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In situ on-farm conservation of crop biodiversity

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Abstract

Agrobiodiversity conservation should be the basic component of any national agricultural improvement programme. Programmes that manage agricultural genetic resources need to reconsider their strategies. Conservation based on genebanks (*ex situ* conservation) must be broadened and be integrated with on-farm/*in situ* conservation to be able to conserve much large species and genetic diversity than would otherwise be possible. *In situ* conservation of agricultural biodiversity (crop and related species diversity) must be made an integral part of agricultural development and supplemented by *ex situ* conservation. It is obvious that the public sector will have to take the lead in implementing such a comprehensive approach, in which the private sector has an important supportive role. National and intergovernmental laws and regulations will have to provide the necessary legal framework. Civil society organisations (CSOs) as well as the private sector are becoming increasingly important in filling this framework with development reality on the ground. There is a great need for us to adapt to changing conditions accepting realities of climate change, which is a complex task and requires much research as much is unknown. We are in early stages of understanding the changing rules of the game, but I believe there is sufficient experience and diverse resources available to deal with the situation on short term basis, but for long term solutions further research is needed. Complacency should be out and we need to be strategic and need to involve several stakeholders and plan early and systematically. Some amount of crystal gazing and innovation (that may or may not seem right, right now). That means we need to be flexible and be able to change fast when situation demands.

Key words : On-farm conservation; *in situ* conservation, germplasm, plant genetic resources for food and agriculture, global warming, adaptation

Introduction

In situ conservation is dynamic in contrast to the semi-static nature of *ex situ* conservation. *In situ* and *ex situ* approaches complement each other to help us maintain much more genetic diversity than it would be possible when only one is used. Due recent awareness on biodiversity conservation, *in situ* conservation has been generally given higher priority over *ex situ*. This is mainly because of its ability to maintain the evolutionary potential of species and populations [1-8], and because it helps increase the access to and control of local communities over their genetic resources [9, 10]. However, given the fact that human activities can cause habitat destruction and loss of biodiversity in some cases, and the maintenance of biodiversity in other cases, it will be necessary to complement it with *ex situ* conservation.

The Convention on Biological Diversity (CBD) requires, under its Article 8, that the countries develop guidelines for selecting areas for *in situ* conservation, establish protected areas, regulate the use of resources so as to make a sustainable use and protect ecosystems and natural habitats. Crop genetic resources (or crop biodiversity) constitute the genetic diversity in a crop species (as designated by different landraces and crop cultivars) and their wild relatives. Although in this paper the terms 'on-farm conservation' and '*in situ* conservation' are used as interchangeable, it is important to note that *in situ* conservation of biodiversity could be considered as having 2 components- on-farm conservation of traditional crop cultivars (landraces) or farming systems by farmers within traditional agricultural systems and *in situ* conservation of crop wild relatives in natural habitat. The later, at times, can be linked with the larger biodiversity conservation efforts (protected areas, forest conservation etc.).

In the case of agrobiodiversity, the effects of growers-practices and preferences are of paramount importance for conservation and utilization. Any conservation efforts of crop biodiversity (including wild relatives of crops) should have sufficient information on the following [11, 12]:

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(1) The extent and distribution of diversity maintained on farm

(2) The processes used to maintain this diversity

(3) Who is maintaining this diversity? Why?

(4) The factors that influence these people to maintain diversity on farm

(5) Direct and indirect values of genetic diversity in terms of economic and socio-cultural benefits, ecological benefits and genetic benefits.

In this paper, an attempt is made to briefly look at the role of *in* situ/on-farm conservation, the process of conservation and how to go about it in a national context. An attempt is also made briefly to review some of the basic information available on the expected impact of climate change on *in situ* conservation.

Role of in situ *conservation*

It is now well recognized that the *in situ*/on-farm conservation of agrobiodiversity helps to conserve the genetic diversity in target crop species and to maintain the evolutionary processes and the ecosystems that host it. *In situ* conservation is the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties (CBD Article 2). It is the sustainable management of genetic diversity of locally developed crop varieties (landraces), with associated wild and weedy species or forms, by farmers within traditional agricultural, horticultural or agri-silvicultural systems [1, 13, 14].

