse-textured soils. On a Vertisol in Central India, Reddy et al. (2000) reported that application of P fertilizer and manure improved soil quality. A 30-year experiment conducted on an Inceptisol in West Bengal showed that manuring and fertilizer use are essential to maintaining soil quality. Indeed, integrated nutrient management or INM (e.g., combined application of inorganic fertilizers with organic manure) is essential to enhancing and sustaining crop yield (Patra et al., 2000; Manna et al., 2005; Sharma et al., 2005; Rekhi et al., 2000; Yadav et al., 2000). For

Table 23. Fuel wood consumption by Indian household sector (Reddy, 2003).

Year	Fuel Wood (mtoe)	% of Total Energy Use
1950	54.1	82.7
1960	67.1	84.6
1980	88.1	84.4
2000	114	75.6

Growth Rate = 3.7%/yr

Table 24. Traditional biofuels used in India (Venkataraman et al., 2005).

Source	Biofuel Consumption (Tg/yr)		Emissions (Gg/yr)	
	1985	1995	1985	1995
Fuel Wood	220	281	110	143
Dried Cattle Manure	93	62	10	8
Crop Residues	86	36	40	21
Total	399	379	160	172

Table 25. Residue Management and sorghum yield on Alfisols in Hyderabad (kg/ha) (Sharma et al., 2005).

Residue	N Rate (kg/ha)	Conventional Tillage	Minimum Tillage	Average
Sorghum stover	0	624	517	571
	30	1052	796	924
	60	1355	925	1140
	90	1476	1003	1240
Glisicidia	0	664	540	602
	30	1091	886	989
	60	1459	1037	1248
	90	1589	1119	1354
No Residue	0	694	575	635
	30	1037	926	932
	60	1274	948	1111
	90	1409	1010	1210

rainfed cropping in Alfisols in Hyderabad, Sharma et al. (2005) showed that application of sorghum stover and *Glisicidia* mulch improved grain yield of sorghum compared with that of the control. For N application rate of 90 kg/ha, sorghum yield was improved by 2.5% with retention of sorghum stover and by 12% with the application of *Glisicidia* clippings as mulch (Table 25). The magnitude of positive impact would increase with continuous application of mulch over a long period on a continuous basis.

Extractive farming, with no use of chemical fertilizers or animal manure and removal of crop residues for other competing uses, decreases the SOC pool and reduces soil quality. The data from a 28-year study conducted on a Vertisol in India showed that rate of change (kg/ha/yr) in Soc pool of 0-15 cm depth was -7.1 for control, 21.4 for 100% N, 57.1 for 50% NPK, 89.3 for 100% NPK and 228.5 for 100% NPK plus manure (Table 26). This rate of C sequestration is about 25% of the rates observed for similar management under a temperate climate. A similar study conducted on 3 sites in central India showed that the humification efficiency is 2 to 9% (Table 27) compared to 10 to 15% in the temperate climate.

Table 26. Management impact on SOC pool in a Vertisol After 28 Years (Recalculated from Hati *et al.,* 2007).

Treatment	SOC Pool (Mg/ha)	Rate of Change (kg/ha/yr)
Control	11.2 c	-7.14
100% N	12.0 c	21.4
50% NPK	13.0 bc	57.1
100% NPK	13.9 b	89.3
100% NPK + Manure	17.8 a	228.5
Initial	11.4	-

Table 27. Carbon input vs. SOC pool in soils of India (Manna *et al.,* 2005).

Site	Soil	Total C input (kg/ha/yr)	System	SOC Conversion Efficiency(% of input)
Barrackpore	Inceptisol	4392	Rice-wheat-jute	5.4
Ranchi	Alfisol	3113	Soybean-wheat	2.2
Akoloa	Vertisol	4159	Sorghum-wheat	8.7

Conversion Efficiency in Ohio = 10-15%

Soil Resilience: It refers to the capacity of a soil to recover following a perturbation (Lal, 1997; Holling et al., 2002). The concept of soil resilience focuses on persistence, adaptiveness, and variability. The resilience view emphasizes domains of attraction and the need for persistence by keeping options open, reviewing events in a regional rather than a local context, and emphasizing heterogeneity (Holling, 1973). The resilience is measured by the magnitude of perturbation that soil can absorb without changing to another state or leading to drastic changing in properties and processes that alter its attributes. The goal of a management strategy is to maintain existence of a soil system. Sustainability depends on soil resilience, flexibility of land use and management, and innovative technology. In this context, the concept of maximum sustainable yield implies harvesting as much of the NPP as possible without compromising soil's future productivity and its capacity for performing the essential ecosystem services.

Soil resilience and adaptation to climate change

Rather than the amount of disturbance that an ecosystem could withstand and the return time to the stable state following a perturbation, Gunderson (2000) introduced the concept of adaptive capacity. Maintaining a capacity for renewal provides an ecological buffer and allows managers to affordably learn and change. Thus, the goal of adaptation is to enhance soil resilience through innovative interventions, so that soil quality can recover after a perturbation caused by drought, inundation, severe erosion, etc. The sustainability of such a system is maintained by strengthening the inter-relationships among a nested set of adaptive cycles arranged as a panarchy or nature's order, because it needs both change and persistence (Holling et al., 2002). The choice of land use and soil management practices must adapt to surprise and unpredictability. The strategy for sustainable management of fragile ecosystems (soils in harsh climates) is to focus on maintaining resilience (Scheffer et al., 2001). A similar approach is relevant to restoring degraded tropical landscapes (Lamb et al., 2005). It is in this context that adaptive management of soil can out-perform intensive management designed to enhance the efficiency. The choice of adaptation strategies can be both on long-term and short-term basis. Short-term strategies include the choice of appropriate farming systems characterized by high complexity, crop/vegetation management such as time of planting (TOP), as facilitated by suitable varieties and cropping sequences including INM and integrated pest management (IPM), and soil management involving conservation tillage in conjunction with mulch farming and cover cropping along with agroforestry. The goals of short-term strategies are flexibility, consistency, and complexity. Long-term strategies with positive impact on soil resilience include choice of judicious land use systems, efficient water management, and increase in C sequestration in soil and biota to enhance the ecosystem C pool. The goals of long-term strategies are to conserve resources and restore ecosystem functions (ecological goods and services).

Soil resilience and food security

Increasing NPP, to meet the demands of increasing India's population and rising aspirations (e.g., change in dietary preferences), agronomic productivity must be increased drastically. In this context Panarchy identifies three types of yield increases: incremental, lurching and transformational (Holling et al., 2002). Incremental increase is predictable such as that caused by change in seedbed preparation (e.g., plow till to no-till farming, mulching, supplemental irrigation, increase in the rate of fertilizer application). In comparison, lurching is an abrupt change, unpredictable and often episodic. Example of such response may be the negative impact on NPP such as that caused by an extremely erosive event (complete loss of topsoil), inundation, soil pollution, etc. The transformational response is through a paradigm shift involving change in land use, farming system, new variety, value addition, etc.

Thus, the long-term strategy of sustainable resource use is to identify key management systems which improve its quality and enhance soil resilience (Lal, 1997). Choice of land use and soil management systems must be such that improve soil's buffering capacity against natural/anthropogenic perturbations through improvement in four distinct but related components of soil quality (e.g., physical, chemical, biological, and hydrological). Improvement and maintenance of soil quality is essential to enhancing and improving soil's resilience. That latter is essential to ensuring India's food security in a changing climate.

Conclusions

India has adequate soil and water resources, an excellent research base, cadre of highly trained professionals, and hard working farmers. Therefore, the objective is to meet future demands in food production while improving quality of soil and water resources and adapting to changing climate. The future gains in production will come from use of improved soil-based systems in combination with adoption of elite germplasm. The strategy is to:

1. Restore degraded soils and ecosystems,
2. Improve use efficiency of fertilizers, water, and other inputs,
3. Improve soil/ecosystems/social resilience,
4. Provide incentives to farmers for payments of ecosystem services, and
5. Adopt land-saving technologies.

The soil resources must never be taken for granted. If soils are not restored, crops will fail even if rains do not; hunger will perpetuate even with emphasis on biotechnology and genetically modified crops; civil strife and political instability will plague the developing world even with sermons on human rights and democratic ideals; and humanity will suffer even with great scientific strides. Political stability and global peace are threatened because of soil degradation, food insecurity, and desperation. The time to act is now (Lal, 2008).

References

Aggarwal, P.K. and R.K. Mall. 2002. Climate change and rice yields in diverse agro-environments of India. II. Effect of uncertainties in scenarios and crop models on impact assessment. Climatic Change 52: 331-343.

Amgain, L.P., N.R. Devkota, J. Timsina and B. Bijay-Singh. 2006. Effect of climate change and CO_2 concentration on growth and yield of rice and wheat in Punjab: Simulations using CSM-CERES-Rice and CSM-CERES wheat model. J. Inst. Agric. Anim. Sci. 27: 103-110.

Annual Report. 1995-96. Year-wise Consumption, Production and Imports of Fertilizers. Govt of India, New Delhi (http://fert.nic.in/annualreport/pr9596annuexure-x.asp).

Attri, S.D. and L.S. Rathore. 2003. Simulation of impact of climate change on wheat. Int. J. Climate 23:693-705.

Aujla, M.S., H.S. Thind and G.S. Buttar. 2007. Fruit yield and water use efficiency of egg plant (*Solanum melongema* L.) as influenced by different quantities of nitrogen and water applied through drip and furrow irrigation. Scientia Horticultura Ural 112: 142-148.

Aulakh, M.S., T.S. Khera, J.W. doran and K.F. Bronson. 2001. Managing crop residue with green manure, urea and tillage in a rice-wheat rotation. Soil Sci. Soc. Am. J. 65: 820-827.

Battisti, D.S. and R.L. Naylor. 2009. Historical warnings of future food insecurity with unprecedented season heat. Science 323: 240-244.

Biggs, T.W., P.K. Mishra and H. Turral. 2008. Evapotranspiration and regional probabilities of soil moisture stress in rainfed crops, southern India. Agric. For. Meteo. 148: 1585-1597.

Boden, T., G. Marland, and R.J. Andres. 2009. National CO2 emissions from fossil-fuel burning, cement manufacture, and gas flaring: 1751-2006 (India). CO2 Inf. Analysis Center, ORNL, Oak Ridge, TN.

Bouma, J.A. and C.A. Scott. 2006. The possibilities for dryland crop yield improvement in India's semi-arid regions: Observations from the field. IWMI, Colombo, Sri Lanka, 17 pp.

Bouman, B.A.M., R.M.P. Lampayan and T.P. Toung. 2007. Water management in irrigated rice. IRRI, Los Banos, Philippines, 54 p.

Das, D.K., K.K. Mishra and N. Kalaa. 2009. Assessing growth and yield of wheat using remotely-reused canopy temperature and spatial indices. Int. J. Remote Sensing. 14: 3081-3092.

Dawe, D., A. Doberman, P. Moya, S. Abdulsachman, B. Singh, P. Lal, S.Y. Li, B. Lin, G. Panaullah, O. Sariam, Y. Singh, A. Swarup, P.S. Tan and Q.X. Zhen. 2000. How widespread are yield declines in long-term rice experiments in Asia. Field Crops Res. 66: 175-193.

Dhawan, B.D. 2000. Drip irrigation: evaluating returns. Economic & Political Weekly. 35: 14-20.

Directorate of Economics and Statistics. 2004. Irrigated area under difference crops in India/ Department of Agriculture and Cooperation, Government of India, New Delhi.

Economic Survey. 1998-1999. Land use patterns and soil degradation in India. Ministry of Finance, Economic Div. Govt. of India, New Delhi, India.

Economic Survey. 2002-2003. Ministry of Finance, Economic Div., New Delhi.

Economic Survey. 2008-2009. Population, production, land area statistics. Government of India, New Delhi (http://indiabudget:nic.in).

Engelman, R. and P. Le Roy. 1993. Sustaining water: population and the future of renewable water supplies. Population Action International, Washington, D.C., 55 pp.

Engelman, R. and P. Le Roy. 1995. Conserving land: population and sustainable food production. Population Action International. Washington, D.C., 48 pp.

FAI. 2008. All India consumption of fertilizers. The Fertilizer Association of India, Fertilizer Statistics, 2009. FAI, New Delhi, India.

FAO. 1994. Land degradation in South Asia: It's severity, causes and effect upon t he people. World Soil Resources Reports. 78, FAO, Rome, Italy, 100.

FAO. 2005. Fertilizer use by crops in India. FAO Corporate Document Repository (http://www.fao.org/docrep/009/a0257) Rome, Italy.

FAO. 2009. Aquastat. FAO, Rome, Italy. (http://www.fao.org/nr/water/aquastat/data/query/results.html).

Gajri, P.R., V.K. Arora and M.R. Chaudary. 2007. Maize growth response to deep tillage, straw mulching and farm yard manure in coarse-textured soils of N.W. India. Soil Use & Manage. 10: 15-19.

Gardner-Outlaw, T. and R. Engelman. 1997. Sustaining water: easing scarcity: a second update. Population Action International, Washington, D.C. 19 pp.

Ghuman, B.S. and H.S. Sur 2001. Tillage and residue management effects on soil properties and yields of rainfed maize and wheat in subhumid subtropical climate. Soil & Tillage Res. 58: 1-10.

Govt. of India. 1997 & 2003. PocketBook on Transport Statistics in India. Ministry of Surface Transport, Govt. of India, New Delhi.

Govt. of India. 2002. Selected Socio-Economic Statistics. Ministry of Statistics and Programme Implementation, Govt. of India, New Delhi.

Gunderson, L.H. 2000. Ecological resilience in theory and application. Annu. Rev. Ecol. Syst. 30: 425-439.

Gunderson, L.H. and C.S. Holling (Eds.) 2002. Panarchy: Understanding Transformation in Human and Natural Systems. Island Press, Washington, D.C., 507 pp.

Hanumantha Rao, C.H. 2002. Sustainable use of water for irrigation in Indian Agriculture. Econ. & Pol. Weekly. 37: 1742-1745.

Hati, K.M., A. Swarup, A.K. Dwivedi, A.K. Misra and K.K. Bandyopadhyay. 2007. Changes in soil physical properties and organic carbon status at the topsoil horizon of a Vertisol of central India after 28 years of continuous cropping, fertilization, and manuring. Agric. Ecosyst. Env. 119: 127-134.

Holling, C.S. 1973. Resilience and stability of ecological systems. Annu. Rev. Ecol. Syst. 4: 1-23.

Holling, C.S., L.H. Gunderson and D. Ludwig. 2002. In quest of a theory of adaptive change. In L.H. Gunderson and C.S. Holling (Eds.) "Panarchy: Understanding Transformation in Human and Natural Systems. Island Press, Washington, D.C., 25-62pp.

Howell, T.A. 2001. Enhancing water use efficiency in irrigated agriculture. Agron. J. 93:281-289.

IEA. 2002. Energy and Poverty (Ch.13). International Energy Agency, (iea.org/textbase/weo/pubs/weo2002/energypoverty.pdf): 1-45.

IPCC. 2007. Climate Change 20007: The Physical Science Basis. Working Group I. Intergovernment Panel on Climate Change, Cambridge Univ. Press, Cambridge, U.K.

Kalra, N. D. Chakraborty, P.R. Kumar, M. Jolly and P.K. Sharma. 2007. An approach to bridging yield gaps, combining response to water and other resource inputs for wheat in northern India, using research trials and farmers' fields data. Agric. Water Manage. 93: 54-64.

Kar, G. and A. Kumar. 2009. Evaluation of post rainy season crops with residual soil moisture and different tillage methods in rice fallow of eastern India. Agric. Water Management. 96: 931-938.

Katyal, J.C., N.H. Rao and M.N. Reddy. 2001. Critical aspects of organic matter management in the tropics: The example of India. Nat. Cycl. Agroeco. 61: 77-88.

Kerr, R.A. 2009. Northern India's ground water is going, going, going. Science, 325: 789.

Kreye, C., B.A.M. Bouman, A.R. Castañeda, R.M. Lampayan, J.E. Faronilo, A.T. Lactaoen, and L. Fernandez. 2009. Possible causes of yield failure to tropical aerobic rice. Field crops Res. 111: 197-206.

Lal, M., K.K. Singh, G. Srinivasan, L.S. Rathore, D. Naidu and C.N. Tripathi. 1999. Growth and yield responses of soybean in Madhya Pradesh, India to climate variability and change. Agric. & forest Meteo. 93: 53-70.

Lal, M., K.K. Singh, L.S. Rahtore, G. Srinivasan and S.A. Saseendran. 1998. Vulnerability of rice and wheat yields in NW India to future changes in climate. Agric. & Fon. Met. 89: 101-114.

Lal, R. 1997. Degradation and resilience of soil. Phil. Trans. R. Soc (B) 353: 997-1010.

Lal, R. 2008. Food insecurity's dirty secret. Science 322: 673-674.

Lamb, D., P. Erskine and J.A. Parratta. 2005. Restoration of degraded tropical forest landscapes. Science 310: 1628-1632.

