Journal of the Andaman Science Association Vol. 21(1):1-13 (2016)
ISSN 0970-4183, Printed in India

Crop Diversity and Climate Change Management

Prof. R.B. Singh
Chancellor, Central Agriculture University, Manipur, Imphal

I. Introduction

India is one of the 12 mega biodiversity centres in the world. Given its diverse agro-ecological systems, the country houses as many as 45,000 species of plants - a great treasure for restructuring forms and functions of crops to meet present and future needs. The national system - the public sector, including the national bureaus on genetic resources, research and educational institutions, NGOs, farmers and private sector have long been conserving and utilizing the resources and continue doing so with still greater efforts.

Yet, under the intensifying twin pressures of accelerated economic growth and development and climate change, the resources have been eroding fast. The climate change - global warming (temperature rise between 2-4°C by 2100), ozone layer depletion, altered precipitation patterns and the resultant increased biotic and abiotic stresses have varyingly been threatening life forms. South Asia, including India is not only a mega biodiversity centre, but also one of the most vulnerable geographic areas to the climate change, rendering the country a hotspot for endangered genetic resources.

The rate of genetic erosion has greatly enhanced and the rate of species extinction has magnified during the past 50 years or so. Impact of deforestation and vegetation losses have greatly increased the accumulation of green house gases besides having caused irreversible losses in the treasure of biodiversity, and thus reducing the options for future growth. Tropical island systems represent unique biodiversity and agro-ecological systems, but are most vulnerable to the climate change. Therefore, the topicality and timeliness of holding this Seminar is highly appreciated.

With the above backdrop, this paper discusses the following aspects:

(i) Role of crop diversity and plant breeding in developing resilience to the climate change,

(ii) Impact of climate change on crop agriculture and food and livelihood security,

(iii) The nature of interdependence of crop diversity and climate smart agriculture

(iv) National and international action plans, agreements and policies for plant diversity conservation, sharing and utilization, and climate change adaptation and mitigation, and

(v) The way forward to harmonize crop diversity conservation with climate change management.

II. Crop Diversity and Plant Breeding for Adaptation

Underpinning the interdependence of biodiversity and climate change management (adaptation as well as mitigation), the Fifth Report of the IPCC (Vermeulen, 2014) has emphasised the centrality of plant breeding for developing climate smart crop varieties endowed with genes resistant/tolerant to abiotic and biotic stresses. It also emphasises the mitigation aspect to minimise the rate of climate change and its footprint on biodiversity (genetic erosion) and habitat.

Conventional plant breeding, lately often integrated with molecular aided selection and with genomics, has channelized the naturally occurring or conserved or created genetic variability to meet the fast changing demands of mankind. Breeding crop varieties tolerant to various abiotic and biotic stresses and combining desirable yield and other agronomic characters is the most effective way to develop climate resilient agricultural system. A good number of QTLs for abiotic stress tolerance (flood, drought, salinity, unusual temperature) have been identified in several crops. For instance, Sub1, an exceptionally strong QTL, conferring submergence tolerance in diverse genetic backgrounds of rice under different environments, is being widely utilised in flood-prone rice growing areas (Fig. 1). A marker-assisted backcrossing (MAB) approach was developed at the International Rice Research Institute (IRRI) and in several national programmes, including India, to introgress Sub1 in mega varieties which are already popular with famers and consumers, such as Swarna, TDK1, and Samba Mahsuri in India (Singh *et al.,* 2013).

Fig. 1. New Sub1 lines after 17 days submergence in the field at IRRI

Source: IRRI, 2011

Swarna-Sub1 has already been released for commercial production and is significantly contributing to enhanced and sustained production under flooded conditions with 2-4 weeks of submergence, out-yielding the original intolerant Swarna by about 30-35%. A recent study in Eastern UP and Odisha provinces had shown that Swarna-Sub1 has yield advantage of 0.7 (23%) and 1.5 tons/ha (95%) over Swarna when length of submergence was 1 to 7 and 8 to 14 days, respectively. Despite most families in the surveyed area in Odisha were affected, only 9% had adopted Swarna-Sub1, whereas in Eastern UP the adoption rate was 35% (Yamano *et al.,* 2013). Thus, the adoption rate of Swarna-Sub1 in both the provinces and other such areas should be promoted to save the huge losses suffered recurrently in the flood-prone areas. The "seeds for needs" approach should be adopted.

The submergence tolerance QTL has now been transferred to several popular lowland varieties like Samba Mahsuri, Savithri, IR64 etc. Other submergence tolerance genes distinct from Sub1 have also been identified and their use will help in diversifying the genetic base and tolerance to varying submergence conditions. Moreover, genes conferring drought as well as salinity tolerance have been pyramided with the submergence tolerance genes, rendering Swarna tolerant to multiple stresses (IRRI-STRASA project).