On-farm conservation can improve the farmers' access to plant genetic resources. Despite implementation of various *ex situ* and *in situ* conservation of agrobiodiversity projects, the efforts to improve farmers' access to germplasm and associated information within communities have been limited. Interventions such as seed/biodiversity fairs could improve access to information and germplasm within and between communities [15,16]. Community seed bank can improve the access to traditional crop varieties by communities [16]. For example, distribution of small quantities of germplasm seed can lead the concept of informal research and development (diversity kits) and could prove effective in adoption of varieties [17]. Efforts with community seed bank to characterise the germplasm, multiply healthy seed, and sell to communities for supporting community seed bank, participatory variety selection, and plant breeding [18]. However, these methodologies have been evolving over time. This is a kind of basic plant breeding that farmers were doing in the past could be done by grassroots institution. All these efforts can improve the access to materials by farmers as well as improve the germplasm on-farm. On-farm conservation can also play a role in other aspects of the ecosystem (such as ecosystem health, services and functions) and in socio-economics of communities that are involved in such conservation efforts. Following are some areas in which on-farm conservation may play some role [11]:

1. Conservation of the processes of evolution and adaptation

2. Conservation of diversity at all levels (ecosystems, species, intra-specific)

3. Integrating farmers/communities into national plant genetic resources conservation systems

4. Contribution to ecosystem services and ecosystem health

5. Maintaining the process of local crop development by strengthening capacity of farming communities in landrace assessment, selection and exchange of crop germplasm

6. Improving the livelihoods and quality of life of farmers

7. Empowering farmers and communities over their crop genetic resources and improving access to them

8. Providing information for national seed policy decisions regarding importance traditional seed supply system

9. A component of complementary conservation strategy-linking farmers to genebank

Establishing an in situ *conservation programme*

Although farmers have been conserving plant genetic resources over centuries, there is a need to integrate rural areas into national and global development efforts. Some interventions that benefit farmers will be required if the farmers have to continue on-farm conservation. There have been several suggestions as to how this could be achieved [1, 9, 19, 20, 48]. On-going research in many locations in the world has shown that it is possible to conserve much of the genetic diversity on

farm by assisting the farmers and communities in doing so while ensuring that they benefit from it at the same time. *In situ*/on-farm conservation could play a significant role in supporting the local, indigenous, and rural communities to treasure their PGR, thereby putting the concept of Farmers' Rights in practice. *In situ*/on-farm conservation can only be realized by recognizing and strengthening communities and their institutions. The Community Biodiversity Management (CBM) approach integrates knowledge and practices embedded within local social and cultural systems [49, 50]. The key point is to institutionalize local level decision-making on agro-biodiversity conservation and use within a livelihood context. Such decision making is the aim of the community empowerment required to realize community management of biodiversity. Consequently, an integrated process as foreseen with the CBM approach for realizing *in situ* conservation of agrobiodiversity requires knowledge, skills and expertise of building social institutions at community levels [48]. Effective implementation would require significant amount of learning by professionals formally engaged in the conservation of genetic resources in matters of CBM [50]. To establish an *in situ* conservation programme for agricultural crops and their wild relatives (note that much of the following discussion focuses on crop species, most of the principles apply to their wild relatives as well, with certain modifications per the context) we will need to consider the following broad requirements:

Institutional framework

As indicated earlier, farmers have been practising *in situ* conservation informally for a long time. However, to successfully implement and sustain it, it would require some level of institutionalising the effort at local levels. Organizations that are committed to *in situ* conservation (similar to organizations that deal with *ex situ* conservation) need to be identified and guidelines for their interactions have to be developed and implemented. Roles of local and national institutions are central to enhance the local management decisions for agro-biodiversity conservation and utilization. PGR programme that is committed to holistic complementary conservation should also committed to cultivate the partnership with institutions that have expertise and comparative advantages in working with community based management of agricultural biodiversity. The role and responsibilities of individual organizations need to be clearly identified from the very beginning (though these could change during the period of the programme) and appropriate linkages for working together will be developed. Thus, *in situ*/on-farm conservation should become a part of larger national conservation programme.

Sensitizing and strengthening local community

Identification of grassroot institutions that match the objectives of on-farm conservation is essential along with the strengthening the capacity of local organisation to implement the programme. The rationale behind this is that the strategy for on-farm conservation will only succeed if indigenous communities and grass-root organisations valued local biodiversity and are involved at different stages and their needs and problems are understood and addressed. This requires better understanding of what they do, how they do it and why they do it that in built in their traditional farming practices and social customs governed by norms and values of local institutions. It has been observed that the scientists working in this field have often ignored this step or often disrespect when establishing framework for collaboration and partnership and this must redressed.

Collaboration

In an effort like on-farm conservation several different organizations and people with different backgrounds will come to work together. In addition to teamwork, as the expertise that is required to carryout an *in situ* conservation programme is very diverse, there is a need for multidisciplinary and multi-institutional teams. To be effective, such teams would need to be well coordinated through effective communication, networking and participatory approaches. Any hurdles to collaboration need to be identified ahead of time, remedial measures need to be taken, so that the work goes on smoothly.