Mall, R.K., M. Lal, V.S. Bhatia, L.S. Rathore and R. Singh. 2004. Mitigating climate change impact on soybean productivity in India: a simulation study. Agric. & Fon. Met. 121: 113-125.

Manna, M.C., A. Swarup, R.H. Wanjari, Y.V. Singh, P.K. Ghosh, K.N. Singh, A.K. Tripathi and M.N. Saha. 2006. Soil organic matter in West Bengal Inceptisol after 30 years of multiple cropping and fertilization. Soil Sci. Soc. Am. J. 70: 121-129.

Manna, M.C., A. Swarup, R.H. Wenjari, H.N. Ravenkar, B. Mishra, M.N. Saha, Y.V. Singh, D.K. Sahi and P.A. Saha. 2005. Long-term effect of fertilizer and manure application on soil organic carbon storage, soil quality and yield sustainability under sub-humid and semi-arid tropical India. Field Crops Res. 93: 264-280.

May, R.M. 1977. Thresholds and breakpoints in ecosystems with a multiplicity of stable states. Nature. 269: 471-477.

Ministry of Chemicals and Fertilizers. 2006-2007. Fertilizer Consumption in India. Government of India, New Delhi.

Mishra, V.K. R.D. Retherford and K.R. Smith. 1999. Biomass cooking fuels and prevalence of tuberculosis in India. Int. J. Infect. Diseases 3: 119-129.

Mohanty, M., D.K. Painuli, A.K. Misra and P.K. Ghosh. 2007. Soil quality effects of tillage and residue under rice-wheat cropping on a Vertisol in India. Soil & Tillage Res. 92: 243-250.

Molden D. (Ed.) 2007. Water for food, water for life: a comprehensive assessment of water management in agriculture. Earthscan, London, 644 pp.

Nagarajan, S. 2005. Can India produce enough wheat even by 2020? Current Sci. 89: 1467-1471.

Nagdeve, D.A. 2008. Population growth and environmental degradation in India. Intl. Inst. Population Sci., Mumbai, India, Mimeo, 30 pp.

Narayanamoorthy, A. 2006. Potential for drip and sprinkler irrigation in India. Gokhale Institute of Politics and Economics. Pune, India.

Narayanamoorthy, A. 2009. Potential for drip and sprinkler irrigation in India. Gokhale Institute of Politics and Economics. Pune, India.

Patra, D.D., M. Anwar and S. Chand. 2000. Integrated nutrient management and waste recycling for restoring soil fertility and productivity in Japanese mint and mustard sequence in Uttar Pradesh, India. Agric. Ecosyst. & Env. 80: 267-275.

PRB. 2007. The Future Population of India. Population References Bureau, New Delhi, India.

Reddy, D.D., A. Suba Rao and T.R. Rupa. 2000. Effects of continuous use of cattle manure and fertilizer phosphorus on crop yields and soil organic phosphorus in a Vertisol. Bioresource Tech. 75: 113-118.

Rekhi, R.S., D.K. Benbi and B. Sing. 2000. Effect of fertilizers and organic manures on crop yields and soil properties in rice-wheat cropping systems. In I.P. Abrol, K.F. Bronson, J.M. Duxbury, R.K. Gupta (Eds) "Long-term Soil Fertility Experiments in Rice-Wheat Cropping Systems". Rice-Wheat Consortium Paper Series 6, New Delhi, India: 1-6.

Rodell, M., I. Velicogna and J.S. Famigliette. 2009. Satellite-based estimates of ground water depletion in india. Nature (doi:1038/nature08238).

Scheffer, M. S. Carpenter, J.A. Foley, C. Folkes and B. Walker. 2001. Catastrophic shifts in ecosystems, Nature 413: 591-596.

Shah, T., M. Giordano and J. Wang. 2004. Irrigation institutions in a dynamic economy: what is China doing different from India. Proc. Int. Symp. on Groundwater Sustainability IWMI, Colombo, Sri Lanka: 93-112.

Sharma, K.L. U.K. Mandal, K. Srivivas, K.P.R. Vittal, B. Mandal, J.K. Grace and V. Ramesh. 2005. Long-term soil management effects on crop yields and soil quality in dryland Alfisol. Soil & Tillage Res. 83: 246-255.

Singh, R.P., S. Roy and F. Kogan. 2003. Vegetation and temperature condition indices from NOAA-AVHRR data for drought monitoring over India. Int. J. Remote Sensing. 24: 4393-4402.

Singh, Y., B. Singh, J.K. Ladha, et. al. 2004. Long-term effects of organic inputs on yield and soil fertility in the rice-wheat rotations.

Sinha, M.K. and M.S. Swaminathan. 1991. Deforestation, climate change and sustainable nutrition security: a case study of India. Climatic Change 19: 201-209.

Thenkabail, P.S., V. Dheeravath, C.M. Birdar, O.R.P. Gangalakunta, P. Noojipady, C. Gurappa, M. Velpuri, M. Gumma and Y. Li. 2009. Irrigated area maps and statistics of India using remote sensing and natural statistics. Remote Sens. 1: 50-67.

Venkataraman, C., G. Habib, A. Eiguren-Fernandez, A.H. Miguel and S.K. Friedlander. 2005. Residential biofuels in South Asia: carbonaceous aerosol emissions and climate impacts. Science 307: 1454-1456.

Venkateswarlu, B., C. Srinivasrao, G. Ramesh, S. Venkateswarlu and J.C. Katyal. 2007. Effects of long-term legume cover crops incorporation on soil organic carbon, microbial biomass, nutrient buildup and grain yields of sorghum-sunflower under rain-fed conditions. Soil Use and Manage. 23: 100-107.

Walker B. and D. Salt. 2006. Resilience Thinking: Sustaining Ecosystems and People on a Changing World. Island Press, Washington, D.C., 174pp.

Wassman, R., S.V.K. Jagadish, K. Sumfleth, H. Pathak, G. Howell, A. Ismail, R. Serraj, E. Redona, R.K. Singh and S. Heuer. 2009. Regional vulnerability of climate change impacts on Asian Rice production and scope for adaptation. Adv. Agron. 102: 91-133.

Yadav, R.L., B.S. Dwivedi, K. Prasad, O.K. Tomar, N.J. Shurpali and P.S. Pandey. 2000. Yield trend and changes in soil organic carbon and available NPK in a long-term rice-wheat system under integrated use of manures and fertilizers. Field Crops Res. 68: 219-246.

Yorque, R., B. Walker, C.S. Holling, L.H. Gunderson, C. Folke, S.R. Carpenter and W.A. Brock. 2002. Toward an integrative synthesis. In L.H. Gunderson and C.S. Holling (Eds.) "Panarchy: Understanding Transformation in Human and Natural Systems. Island Press, Washington, D.C., 419-438pp.

Climatic Changes, Disasters and Their Management in India

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Abstract

Climate change has created several challenges as well as opportunities world over. Frequency and intensity of chaotic weather events like late/early onset of rains, late or early withdrawal, long dry spells, droughts, floods, cold/heat waves, cyclones, hailstorms, etc. have increased due to global warming. India has evolved appropriate policies, institutions, enacted/amended laws, set up authorities and committed financial resources for immediate relief, adaptations, mitigation and reducing vulnerability to extreme climatic events in the medium and long terms. Crops contingency plans, compensatory production systems and safety nets to manage chaotic climatic changes have been illustrated for droughts to which 28% geographical area of India is vulnerable. Medium and long term measures for *in situ* conservation of rainwater, developing and recharging of ground water, enhancing efficiency of surface water resources, breeding tolerant crops, varieties, trees and animal breeds to offset vulnerability are in the pipelines.

Introduction

Climate is an important natural endowment of vast agro-ecologies and most appropriate production systems matching with bio-physical, socio-economic and market environment have been evolved traditionally as well as with modern scientific inputs. Scientific innovations and social capital of human beings can adjust with long ranged and very slow climatic drifts through various coping mechanisms of evolutions, adaptations, resilience, reducing vulnerability, mitigations and devising safety nets. However, extreme weather events or climatic chaos like droughts, late/early arrival or withdrawal or rains, long dry spells, floods, cyclones, tsunami, cold/heat waves, hailstorms etc. cause serious damages as shown in Table 1 (emdat. be 2009). During the period 1877 to 2009 India has witnessed 24 major droughts and top severest six occurred in 2002, 1987, 1972, 1918, 1899 and 1877 (*Samra et al 2002*). On long term average about 57% geographical area of India is vulnerable to earthquakes, 28% to droughts, 12% to floods and 8% to cyclones.

Table 1. Average impact of climatic disasters in India from 1900 - 2000

Rank		No. of Events	Persons Killed	Persons Affected	Damage (Million US$)
1	Drought	13	326,948	81,680,077	188
2	Flood	223	254	2,932,808	94
3	Tsunami	1	16,389	654,512	1,023
4	Cold Wave	22	212	1	6
5	Heat Wave	22	392	10	18
6	Landslide dry	1	45		
7	Landslide wet	39	131	58,881	4
8	Storm	145	630	355,787	71

www.emdate.be

Intensity and frequency of the extreme weather events has increased in India during the past 15-20 years due to global warming (UNDP 2008). Droughts in flood frequented and floods in high probability drought afflicted regions have been witnessed in the year 2009 (NRAA 2009). Bundelkhand region of Central India used to have droughts once in 16 years during 18th and 19th centuries, occurrences increased by 3 times during 1968 – 1992 and is deficient in rains continuously from 2005 to 2009 (NRAA 2008). A very classically drought potential region of Saurashtra (Gujarat) witnessed widespread floods in the year 2009 (NRAA 2009).

Mitigation of climatic changes is a long drawn process with inter-sectoral and international ramification. India has launched 8 missions for mitigating climate change and one of them is dedicated to sustainable agriculture. Other missions on Water, Hills and Mountains also include agriculture and food security related activities. R&D for developing new technologies of redressing climatic changes has considerable gestation period and different agencies like Indian Council of Agricultural Research, agricultural Universities and other institutions are mandated for that. There is a host of institutions, and universities in various other sectors of economy for climate related research and disaster management (NDMA 2009). Ministry of Agriculture, Government of India is overall responsible for managing droughts, hailstorm, pests and disease epidemics. Flood related, geological, chemical, biological and nuclear disasters is the responsibility of Ministry of Home Affairs, Health, Defence and others.

In the federal system of India, managing droughts and other calamities is the primary responsibility of the provincial States whereas central or federal government aids and provide advisory and monetary support specifically demanded for the purpose. Calamity Relief Fund (CRF) authorized by the Finance Commission of India and reviewed every five years is parked with the State for enabling immediate relief and reimbursed by the Central Government afterwards. There is another bigger window of National Calamity Contingency Fund (NCCF) for which the states submit memorandum of losses to the federal government and assistance is decided after verification by a Central Committees.

Declaration of drought/disaster

Droughts develop gradually, affect large population, geographical area or animals, phase out slowly and India has witnessed 24 major droughts during 1877 to 2009. Ministry of Agriculture maintain a Weather Watch Group consisting of representatives of Indian Meteorology Department, Ministry of Food and Consumer Affairs (monitoring prices), Central Water Commission (monitoring major water reservoir), ICAR (R&D), NRAA (policy formulation, advisory) and others. This Group meets once a week or more frequently whenever required. Inputs received about monsoon onset, rainfall shortfall, water flow into large reservoirs, loss in area sown in the states, crop growth conditions, market prices, reports of press and media etc. lead to the declaration of droughts by the States. Drought can be declared for any administrative unit from the lowest village level to any higher unit of block, tehsil (sub-county), district (county) and state of any size. A Group of Ministers is immediately constituted by the Prime Minister to take quick policy decisions. A Crisis Group under the Chairmanship of Cabinet Secretary becomes active. Ministry of Agriculture appoints a Relief Commissioner who sets up an IT enabled dedicated control room which remains open 24 hours to exchange all kind of information in the country. Similar arrangements are also activated in the states and districts (610 maximum) experiencing drought. National Rainfed Area Authority provides technical backstopping for contingency planning and monitoring. Recovery of loans is deferred immediately or even waived off partially or fully later on. Farmers and consumers become entitled to various aids, assistance, supplies of food, fodder, feed, employment etc.

Main distinguishing features of 2009 drought

i) Arrival of monsoon in Kerala (South Coast) on 23rd May, 2009 i.e. one week in advance, its spread in the South and normal forecast of Indian Meteorological Department (IMD) was a welcome start. Sowing of crop was initiated in the Southern region. A cyclone named Aila devastated ecologically important Sunderban area on the East Coast (West Bengal), damaged infrastructure, properties, land with saline sea water and advance of rains to North was stalled. There was complete stagnation in the progress of rains northward (around 15^0N latitude) from 8 to 20th June, 2009 due to cold circulation anomalies in the middle of upper troposphere. This led to a long dry spell of about 20 days from June 9 to 29 (Fig. 1), all India average rainfall deficiency increased progressively to -54 and was comparable to 1926 June deficit. During this 1st dry spell, deficiency was highest in Central India (-73%) followed by North East (-55%), North West India (-49%) and South Peninsula (-38%) and withered germinated crops in Karnataka and surrounding areas. Rainfall revived to normal for the month of July (as compared to -48% in July, 1918) and all India average deficiency of rainfall went down to -19%. Most of the area under un-irrigated conditions was sown during this month. A second long dry spell again appeared from July 24 to August 12. All India rainfall deficiency again stepped upto -29% being highest in North West (-43%), followed by North East (-36%), South Peninsula (-23%) and Central India (-19%) and raised concerns about survival and growth of kharif (summer) crops especially the staple food of paddy being most sensitive to drought. Fortunately the rainfall was restored on August 13, revived the crops growth and sowing of unsown area in a few places. Overall rainfall deficiency was -21% at the end of season.

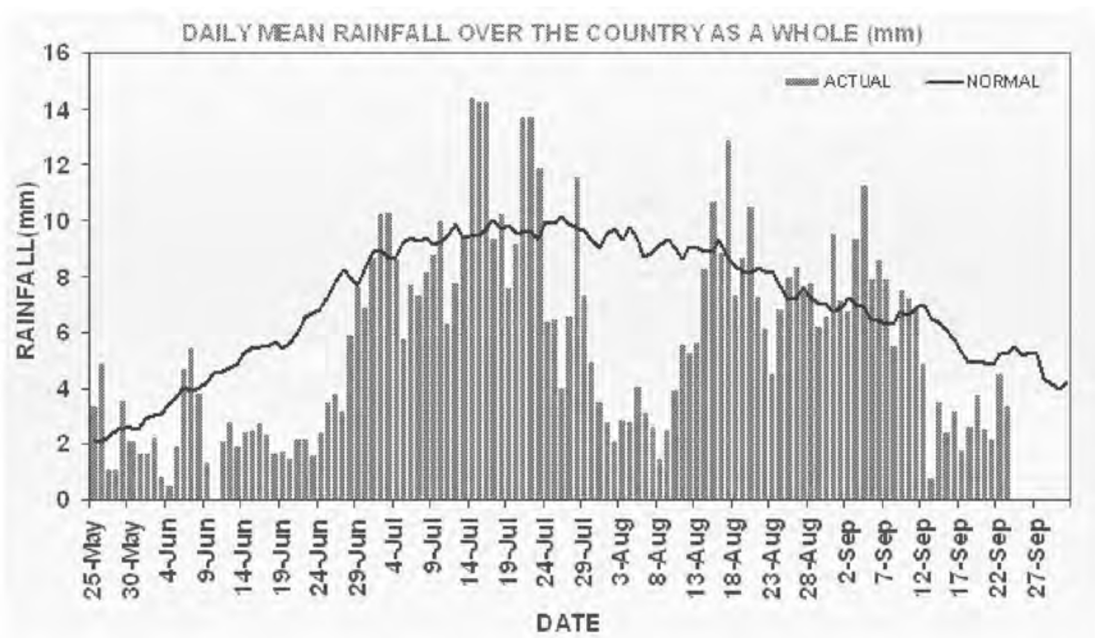

Fig. 1. Rainfall in India 2009 (May to September)

ii) Unlike 2002, the drought appeared in flood frequented states of Assam, Bihar and high rainfall regions of Jharkhand and Himachal Pradesh and intensively ground water irrigated region of North West. Rajasthan, having highest probability of droughts, was relatively better off than 2002 drought especially in the early monsoon season (Samra & Singh 2002). The central India witnessed highest rainfall deficiency of -73% in June, 2009 whereas on 10th September, 2009, seven districts of this region were flooded. Saurashtra region of Gujarat State is traditionally drought prone but in September, 2009, eight districts were flooded and rainfall in Saurashtra Meteorological sub-division was above normal. Floods also revisited the traditional Bihar, West Bengal, Assam and few pockets in other States of North India. It was a very chaotic rainfall re-distribution pattern.

iii) Water flow into 81 large reservoirs was less than normal except in Karnataka and Kerala States.

iv) Unlike previous droughts there was exceptionally high demand for additional supply of electricity and diesel to extract ground water. This was a redeeming feature since emphasis shifted from empirical relief to remediation for maintaining productivity and production, of course, at higher financial and ground water costs.

v) During first week of September, 11 states with 278 drought affected districted claimed additional central financial assistance of more than Rs.720 billion (US$ 16 billion) which are being scrutinized. In 2002 drought 300 million people in 180 mha of geographical area were affected and agriculture production was reduced by 29 million tonnes as compared to previous normal year.