Several notable products (varieties) are already in the farmers' fields. Some of the achievements in terms of stress tolerance in rice achieved during the past 50 years are listed below (Table 1). Through marker assisted breeding, several bacterial blight, blast and sheath blight resistant highly popular high yielding rice varieties have been developed during the last 14 years (Table 2). Major trait specific donors from India have contributed globally for climate resilience, as stipulated under the free exchange policy for PGRFA (Table 3). Recent releases of varieties like Pusa Basmati 1509 are a milestone development towards "more from less" and "save and grow". Being a 115 to 120 day high yielding quality rice, its per day, per litre water, and per kg fertilizer productivity is the highest in the contemporary world of Basmati or scented rices. This is easily a brilliant example of genetic alchemy for convergent economic, environmental and social transformation. This genetic improvement will further consolidate India's position as the world's leading rice exporter, particularly of high quality aromatic rice, currently valued at US$ 5.0 billion. These developments must also induce creation, implementation and institutionalization of niche and differentiated production.

Pusa Basmati 1509 saves at least five precious irrigations and this saved water could be deployed for producing an excellent wheat crop in the subsequent season for free (in context of water) – "save and grow" in true sense.

Table. 1. Biotic and abiotic stress resistant rice varieties

TKM6, 1964, resistant to stem borer and was involved as parent in the development of internationally popular varieties such as IR 20, IR26 and IR36

Khonorullu,1965, a highly cold-tolerant selection from the local germplasm identified at Shillong,

Jalmagna,1969, a selection from local variety Barho possessing submergence tolerence, Eastern U.P.

Nagina 22,1978, drought and heat tolerant, U.P.

IR36,1981, the “miracle rice”, bred at IRRI, resistant to multiple biotic stresses such as bacterial blight, gall midge, green leaf hopper, rice tungro virus and grassy stunt virus

FR13A,1988, a pure line selection fromKalam Banka, served as donor for submergence tolerance gene ‘Sub1’

IR64,1989, one of the most widely cultivated rice varieties introduced by IRRI, Philippines. This variety is resistant to multiple biotic stresses such as bacterial blight, green leaf hopper, rice tungro virus and grassy stunt virus and moderately resistant to sheath blight and blast.

Vandana,1992, a semi-tall, photoperiod insensitive variety possessing high degree of drought tolerance. It was released for the states of Bihar and Orissa.

Improved Pusa Basmati 1 (Pusa 1460),2007, the first product of molecular breedingin rice, developed by marker assisted pyramiding of genes *Xa13* and *Xa21* for resistance to bacterial blight in the genetic background of Pusa Basmati 1.

Improved Sambha Mahsuri (RP-Bio 226),2007, an improved version of Sambha Mahsuri, developed through molecular breeding by pyramiding the genes *Xa5, Xa13* and *Xa21* for resistance to bacterial blight.

Swarna Sub1,2009, an improved version of Swarna, the mega rice variety, developed through MAS by incorporating the Sub1 gene from FR13A.

Source: Hundred Years of Science for Agricultural Development, NAAS, 2015

Table. 2. Improvement of elite rice varieties for various diseases through marker assisted breeding

Sl. No.	Recurrent Parents	Donor Parent	Trait	Gene	References
1	PR106	IRBB59	BB	xa5+xa13+ Xa21	Singh *et al.,* (2001)
2	Pusa Basmati 1	IRBB55	BB	xa13+Xa21	Joseph *et al.,* (2004) and Gopalakrishnan *et al.,* (2008)
3	Sambha Mahsuri	SS1113	BB	xa5+xa13+ Xa21	Sundaram *et al.,* (2008)
4	PRR78 and Pusa6B	Pusa1460	BB	xa13+Xa21	Basavaraj *et al.,* (2010)
5	Type 3	SS1113	BB	xa13+Xa21+sd1	Rajpurohit *et al.,* (2010)
6	Basmati-370 and Basmati-386	SS1113	BB	xa5+xa13+Xa21	Bhatia *et al.,* (2010)
7	Basmati-370 and Taraori Basmati	Improved Sambha Mahsuri	BB	xa13 + Xa21	Pandey *et al.,* (2012)

8	PRR78	Tetep and C101A51	Blast	Piz5 + Pi54	Singh *et al.,* (2012)
9	Pusa 6B	Tetep	Blast and Sheath Blight	Pi54 + qSBR11-1 + qSBR11-2 + qSBR7-1	Singh *et al.,* (2014)
10	Improved Pusa Basmati-1	Tetep	BB, Blast and Sheath Blight	xa13 + Xa21 + Pi54 + qSBR11-1	Singh *et al.,* (2012)
11	ADT43	IRBB60	BB	xa5 + xa13 + Xa21	Perumalsamy *et al.,* (2009)
12	Triguna	PR106	BB	xa5 + xa13 + Xa21	Sundaram *et al.,* (2009)

Source: Hundred Years of Science for Agricultural Development, NAAS, 2015

Table. 3. Globally shared major trait specific donors from India

Pokhali: It is a salinity stress tolerant rice variety of Kerala which has been used as the source for mapping a major QTL "Saltol" responsible for seedling stress salt tolerance in rice at IRRI.

Kasalath: An aus type rice variety from north-eastern India, was used for mapping a major QTL Pup1 for phosphorous uptake, which lead to cloning of gene PSTOL (Phosphorous Starvation Tolerance) at IRRI.