Framework for collaboration

In order to have institutional understanding for the people to work together in teams some sort of agreements such as Memorandum of Understanding (MOU) may need to be formalised at national level. Teams have to build close rapport with various rural people and in particular build up collaboration with farmers and farming communities. It is important to note that building rapport and making collaborative arrangements with farming communities are the most essential steps for the success of *in situ* conservation programme and this may need time to develop a framework for collaboration. The participation of farmers is crucial in setting goal(s), as they knew better their needs in their local varieties. Often, they are receptive to ideas from outside, but inserting the ideas needs care and should be through a consultation and consensus

process. Farmers participation in agricultural research may be classified into four categories: contractual, consultative, collaborative and collegial. As the decision-making capacity of local institutions improved the quality of participation is enhanced from collaboration to collegial participation [21, 22]. It is essential to link on-farm conservation of PGR with various market outlets and incentives so that the farmers see the value of conservation. Currently there are several tools available to determine the strengths and weaknesses of different organizations; determination of key organizations, etc., and such tools must be used to evaluate the initial conditions and suitable mechanisms for continuous collaboration based on competency and trust have to be established [22, 52-54].

Representative partnerships and equitable sharing of benefits

On-farm conservation initiatives should promote equity at all project levels, from farmer participation to research to project management and decision-making. Equitable gender, ethnic and other minority involvement not only for data collection but also as members of research and management teams is the key for ensuring representative partnerships and benefit sharing. Increased women, minority, and farmer participation in decision-making is essential to ensure that diverse perspectives are incorporated into project objectives and that all stakeholders feel ownership in the project. This is crucial to success of the efforts and it must be noted that many of the researchers are not well versed with the participatory research approaches and hence there is need to retrain and reorient ourselves in this aspect. It is important to note that institutional hegemony should be avoided at all costs. The 'team' should work together for the benefit of the poor farmers and users of agricultural biodiversity that is the focus of conservation efforts.

Process of on-farm conservation

Once understanding between institutions, collaborators and farming communities has been reached, and most of the researchers and other partners understand the nuances of participatory approaches to conservation, the actual on-farm conservation work could start. This would include preparation, site selection, sampling and developing and putting in place the mechanisms for on-farm management of agro-biodiversity. Ahead of site selection, the existing data such as descriptor lists, databases of e*x situ* germplasm collections, herbarium collections, published literature in the natural and social sciences and other unpublished information shall be collected and used for eliminating inappropriate sites. Personal knowledge of experts, including personnel from NGOs, CBOs, and others existing local institutions would be most valuable. Simultaneously, the criteria for site and farmer selection have to be well defined. Broadly speaking, the criteria would be based on the genetic diversity, accessibility and interest of the farmers to continue to grow the varieties that are being targeted and these will have to be evaluated through a survey. Some generalized criteria that could be used for developing an on-farm conservation programme could include [11]:

1. Ecosystems: It will be important to select sites in diverse agro-ecosystems preferably with different ecotypes. This will increase the chances of conserving genetic diversity, as this may be associated with agro-ecosystem diversity.

2. Intra-specific diversity within target species: It is important that the areas selected are grown to different landraces.

3. Specific adaptations: Efforts should be made while selecting different agroe-cosystems (see 1 above) to select sites with extreme environmental conditions (high soil salinity, cold temperatures, etc) and variation in pests so that types with specific adaptations might be included.

4. Genetic erosion: For obvious reasons, it is better to select sites with less threat of genetic erosion to increase the life of conservation efforts.

5. Diverse use values: It is possible to ensure conservation of hidden genetic diversity by selecting sites with diverse use values of crops for food and other uses.

6. Farmers and communities: Farmer's interest and willingness to participate are keys in site selection. This may require preliminary work in community sensitization on the benefits to farmers of conserving crop varieties. Site selection should also include sites with: socio-cultural and economic diversity; diversity of livelihoods, and importance of target crops for various ways of life; farmers' knowledge and skills in seed selection and exchange; and market opportunities

7. Partners: Partners with interest, preferably experience, in community and cooperation, experience in conservation interventions will be beneficial to the programme.

8. Logistics: These would include mainly the accessibility of the site throughout the year (in *in situ* conservation monitoring is essential) and availability of resources.