Economic losses

i) A limited area sown in South during early rains, and maize generally sown during pre-monsoon rains in north India was re-sown due to 20 days dry spells in June.

ii) Sowing in South (Rayalseema, Telengana, Marathwada), Eastern India (Assam, Bihar, Jharkhand and UP) was delayed and deficient. Excessive electricity and diesel was consumed in North West (Punjab, Haryana, UP, Bihar), etc. in extracting ground water for transplanting paddy at higher subsidy, private cost to the farmers and permanent loss of ground water.

iii) Temperature also went high during first dry spell of June which damaged vegetables and their market prices went up. Incidence of animal diseases like Hyperthermia, Ephemeral Fever, reproductive infertility and loss in milk production especially in cross bred cattle increased. High toxicities of fatal Hydro Cyanic acid, nitrates and low concentration of phosphorus in fodder were reported in few cases.

iv) Reduced fruit size and production of apples, cherries and tomatoes was reported in Himalayan region.

v) Stagnation in the crop growth of sorghum, castor, pulses, transplanting of paddy, sowing of maize, was observed during the second dry spell in first half of August, 2009. A shortfall of 6.5 (7%) m ha of kharif (summer) sown area consisting of 6.2 m ha in rice as compared to previous year was reported. However, there was over-sowing of cotton by 1.1 m ha and less sowing of 1.2 m ha in oil seeds.

vi) Due to dry conditions and high temperature superfine rice variety of Pusa Basmati 1121 was afflicted by Bacterial Blight (Jhulsa Rog) in North West India.

vii) More than 10% losses in hydro-electric power generation in the month of July 2009 were recorded.

viii) Rainfall again revived after 13th August and actual losses will be quantified at the time of harvesting.

ix) Late revival of rain and filling up of 81 large and thousands of small water reservoirs will certainly stop further damages and revive most of the crops. Short-duration pre-rabi (winter) crops like Toria (Brassica Sps.), pulses etc. can be seeded on unsown area and has enhanced chances of higher production in the rabi (winter) season of the country.

x) North West States of Punjab, Haryana and many others purchased additional electricity in the spot market at double the normal rates to save standing crop by extracting ground water. Sale of diesel in Punjab in June 2009 was 40% more as compared to the previous years. Bihar and UP having more than 70% bore wells being energised with diesel demanded subsidy on diesel consumed by the farmers. Irrigation by diesel pumps is 4 times more expensive than electric pumps.

xi) In 2002 drought, nearly 300 million persons in 180 mha geographical area were affected. About 22 mha area was not sown, 47 mha of sown area was damaged and food production reduced by 29 MTs.

Contingency plans

Keeping in view the forecast of rainfall, interaction with farmers, agricultural scientists and officials of States a “Drought Management Strategy - 2009” was prepared by the National Rainfed Area Authority, hosted on website and widely circulated through print, radio, television and other media sources. Contingent measures for early, mid and late rainfall scenarios for districts within states, agro-ecological regions and Indian Meteorology sub-divisions were elaborated. The strategy consisted of immediate, short, medium and long term measures and only main features are summarized below:

i) Alternative crops, fodders, vegetables and their varieties for early, mid and late sowing for various meteorological sub-divisions, agro-ecological regions and districts of the states were recommended.

ii) Availability of alternative seeds, other inputs and their sources for various contingencies was made public.

iii) Various measures for *in-situ* conservation of rains, run-off harvesting, its recycling with most efficient micro irrigation system and recharging of dried up dug wells were elaborated.

iv) Application of fertilizers, soil amendments and inter-cultural operations were suggested.

v) Revising canal irrigation rosters to reschedule equitable distribution of limited water resources for optimizing production.

vi) Uninterrupted supply of electricity without tripping to improve efficiency of ground water.

Compensatory production

Food security, guarantee and affordability is top most priority of the highly populated agrarian economy of India. Following measures were advocated to offset production losses due to drought:

i) Realizing higher productivity in the States, regions and districts having normal or above normal rainfall was emphasised. Seed replacement with latest varieties, extra dose of fertilizers, weeding, diseases and pest control provided many opportunities.

ii) Inter-cropping with black gram and beans in the maize crop where there was mortality and plant population was sub-normal.

iii) Revival of late rains during second half of August 2009 saved standing crops and a pre-rabi crop of toria (Brassica Sp.), horse-gram, niger and fodder on the area where main summer crop could not be sown was targeted to offset the losses.

iv) Early sowing of wheat, mustard, chickpea etc. with zero tillage was advocated to avoid losses due to terminal heat in February-March, 2010 and to reduce cost of cultivation.

v) There are about 12 m ha of rice-fallow area especially in the high rainfall regions of eastern India. A rabi (winter) crop of pulses, oilseed, vegetable and fodder by rainwater harvesting, digging open wells and installing shallow tube-wells was argued.

vi) Boro rice: This is a traditional practice of cultivating rice during post-rainy and flood free period with least risks. It supports relatively long duration (170-180 days) varieties as compared to about 130 days of kharif (summer) crop. Its productivity is about 2-3 times higher than summer rice but requires committed irrigation. It was promoted in areas like West Bengal, Assam, Orissa, Eastern UP etc. having sufficient ground water resources. Installation and incentivization of shallow tube wells or lift irrigation from water streams was recommended.

vii) Winter Maize: Like Boro rice, late winter (spring season) maize is also long duration than summer crop with almost double the productivity potential (six tonnes/ha). It can be grown with assured irrigation in about 100 districts (counties) which were listed in the strategy document.

viii) Late winter or Spring Groundnut: It is an important oilseed, feed and fodder crop and was a casualty of drought on about one million ha in well known areas around Anantpur (A.P.) of South India. Offsetting losses of its production by growing in the non-traditional late winter/spring season in coastal States of West Bengal, Orissa Andhra Pradesh, Tamil Nadu, Goa, Karnataka, Rajasthan etc. on residual moisture and preferably irrigated conditions was argued.

Safety nets

Traditional farmers of desert region generally stored food, fodder and feed at least for three years during favourable rainfall seasons/years. Other practices of growing deep rooted drought tolerant multi-purpose trees and rearing of animals which can migrate during fodder and water scarcities and calamities or even liquated are not enough in the present context. Seasonal migration of persons to earn income from elsewhere creates social problems and is also inadequate. The modern safety nets take into account the traditional mechanisms, emerging demands and supplies, new technologies, governance, innovative policies and programmes.

Food grains buffer stocks

Department of Food ensures prescribed minimum quantities of wheat in April and rice in November and present stock of food grains of 50 million tonnes were in excess of the minimum. This stock can feed the country for 13 months and supplies are ensured by declaring Minimum Support Price at the time of crop sowing and procurement in the grain market by the Central and State agencies. Prompt payments of purchased grains to the farmers, storage in godowns and evacuation of stocks to the high scarcity regions through railway network are well planned. In case of shortage in the minimum procurement of food grains, duty free imports are made to regulate the market prices and public sentiments.

Consumer prices

In 2009 overall there was negative inflation in Weighted Price Index of India due to economic recession but prices of food articles went up. During early rainy season temperature went above normal by 4-6^{0}C in the end of June, it damaged vegetable crops and supply was less than the demand and led to higher consumer prices. Similar was true for apples, cherries and other stone fruits in the Himalayan states and sugar production elsewhere. There was a buffer stock of rice and wheat of about 50 million tonnes sufficient for 13 months and price rise was not due to imbalanced demand-supply but due to speculations and other market sentiments. Enforcement of laws against hoarding and forward trading was watched carefully to check inflation in prices of food articles. Release of stocks into the market from the buffer pool and public display of stock is quite common to prevent artificial inflation.

Insurance

All loanee farmers are provided with an insurance cover subsidized by the Government of India and claims are settled by the banks if there is damage to the crops after assessing losses. Loanee and non-loanee farmers especially cultivating cash crops are preferring more pragmatic weather based insurance derivatives where claims can be settled within 2-3 weeks as compared to 4-6 months in the conventional insurance schemes. Similarly there are insurance schemes available for livestock and other products and farming systems. The insurance systems are being continuously improved upon depending upon the feed-back on the valuation system and promptness in the delivery of the claims.

Credit management

With the declaration of the drought, credit and interest repayments were deferred and in a few cases of distress they were even waived off partially or wholly and relief borne by the government of India. Under rainfed situation different products of credit with longer duration of re-payment, rolling system and loan for domestic consumption are also being devised to prevent diversion of the crop loans for non-productive or consumptive purposes.

Harnessing genetic potential

This approach is designed for the medium and long term measures of reducing vulnerability. Depending upon the rainfall, topography, soil profile characteristic etc., lengths of the crop growing periods are modelled for various agro-ecologies. The length of growing period is primarily derived from the moisture holding and releasing capacity of the soil, topography and rainfall pattern. There are crop varieties of *moth* bean (legume) which can mature in 65 days and is ideally suited for semi-arid and arid region. Duration of the varieties in soybean has been reduced from 120 days to

85 days, pearl millet from 130 to 70 days and many others. The whole idea in genetic manipulation is to evolve a large range of crops and varieties to match the length of growing period of various micro-ecologies and rainfall deficiencies.

Similarly there is Tharparkar breed of cow in the Rajasthan desert which gives higher yield when the temperature is very high as compared to cross bred cattle who lose their appetite and milk production during high temperature. There is a multipurpose tree of *Khejri* (*Prosopis sceneraria*) with very extensive lateral and deep taproot system which can scan large volume of soil for moisture and can survive 7-8 years of scanty rainfall. There are immense genetic possibilities in various crops, trees, animal breeds, grasses which are quite tolerant to drought and are being genetically improved upon constantly.

Fodder and feed banks

In India about 67% of the fodder requirement is met by the crop residues which become a scarce commodity during drought. The traditional drought affected farmers have devised ways and means to store dried stalks of sorghum, pearl millet, grasses, etc. for a period up to 3 years. Fodders are also moved through railway network free of cost from non drought affected areas to the drought affected regions. Fortification of the dried fodder with various minerals and sugarcane jaggery etc., making feed blocks and baling of the bulky material for easy handling, transportation and reducing storage space are the other activities of the safety net.

Rainwater harvesting and groundwater re-charging

Water is the most important input for moderating adverse effect of cold/heat wave, drought and other stresses to maintain productivity and alleviate vulnerability. There are many preventive and proactive interventions to mitigate or reduce severity of the drought. These measures are specifically designed to harvest rainwater during the normal rainfall periods both for limited irrigation and ground water re-charging. Long dry spells during the monsoon season are also very common and the rainwater harvested into ponds, check dams, tanks and re-charged profile are very handy to save the crops. Adequate budget is provided to take up watershed management programme sequenced from ridge to valley with participation of local communities in the country. Capacity building of technical manpower and community mobilization is given very high priority.

National rural employment guarantee act (NREGA)

Maintaining food supplies and purchasing power of poor or access to food was important to ensure social harmony and equity. NREGA has given right of 100 days employment per year to a family and employment creates assets in such a way that it leads to self or more employment. Under this law work or compensation has to be provided within 15 days of demand raised. Payments are made through bank account within 7 days in transparent manner with public display on internet.

References

UNDP. 2008. Climate change adaptation activities in India. Gorakhpur Environmental Action Group 224, Purdilpur, M.G. Road, Nobo Gorakhpur (UP) India 27300. 105pp.

Samra, J.S., Gurbachan Singh, J.C. Dagar. 2002. Drought Management Strategy in India. Central Soil Society Research Institute, Karnal - 132001 (India).

NRAA. 2009. Drought Management Strategy 2009. National Rainfed Area Authority, NASC Complex, DPS Marg, Pusa, New Delhi - 110012, India. (www.nraa.gov.in)

NRAA. 2008. Drought Management Strategy for Bundelkhand region in Uttar Pradesh and Madhya Pradesh. National Rainfed Area Authority, NASC Complex, DPS Marg, Pusa, New Delhi - 110012, India. (www.nraa.gov.in)

NDMA. 2009. National Disaster Management Authority of India. (www.ndma.gov.in)

Conservation Agriculture as an Adaptive and Mitigation Strategy to Combat Climate Change

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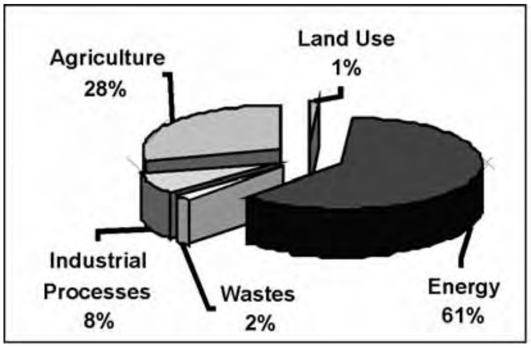
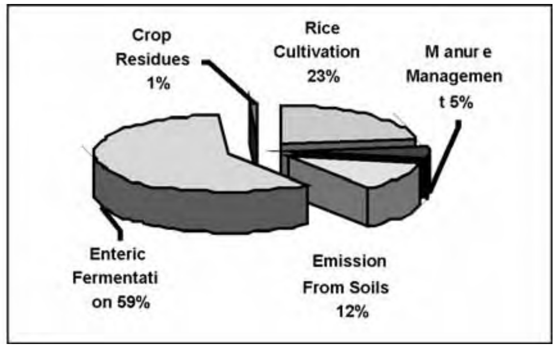
Introduction

Contributing 21 percent to country's GDP, accounting for 11 percent of total export, employing 56.4 percent of total work force and supporting 600 million livelihoods directly or indirectly; agriculture is vital to India's economy. Global warming and associated climate changes are increasingly impacting agriculture in a number of ways which have serious implications for national and global food security. At the same time, agriculture related activities contribute significantly to climate change through release of green-house gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) and also by altering land cover which changes its ability to absorb or reflect heat and light, thus contributing to radiative forcing. Land use changes through deforestation and desertification together with use of fossil fuels is the major anthropogenic source of carbon dioxide, while agriculture is the primary contributor of methane and nitrous oxides.

According to Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, agriculture sector consisting of cropland, pasture and livestock production, and forestry contribute 13 and 17 percent of total anthropogenic greenhouse gas emissions (GHG), respectively. This does not include agriculture associated emissions such as production of fertilizers (accounted under industry), food supply (transport and industry), cooling and heating (energy supply). While contribution of agriculture sector to CO_2 emission is relatively small, the sector accounts for about 60 percent of N_2O and 50 percent of CH_4 emitted mainly from soils and enteric fermentation respectively. The GHG impact through radiative forcing of N_2O is nearly 300 times that of CO_2. Methane and nitrous oxide emission increased by 17 percent from 1990 to 2005 and are projected to increase by another 35 to 60 percent by 2030 driven by growing nitrogen fertilizer use and increased livestock production. Increase in agriculture emission is expected, as population and economic growth increases demand on food.



Contribution of major sectors to emission of green house gases in India



Relative contribution of sub-sectors of agriculture to GHGs in India

According to MoEF estimates (NATCOM 2004), agriculture sector in India contributes about 28 percent of total GHG emissions and this is likely to increase due to the need to increase production to meet increasing food demand. Of these, emissions by livestock (through enteric fermentation) accounts for about 59 percent of emissions, while growing rice-paddy accounts for another 23 percent. Emissions from soils account for about 12 percent while manure management and crop residues burning account for the remaining 6 percent of the emissions. Over 90 percent of nitrous oxide emissions constituting 4 percent of India's GHG emission come from agriculture sector, largely due to fertilizer use.

In what way does climate change impact agriculture?

According to the IPCC Third Assessment Report, the impact of climate change on agriculture will be mediated through a combination of one or more factors:

- Direct impact of changes in atmospheric composition (e.g. increased CO_2 concentration),
- Increased mean/maximum temperature, and
- Changes in availability of water due to changes in pattern and amount of rainfall, resulting in increased GHG emissions.

Although increase in CO_2 can be beneficial to several crops, the associated increase in temperature and variability in rainfall will considerably impact food production. These broad implications will influence agriculture in a number of ways, importantly; changes in crop yields and cropping patterns due to direct effect of

Table 1. Projected Climate Change Impact (IPCC, 2007)

Climate Related Changes	Likely Impact
Warmer and fewer cold days and nights: warmer and more frequent hot days and nights over most land areas	Decreased yields in warmer and increased yields in colder regions: increased pest incidence
Warm spells and heat waves increasing in frequency over most land areas	Reduced crop yields due to heat stress, adverse impact on health and productivity of livestock, increased danger of wild fires
Increased frequency of heavy precipitation events over most areas	Damages of crops increased soil erosion: increased problem at time of cultivation due to water logging etc.
Area affected by frequent drought will increase	Reduced crop yields from crop damage and failures, increased livestock deaths, accelerated land degradation/soil erosion, reduced arable land, migration
Intense tropical cyclone activity increase	Damage to crops/trees/coastal ecology
Increase in incidence of high sea level	Stalinization of estuaries and freshwater systems, loss of arable land, increased migration

Source: FAO (2008)

changes in temperature, precipitation and CO_2 concentration. Available evidence shows that a significant reduction in the potential yield of most crops will take place. This fall in production could have a significant impact on GDP, with rainfed areas being worst affected.