Oryzalongistaminata: Accession identified at CRRI Cuttack by Dr.DeoDutt for resistance to Bacterial Blight, later gene Xa21 was cloned from it at IRRI.

Oryzanivara: a major source of donor for tungro virus resistance and was one of the parents of the "Miracle Rice" IR 64.

Source: Hundred Years of Science for Agricultural Development, NAAS, 2015

An equally brilliant complementary development in form of wheat variety HD 2967, is an exceptionally high yielding and widely adapted variety possessing multiple resistance to rust, especially yellow rust, and, most importantly, is resistant to extreme weather fluctuations, especially heat and cold. Further, fortunately, 60 day mungbean varieties capable of yielding about 1 t/ha on an average are available. Using conservation agriculture techniques, depending on soil moisture and water availability, a catch crop of mungbean between wheat and rice is a distinct possibility, augmenting the nitrogen and carbon economy, income growth and, above all, protein nutrition.

Recent releases of varieties like Pusa Basmati 1509 are a milestone development towards "more from less" and "save and grow". Being a 115 to 120 day high yielding quality rice, its per day, per litre water, and per kg fertilizer productivity is the highest in the contemporary world of Basmati or scented rices. This is easily a brilliant example of genetic alchemy for convergent economic, environmental and social transformation. This genetic improvement will further consolidate India's position as the world's leading rice exporter, particularly of high quality aromatic rice, currently valued at US$ 5.0 billion. These developments must also induce creation, implementation and institutionalization of niche and differentiated production.

Pusa Basmati 1509 saves at least five precious irrigations and this saved water could be deployed for producing an excellent wheat crop in the subsequent season for free (in context of water) – "save and grow" in true sense. An equally brilliant complementary development in form of wheat variety HD 2967, is an exceptionally high yielding and widely adapted variety possessing multiple resistance to rust, especially yellow rust, and, most importantly, is resistant to extreme weather fluctuations, especially heat and cold. Further, fortunately, 60 day mungbean varieties capable of yielding about 1 t/ha on an average are available. Using conservation agriculture techniques, depending on soil moisture and water availability, a catch crop of mungbean between wheat and rice is a distinct possibility, augmenting the nitrogen and carbon economy, income growth and, above all, protein nutrition.

The rice-wheat system has often been hard particularly on underground water resources. Crop diversification out of the system to save water without sacrificing farmers' income should be a viable option. Short duration (120-125 days) pigeonpea genotypes now available can fit in a pigeonpea-wheat cropping pattern with economic returns analogous to those from the prevalent rice-wheat system, plus a huge bonus in terms of soil fertility, reduced water consumption and enhanced human nutrition. The system could be still more productive and sustainable with drip irrigation for the pigeonpea crop. Notwithstanding the bright prospect, the high vulnerability of determinate pigeonpeas to pod borers should be overcome. While other options must be developed as per location-specific settings, GM/GE pigeonpea and other GM crops, as Bt cotton, should prove a boon.

Stress-tolerant varieties will thus be the main plank of climate resilient agriculture. Plant adaptation to stress involves key changes in the 'central dogma', the '-omic' architecture, adaptive changes in genes, proteins and metabolites after individual and multiple environmental stresses. Basic understanding of physiological and molecular bases of stress management will help adopt effective crop-stress protection strategy and develop more robust varieties for high risk environments. Systems-biology and systems level modelling and development of computational models will strengthen efforts to enhance plant fitness to changing climates and varying stresses.

Integrated genomics, GMs and other cutting-edge technologies are, however, being throttled by some "green peace" agents. Rice, wheat, pigeonpea, tomato and mango genomes have already been mapped, mostly by our own scientists, and offer unique opportunities for designing our crops as per our needs. The academic and other stakeholders must rise to the occasion and take the proven safe science and technology to those who need it the most, especially the huge population of the poor and the hungry, who are most vulnerable to climate change (NAAS 2011).

III. Impact of Climate Change on Crop Agriculture and Livelihood Security

The negative impact of climate change is increasingly visible not only in depressing agricultural productivity and agro-biodiversity but also in increasing variability and volatility in total production. The impact of climate change on biodiversity will be most severe. For instance, it is predicted that of the existing 16 wild species of *Arachis* (wild relatives of groundnut) in Latin America, 11 will be extinct by 2055, two will be in the threatened category and two near-threatened. Given the global dimension of climate change, the production uncertainties will enhance the intensity and frequency of food price spikes. All these will hurt the poorest and the hungriest the most. Unfortunately, one-fourth of the world's such deprived people have their homes in India.

The Fifth Assessment Report (AR5) of the Inter-governmental Panel on Climate Change (IPCC) (2014), discussing the climate change drivers, impacts, adaptation and mitigation had highlighted that the climate change impacts on food security are happening now, and the tropical areas are most exposed to increasing climate risks which also house a large proportion of the world's food insecure and poor people. The AR5 has highlighted the following:

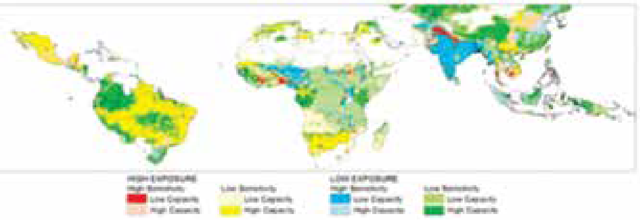
- Climate change has impacts on all aspects of food security – production, (availability), distribution, access to food (affordability), utilization of food and stability of food supplies over time
- Impacts of climate change on crop yields are already evident across several regions of the world. On an average, although some positive impacts are evident in certain areas/pockets, largely the impacts are negative, net global yields of maize and wheat will be

suppressed by 4 and 5 percent, respectively by 2050s, average yields for eight major crops in South Asia will decline by 8 percent

- Climate change is affecting the current abundance and distribution of freshwater and marine fish harvests. By 2050s, while fisheries yields in high latitudes are predicted to increase by 30 to 70 percent, these will decrease in the tropics by about 40 percent, primarily due to the rises in sea temperature. These changes will adversely impact small-scale coastal fisheries in tropical countries
- In recent years most price spikes for food have been related to climate extremes in major production areas. The spike hurts the poor the most as they spend more than 70% of their income on food
- Climate change has impacts on the nutritional quality and safety of food. Elevated carbon dioxide levels cause decrease in protein and micronutrient contents. Further, often the mycotoxins levels increase from enhanced fungal infections in tropical regions
- Tropical crops, livestock and fisheries are most affected by current climate change; regions of major exposure to climate change coincide with high prevalence of poverty and food insecurity. South Asia is most vulnerable to climate change and it is this region which has the highest concentration of food-insecure people and undernourished children
- Greater exposure to climate risks increases the vulnerability of food insecure individuals and households. High recurrences of climate extremes, such as droughts, floods, heat, and cold waves exacerbate the vulnerability of the hungry. Intense seasonal hunger further deepens chronic hunger and overall livelihood insecurity

Freshwater availability in South Asia is likely to decrease. Even the most optimistic studies indicate that South Asian agriculture will be particularly hard hit by climate risks (Fig. 2). During the last 130 years, the region has faced more than 26 droughts. Nearly 70% of the land is drought-prone, 12% flood-prone and 8% cyclone-prone. While frost is common in northern regions, heat is a frequent incidence at many places.

Fig. 2. South Asia faces increasing challenges due to climatic risks



Source: Erickson et al., 2011 cited in Aggarwal, P.K. et. al., (2011).

Crop models indicate that average yields in 2050 may decline by about 50 percent of wheat, 17 percent for rice, and about 6 percent for maize from their 2000 levels. The Indo-Gangetic plain, which produces one-fifth of the world's wheat, is likely to be especially adversely impacted. This alone could threaten the food security of 200 million people. Globally, over 1.4 billion will be affected by the increasing frequency of drought and decreasing precipitation. According to an IFPRI study (Nelson *et al*., 2010), an increase of between 8.5 and 10.3 percent is expected in the number of malnourished children in all developing countries, relative to scenarios of perfect climate change mitigation.

The Crisis Management Plan of the GOI (2012) reported that annually 50 million people are exposed to chronic drought. Sixteen percent of India's land area is drought prone and 68% of the land area sown is exposed to drought. The Southwest monsoons account for 86% of rainfall occurring in 100-120 days. Thirty three percent of land receives less than 750 mm of rainfall, and is classified as chronically drought prone. Rainfall is erratic in four out of ten years. Per capita water availability is rapidly declining due to population and urban growth, industrialization, cropping intensity and depleting groundwater. Unfavourable rainfall pattern and frequency of occurrence of extreme events such as drought and temperature events are becoming highly discernible over the years. It is estimated that 5700 sq. km of coastal area in India will be lost due to 1 m sea level rise, displacing 7.1 million people resulting in significant economic losses (GOI, 2012).

The highly excessive and untimely rains, hailstorms and strong winds – the western disturbance in the recent weeks have caused 15 to 50 percent crop losses in several states of the country and exacerbated livelihood security of millions of small and marginal farmers. Recent prediction of 50 to 70% chances of El Nino this summer, when coupled with the global warming, will create serious disturbances in rainfall patterns. Such uncertainties have intensified in recent decades and seek priority attention of all stakeholders and development partners.

IV. Interdependence of Crop Diversity and Climate Change

Climate change and biodiversity are interconnected. Biodiversity is negatively impacted by climate change. Conversely, biodiversity through ecosystem services contributes to climate-change adaptation and mitigation. Thus, conservation and sustainable use of biodiversity is critical to addressing the climate change. The Millennium Ecosystem Assessment shows that climate change will lead to global temperature rise of upto 4^{o}C and mean sea level rise of upto 1 m by the end of 21st Century (against 0.76^{o}C and 12 to 22 cm, respectively, during the 20th century). These will lead to serious biodiversity losses.