These factors will impact agriculture differentially depending on the nature and extent of change. The exact manner in which these climates related changes will impact agriculture in a region is uncertain due to uncertainties in nature and extent of changes. However, in a broad manner, climate change will impact agriculture through:

- Greater stress on land and water resources such as, shifts in land use, resulting coastal areas in response to rise in sea level
- Increasing threat to ecosystem functioning and biodiversity through indirect effect of changes in soil moisture, distribution and frequency of infestation by pest and disease
- Increased vulnerability to extremes of climate events like droughts, floods, and cyclones, particularly in coastal areas

- Potentially drier regimes in the arid and semi-arid regions. There is sufficient evidence to support those vulnerable sections of farming will be the worst affected and more vulnerable to hunger and food security.

There are predictions such as, changing rainfall pattern and rising temperatures during the coming decade will contribute to severe water shortages or flooding and cause shift in crop growing seasons. The predicted temperature rise of 1°C to 2.5°C by 2030 has serious implications by way of reduced crop yields, water availability and overall food shortage. Changes in mean rainfall and temperature as well as increase in extreme events will adversely impact agriculture, livestock, as well as fisheries; that will need to be addressed. There are projections on loss in production of wheat by 4 to 5 million tonnes for every rise in temperature by 1°C, while another projection indicated a probability of 10 to 40 percent loss in crop production with increases in temperature by 2080-2100 (IARI study, 2008).

Responding to Climate Change

Agriculture is both a culprit and a victim of climate change. There are opportunities, both to reduce the contribution of agriculture to climate change by reducing gaseous emissions and to define and pursue strategies to develop cost effective ways to assist the farmers adapt to changes. Interventions which are aimed at reducing the source or enhancing the sink of greenhouse gases constitute the mitigation strategy while adaptation refers to adjustments in the system in response to actual or anticipated climatic stimuli to moderate the potential harmful impacts and exploit the beneficial opportunities from expected changes.

IPCC sees agriculture sector as having a significant GHG mitigation potential and that a major portion of this is assumed to come from carbon sequestration in soils. Soil carbon sequestration is one of the most promising options. Increasing carbon content in soil through better management practices offer benefits for biodiversity, soil fertility and productivity and improved water storage capacity. Further such efforts help stabilize and result in increased production while optimizing use of inputs and reversing land degradation, also helping restore the ecological health.

There are other potential ways to mitigate GHG emissions through changes in agriculture technology and management practices. Changing crop mixes to include more perennials (agro-forestry system) or those having deep rooted system increase the amount of carbon stored in soils. Cultivation systems that reduce tillage and leave residue encourage build up of carbon. Improved crop, soil, water and nutrient management strategies can reduce both nitrous oxides and methane emissions. Mitigation options to reduce emissions from livestock include improving livestock waste management, and ruminant livestock management through improved diet, nutrients and increased feed digestibility. Farming practices that aim to achieve desired production level with reduced dependence on purchased inputs (e.g. through improved recycling of nutrients/ nitrogen fixing cover crop) would offer a sound mitigation option that simultaneously enhances adaptation.

Recognizing the main sources, efforts at mitigation of GHG emission need to focus on:

- Sequestering atmospheric CO_2 through enhanced storage in soils
- Enhancing agricultural/livestock productivity so as to reduce pressure on deforestation and denudation
- Emphasis on reduced dependence on non-renewable energy sources by improving use efficiency of inputs through available management options.

Table 2. Green House Gas Mitigation Opportunities.

GHG mitigation strategy	Opportunities
Enhance carbon sequestration in soils and biomass	• Improved crop and grazing land management emphasizing agro forestry, cover crops, crop residue management • Restoration of degraded lands
Reduce CO_2 emissions	• Reduce biomass/crop residue burning· Reduced tillage system, recycling bio wastes· Efficient use of energy to reduce dependence on fossil fuels
Reduce CH_4 emissions	• Improved rice cultivation technologies • Improved livestock and manure management • Reduce biomass burning
Reduce N_2O emissions	• Develop and promote technologies for improved use efficiency of fertilizers • Enhance biologically mediated N2 fixation in agricultural systems
Reduce dependence on non renewable energy sources	• Promote energy efficient technologies • Reduce use chemical fertilizers and pest control chemical through integrated management approaches

Adapting to Climate Change

The term adaptation refers to adjustments which a system (natural or human) takes up in response to actual or expected climate stimuli or their effects which moderate harm or exploits beneficial opportunities. The term adaptive capacity accordingly refers to the ability of a system to adjust to climate change or variability in ways that it moderates the potential adverse effects or takes advantage of opportunities to cope with consequences. The term also refers to capabilities, resources and institutions of a country or a region to implement adaptive measures. As indicated earlier, the likely impact and possible adaptive strategies and interventions in response to climate change elements will be location specific, recognizing however, the need to include interventions into large scale and coherent adaptation programs. The most effective adaptation approaches, as highlighted in United Nations Framework Convention on Climate Change (UNFCC) meetings are those that address a combination of environmental stresses and factors aimed at enhancing food security and water availability, combating land degradation and soil erosion, reducing loss of biological diversity and ecosystem services as well as improving adaptive capacity within the framework of sustainable development. Addressing food security concern has to be the main criteria for effectiveness of adaptation strategies at national and local levels.

Conservation Agriculture

The concept of 'Conservation Agriculture' which is rooted in giving a practical shape to a few scientifically proven basic guiding principles has globally emerged as a way to achieve sustainability goals. The basic guiding principles that can leverage a change from the conventional agriculture system include:

- Developing and promoting a system of raising crops with minimum soil disturbance through operations involving direct seeding of crops in untilled soils
- Keeping the soil surface covered by practices such as leaving and maintaining crop residues cover on the soil and/or growing cover crops
- Adopting diversified crop sequencing, spatially and temporally

Farming practice based on these basic principles when adopted in an integrated fashion over a period of time contribute to sustainable increases in crop productivity, improving soil health, biodiversity and in reversing processes contributing to land and water degradation. Sufficient evidence has accumulated to show that CA practices have both the potential to mitigate GHG emissions from agriculture related activities and as an adaptive strategy to cope increasingly with climate related changes. Table below summarizes the way in which elements of CA approach can mitigate climate change and provide a way to adapt to new situations.

Conservation agriculture constitutes an integrative approach to address multiple challenges facing the agriculture and environmental sectors – enhancing productivity in the face of acute and wide spread problems of resource degradation (soil erosion, declining water availability and quality, declining diversity) and increasingly stressed ecosystems and climate change. The approach enables addressing the immediate concerns of enhancing productivity, long term sustainability, and food security

Table 3. Adaptation Strategies to Cope with Climate Change.

Likely impact on agriculture	Possible adaptative strategy
Greater vulnerability of production systems through:	
• Direct impact increased temperature	• Promote agro-biodiversity (plant and animal) including agroforestry that can import greater resilience to changing environmental conditions and stresses
• Indirect impacts on water availability resulting from increased incidence of draughts and higher intensity rains	• Develop and promote adoption of draught resistant/ flood and salinity resistant crops, and livestock breeds with greater ability to withstand stressed environments
	• Develop, adopt and promote soil, crop and water management practices aimed at efficient use of water available water resources in a watershed; to enhance use efficiency of nutrients
	• Develop and promote practices for improved livestock nutrition and management to cope with stress

concerns. It is well recognized that the problems of enhancing productivity which are intimately linked to resource degradation and climate change issues are region specific and therefore the solutions have to be found in the context of prevailing problems. Thus, while Conservation Agriculture principles are fairly universal in nature, technologies aimed at translating these into practical solutions have to be specific to a region and the existing farming system. The principles of Conservation Agriculture are not new. They have been well known and tested for some time. What is new is the recognition of the need to pursue these in an integrated fashion - this is the real challenge.

It is apparent that CA based practices when adopted in an integrated manner and over a period of time hold a significant potential to mitigate GHG emissions and at the same time offer opportunities as an adaptive strategy to cope up with climate change related challenges increasingly facing the agriculture sector.

Policy Initiatives Needed

Elements of CA and the objectives to be achieved through CA are scattered around various development programmes of the central government sponsored by different Ministries such as Ministry of Agriculture, Ministry of Rural Development, and Ministry of Environment and Forests. However, these are largely being promoted at the farm level in an isolated manner resulting in limited impact. Similarly, research and technology generation efforts have also been viewed and pursued in a fragmented disciplinary mode and not in the context of a farming system or a problem solving integrative mode. To do this it is important that technologies are refined and adapted to different farming situations working together with farmers building on their experience and knowledge. This would ensure wider uptake of technologies in an integrated manner.

An important consideration is the development and operationalization of CA research projects that need to link and feed into major ongoing development programmes of the Government. There are several central/state government programs and schemes that have objectives of achieving both enhanced productivity and resource conservation. It will be crucial to ensure integration of CA objectives with the focus of central government programmes. In the next issue we would attempt a detailed analysis of various government schemes and bring to the fore the opportunities of CA integration into the current focus of these programmes, eg., Mission of the National Action Plan on Climate Change, and Biodiversity Conservation of the Ministry of Environment & Forest. Integration of technologies and practices based on CA principles would help recognize agriculture as part of a larger environmental concern. In specific agro-ecosystems CA will help to provide an effective, adaptive and mitigative strategy to overcome climate change related impacts through carbon sequestration. CA's induction as a preferred practice will help position relevant mechanisms related to climate change adaptation. Similarly, CA facilitated through state/districts plan schemes of the Ministry of Agriculture through Rashtriya Krishi Vikas Yojana (RKVY), National Food Security Mission and National Rainfed Area Authority will help bring about integrated development of foods crops, mechanization needs, soil health and productivity for specific farming systems to help farmers facing problems to cope with changing technological needs.

To operationalise the CA approach, therefore, it would be important to put in place a 'CA Adaptive Research, Policy and Development' initiative that cuts across scientific disciplines and links to development department activities in respective regions. The primary aim of the initiative will be to contribute build and enhance capacity of farmers to sustainably manage their own resources to respond to multiple challenges. CA approaches have the potential to benefit both small and large holding farmers and both irrigated and rainfed farming situations. It also has the potential to take an integrated view of interconnected concerns relating to enhancing productivity and conserving resources. CA principles can thus facilitate integrated approaches to meet larger goals of sustainable agriculture.

Global Climate Change and Indian Agriculture: A Review of Adaptation Strategies

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Introduction

India needs to enhance its agricultural production to meet the demands caused by a growing population and increasing affluence. We are, however, witnessing a period of stagnation/slow growth in production, deterioration of natural resources, and increasing competition for land, water and capital. To compound the problem further, global climate change is likely to impact crop and livestock production, hydrologic balances, input supplies and other components of agricultural systems, making production much more variable than at present. The following section provides a summary of the currently understood impacts of climate change on Indian agriculture based on the review of Aggarwal (2008):

1. Production of most cereals is projected to decrease between 10 to 40% by the end of this century due to increased temperatures, variable rainfall and associated droughts and floods and reduced irrigation water supplies (Rosenzweig et al., 1994; Fischer et al., 2002; Parry et al., 2004, Cline, 2007; Stern 2007). Some evidence of such changes is already available. Analysis of the historical trends in yields in the Indo-Gangetic plains has shown that rice yields during last 3 decades are showing a declining trend and this may be partly related to the gradual change in weather conditions(Aggarwal et al., 2000; Pathak et al., 2003). In March 2004, temperatures were higher in the Indo-Gangetic plains by 3-6°C, which is equivalent to almost 1°C per day over the whole crop season. As a result, wheat crop matured earlier by 10-20 days and wheat production dropped by more than 4 Mt in the country (Samra and Singh, 2005). Reduction in average productivity of apples in Himachal Pradesh in recent times may have been due to inadequate chilling in recent decades, crucial for good apple yields. This seems to have resulted in a shift of apple belt to higher elevations.
2. Increasing climatic variability associated with global warming will result in considerable seasonal/annual fluctuations in food production. All agricultural

commodities even today are sensitive to such variability. Droughts, floods, tropical cyclones, heavy precipitation events, hot extremes, and heat waves are known to negatively impact agricultural production, and farmers' livelihood. For example, recent drought of 2002 led to reduced area coverage of more than 15 Mha of the rainy-season crops and resulted in a loss of more than 10% in food production.

3. There are indications that cold waves and frost events could decrease in future due to global warming. As a consequence, we can expect less frost damage to crops such as potato, peas, mustard and other vegetables and fruit crops.
4. There will be significant increase in runoff resulting in increased frequency and duration of floods. The increasing probability of floods and droughts and other uncertainties in climate may seriously increase the vulnerability of eastern India and of resource-poor farmers to global climate change. The increased melting and recession of glaciers associated with global climate change could further change the runoff scenario especially in the Indo-Gangetic plains, which, in turn, would have consequences on food production.
5. Increase in temperature may have significant effect on the crop-pest interactions. Crop-pest, crop-weed interactions may alter significantly with climate change. The appearance of black rust in north India in sixties and seventies was also related to the temperature-dependent movement of spores from south to north India.
6. Global warming could increase water, shelter, and energy requirement of livestock for meeting projected milk demands. Climate change is likely to aggravate the heat stress in dairy animals, adversely affecting their productive and reproductive performance.
7. Increasing sea and river water temperature is likely to affect fish breeding, migration, and harvests. A rise in temperature as small as 1°C has important effects on the mortality of fish and their geographical distributions. Coral reefs in the Indian seas are predicted to decline from 2040.

Adaptation strategies to climate change

Adaptation strategies i.e., adjustment in agriculture in response to actual or expected climatic *stimuli* or their effects, which moderates harm or exploits beneficial consequences, should be devised and implemented. Adaptation to climate change will require development of suitable technologies along with socio-economic and political interventions for their speedy adoption. Adaptation strategies in agriculture to climate change have recently been reviewed by Esaterling et al. (2007), Aggarwal and Shivkumar (2009), and Aggarwal et al. (2009). Some of these potential adaptation strategies and the information needs to adopt them are discussed below.

Developing climate-robust crops: It is clear that due to climate change the current technologies alone will not be sufficient to meet the future food demand even if all necessary support is provided for bridging yield gap. New genotypes with higher yield potential will be required. For any crop improvement programme, the source is variability in its germplasm. In the event of lack of enough desirable variability, the genetic engineering interventions provide opportunity for inter specific and intra specific intervention of desirable gene pools. Source of the novel genes may be from plant, animal or microbes. The coupling of new genomic tools, technologies, and resources with genetic approaches is essential to underpin crop breeding through marker-assisted selection (Habash et al., 2009). The crop improvement programme of the country is more equipped now than earlier and it is essential to exploit this opportunity arising out of challenges posed by climate change and variability. The strategies to develop new genotypes may include the following.

- Improvement of germplasm for heat tolerance is treated as one of the targets of wheat breeding programme (Ortiz, et al., 2008). Wheat varieties, for example, capable of maintaining high 1000-kernel weight under stress seem to possess tolerance to hot environments (Reynolds and Borlaug, 2006).
- Similarly, it is essential to develop tolerance to multiple abiotic stresses as they occur in nature. The abiotic stress tolerance mechanisms are quantitative traits in plants. Germplasm with greater oxidative stress tolerance may be exploited as oxidative stress tolerance is one example where plant's defense mechanism is targeting several abiotic stresses.
- As several research efforts have been on to convert rice from C3 to C4 crop, such efforts may also be useful for improvement of radiation use efficiency of other C3 crops such as wheat as well.
- Current long duration varieties may have a reduced phenology, when exposed to high temperatures. This may offset the reduction yield due to shorter crop growth and grain filling period because of the rise in atmospheric temperature. Exploitation of genetic variability in grain filling duration may also form one of the strategies to minimize the reduction in grain filling duration due to rise in temperature in climate change scenarios.
- Improvement for water use and nitrogen use efficiency has been attempted since long. These efforts become more relevant in the climate change scenarios as it is likely that the water resources for agriculture may dwindle in future. Nitrogen use efficiency may be reduced in the climate change scenarios because of high temperatures and heavy precipitation evens causing volatilization and leaching losses. Apart from this, for exploiting the beneficial effects of elevated CO_2 concentrations, crop demand for nitrogen is more likely to increase. Thus it is

important to improve the root efficiency for mining the water and absorption of nutrients.

- Exploitation of desirable genes from relative wild types.
- Varieties with high revival capacity after stress become important particularly in view of the increase in climatic variability. Increase in frequency of events such as heavy precipitation, heat wave, cold wave pose challenge to standing crop. For crop need to not only be tolerant to the stress but also should recover faster to produce better yields.
- Exploitation of genetic engineering for 'gene pyramiding' becomes essential to pool all desirable traits in one plant to get the 'ideal plant type' which may also be 'adverse climate tolerant' genotype.