The Darwinian evolutionary theory of origin of species, the Mendelian genetics and population shifts under natural and artificial selection as well as Waddington's epigenetic inheritance or neo-Lamarkism are all at work. We must view the evolutionary processes in context of the situation. For instance, a plant breeding program will essentially be guided by the Mendelian principles, whereas an *in situ* conservation initiative will be guided also by the Darwinian and Waddington's concepts.

In line with the Convention on Biological Diversity (CBD 1992) and the United Nations Framework Convention on Climate Change (UNFCCC 2003), biodiversity conservation means conservation of terrestrial, freshwater and marine ecosystems as well as restoration of the degraded ecosystems, including their genetic and species diversity. In context of the present Seminar, we must analyse the organic inter linkages among the coastal and island systems, the mangroves and the protection against tsunamis.

It is well known that adaptive peaks of biological species/populations represent different specific gene pools and constellations. Analogous weather, climatic, and overall environmental variables, irrespective of their geographic and temporal dimensions, are likely to create corresponding analogous genetic constitutions, which was referred to as homeologous series of variation by Vavilov (1950). This concept of parallel variations or "climate analogues" is extremely helpful in germplasm exploration, collection, introduction and exchange, and particularly in breeding crop varieties adapted to climate change.

According to the Climate Change, Agriculture and Food Security programme of the CGIAR (CCAFS/ CGIAR), the term "climate analogues" describes two sites that share similar climate conditions, and the two sites may be separated geographically and/or temporally as climatic conditions change and migrate" (CCAFS, 2013). Estimates hold that 70% of future climates already exist somewhere in the world, meaning thereby that climate adaptation solutions today are not only a distinct possibility, but also a necessity.

The use of climate analogues -"finding tomorrow's climate adaptation solutions today" will thus significantly improve knowledge of possible management techniques under changing climatic conditions, and help adoption of appropriate adaptation strategies. CCAFS has developed climate analogues tool which will facilitate in selecting most appropriate adaptation options based on real models and real world experiences. The tool can help in identifying desirable traits and varieties for particular locations, in locating hotspots and endangered genetic resources crying for priority collection/conservation and utilization, and in international exchange of genetic resources.

V. National and International Action Plans, Agreements and Policies on Crop Diversity and Climate Change

Crop diversity – plant genetic resources conserved through ages, comprising wild and domesticated forms constituting landraces, primitive varieties, farmers' varieties and scientists-bred modern varieties have been widely shared since time immemorial. The sharing and free exchange among breeders had expanded the process both nationally and internationally. The sharing process has however, been significantly impacted by several international treaties, agreements and conventions during the past 35 years or so (Jain, 2015).

In 1983, the FAO undertaking on Plant Genetic Resources had pronounced the resources as "common heritage" of mankind, encouraging free exchange. In 1992, the UN Biological Diversity Convention (UNCED/CBD, 1992) had declared that the plant genetic resources are the "sovereign property of the country in whose territory they are found", and access to them is not "free" and should be negotiated between the donor and the recipient country. In 2004, an International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA-FAO 2011), popularly known as the International Seed Treaty was brought out by the FAO Commission on Plant Genetic Resources internalising the CBD provisions (ITPGRFA 2011).

The Global Crop Diversity Trust (A Foundation for Food Security) was established in 2004 jointly by FAO and Bioversity (CGIAR) to promote public-private partnership to help develop an effective, efficient and sustainable global system to ensure the conservation and availability of plant genetic resources for food and agriculture. The Trust predicts that climate change by 2030 will depress rice, wheat, millet and maize yields by 4 to 5 per cent, and will cause extinction of a good number of wild relatives of major crops by 2055. The Trust has been promoting use of competitive grant scheme for germplasm evaluation and in partnership with FAO has launched Global Initiative on Plant Breeding. It is also strengthening the data management system for genebank and is creating searchable global accession level PGRFA information system.

While the international regime, particularly the concerned UN bodies were promulgating and transforming laws and agreements for sharing genetic resources for development, and often becoming more restrictive in exchanging the building blocks of new forms and functions, global climate change had become more discernable with profound adverse impacts. The IPCC (2014) had strongly advocated extensive use of plant genetic resources for breeding new crop varieties resilient to climate change. The paradox must be resolved to serve the humanity at large as elucidated earlier.

India has paid attention to the necessity of conservation and utilization of its agrobiodiversity, including the institutionalization of the system through its national bureaus/institutes of plant, animal, fish, forest and microbial genetic resources. The process has been duly strengthened by the national Protection of Plant Variety and Farmers Right Authority (PPV&FRA). In line with the Global Action Plan for Plant Genetic Resources for Food and Agriculture (PGRFA), India has been updating its National Action Plan. Recently, on December 23-24, 2014, led by the National Bureau of Plant Genetic Resources (NBPGR) through a Brain Storming Session organized by the National Academy of Agricultural Sciences (NAAS), the Plan was updated to have the following Action Groups for PGRFA (NAAS, 2014):

- Surveying and inventorying PGRs for food and agriculture
- Supporting on-farm management and improvement of PGRFA, especially of landraces which have evolved locally over time directly on response to how farmers select seed to meet their needs
- Assisting farmers in disaster situations to restore crop systems
- Promoting *in situ* conservation and management of crop wild relatives
- Supporting targeted collecting of plant genetic resources for food and agriculture
- Sustaining and expanding *ex situ* conservation of germplasm
- Regenerating and multiplying *ex situ* accessions