Changes in land-use management practices : Changing land-use practices such as the location of crop and livestock production, rotating or shifting production between crops and livestock, shifting production away from marginal areas, altering the intensity of fertilizer and pesticide application as well as capital and labor inputs can help reduce risks from climate change in farm production. Adjusting the cropping sequence, including changing the timing of sowing and harvesting, to take advantage of the changing duration of growing seasons and associated heat and moisture levels is another option. Altering the time at which fields are sowed can also help farmers regulate the length of the growing season to better suit the changed environment. However, these adaptations may cost additional expenditure which needs to be analysed and understood.

Climate change in terms of increased temperature, CO_2, droughts and floods would affect production of crops. But the impact will be different for different crops and regions. There is need to identify the crops and regions that are more sensitive to climate changes/variability and relocate them in more suitable areas. For example, it is apprehended that increased temperature would affect the quality of crops, particularly important aromatic crops such as basmati rice and tea. Alternative areas that would become suitable for such crops from quality point of view need to be identified and assessed for their suitability.

Improved pest management: Changes in temperature and variability in rainfall would affect pests' and disease incidence and virulence of major crops. This is because climate change will potentially affect the pest/weed-host relationship by affecting the pest/weed population, the host population and the pest/weed-host interactions. Some of the potential adaptation strategies could be (1) developing cultivars resistance to pests and diseases; (2) integrated pest management with more emphasis on biological control and changes in cultural practices, (3) pest forecasting using recent tools such as simulation modelling, (4) alternative production techniques and crops, as well as locations, that are resistant to infestations and other risks.

Efficient use of resources: Improving farmers' ability to use water more efficiently and to better manage their fragile soil is essential if they are to adapt to the shocks of climate change. In many farming systems, as much as 70 percent of the rain falling on a crop is lost to evaporation and runoff and cannot be used by the plants. Improved water management, therefore, will be vital to sustaining crop productivity levels in the face of climate variability and change. Changing land topography through land contouring and terracing and construction of diversions and reservoirs and water storage and recharge areas can help reduce vulnerability by reducing runoff and erosion and promoting nutrient restocking in soils. In light of the increased frequency of droughts, farmers can further adapt by changing the selection of crops. Inevitably, this will lead to shifts in the distribution of agricultural land use, which in itself will have impacts on soils. Alternatively, the introduction of other management techniques that conserve soil moisture, such as reduced or no tillage, in order to maintain soil organic carbon contents can result in improved soil structure and fertility.

Resource-conserving technologies involving zero- or minimum tillage with direct seeding, permanent or semi-permanent residue cover, and crop rotations with sod crops (i.e., forages) have potential to improve the efficiency of use of natural resources, including water, air, fossil fuels, soils, inputs and people. Among other things, the efficiencies gained include less land and time needed to produce the required staple cereals, allowing farmers to diversify crops and cropping patterns or pursue other gainful activities. The technologies can improve the sustainability of the cropping system by conserving the resource base and higher input use efficiency.

Augmenting food production and farmers' income: One way to avoid the risks of climate change and the increased climatic variability would be to increase the production and income of the farmers. Climatic factors in India allow reasonably high yield potential of most crops indicating large yield gaps. Even if a fraction of these yield gaps could be bridged, food security of the region will get strengthened and its vulnerability to climate change reduced. Fragile seed sector, poor technology dissemination mechanisms, lack of adequate capital for inputs, and poor markets and infrastructure are the key reasons for yield gaps. A mission approach for key crops focusing on eliminating these constraints will enhance food security. Similarly income from agriculture can be increased through reduced costs, minimizing risks, exploring new trade opportunities, improving qualities, producing high value crops and with value addition.

Harnessing the indigenous technical knowledge of farmers: Farmers in south Asia, often poor and marginal, have experimenting with the climatic variability for centuries. There is a wealth of knowledge of a range of measures that can help in developing technologies to overcome climate vulnerabilities. There is a need to harness that knowledge and fine-tune them to suit the modern needs.

Reducing dependence on agriculture: In most of the developed countries only 3-4% of population depends on agriculture while 60% of Indian population is dependent on it. Though the contribution of agriculture towards gross domestic product has gone down in recent years to about to 20%, dependency of population on agriculture has remained unchanged. This has created the problems of unemployment, land fragmentation, inefficiency and low volume of marketable surplus, which increased the vulnerability of agriculture to climate change. Contract farming, mechanization and agri-industries for post-harvest food processing would reduce the vulnerability for a large number of small and medium farmers. Policies need to be formulated to encourage institutional arrangements to bring small and marginal farmers and landless labourers to opt for contract farming.

Better forecasts, crop insurance and other policy options: A pre-requisite for managing climatic risks, and thus increasing adaptive capacity, is timely knowledge of their spatial and temporal magnitude. A dense network of Weather Stations for standardized, real-time monitoring of rainfall and temperatures needs to be established in the whole region. SAARC Centre on Meteorology could be very effective for this purpose. This weather data, together with short- and medium- range weather forecasts, will enable scientists and extension workers to quickly translate this into region-specific, value-added agricultural services for farmers such as time of crop planting, applying inputs, and timing the farm operations. Information and communication technologies (ICT) could greatly help researchers and administrators develop contingency plans.

Crop insurance schemes should be put in place to help the farmers in reducing the risk of crop failure due to these events. Crop insurance schemes have been launched in many countries to cover the yield losses caused by weather extremes such as due to droughts and floods. In general, most of these schemes have not been very successful due to spatial and temporal variability in weather elements and associated risks, limited consideration of soil, biotic and socio-economic considerations in risk assessment, determination/verification of crop loss, and absence of clear links between risk profile and premiums.

Conclusions

Agriculture is sensitive to short-term changes in weather and to diurnal, seasonal, annual and long-term variations in climate. The climate change may considerably affect the food supply and access through direct and indirect effects on crops, soils, livestock, fisheries and pests. The climate change may reduce average crop yields and may lead to decreased yield stability. With India's dependence on monsoon rains, Himalayan glacier-fed rivers and its long coastline; climate change would have a serious impact. There are, however, several ways by which the adverse impact of climate change may be reduced and agriculture adapted to changed climate. There is a need to develop policy framework for implementing the adaptation and mitigation options so that the farmers are saved from the adverse impacts of climate change.

References

Aggarwal, P.K., Bandyopadhyay, S.K., Pathak, H., Kalra, N., Chander, S., Sujith Kumar, S. 2000. Analysis of the yield trends of rice-wheat system in north-western India. Outlook on Agriculture 29(4): 259-68.

Aggarwal, P.K. 2008. Global climate change and Indian agriculture: impacts, adaptation and mitigation. Indian J. of Agric. Sci.. 78: 911-919.

Aggarwal, P.K., Sivakumar, M.V.K. 2008. Global Climate Change and Food Security in South Asia: An Adaptation and Mitigation Framework. Concept paper presented at the International Symposium on 'Climate Change and Food Security in South Asia' held in Dhaka, Bangladesh, from 25-30 August 2008.

Aggarwal, P.K. 2008. Impact of climate change on Indian agriculture: impacts, adaptation and mitigation. Indian J. Agric.Sci.. 78: 911-19.

Aggarwal, P.K., Baethegen, W.E., Cooper, P., Gommes, R., Lee, B., Meinke, H., Rathore, L.S., Sivakumar. M.V.K. 2009. Managing climatic risks to combat land degradation and enhance food security: key information needs. Paper presented at the World Climate Conference. September 2009. World Meteorological Organization. Geneva.

Cline, W., 2007. Global warming and agriculture: Impact estimates by country. Peterson Institute for International Economics, 250pp.

Easterling W.E., Aggarwal P.K., Batima P., Brander K.M., Erda L., Howden S.M., Kirilenko A., Morton J., Soussana J.F., Schmidhuber J. and Tubiello F.N. 2007. Food, fibre and forest products Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry M.L., Canziani O.F., Palutikof J.P., van der Linden P.J. and Hanson C.E. Eds., Cambridge University Press, Cambridge, UK 273-13.

Fischer, G., Shah M Velthuizen, H. van. 2002. Climate Change and Agricultural Vulnerability, International Institute for Applied Systems Analysis. Laxenburg, Austria

Habash D.Z., Kehel Z., Nachit M. 2009. Genomic approaches for designing durum wheat ready for climate change with a focus on drought. J. of Experimental Botany. 60 (10): 2805-2815.

Ortiz. R., Sayre, K.D., Govaerts, B., Gupta, R., Subbarao, G.V., Ban, T., Hodson, D., Dixon, J.M., Ortiz-Monasterio, J.I., Reynolds, M. 2008. Climate change: Can wheat beat the heat?. Agriculture, Ecosystems and Environment. 126: 46-58.

Parry, M.L., Rosenzweig, C., Iglesias Livermore, A.M., Fischer, G. 2004. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Global Environ. Change. 14: 53-67.

Pathak, H., Ladha, J.K., Aggarwal, P.K. 2003. Climatic potential and on-farm yield trends of rice and wheat in the Indo-Gangetic plains. Field Crops Res. 80(3): 223-234.

Reynolds, M.P., Borlaug, N.E. 2006. International collaborative wheat improvement: impacts and future prospects. J. Agric. Sci. (Cambridge). 144: 3-17.

Rosenzweig, C., Parry, M.L. 1994. Potential impact of climate change on world food supply. Nature. 367: 133-138.

Samra, J.S., Singh, G. 2005. Heat wave of March 2004: impact on agriculture. Indian Council of Agricultural Research, New Delhi. 32 pp.

Stern, N. 2007. Stern Review on the Economics of Climate Change. Cambridge University Press. Cambridge. 692 pp.

Genetic Enhancement for Adaptation to Climate Change and Abiotic Stresses

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Introduction

Plant breeding is a continuous process that helps in converging desirable traits in a genotype over generations/a period of time. One of the most visible realities of post-Green Revolution crop breeding is the realization of reduced incremental changes in the yield potential of the major crops such as wheat and rice. For example, in wheat, after the genetic enhancement from less than 2 t ha^{-1} yield potential in the late 1960s it jumped to 4 t ha^{-1} in the next decade and to 5 t ha^{-1} in the 1980s. Since then, the increments are less than 0.1-0.2 t ha^{-1} with the maximum yield achieved by varieties such as PBW 343 (up to 6.0 t ha^{-1}) to the latest varieties such as DBW 17 (6.3 t ha^{-1}) and HD 2967 (6.5 t ha^{-1}). On an average, over large areas, these incremental changes hover around 4.5-4.7 t ha^{-1} from each of these varieties provided any of these does not succumb to diseases such as rusts (PBW 343) or drought/lack of irrigation water or all of these. Quantum jumps in yield as recorded in the first two decades of Green Revolution are not likely to be repeatable anymore while incremental yield enhancement is a possibility which requires accumulation of genes that increase component traits that influence yield and genes which protect the yielding ability from the ill effects of abiotic and biotic stresses. The scenario is the same for rice and other mega crops where quantum jumps were achieved through exploitation of yield potential enhancing genes such as reduced height, photo-thermo insensitivity, nutrient responsiveness, etc.

Effect of Climate Change on Crops

The changing climatic factors visualized over the last decade is apparently a reality which is there to stay and it is of paramount importance that appropriate scientific interventions are put in place to overcome the obvious environmental changes effected by global climate change. Introducing genes which are able to tolerate changes to the parameters representing climate change is one of the most reliable, economically viable and easily adaptable strategies that can be practiced in the form of genetic enhancement in the crops. The major factors which reflect the changing environment are:

a. Increasing carbon dioxide (CO_2) concentration
b. Temperature extremes during crop growth period
c. Frequent droughts and drought like conditions during crop growth period
d. Increasing pest and pathogen load due to congenial conditions

It is, therefore, crucial to put together genes which can help the crops withstand the above stresses and enable realization of the genetic potential in yielding abilities despite the adverse climate factors. The effects of these factors alone and in combination are discussed below:

Effects of increasing carbon dioxide concentration: Climate change in terms of enhanced carbon dioxide concentration as has been observed from less than 300 ppm in the 1950s to 370 ppm and above since the year 2000 has consistently resulted in changed productivity, quality and nutrient contents in grains, especially the winter crops, such as wheat in the tropical environments of India. The obvious effects likely to happen till water crisis crosses the threshold limits are:

- Increased grain yield (6 – 35%)
- Decreased protein content (to < 8% in wheat)
- Changes in carbohydrate packing resulting in poor storage and edibility value
- Lower mineral and vitamin contents

Effects of temperature extremes during crop growth period: Among the countries producing large quantities of wheat and rice, as such India suffers the exposure to high minimum and maximum temperatures. This makes the Indian crops even more vulnerable to minute changes in the temperature increments in both minimum and maximum values during the growth period. The expected effects on crop by increasing temperatures are:

- Increased crop transpiration and respiration - hence reduced productivity
- Forced maturity of crops - hence decreasing yield
- Increased pest attack that further reduces crop yield
- Shift in the onset and termination of crop season/duration

In contrast to the likely increment in productivity due to rising CO_2 concentration, the increased temperature consequentially causes the crop to spend more energy in coping with the load of increased transpiration and respiration rates with every unit rise in temperature. This also causes a depletion of ground water at a faster than normal rates. Thus the advantage of increased CO_2 is nullified in the form of increased physiological stress on the crop, unless there was compensation by increased relative humidity or precipitation during the raised temperature period. As has been visualized over the last few seasons in the north-western and north-eastern productive belt, there has been forced drying and curtailed grain filling period resulting in the reduction of yield as well as quality of the grain as produced. Changing relative humidity in the crop canopy area also enables pests and pathogens to flourish and harm the crop by causing increased infestation and disease.

Another increasingly noted phenomenon in the north-western and central plains of India is the changing time of sowing and harvesting in wheat in such a manner that the whole season is getting shortened by a few days because the temperatures which need to exist during second week of November is shifting towards the third week of November and grain hardening temperatures preceding harvest which used to be reached in April last week are getting achieved in April third week. Such changes are bound to cause the variety to have to expend compensatory energy portion which may also cause reduced yield.

Frequent droughts during crop growth period: While reduced rainfall or erratic distribution of rainfall may cause drought or drought-like situations during the entire growth period or during a phase of growth period of a crop, excessive transpiration loss may cause drought situation due to lowered water table in the irrigated production conditions. Lower water availability results in obvious yield reduction in the suffering crop.

Increasing pest and pathogen load due to congenial conditions: Increase in temperature accompanied by changing vapour pressure deficits that result in altered RH in the canopy region of the crop enables creation of conditions favourable for the insect-pest and disease causing pathogens to parasitize on the crop at a frequency and intensity higher than normal. An example of such a scenario is the epidemic-like situation of yellow rust severity on variety PBW343 in Punjab in February 2009 and unprecedented infestation by brown plant hopper on rice varieties in Kharif 2008 in Punjab and Haryana. Such an adaptation by a race of yellow rust was never noticed at such temperature situations before. Such consequences are unpredictable and likely to occur with many other pathogens and pests.

Genetic Enhancement Strategies to Cope with Changing Climates

Plant breeding is one of the easily accessible and practically adaptable interventions to overcome/reduce the effects of climate change and insulate crop production potential. It is possible to utilize existing variation in the genera or species through focused breeding efforts directed towards adaptability to changing growing environment. Genetic improvement of crops for drought adaptation is, however, considered probably as the greatest challenge due to the complexity and unpredictability of the drought environment. Some of the breeding options available are:

a. Exploitation of alien genetic variation (wild species and genera)
b. Breeding for enhanced water productivity
c. Breeding for earliness
d. Varieties for fragile ecosystems

Exploitation of alien genetic variation: Although the genetic resources and parental genetic stocks utilized in plant breeding are relatively restricted, the efforts made by genetic resources management activities in most countries including India have enabled the accessibility to a large range of genetic variation for plant breeding activities. However, a vast majority of genetic resources remain unused in plant breeding due to the uncertainties associated with use of undomesticated or unimproved genetic backgrounds. But, the physiological traits such as osmotic adjustment and transpiration efficiency are less likely to show interaction with plant type and can be estimated on all gene pools for their transfer to cultivated crop species or genotypes from wild relatives.

As such the entire gene pool documented and collected globally before 1992 is available for exploitation by plant breeding community facilitated under the Convention on Biodiversity (CBD). In addition to local adapted landraces, primary gene pools represented by germplasm that share a common genome and *secondary gene pool* represented by closely-related genomes can be utilized through intra- and inter-specific hybridization. Most commonly, this approach has been employed in the past by plant breeders to breed for disease resistance in most crops such as wheat, rice and maize. Prominent plant scientists like, Sears, Riley and McIntosh were able to transfer a large number of genes from related wild species of wheat for imparting resistance to the rust diseases. Drought tolerance component traits such as narrow & erect leaves, deeper root system and better water use efficiency traits have ample scope to be taken out from the wild species and introgressed in the genetic stocks for their use as parental materials. Similar traits have been transferred into chickpea from *Cicer reticulatum* at the Indian Agricultural Research Institute, New Delhi to enable deeper root, better water use efficiency accompanied by longer grain filling period in the cultivated *desi* as well as *kabuli* chickpea.

In wheat, Mujeeb-Kazi *et al.* (1998) used wide crossing to introduce stress adaptive genes from diploid and tetraploid genomes. This was achieved through the production of synthetic hexaploids by crossing tetraploid durum wheats with *Aegilops tauschii*, the donor of the D genome. Wide-crossing has contributed significantly to the drought adaptation of CIMMYT wheat germplasm. The synthetic derived wheat lines have improved ability to extract water at intermediate (30–90 cm) rooting-depths.

Allele mining for genes and/or QTLs associated with adaptive traits is one immediately available option in search of new genes/alleles that result in imparting drought tolerance. These alleles in turn, are expected to facilitate genome mining in the future by identifying the location of promising alleles and facilitating their translocation through use of perfect markers. Functional genomics is, therefore, a powerful tool to explore this naturally existing variation in a crop species.

Breeding for enhanced water productivity: Water use efficiency is essentially physiological manifestation enabled by genes in combinations that regulate activities related adaptive parameters under low water availability. For this purpose, through an exhaustive review, Reynolds *et al.* (2005) proposed a conceptual model for drought adaptation in wheat based on literature which they suggest is extendable to all crop species. It was proposed to place the adaptive traits in four groups such that the genes and/or physiological effects among groups were likely to be relatively independent and when parents with contrasting expression in trait-groups were crossed, drought-adaptive genes were more likely to be pyramided together in the sergeants'. The grouping of the plants according to their hypothesis is as follows:

Group 1. Traits related to pre-anthesis growth: In the majority of drought-prone environments, water stress intensifies as the crop cycle progresses. Therefore the purpose of focusing on traits associated with pre-anthesis growth is to maximise opportunities for assimilation during this more favourable period. The traits considered for transfer are crop establishment to ensure rapid ground cover and pre-anthesis biomass and partitioning of assimilates to stem reserves to facilitate better stand or culm strength for enabling the fructans to contribute during grain filling period related drought that restricts photosynthesis.

Group 2. Traits related to access to water: These traits are deeper root system, stomatal aperture related traits and osmotic adjustment which are expected to help the plants take on the pressure of drought conditions. The traits such as relative leaf water content, stomatal conductance, carbon isotope discrimination and canopy temperature (CT) can give indications of water extraction patterns. Traits that are indicative of the water status of a plant are useful indicators of a plant's capacity to match evaporative demand through the ability to extract soil water.

Of these by far the easiest to measure in the field is CT, which shows good association with performance under drought of genotypes. Measurement of these traits in conjunction with soil moisture sampling may be useful in selecting deep-rooted germplasm. A vigorous root system as an adaptive phenomenon results in the expression of a set of traits associated with improved water relations which are also likely to have pleiotropic effects of genetic improvement in the genes associated with the pre-anthesis adaptive traits (Group 1).

Group 3. Traits related to water use efficiency (WUE): Success in improving WUE of crops under stress has been limited as the trait is not easy to measure directly. The estimation of WUE at canopy level involves quantification of moisture fluxes between the soil at different depths and atmosphere, occurring both by transpiration from leaves as well as evaporation from the soil surface. However, the discovery of a method for accurate ranking of differences in WUE on the basis that the CO_2 fixing protein Rubisco discriminates against the heavier carbon isotope ^{13}C in favour of ^{12}C resulted in the ability to detect plants operating with a higher stomatal resistance to diffusion of CO_2 having higher transpiration efficiency and fixing relatively more $^{13}CO2$, which can be detected in plant tissue using mass spectrometry (Farquhar & Richards, 1984). Measurement of 13C isotope discrimination (CID) of non water-stressed leaf tissue estimates the intrinsic WUE of a genotype in the absence of the confounding effect of water availability.

Another trait under this group that is adaptively important is the photosynthesis in the inflorescence. The reproductive parts such as inflorescence having photosynthetic ability can also play a major role in grain filling under severe drought which can contribute up to 40% of total carbon fixation, for example, in wheat. In addition the inflorescence has higher WUE than leaves with longer survival compared to premature senescence by leaves when under considerable drought stress pressure.

Harvest Index is also considered as an adaptive trait that is associated with improved WUE since the genes that affect a greater relative partitioning of assimilates to the sink, resulting in a higher harvest index, would be expected to improve yield under drought are not likely to be associated with the traits that build biomass. Whenever HI is not a direct consequence of genes such as Rht2 in wheat, it becomes an adaptive trait which can be effective in the improvement of grain filling, remobilization of stem reserves, etc.

Group 4. Traits related to photo-protection: It is well known that drought stress exposed plants will be subjected to higher loads of radiation and the consequent damage unless they have the adaptive capacity to overcome the effects of excessive radiation. These adaptive traits can be biochemically modulated protection or anatomical adaptations. Drought stress results in warmer leaf temperatures and lower CO2 concentration in the leaf which in turn lead to the accumulation of free oxygen radicals. If the plant system has the ability to have induced synthesis of antioxidants such as super-oxide dismutase under drought situation, the antioxidants enhance drought adaptation by minimizing the organelle damage due to radiation. Some of the simply inherited traits like leaf rolling, pubescence, erect posture, and cuticle-wax can potentially decrease radiation load to the leaf surface, thus reducing the radiation caused damage. However, there is a large amount of genetic variability for these traits among different crop species which potentially can be explored for improving drought tolerance. The genetic stock characterized in the Gene bank at NBPGR, New Delhi is a good source to begin this approach with a focus on the drought adaptive traits to be introgressed into the cultivated species.

Breeding for earliness: One of the logical approaches which results in the genotypes that can overcome the drought and water stresses is to breed varieties with shorter duration of growth so that they could avoid long spells of water or heat stress seeking energy to cope with diverting the energy required during the physiological stages for accumulating dry matter and translocating it to sink. In order to reduce the growth period, there have to be certain basic features packed into a genotype such as

- Adaptation to environmental changes with differential sensitivity or insensitivity to photoperiod, vernalization and thermoperiod
- Reduced height through genetic manipulation that accumulates appropriate number of genes/QTLs for height that is just sufficiently tall to provide the biomass required for maximised photosynthate production that is potentially translocated to the sink. The optimum height (not the most dwarf plant type) may be defined as that height which does not succumb to lodging, has increased harvest index and increased responsiveness to inputs converting it into higher yield. This feature is best understood by the preference of two-gene dwarf wheat or semi-dwarf wheat compared to three-gene dwarf wheat. The latter reduced height to such an extent that it disabled sufficient biomass accumulation for its conversion into maximum grain yield matching the potential of wheat even after maximized harvest index close to 50%. The reduced height of two-gene dwarf was more appropriate in realized yield close to its potential in wheat. In each crop such optimal height levels and the genes responsible for the same need to be deciphered and targeted in breeding programs.
- Canopy architecture that supports maximum photo-energy usage, minimizing the radiation and water-stress adaptation energy is the appropriate plant type to adapt to erratic climate variations during crop growth phases. For example, erect leaves of cereals or erect plant type of legumes is more preferable trait to make

efficient use of light energy and least loss of energy during water balance management activity while coping with water stress. A more recent concept is to consciously select for the 'stay-green' trait that retains the capacity of a plant to keep the photosynthetic machinery operative in times of need even during grain filling period if during vegetative phase, there was a prevailing drought or heat stress that restricted photosynthesis while inducing forced senescence.

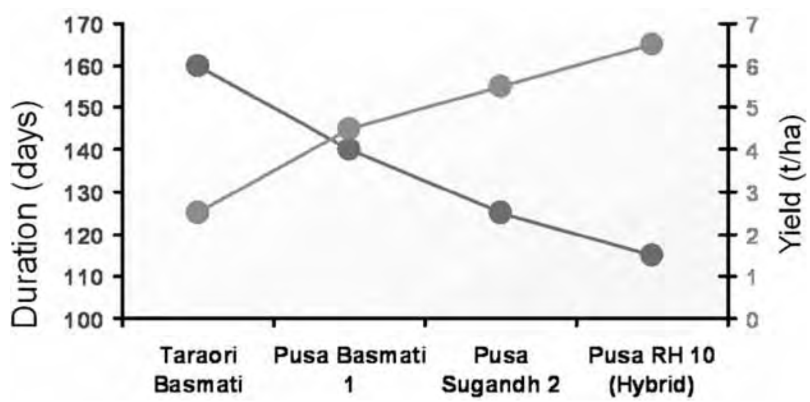

Fig. 1. Breeding basmati rice for increased yield with reduced crop duration, lower water requirement and photo-thermo insensitivity at IARI, New Delhi.

A successful example of incorporating all these characteristics through breeding for earliness is the successive development of high yielding semi-dwarf basmati rice varieties by IARI over a period of last fifteen years. The low yielding (2.5 t ha^{-1}) long duration basmati varieties taking 165 days to mature were improved by reducing the maturity to 140 days in Pusa Basmati 1 and Pusa Basmati 1121 with yields increased to 4-5 t ha^{-1}. Continued breeding further reduced the maturity to 125 days in Pusa Sugandh 5 and Pusa Sugandh 2 with yield increased to 5-6 t ha^{-1} which has further reduced to 115 days of maturity with 7 t ha^{-1} with Pusa Rice Hybrid 10. All this varieties/hybrid have erect leaf habit, photo-thermo insensitivity and reduced height by at least 40 cm over the tall-long duration based traditional basmati (Fig 1).

Breeding for fragile ecosystems: An imminent consequence of changing climate is increasing fragility of environment to degrading causes reduced water levels, heat stress; nutritional imbalance caused by overuse of major nutrients, lower organic matter, etc. These factors are likely to increase the number of fragile ecosystems where crop cultivation is taken up. The heavy water logging during crop season, salinity, sodicity, alkalinity, toxicity to heavy metals, etc., are expected to be on the rise in vulnerable locations, the marginal ecosystems where rice and minor millets are cultivated. While efforts are being made through investment in conservation agriculture, water resources management, watershed development, coastal agriculture, there is a need to utilize genetic tools to breed varieties which can buffer the genotype to withstand the vulnerability factors in marginal lands targeted for the specific fragility element, such as salinity or sodicity tolerant varieties or alkalinity tolerance varieties of crop plants. The aim is enable such low-productivity ecosystems into optimum-productivity ecosystem. Fair amount of success has been achieved in breeding crops like rice and wheat for salinity tolerance, submergence tolerance and sodicity tolerance.

Physiological models to support breeding for climate change and abiotic stress tolerance

Globally, there is sufficient information and application of frontier science interventions accomplished through genetics, molecular biology and biotechnology in identifying molecular markers linked to genes which provide tolerance to biotic stresses in most crops or at least directed efforts are on in almost all crops towards achieving the objective. However, cost effective biotechnological interventions have yet to be developed for genetically more complex quantitatively inherited abiotic stress tolerance traits in any crop. However, the renewed interest among plant breeders in physiological inputs into breeding have led to changing orientation in breeding for abiotic stresses (Richards et al. 2002 and Reynolds and Trethowan, 2007)

In order to specifically introduce physiological traits related to drought and heat stress improvement in wheat breeding, the International Maize and Wheat Improvement Centre's (CIMMYT) Wheat Program developed a general conceptual model of drought adaptation in wheat with a potential application in breeding (Reynolds et al., 2005). The model is based on considering traits manifesting the pre-anthesis growth, accessing of water by root from deeper regions (root length), WUE and photoprotective mechanisms, all of which are known to be under simple or quantitative inheritance which can be manipulated through breeding applications. The basis for the model is as follows:

Breeding for Drought stress:

Yield (water limited) = WU×WUE×HI (Passioura, 1977),

Where, WU is water use, WUE is water use efficiency and HI is harvest index.

Breeding for Heat stress

Yield (non-water limited) = LI×RUE×HI (Reynolds and Trethowan, 2007)

Where, LI is light interception, RUE is radiation use efficiency and HI is harvest index.

The success achieved in developing breeding stocks and those which have been accessed for the purpose of drought and heat stress resistance in wheat have indicated that these models and approaches are potentially applicable in all crops and simplest and most robust equipment to be utilized to cater to most of the trait expression is the infrared thermometer which can be utilized to measure the canopy temperature depression (CTD) that sums up the genetic expression of the genotype as a manifestation of the component physiological traits explained above. It is recommended to breeders that canopy establishment and cooler canopies may be considered generic across drought- and heat stressed environments as both traits are easy to measure, even on a large scale, using spectral reflectance and infrared thermometry.

However, physiological trait improvement involves among others, (i) investment in phenotyping (ii) simultaneous evaluation of candidate traits for their complementation with others (iii) adoption of a breeding strategy where parental combinations provide realization of cumulative gene action of component traits and (iv) determination of such traits which are more likely to be stable across environments.

Biotechnological options for genetic enhancement for abiotic stresses

There are numerous biotechnological options available to genetically enhance a crop species with added abiotic stress resistance. The different tools that can be integrated in their use for genetic manipulation in crop plants are:

a. Genomics to identify new genes and genomic regions (QTLs) from within the species for their accumulation through breeding (pyramiding)

b. Characterize the transcripts and proteins to evaluate the key genes involved in the process and pathways that are associated in the metabolic pathways

c. Molecular marker identification and marker assisted selection for key genes whose sequence information is not available or QTLs which are less amenable for cloning if are associated with low contribution to the variation in the trait.

d. Transgenics to integrate gene or genes cloned from drought or heat tolerating expression related products in different life species. Some of the genes being utilized in transgenic development for abiotic stress resistance in crop plants are listed in Table 1.

Deployment of tools available in the hands of plant breeders has resulted in production and release of abiotic stress tolerant varieties of several crops some of which are as follows:

Wheat Crop

Through conventional and strategic breeding options, utilizing wild species and distant relatives, in wheat, a fair amount of success has been achieved in breeding varieties for the following adaptive traits:

- *Development of varieties to cope with high temperatures:* In India, varieties of wheat such as Sujata, Kundan, Vidisha and Urja are typically suited to increases in temperature during post-anthesis. These varieties have higher canopy temperature depression (CTD) compared to the sensitive varieties and do not show significant reduction in yield over normal cultivation even when temperatures shoot high. Amani et al. (1996) tested large number of heat tolerant varieties with high yield and discovered that there was a direct relationship between CTD and high yield.

Table 1. Some genes and their traits, being employed for transgenic crops development.

Gene/QTL	Tolerance
HARDY gene	Drought
Sub1 (QTL)	Submergence tolerance
OsDREB1A	Drought, high-salt and low-temperature stresses
otsA and otsB - trehalose biosynthesis	Drought and/or salinity
CBF1	Salinzation, drought and chilling in tomato
HSFs	Heat stress
SNAC1	Drought resistance and salt tolerance in rice
OsCOIN	Chilling, salt and drought, and enhanced proline levels
ABF3	Drought and cold

- *Varieties suited to change in planting dates to avoid heat stress:* The varieties like HD2932 and WR544 are fully suited to flexibility in planting date (delayed planting) which is still able to avoid heat stress by being able to attain maturity early.
- *Varieties with high WUE, suited to low water availability:* Although C 306 is a traditional variety which has been displaying the best water use efficiency yet, there are a number of durum and aestivum varieties which have relatively better WUE and can yield as much as the best yielder even when only two irrigations are given. HI 8638 is one such example which can yield close to potential with just two irrigations. Utilizing early vigour, erect leaves, WUE and CTD, as many

as 40 genotypes have been selected for yield trials with potential for high degree of drought tolerance and WUE.

- *Varieties suited to altered crop rotations:* Climate change is bound to upset cropping systems due to inability of sticking to schedules in an intense cropping system by temperatures or moisture not being appropriate for the timely planting. As a consequence, varieties need to develop which can be planted much later in the planting where in the crop rotation is adjusted with and not done away with. Pusa Gold, is a wheat variety which can be planted in time in November and as late as in January 2nd week, keeping the vegetable-rice-wheat rotation in tact.
- *Development of varieties for new agricultural areas resulting due to shift in climatic pattern:* Temperature and water levels are changing their quantity per annum as much as they are changing their features. Varieties therefore have to be ready in pipeline to compensate a normal crop which may have failed. For example, due to lower than normal temperature in some districts of Tamilnadu traditionally planted to finger millet or rice two wheat varieties HWCOO 1 and Pusa Savagery have found their suitability in an otherwise non-wheat growing region.
- *Pyramiding QTLs for drought tolerance:* Several QTLs identified for various traits under drought stress conditions located on 3A, 3 B, 3 D and 7B (yield traits) (Kordenaeej et al. 2008, CSIRO), on 7A for biomass under drought and under validation for drought survival with yielding ability (ICAR network on functional genomics, IARI) are being accumulated into desirable backgrounds in a network mode involving IARI, PAU (Ludhiana), JNKVV (Powarkheda), BHU (Varanasi) and ARI (Pune) in India.

Rice Crop

In the case of rice, significant efforts are made some of which have produced the results aided by the fully sequenced genome information, saturated map and functional annotation of genomic regions. The pace of research to face the consequence of changing climate is at a national network mode in collaboration with IRRI, Philippines. Varieties have been identified to suit to changing agronomies as a consequence of insufficient and less than normal rain in India. It is required to cope up to similar situations as rice is most water requiring food crop of India.

- The system of direct seeding is being recommended with some varieties which have shown adaptation to the non-puddled directly planted seed without involving transplanting. Some varieties suitable for the purpose are Pusa Sugandh 2, Pusa Sugandh 5 and Vandana. The varieties need to have tillering capacity without having undergone the root and culm priming for tillering in the form of transplanting.