- Expanding the characterization, evaluation and further development of specific subsets of collections to facilitate use; genetic resources need to be evaluated for knowing the outer limits of their tolerance of the stresses to be effectively used in breeding programs.
- In context of climate change, the useful germplasm sources should be identified and their details shared with all bonafide users
- Supporting plant breeding, genetic enhancement and base-broadening efforts
- Promoting diversification of crop production and broadening crop diversity for sustainable agriculture
- Promoting development and commercialization of all varieties, primarily farmers' varieties/landraces and underutilized species
- Supporting seed production and distribution
- Building and strengthening national programmes
- Promoting and strengthening networks for PGRFA
- Constructing and strengthening comprehensive information system for PGRFA
- Developing and strengthening systems for monitoring and safeguarding
- Building and strengthening human resource capacity, and
- Promoting and strengthening public awareness of the importance of PGRFA

Each Action Group had defined specific actions. For instance, the Action Group no 3, Assisting Farmers in Disaster Situations to Restore Crop Systems, has the following four specific actions:

- Mainstreaming of community managed seed system through community seed banks and plant biodiversity registers to ensure on farm conservation and assisting farmers in disaster situations to restore crop systems
- Systematic documentation of information on adaptations developed by populations exposed to constant environmental pressures as well as adaptations endangered by radical environmental stress (stochastic events)
- Documenting information on landraces that survive stochastic events as they are likely to be well adapted to the particular stress, and future generations may possess that adaptation, and
- Modalities to repatriate the diversity in disaster situations in the event of large scale diversity loss in reference region.

Similar action plans, although not in as detail, were chalked out for other GRFAs, namely, animals, aquatic resources, agriculturally important microbes and agriculturally important insects. The new NAP should elucidate also the needs and actions for conservation and use of islands biodiversity.

It would be helpful to analyse the implementation of the First NAP prepared in 1999 and to internalise the lessons learnt in the Second Plan currently under preparation. As highlighted during the December 2014 Workshop, the following initiatives will be required:

- Increase the use of cutting-edge sciences such as informatics, molecular biology, space sciences, and nanotechnology for assessing vegetational cover and pattern
- Each major GRFA institute/programme should have inputs of socio-economists and ecologists for adequate spatial and temporal valuation of the genetic resources
- The huge existing gap in the trained human resources in the GRFA sphere should be filled, and
- Coordination and partnerships among central and state governments, concerned Ministries and disciplines should be strengthened. Likewise, the veritable international programmes *viz.* CBD, IPCC, ITPGRA etc. pursued in the country should adequately be converged.

VI. Way Forward to Harmonize Crop Diversity and Climate Change Management

The negative effects of the changing climate would need to be offset by commensurate turnover of new stress tolerant varieties, which is possible only with the availability of desired genetic resources. Therefore, Prof. Jain's appeal (2015) to rethink of the policy governing the management and sharing of PGRFA and also of the mandate of the national and international gene banks assumes thigh importance. In interest of the humanity at large, we may have to re-envision GRFA as the common heritage of mankind with built-in mechanisms to humanise the process and to prevent their mis- and under-exploitation. The National Bureaus of Genetic Resources, the National Biodiversity Authority and the PPV&FRA should jointly prepare the national policy option which may guide not only India but also the whole world in converging and harmonizing biodiversity conservation with climate change management for sustainable development.

The UN Conferences on Sustainable Development, the first one in June 1992 in Rio and the second one 20 years later, Rio+20 in 2012 June, again in Rio had emphasised that the humanity will face threats to water, food, biodiversity and other critical resources which will continually intensify economic, ecological and social crises under the fast changing climate (UNCED, 1992, UNCSD, 2012). These have emphasised Green Economy for improved human well-being and social equity, whilst significantly reducing environmental risks and ecological scarcities. FAO (2012) has emphasised that Green or Climate Smart Agriculture is needed for achieving Green Economy.

Rio+20 had alluded to the nine planetary boundaries and emphasised that three of these, including biodiversity loss and global warming, have already been crossed. Knowing that, with the fast changing climate, more wild relatives of most crops will be threatened and extinct within the next 50 years or so, concerted national and international effort must be made to capture the genetic resources while they are still there. The hot spots are generally known and should further be delineated and prospected on priority basis. The Global Crop Diversity Trust had analysed the gaps in *ex situ* collections of several crops and found that while more than 90% of the genepools of rice, wheat maize and potato have been collected, about 40 to 65% of the genepools of beans, soybean, sweet potato and cassava remain to be collected.