The advantages of direct seeded rice (DSR) are,

- Saving in water up to 30%
- Saving in fuel and labour 25%
- Production cost less by 22%
- Reduction in CH_4 emissions by 19%

- However, some of these varieties have become prone to nematode infestation and weeds. Therefore, fresh efforts need to be made for strengthening the varieties with these traits which also create additional load of biotic stress over and above the abiotic stress load.
- The SRI or system of rice intensification which involved intense nursery and transplanting management also is an adaptive strategy to changing climate or drought as the system encourages lower water use and low level of flooding of fields for shorter durations. Information is being generated on the suitability of different varieties for SRI pattern. However, where it is adopted, average yields of up to 1.5x-2x have been obtained in Orissa, Andhra Pradesh and Tamilnadu.
- Salinity tolerant rice: Accelerated salinization of the Punjab and Haryana rice belt is occurring due to over exploitation of ground water that is accentuated by increasing temperature in the region. Efforts are being made as in wheat to utilize wide crossing to transfer the trait from donors identified possessing the parameters like sodium ion exclusion, potassium uptake and early vigour under saline conditions.
- In addition, a gene 'saltol' has been cloned from a genetic stock IR65192-4B-10-13 which is being transferred into parents of rice hybrid PRH 10 being grown in the region and in other varieties which may be expected to tolerate higher levels of salt concentration.
- Submergence tolerance through 'Sub1': Hailed as one of the most significant research of applied value, the gene Sub 1 was cloned from a Orissa landrace and transferred into varieties. These are mega varieties with more than 5 million hectares of land coverage which makes the output sustainable even in the event of untimely rains for long periods causing complete submergence of seedlings. The varieties with Sub1 are Swarna, BPT 5204 and IR 64. Through MAS, using these lines, the gene 'sub1' can be transferred into varieties grown in the rain prone areas.

Maize Crop

Approximately 80% of maize in India is grown under rainfed conditions and is severely prone to drought stress at flowering stage and waterlogging at early vegetative stage is a serious problem in NE India when there is rain. These two abiotic stresses, along with heat stress, are expected to significantly increase during the coming decades due to global climate changes.

- In a collaboration with CIMMYT, several inbred lines screened for different parameters of drought tolerance and suitability to different planting durations have been identified and are being utilized in the Indian programme. These lines are,
  - Early maturity – Yellow (Pool 18 Seq)
  - Early maturity – white (Pool 16 BN Seq)
  - Medium maturity – Yellow (DTPY c9)
  - Medium maturity – white (DTPW c9)
  - Late maturity – Yellow (Pool 26 Seq)
  - Late maturity – White (LP C7& TS c5)
- In an extensive programme at IARI, two QTLs have been identified on chromosomes 2 and 10 which influence the secondary yield traits under drought situation. These have been transferred into the parents of popular maize hybrids, validation and heterosis verification of which combinations are under way.
- Marker-assisted Recurrent Selection (MARS) is a potential strategy for improving drought tolerance since the procedure has the ability to accumulate and enhance the frequencies of favourable alleles from diverse donors which can be remobilized during inbred development in segregating generations.
- In the ICAR Network Project on Transgenics in Crop Plants involving transcriptome profiling under drought stress using DTPYC9F115 (drought-tolerant) and DTPYC9F46 (drought-susceptible) parents, identification of differentially expressed genes based on analyses of microarray data from experiments in two years at is underway at IARI. This would provide functional markers for specific loci transfer and drought tolerance breeding in maize.
- Allele mining for water logging tolerance is being practiced with 10 candidate genes involving large number of land races and inbreds of maize is being carried out to identify effective alleles for water logging resistance, a commonly increasing stress due to changing climate change.

Conclusion

Climate change is a reality and it is becoming visible much faster than it was expected. The sub-tropical and tropical agriculture in India is likely to suffer losses due to heat, erratic weather and reduced water availability. The crop plants have been able to evolve adaptive strategies by expressing some traits which have high degree of adaptation to the consequences of changing climate and erratic rainfall. The conventional means of genetic enhancement to capitalize on the adaptive traits to cope with drought, heat or salinity such as use of germplasm from the gene banks, alleles mined out from these identified stocks, wide hybridization for introgression from related species, etc., need to be integrated with biotechnological options including marker tool, transgenics and genomics. The available information and leads from research being carried out in India and other parts of the globe have shown the potential for exploring genetic enhancement as a mechanism for minimizing the consequences of changing climate and increasing abiotic stress tolerance in crop plants.

Table 2. Other crops in which targeted QTL transfer is being carried out under ICAR Functional Genomics programme

Trait	**Cropt**	**Gene (and proportation of variance explained)**	**Encoded protein**	**Difference between the parental varieties**
Fruit size	Tomato	*fw 2.2* (30%)	RAS-related protein	Expression level
Grain size (weight)	Rice	*gs3* (20%)	Transmembrane protein	Nonsense mutation
Grain size (length)	Rice	*gs3* (55%)	Transmembrane protein	Nonsense mutation
Grain size (width)	Rice	*gs2* (5-8%)	Transmembrane protein	Nonsense mutation
Grain number	Rice	*Gn1a* (44%)	Cytokinin oxidase/ dehydrogenase	Expression level
Submergence tolerance	Rice	*Sub1A* (70%)	ERF-related factor	Presence of obsence
Aluminium tolerance	Wheat	*ALMT1* (80%)	Malate efflux transporter	Expression level
Aluminium tolerance	Sorghum	*MATE* (80%)	Citrate efflux transporter	Expression level
Boron toxicity tolerance	Barley	*Bot1* (34%)	Boron efflux transporter	Expression level
Salt tolerance (shoot K^+ concentration)	Rice	*SKC1* (40%)	HKT-type Na^+transporter	Amino-acid substitution
Salt tolerance (low Na^+ inleaves)	Wheat	*Nax1* (38%)	HKT-type Na^+transporter	Exression leve

References

Amani, I., Fischer, R.A., Reynolds, M.P. 1996. Canopy temperature depression association with yield of irrigated spring wheat cultivars in hot climate. J. Agron. Crop Sci. 176: 119-129.

Farquhar, G.D., Richards, R.A. 1984. Isotopic composition of plant carbon correlates with water use efficiency of wheat genotypes. Australian J. of Plant Physiol. 11: 539-552.

Mujeeb-Kazi, A., Gilchrist, L.I., Fuentes-Davila, G., Delgado, R. 1998. Production and utilization of D genome synthetic hexaploids in wheat improvement. In *Triticeae III*, (Ed.) A.A. Jaradat. Enfi eld, NH: Science Publishers. pp: 369-374.

Reynolds, M.P. Mujeeb-Kazi, A., Sawkins, M. 2005. Prospects for utilising plant-adaptive mechanisms to improve wheat and other crops in drought- and salinity-prone environments. Ann. Appl. Biol.146: 239-259.

Reynolds, M.P., Trethowan, R.M. 2007. Physiological interventions in breeding for adaptation to abiotic stress. In scale and complexity in plant systems research (Ed.) J.H.J. Spiertz *et al.* 129-146.

Richards, R.A., Rebetzke, G.J., Condon, A.G., Van Herwaarden, A.F. 2002. Breeding opportunities for increasing the efficiency of water use and crop yield in temperate cereals. Crop Sci. 42: 111-121.

Imperatives of Global Climate Change for Agricultural Research in Asia-Pacific

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The major challenges in the twenty-first century are the rapid increase in the world population, the degradation of agricultural land and other natural resources and above all the emission of greenhouse gases in the atmosphere that contribute to climate change. Hence, the growing threat of food insecurity (Brown, 2008; FAO, 2006, 2007), and rapidly engulfing poor and under-privileged population leading to increased poverty across the globe (FAO, 2007; Anon., 2008) will be exacerbated by the projected threats to agriculture due to climate change (Cline, 2007). Emissions of green house gases (GHGs), like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), resulting from human activities, are substantially increasing the average temperature of the earth's surface. Fifty percent of the increase in global warming, since the industrial revolution, is considered to be the consequence of an increased level of carbon dioxide and other gases in the atmosphere (Lal, 1999). The concentration of carbon dioxide (CO_2) in the atmosphere increased from 285 ppm at the end of the 19th century, before the industrial revolution, to about 366 ppm in 1998 (equivalent to a 28 % increase) as a consequence of anthropogenic emissions of about 405 ($\pm$ 60) giga tonnes of carbon (C) into the atmosphere (IPCC, 2001). Of this increase, industrialization (fossil-fuel combustion and cement production) contributed 67 % and the remaining 33 % by the land-use change. The increase in GHGs in the atmosphere is now recognized to contribute to climate change (IPCC, 2001).

Asia is the home for more than one half of the world population living on 1/3rd of global land. The rapid and continuing increase in population and economy implies increased demand for food in the region. It is estimated that by 2020, food grain requirement in Asia would be 30-50% more than the current demand which will have to be produced from same or even less land that too with inferior quality of other natural resources. Hence, the world food situation will be strongly dominated by the changes that would occur in Asia because of its huge population, changes in diet pattern and asso-ci-ated increased demand for food, feed, fibre, fuel etc.

Alleviating poverty and attaining food security under adverse environmental scenario due to global climate change and spiraling cost of inputs, as experienced in the recent past, would be a major challenge in the 21st century to most of the countries in the Asia-Pacific region. Agriculture, consisting of cropland, pasture, and livestock production, presently contribute 13% of total anthropogenic greenhouse gas emissions. This does not include indirect sources relating to agricultural inputs such as fertilizer, food processing industries and other energy requiring operations.

Also the direction that Asian countries would embark to meet their energy needs during the coming 30 years will have profound impacts on global climate change and energy security for the region and the world. Asia currently accounts for about 26% of global carbon dioxide (CO_2) emissions, and its share of emissions is projected to increase to nearly 50% by 2030 (USAID, 2007). By 2009, China is expected to surpass the United States as the world's largest emitter of greenhouse gases (GHGs)-a decade earlier than anticipated (IEA, 2006). In addition, the burning of coal to meet Asia's energy needs is projected to increase five-fold by 2030, accelerating GHG emissions and further contributing to global climate change (IEA, 2006). Increasingly, Asian countries are importing fossil fuels to sustain their rapid economic growth, and this is raising concerns for further energy security. By 2030, it is expected that 80% of Asia's oil will be imported from the Middle East (Saha, 2006). Reserves of natural gas in Asia (a cleaner burning fossil fuel) are limited, and 40-75% of natural gas will have to be imported by 2030 to satisfy demand (APERC, 2006). This future dependence on imported fossil fuels raises legitimate concerns for Asian countries about price volatility and shocks, and supply disruptions. Also the majority of the world's most polluted cities are in Asia and the impact of urban air pollution on health and mortality in Asia is severe. Urban air pollution in Asia is linked to 500,000 premature deaths every year, accounting for 65% of premature deaths from air pollution worldwide (UNEP, 2006).

Above facts draw global concerns and urgency to address the options by which threats to Asian agriculture due to climate change can be met successfully in the near future. On positive side, the agriculture sector also provides significant potential for the greenhouse gas mitigation and adaptation to climate change effects. This, however, would demand reorientation of agricultural research that would comprehensively address all urgent concerns of climatic change through well defined adaptation and mitigation strategy which could help maximize food production, minimize environmental degradation and attain socio-economic development.

Impact of climate change on agriculture

The climate change is projected to impinge on sustainable development of most developing countries of Asia as it compounds the pressures on natural resources and the environment associated with rapid urbanization, industrialization, and economic development. The impact of climate change on agriculture is now real and without adequate adaptation and mitigation strategies to climate change, food insecurity and loss of livelihood are likely to be exacerbated in Asia. In this regard, the fourth assessment report of the Inter-Governmental Panel on Climate Change (IPCC), released in 2007, has clearly revealed that increases in the emission of green house gases (GHGs) have resulted in warming of the climate system by 0.74°C between 1906 and 2005. It has further projected that temperature increase by the end of this century is likely to be in the range 2 to 4.5°C. It is expected that future tropical cyclones will become more intense, with larger peak wind speeds and heavier precipitation. Himalayan glaciers and snow cover are projected to contract. It is also very likely that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent. Increases in the amount of precipitation are expected more in high-latitudes, while decreases are likely in most sub-tropical regions. At the same time, the projected sea level rise by the end of this century is likely to be between 0.18 to 0.59 meters. The freshwater availability in Central, South, East and Southeast Asia particularly in large river basins is projected to decrease due to climate change which, along with population growth and increasing demand arising from higher standards of living, could adversely affect more than a billion people by the 2050s.

Such climatic changes are affecting agriculture through their direct and indirect effects on crops, soils, livestock and pests, and hence the global food security. IPCC report has particularly indicated vulnerability of developing countries of the Asian region, especially its megadeltas to increasing climate change and variability due to its large population, predominance of agriculture, large climatic variability, and limited resources to adapt. There are likely to be negative effects also on livestock productivity due to increased heat stress, lower pasture productivity, and increased risks due to animal diseases. Increase in sea surface temperature and acidification will also lead to changes in marine species distribution as well as production.

Extreme events including floods, droughts, forest fires, and tropical cyclones have already increased in temperate and tropical Asia in the last few decades. Runoff and water availability are projected to decrease in the arid and semi-arid regions of Asia.

Sea-level rise and an increase in the intensity of tropical cyclones is expected to displace tens of millions of people in the low-lying coastal areas of Asia with expectation of around 17 % land getting inundated in Bangladesh alone. On the contrary, the increased intensity of rainfall and contraction of monsoon period would increase flood risks in temperate and tropical Asia.

Asia-Pacific Association of Agricultural Research Institutions (APAARI) which has been instrumental in promoting regional cooperation for agricultural research in the Asia-Pacific region has been organizing series of expert consultations for debating on emerging issues vis-à-vis agricultural research and development (ARD) concerns in the Asia-Pacific region. In this endeavor, 'biofuel' and 'climate change' were identified as major themes during the expert consultation on "Research Need Assessment" organized by APAARI during 2006. Accordingly, the issue of climate change and its imperatives for agricultural research in the Asia-Pacific region was deliberated in an International Symposium organized jointly by APAARI and JIRCAS. Participants representing NARS, CGIAR, IARCs, GFAR, ACIAR, JIRCAS, ARIs, universities and regional fora from 30 countries came out with agricultural research priorities for adapting agriculture to climate change in the form of "Tsukuba declaration on adapting agriculture to climate change" (APAARI, 2009) described below:

Tsukuba Declaration on Adapting Agriculture to Climate Change

- Asia-Pacific region sustains almost half of the global people, with high rates of population growth and poverty. Agriculture continues to play a critical role in terms of employment and livelihood security in all countries of the region. At the same time, this region has the largest concentration of hungry and malnourished people in the world. Droughts, floods, heat waves and cyclones occur regularly. Climate change is likely to raise regional temperatures and lead to decline in fresh water availability, sea level rise, and glacial melting in the Himalayas. The IPCC has considered the developing countries of the Asia-Pacific region, especially the mega-deltas of Asia as very vulnerable to climate change.
- Attainment of Millennium Development Goals (MDGs), particularly alleviating poverty, assuring food security and environmental sustainability against the background of declining natural resources, together with a changing climate scenario, presents a major challenge to most of the countries in the Asia-Pacific region during the 21st century.
- Water is a key constraint in the region for attaining food production targets and will remain so in future as well. Steps are, therefore, needed by all the stakeholders to prioritize enhancing water use efficiency. In addition, measures for water

storage using proven approaches such as small on–farm ponds, large reservoirs, groundwater recharge and storage, and watershed approach managed by the farming communities require attention.

- It was fully recognized that increasing food production locally will be the best option to reduce poor people's vulnerability to climate change variations. Available agricultural technologies can help increase the yield potential of crops that has not yet been tapped in many countries of the Asia-Pacific region. Hence, a concerted effort, backed by policy makers at the national level would be the key to enhance food security as well as ensuring agricultural sustainability.
- New genotypes tolerant to multiple stresses: drought, floods, heat, salinity, pests and diseases, will help further increase food production. This would require substantial breeding and biotechnology (including genetically modified varieties) related efforts based on collection, characterization, conservation and utilization of new genetic resources that have not been studied and used. CGIAR Centers, Advance Research Institutes (ARIs) and the National Agricultural Research Systems (NARS) of the region have a major role to play in this context. This will require substantial support in terms of institutional infrastructure, human resource capacity and the required political will to take up associated agricultural reforms. We, therefore, fervently call upon the national policy makers, overseas development agencies (ODA), other donor communities as well as the Private Sector to increase their funding support for agricultural research for development in the Asia-Pacific region.
- It was also recognized that a reliable and timely early warning system of impending climatic risks could help determination of the potential food insecure areas and communities. Such a system could be based on using modern tools of information and space technologies and is especially critical for monitoring cyclones, floods, drought and the movements of insects and pathogens. Advanced Research Institution, such as JIRCAS, could take the lead in establishing an 'Advance Center for Agricultural Research and Information on Global Climate Change' for serving the Asia-Pacific region.
- The increasing probability of floods and droughts and other climatic uncertainties may seriously increase the vulnerability of resource-poor farmers of the Asia-Pacific region to global climate change. Policies and institutions are needed that assist in containing the risk and to provide protection against natural calamities, especially for the small farmers. Weather-crop/livestock insurance, coupled with standardized weather data collection, can greatly help in providing alternative options for adapting agriculture to increased climatic risks.

- Governments of the region should collaborate on priorities to secure effective adaptation and mitigation strategies and their effective implementation through creation of a regional fund for improving climatic services and for effective implementation of weather related risk management programs. Active participation of young professionals is also called for.
- It was recognized that there are several possible approaches to enhance carbon sequestration in the soils of the Asia-Pacific region such as greater adoption of scientific soil and crop management practices, improving degraded lands, enhanced fertilizer use efficiency, and large scale adoption of conservation agriculture. To be effective, these would require simultaneously improved use of inputs such as fertilizers, crop residues, labor and time. This soil carbon sequestration has the added potential advantage of enhancing food security at the national/regional level. We do urge the global community to ensure appropriate pricing of soil carbon and related ecosystem/environmental services in order to motivate the small farmers to adopt new management practices that are linked to proper incentives and rewards.
- APAARI has been instrumental in stimulating regional cooperation for agricultural research in the Asia-Pacific. Global climate change and its implications for agriculture underline the need for such an organization to become even more active at this juncture. APAARI, in collaboration with its stakeholders, especially CGIAR Centers, ARIs, GFAR and other regional fora, should continue facilitating regional collaboration in a Consortium mode and take advantage of new initiatives such as Challenge Program on Climate Change for building required capability to adapt and mitigate the effects of climate change and ensure future sustainability of all concerned in the region.

The deliberations also led to identification of research priorities and both adaptation and mitigation strategy to deal with the challenge of climate change. These were:

Research strategies for coping with global climate change

Coping with global climate change is a must and for that there are two strategies (i) Adaptation through learning to live with the new environment (e.g., time of planting, changing varieties, new cropping systems, etc.) and (ii) Mitigation through offsetting the causative factors such as reducing the net emission of greenhouse gases.

Adaptation strategies: The potential strategies and actions for adaptation to climate change effects could be as follows:

1. New genotypes
   - Intensify search for genes for stress tolerance across plant and animal kingdom
   - Intensify research efforts on marker aided selection and transgenic development
   - Develop genotypes for biotic (diseases, insects etc) and abiotic (drought, flood, heat, cold, salinity) stress management either by traditional plant breeding, or genetic modification
   - Attempt transforming C3 plants to C4 plants
2. New land use systems
   - Shift of cropping zones
   - Critical appraisal of agronomic strategies and evolving new agronomy for climate change scenarios
   - Exploring opportunities for maintenance /restoration/ enhancement of soil properties
   - Use of multi-purpose adapted livestock species and breeds
3. Value-added weather management services
   - Developing spatially differentiated operational contingency plans for temperature and rainfall related risks, including supply management through market and non-market interventions in the event of adverse supply changes
   - Enhancing research on applications of short, medium and long range weather forecasts for reducing production risks.
   - Developing knowledge based decision support system for translating weather information into operational management practices
   - Developing pests and disease forecasting system covering range of parameters for contingency planning and effective disease management.
4. Integrated study of 'climate change triangle' and 'disease triangle', especially in relation to viruses and their vectors
5. Documentation of indigenous traditional knowledge (ITK) and exploring opportunities for its utilization
6. Reforming global food system

Mitigation strategies: The basic strategies for mitigating climate change effects are reducing and sequestering emissions. However, before jumping to band-wagon of mitigation strategies, the following points should be considered for effective implementation of mitigation strategies.

- Improve inventories of emission of greenhouse gases using state of art emission equipments coupled with simulation models, and GIS for up-scaling
- Evaluate carbon sequestration potential of different land use systems including opportunities offered by conservation agriculture and agro-forestry
- Critically evaluate the mitigation potential of biofuels; enhance this by their genetic improvement and use of engineered microbes
- Identify cost-effective opportunities for reducing methane generation and emission in ruminants by modification of diet, and in rice paddies by water and nutrient management. Renew focus on nitrogen fertilizer use efficiency with added dimension of nitrous oxides mitigation
- Assess biophysical and socio-economic implications of mitigation of proposed GHG mitigating interventions before developing policy for their implementation

1. *Reducing Emissions:* The strategies for reducing emissions includes-
   - Avoiding deforestation
   - Minimizing soil erosion risks
   - Eliminating biomass burning and incidence of wild fires
   - Improving input use efficiency (e.g., fertilizers, energy, water, pesticides)
   - Conservation Agriculture
2. *Sequestering Emissions:* The stored soil carbon is vulnerable to loss through both land management change and climate change. There are numerous agricultural sources of GHG emissions (Duxbury, 1994) with hidden C costs of tillage, fertilizer, pesticide use and irrigation. In general, net C sequestration must take into account these costs. The important strategies of soil C sequestration include restoration of degraded soils, and adoption of improved management practices (IMPs) of agricultural and forestry soils. For example in India, the potential of soil C sequestration is estimated at 39 to 49 (44 ± 5) Tg C/y of which 7 to 10 Tg C/y for restoration of degraded soils and ecosystems, 5 to 7 Tg C/y for erosion control, 6 to 7 Tg C/y for adoption of IMPs on agricultural soils, and 22 to 26 Tg C/y for secondary carbonates (Lal, 2004). Therefore, agricultural practices collectively can make a significant contribution at low cost to increasing soil carbon sinks and reducing GHG emissions. A large proportion of the mitigation potential of agriculture (excluding bio-energy) arises from soil carbon sequestration, which has strong synergies with sustainable agriculture and generally reduces vulnerability to climate change. A considerable mitigation potential through sequestration is available from reductions in methane and nitrous oxide emissions in some agricultural systems. However, there is no universally applicable list of

mitigation practices and the mitigation through sequestration practices need to be evaluated for individual agricultural systems and settings (e.g. conservation tillage). The biomass from agricultural residues and dedicated energy crops can be an important bio-energy feedstock, but its contribution to climate mitigation to 2030 depends on demand for bio-energy from transport and energy supply, on water availability, and on requirements of land for food and fibre production. Hence, widespread use of agricultural land for biomass production for energy may compete with other land uses and can have positive and negative environmental impacts and implications for food security.

Epilogue

Impact of climate change on agricultural production in Asia Pacific is real. Hence, immediate action at national level to understand and address the issues of climate change becomes a priority. Strategy around both adaptation and mitigation is called for, which would require research reorientation and major policy interventions. Regional and global collaboration would help in addressing these concerns and for building both institutional and human resource capabilities being the two cradles for sustainable agriculture.

References

Anonymous. 2008. Deserting the hungry. Nature. 451: 223-224.

APAARI. 2009. Imperatives for agricultural research in Asia-Pacific. In proceedings of symposium on global climate change, 21-22 October 2008, Tsukuba, Japan Asia Pacific Association of Agricultural Research Institutions. 31pp.

APERC. 2006. APEC Energy Demand and Supply Outlook 2006 (1& 2). Asia Pacific Energy Research Center (APERC).

Brown, L.R., 2008. Why Ethanol Production will Drive World Food Price Even Higher in 2008? Earth Policy Institute (24th January 2008).

Cline, W.R., 2007. Global Warming and Agriculture: Impact Estimate by Country. Peterson Institute.

Duxbury, J.M. 1994. The Significance of Agricultural Sources of Greenhouse Gases. Fertilizer Research. 38: 151-163.

FAO. 2006. The State of Food Insecurity in the World. FAO, Rome, Italy.

FAO. 2007. Food Balance Sheet 1961-2006. FAO, Rome, Italy.

IEA. 2006. World Energy Outlook 2006. International Energy Agency: Paris.

IPCC. 2001. Climate change: the scientific basis. Inter-Governmental Panel on Climate Change (IPCC). Cambridge, UK, Cambridge University Press.

Lal, R. 2004. Soil carbon sequestration in India. Climatic Change. 65: 277-296.

Lal, R. 1999. Global carbon pools and fluxes and the impact of agricultural intensification and judicious land use. In FAO: Prevention of land degradation, enhancement of carbon sequestration and conservation of biodiversity through land use change and sustainable land management with a focus on Latin America and the Caribbean. Proceedings of the IFAD/FAO Expert Consultation. Rome 15 April 1999. 45-52pp.

Saha, P.C. 2006. Overview of energy security and policies development in Asia-Pacific. Presented at the Asia-Pacific Consultations on Climate Regime Beyond 2012 Southeast Asia, Bangkok, Thailand.

UNEP. 2006. Geo Year book 2006. United Nations Environment Programme. Retrieved from http://www.unep.org/geo/yearbook/yb2006/057.asp#fig5

USAID. 2007. Clean Energy Priorities for Asia: A Regional Imperative for Clean Development, Climate Change, and Energy Security. Review draft for USAID Regional Development Mission/Asia. United States Agency for International Development, Bangkok.

Program

Chairperson: Dr. M.S. Swaminathan, Chairman, MSSRF
Co-Chairperson: Dr. R.S. Paroda, Chairman, TAAS

Technical Session

Time	Topic	Speaker
0930 - 1030	Managing Soil Resilience for a Warming Climate and Decreasing Resources	Prof. Rattan Lal
1030 - 1100	Strategies for managing soils for improved productivity in the rainfed areas	Dr J.S. Samra
1100 - 1120	*Tea Break*	
1120 - 1150	Conservation Agriculture - Addressing emerging soil health, climate change and food security concerns	Dr I.P. Abrol
1150 - 1220	Adaptation to climate change and improving soil health	Dr. P.K. Aggarwal
1220 - 1250	Genetic enhancement of crops for adaptation to climate change and abiotic stresses	Dr. H.S. Gupta
1250 - 1330	Imperatives of global climate change for agricultural research in Asia-Pacific	Dr. R.S. Paroda
1330	*Lunch*	

List of participants

1. Dr. M.S. Swaminathan , Chairman, MS Swaminathan Research Foundation
2. Dr. R.S. Paroda, Chairman, TAAS
3. Prof. Rattan Lal, Director, Carbon Management and Sequestration Center, Columbus
4. Dr. JSP Yadav, Former Chairman, ASRB
5. Dr. A.K. Singh, Senior Scientist, Division of Genetics, IARI
6. Dr. K.R. Koundal, Joint Director (R), IARI
7. Dr. Yash Saharawat, Scientist, IRRI
8. Dr. R.K.Malik, Coordinator (DAR), Eastern UP, IRRI-CIMMYT
9. Dr. Sain Dass, Project Director, DMR
10. Dr. R.P. Singh, Secretary General, IAUA
11. Dr. Ashutosh Sarker, Coordinator, ICARDA
12. Dr. J.L. Karihaloo, Coordinator, APCoAB
13. Dr. Suresh Pal, Head, Economics Division, IARI
14. Dr. M.L. Jat, Coordinator (DAR), Haryana, IRRI-CIMMYT
15. Dr. Bhagmal, Consultant, Bioversity International
16. Dr. S. Nagarajan, Chairperson, PPV&FRA
17. Dr. Anand Swarup, Head, Soil Science & Agricultural Chemistry, IARI
18. Dr. H.C. Joshi, Head, Environmental Sciences, IARI
19. Dr. B.R. Sharma, Liaison Officer, IWMI - South Asia Office
20. Dr. J.K. Ladha, Representative, IRRI
21. Dr J S Samra, CEO and Chairman, NRAA
22. Dr V K Bahuguna, NRAA
23. Dr Alok Sikka, NRAA
24. Dr. P.K. Aggarwal, Secretary, National Academy of Agricultural Sciences
25. Dr. IP Abrol, Director, CASA

26. Dr. HS Gupta, Director, IARI
27. Dr. P.D. Sharma, ADG (Soils), ICAR
28. Sh. Ramesh Chand, ICAR National Professor
29. Dr. Mahesh Gathala, Sr. Soil Scientist, IRRI
30. Dr. Gurbachan Singh, Director, CSSRI, Karnal
31. Dr. Ramendra Singh, TATA Chemicals
32. Dr. Himanshu Pathak, Div, Environmental Sciences, IARI
33. Dr. KK Dahiya, HAU, Hissar
34. Dr. B.S. Dwivedi, PS, Soil Science, IARI
35. Dr. R.K. Rai, Prof. Agronomy, IARI
36. Dr. TBS Rajput, Principal Scientist, WTC
37. Dr. Anupama, Sr. Scientist, Agri.Chemicals, IARI
38. Dr. Raj Gupta, Regional Coordinator, CIMMYT
39. Mr. Naveen Kalra, Tata Chemicals
40. Mr. Subendhu Bhadaray, Tata Chemicals
41. Dr. Y.P. Abrol, Adjunct Professor & INSA Honorary Scientist, Hamdard University
42. Dr. M.S. Rao, Project Coordinator, IRRI
43. Prof. Anupam Varma, INSA Senior Scientist, IARI
44. Dr. P.K.Chhonkar, ICAR Emeritus Scientist
45. Dr. Virender Kumar, Weed Scientist, IRRI
46. Ms. Neelam Chaudhary, Entomology, CIMMYT
47. Dr. Ram Singh, Economcis, CIMMYT
48. Dr. Sheetal Sharma, Soil Scientist, IRRI
49. Dr. Parvesh Chandana, GIS Specialist, IRRI
50. Dr. Rajendra Chowdhary, Laision Officer, ICARDA
51. Dr. Kanwar Singh, CCA Coordinator, IRRI

Dr. M.S. Swaminathan at the registration counter

Dr. M.S. Swaminathan chairing the Seminar with Dr. R.S. Paroda as co-chairman

Dr. R.S. Paroda addressing the audience

Prof. Rattan Lal making his presentation

Dr. J.S. Samra presenting his paper

Dr. I.P. Abrol addressing the audience

Dr. P.K. Aggarwal presenting his paper

Dr. B.R. Sharma speaking during the discussion

Dr. R.P. Singh speaking during the discussion

Dr. H.S. Gupta making his remarks during the discussion

A view of the audience

Progress Through Science

TRUST FOR ADVANCEMENT OF AGRICULTURAL SCIENCES (TAAS)

List of TAAS Publications

Following publications/reports have been brought out based on various activities organized by TAAS:

1. Regulatory Measures for Utilizing Biotechnological Developments in Different Countries - First Foundation Day Lecture, delivered by Dr. Manju Sharma, Secretary, Department of Biotechnology, Government of India, October 17, 2003.
2. Enabling Regulatory Mechanisms for Release of Transgenic Crops - Brainstorming Session, October 18, 2003.
3. Challenges in Developing Nutritionally Enhanced Stress Tolerant Germplasm - Special Lecture, delivered by Dr. S.K. Vasal, Distinguished Scientist, CIMMYT, Mexico, January 15, 2004.
4. Role of Science and Society Towards Plant Genetic Resources Management - Emerging Issues - Brainstorming Session, January 7-8, 2005, Highlights and Recommendations.
5. Role of Information Communication Technology in Taking Scientific Knowledge/Technologies to the End Users - National Workshop, January 10-11, 2005, Recommendations.
6. Public Private Partnership in Agricultural Biotechnology - Second Foundation Day Lecture, delivered by Dr. Gurdev S. Khush, Adjunct Professor, University of California, Davis, USA, October 17, 2005.
7. First Dr. M.S. Swaminathan Award for Leadership in Agriculture, March 15, 2005 - Highlights.
8. Farmer-Led Innovations for Increased Productivity, Value Addition and Income Generation - Brainstorming Session, October 17, 2005 - Highlights & Recommendations.
9. Strategy for "Increasing Productivity Growth Rate in Agriculture" - Strategy Paper by Dr. R.S. Paroda, August, 2006.
10. The Second Dr. M.S. Swaminathan Award for Leadership in Agriculture, October 9, 2006 - A brief report.
11. Farmer-Led Innovations Towards Plant Variety Improvement, Conservation and Protecting Farmers' Rights", November 12 - 13, 2006, National Dialogue Highlights & Recommendations.
12. Brainstorming Session on "Models of Public-Private Partnership in Agricultural Biotechnology", April 7, 2007 - Highlights & Recommendations.
13. Symposium on "Farmer-Led Innovations for Sustainable Agriculture", December 14-15, 2007 – Proceedings.
14. National Symposium on Quality Protein Maize for Human Nutritional Security and Development of Poultry Sector in India and Presentation of the Third Dr. M.S. Swaminathan Award for Leadership in Agriculture, May 3, 2008 – Proceedings and Highlights.
15. Overcoming the World Food and Agriculture Crisis through Policy Change, Institutional Innovation and Science– Fourth Foundation Day Lecture, delivered by Dr. Joachim von Braun, Director General, International Food Policy Research Institute, Washington, March 6, 2009.
16. Brainstorming Workshop on "Emerging Challenges before Indian Agriculture - The Way Forward", March 6, 2009 - Proceedings & Recommendations.
17. Brainstorming Workshop on 'Strategy for Conservation of Farm Animal Genetic Resources' 10^{th} – 12^{th} April, 2009 – Ranchi Declaration.
18. Millions Fed: Proven Successes in Agricultural Development, January 19, 2010. (Jointly published by IFPRI, APAARI and TAAS)

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