In the above context, based on experiences of several countries, FAO suggests the following steps towards achieving CSA alongwith genetic diversity conservation:

- Assess the current situation, defining the baseline (business as usual) and alternative development pathways
- Understand barriers to adoption of CSA and germplasm conservation practices which may include technological, institutional, financial, services and market constraints
- Collect information on existing and expected social, economic and environmental development settings as assessed through deploying effective and realistic indicators
- Assess efficacy of various CSA practices and strengthen both autonomous adaptation and adaptation to abnormal weather fluctuations and to extreme variations, and enrich insurance products and provisions
- Define coherent policies (technical, institutional and economic) and provisions and policy levers for adoption of cost-effective adaptation and mitigation measures, such as community gene banks and *in situ* conservation and farmers' participatory breeding
- Guide investment based on cost benefit analyses of various adaptation and mitigation practices, including adoption of climate resilient crop varieties, and the trade offs

Not withstanding the ongoing plant breeding efforts to develop climate resilient crop varieties, it is being increasingly felt that the climate change is putting new and enhanced demand for plant genetic resources. Making use of the climate analogues, more and more breeders should be targeting new varieties with adaptations to future climate stresses. The pressure for collecting, conserving and sharing by the centres of origin or of crop diversity will increase significantly. The UN and other concerned international systems viz. CGIAR, Global Crop Diversity Trust should work closely with the national program in this drive. The development partners should view conservation as a part of development and allocate resources accordingly.

The climate smart agriculture movement should be rooted in climate smart villages. Such villages could be created only by ensuring them to be congruently water smart, energy smart, carbon smart, nitrogen smart, weather smart and knowledge smart. Under the Saansad Model Village initiative of the Govt, each MP may develop at least one climate smart village in his/her constituency.

The approach must be to create rich and dynamic knowledge domains to produce more from less. This is very much in line with FAO's call "Save and Grow", and one can often substitute knowledge for purchased inputs. In this context, selecting the most appropriate variety, the landraces, changing land-use practices such as the location of crop and livestock production, crop rotation, especially inclusion of legumes in the rotation, sequence and duration, rotating or shifting production between crops and livestock, and altering the intensity of inputs use can help increase productivity and at the same time reduce risks from climate change in farm production. In this direction, the National Initiative on Climate Resilient Agriculture (NICRA) project of India, encompassing : (i) strategic research to address long-term climate change, (ii) demonstration of innovative and risk management technology in different parts of the country, (iii) funding competitive research, and (iv) capacity building of different stakeholders for greater awareness and community action, is an exemplary step and deserves continued support (Venkateswarlu, 2013).

As we move forward, adaptation and mitigation must be seen as two mutually reinforcing pillars of climate smart agriculture, and adaptation-led mitigation should be the way ahead. Moreover, climate is ever-changing, hence one-time adaptation response is not enough, and the adaptive capacity should continually be improved. India's agriculture, agro-ecologically diverse as it is, should be assessed for its carbon, methane and N footprints across agro-ecologies and differentiated adaptation-mitigation plans should be prepared. In particular, dynamic relations of rice ecologies and livestock farming in context of GHG emissions should be analysed. Genetic restructuring, altered agronomic practices, diversification, integrated cropping and farming systems, and efficient use of biodiversity and other natural resources should meet the micro (farm level) as well as macro level situations (Singh, 2013).

Risk profile of CSA practices should be understood to be prepared to reduce the vulnerability of farmers to climate risk. New studies undertaken by the South Asian program of the CCAFS of the CGIAR has recently come up with excellent insurance products which offer triple wins: a) reduced premium rate, b) expanded, most effective and timely disbursement, and c) savings for the Govt in terms of reduced subsidy, hence lesser load to the exchequer. This new product should be widely piloted and linked with the Prime Minister's Jan Dhan Yojana.

We have generally failed both at national and international levels to suitably and adequately communicate the outstanding achievements to the veritable stakeholders – political leaders, policy makers, scientists, development partners, farmers, consumers, and the civil society. Our national research, education and extension systems, the NARIs, must strengthen their communication science and technology capacities to ensure effective and timely communication of actual and potential impacts of their products and outcomes.

As championed by IFFCO Kisan Sanchar Limited (IKSL), ICT-based agro-advisories must be promoted also by private sector in India. Other such initiatives, viz. Digital Green deserve public sector support for content development, training at grassroot level, and for augmenting the feedback mechanisms and the knowledge pool. The current Digital India initiative should be effectively used for connecting the development partners with farmers.

It can hardly be overemphasised that multi- and inter-disciplinary research, technology generation and technology transfer in a partnership mode is the only way to go forward. Not withstanding the unmindful splitting of SAUs, ICAR may also be required to undertake institutional transformation to ensure effective synergistic integration of activities and sub-systems. Having shown the paths for increasing productivity and environmental security, national institutes and deemed universities should be empowered to judiciously and rigorously integrate and harmonize the efforts located within the four walls of the institute and beyond without compromising the proverbial independence and autonomy of individual scientists and centres. The process needs to be critically evaluated with clearly defined accountability of all partners.

Efficacies of different policies related to climate resilient agriculture and effectiveness of their implementation should be critically assessed. Policies such as those on Agriculture, Biosecurity, Biodiversity, Disaster Management, Food Security, Water, Land etc. should be synergistically converged at different levels, particularly at the grassroots, such as at the level of the climate-smart villages. Institutional adjustments and inter-ministerial convergence are needed to ensure judicious implementation. Development of climate smart agriculture and germplasm conservation should be mainstreamed into the national policy with suitable investment and financing provisions.

CIARI should develop Andaman Nicobar specific adaptation measures. In doing so, advantage should be taken of the proven measures in island settings in different parts of the world. The climate analogues concept should benefit particularly the islands and island countries in technology, germplasm, strategy and policy sharing.

VII. Epilogue

Biodiversity impacts as well as gets impacted by climate change. Crop diversity regimes, especially landraces and farmers' varieties, which must sustainably increase productivity, resilience (adaptation), mitigation (removal of greenhouse gases) and biodiversity conservation are needed. These outcomes and the related activities interact in a complex manner and cut across a number of stakeholders, seeking synergistic integration of gene smart, water smart, soil and nitrogen smart, energy smart, carbon smart, weather smart, and knowledge smart development pathways to green the economy.

Investment in science, especially in the sciences of plant genetic resources conservation and utilization and in climate smart agriculture, for development, and in the associated human resources should be suitably enhanced and linked with an effective monitoring, evaluation and impact mapping system.

Innovative approaches to social safetynets, including enw insurance products, will be needed to augment house hold resilience. The science-policy interface must be institutionalised to ensure that the rigour of science sensitizes policy makers and guides the policy process, options, actions, investment, incentives, and even implementation.

As we move towards an Ever Green Economy, crop diversity and overall biodiversity conservation and sharing of the genetic treasure – the common heritage of mankind should be mainstreamed into the national and international policies in mutual harmony with climate smart agriculture.

References

CCAFS. (2013). Climate analogues. Climate Change, Agriculture and Food Security, CGIAR.

Erickson *et al*, (2011). cited in Aggarwal, PK, Joshi, P Campbell, Bruce, Vermeulen, S. And Kristjanson, P (2012). Adapting South Asian Agriculture to Climate Change and Declining Resources, CGIAR Research Program on Climate Change, *Agriculture and Food Security (CCAFS)* http://blogs.ubc.cafoodsecuritypolicyinasia/files/2012/02/Presentation_Aggarwal.pdf.

FAO (2012). Developing a Climate-Smart-Agriculture Strategy at the Country Level: Lessons from Recent Experience. Background paper for the Second Global Conference on Agriculture. Food Security and Climate Change. Hanoi, Vietnam, 3-7 September 2012.

GOI (2012). The Crisis Management Plan: Drought, Government of India, Ministry of Agriculture, *Department of Agriculture and Cooperation.* p. 33.

ITPGRFA Secretariat FAO Rome. (2011). Introduction to the international treaty on plant genetic resources for food and agriculture, FAO, Rome, p. 155

Jain, H, K. (2015). Plant genetic resources policy in changing climate. *Agric Res* **4**:1-6

NAAS. (2011). Biosafety Assurance of GM Food Crops in India. Policy Paper No. 52. *National Academy of Agricultural Sciences,* New Delhi p. 16.

NAAS. (2015). Hundred Years of Science for Agricultural Development. *National Academy of Agricultural Sciences,* New Delhi (in press)

NBPGR. (2014). Redefining the priorities in National Action Plan for Management of Plant Genetic Resources. Workshop held at New Delhi.

Singh, R.B. (2013). Climate Smart Agriculture Towards an Evergreen Economy. Presidential Address. *National Academy of Agriculture Sciences,* New Delhi p. 32

Singh U,S., Dar, M,H., Singh, S., Zaidi, N,W., Bari, M,A., Mackill, D,J., Collard, B,C,Y., Singh, V,N., Singh, J,P., Reddy, J,N., Singh, R,K.& Ismail, A,M,. (2013). Field performance, dissemination, impact and tracking of submergence tolerant (Sub1) rice varieties in South Asia. *SABRAO Journal of Breeding and Genetics,* **44**:112-131.

UNCED/CBD. (1992). United Nations Conference on Environment and Development. Convention on biological diversity, *Rio de Janeiro,* Brazil.

UNCED/UNFCCCC. (1992). United Nations Conference on Environment and Development. United Nations Framework Convention on Climate Change.

UNCSD. (2012). United Nations Conference on Sustainable Development. The Future We Want, Rio+20, *Rio de Janeiro,* Brazil.

Vavilov, N,I. (1950). The origin, variation, immunity and breeding of cultivated plants. Chronica Botanica, Waltham, M,A, p. 364

Venkateswarlu, B. (2013). NICRA and Linkages Opportunities with CCAFS. Paper presented at Workshop on Impact Pathways for Climate Change, *Agriculture and Food Security in South Asia,* 26-28 Feb. 2013, Dhaka.

Vermeulen, S,J. (2014). Climate change, food security and small scale producers. CCAFS Info Brief. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark. Available online at www.ccafs.cgiar.org

Yamano, T, Malabayabas, M and Gumma, M,K. (2013). Adoption, Yield and Ex Ante Impact Analysis of Swarna-Sub1 in Eastern India. STRASA Economic Briefs, No. 2 (March 2013). *International Rice Research Institute,* Philippines. p. 4.