The existing data should be combined with an exploratory survey, using a Rapid Rural Appraisal (RRA), Participatory Rural Appraisal (PRA), or a similar approach. The Community needs to be sensitised to issues on hand and for this use of participatory approach is recommended [11, 20]. The following are primary considerations before launching and *in situ* conservation of crop genetic diversity:

Benefits to farmers

Farmers would grow a particular crop or crop cultivar only when they benefit from it. The benefit may be in the form of subsistence or livelihood, cash income, cultural uses, pride, adaptation to particular abiotic or biotic stresses, etc. As noted earlier, the needs and preferences of farmers may change over time, leading to cessation of cultivation of particular crop species or a cultivar. So, if we aim to conserve a particular crop or cultivar, it is necessary to enhance the benefits to farmers from local crop diversity so that the farmer would continue to cultivate the same crop or cultivar and. In the changing scenario in the country, *in situ* conservation of crop diversity can be linked with eco-tourism/agro-tourism, for example, agricultural habitat used as a resort or agro-tourism site, adding value and enhancing the sustainability of the effort.

Identifying crop genetic diversity to conserve in situ

Genetic diversity is central to conservation and utilization of plant genetic resources and information on the extent and distribution genetic diversity and its use value is vital. Presently little information is available on the status of genetic diversity on farms. In this context, crop history (origin etc.) can help to some extent. However, another source of information on genetic variation and uses of crop plants is the farmers' knowledge/traditional knowledge. There is a need for systematic documentation of farmers' on crop diversity and uses. The determination of genetic diversity at the beginning is bit tricky as one can not undertake large scale genetic diversity studies but must base on rapid assessment of crop biodiversity in a site. This could be done through questionnaire based rapid agricultural biodiversity assessment supplemented with on-site observations and rapid *in situ* evaluation. Based on this, determination of the number of sites or choosing additional sites will be possible. Community based organisations could be mobilized to locate and monitor crop plant diversity through participatory methods such as diversity fairs and biodiversity register [49]. Where it is feasible, molecular markers may be used to estimate genetic diversity from tentatively identified sites and to finalize them. In any case, a baseline of genetic diversity has to be established for the purpose of monitoring it over the years.

Other considerations

It should also be underlined that, during the course of *in situ* conservation, there can always be unforeseen developments (social, developmental, environmental) that can interfere with the continued conservation of crop genetic diversity; however, such situations need be dealt with when they occur and should not be factor to dissuade our on-farm conservation efforts.

Thus, the essential elements of an *in situ* conservation programme for any crop genetic resource, including wild relatives, could be:

- Identification of sites with typical ecotypes/ landraces of the country concerned based on traditional knowledge and historical information and any available information on genetic diversity
- Identification of crop wild relatives is in natural habitats, forested areas, protected areas etc. and mapping the located areas
- Identification of organizations that are stakeholders in such an effort, including community based organizations and user's group of the natural forest.
- Identification of threats to continued maintenance of farms and forested areas with unique and diverse crop cultivars and wild relatives
- Identification of means to remove the threats in short term (to gain time to put in place the longer term efforts)
- Ensuring continued management of such farms and forested areas by enhancing benefits to farmers or user groups (in case of those depending on wild species/relatives).
- Identification of means to remove the threats in the long term (E.g. study to understand the basis for *in situ* conservation of crops and wild relatives, adding value, market incentives, improving the current cultivar for specific traits, ecotourism, sustainable harvesting etc.)

- Identification of sustainable ways to monitor genetic erosion of crop genetic diversity using help of local institutions or organizing participatory approaches such as diversity fairs, community biodiversity register (CBR), community seed bank)

Next steps

The following general process of *in situ* conservation may be useful in moving forward:

- Creating (or using existing) institutional framework and management.
- Site selection (Training in participatory approaches may be needed).
- Sensitizing and strengthening local community and institutions.
- Locating diversity (e.g. *in situ* evaluation, questionnaire, crop diversity fair).
- Measuring and assessing diversity (establish diversity rich sites and baseline).
- Understanding value of genetic diversity.
- Understanding and validating the processes that maintain diversity.
- Monitoring diversity (e.g. Community biodiversity register).
- Developing strategy for on-farm conservation.
- Linking problems with new opportunities (capacity of local farming community enhanced using CBR and diversity fair, adding value etc.).
- Institutionalizing on-farm strategy integrating farmers into national PGR system.

There will be a need for national partners to spend some time to work out above processes in the context of specific target crop farming system. Community participation is central to *in situ* conservation, which needs substantial input from national partners to sensitize the national programmes and communities before a pilot scale *in situ* conservation strategy for any crop could be developed.

Climate change, agriculture and agricultural biodiversity

In spite of what has been written in most recent literature, the implications of climate change for agriculture are still a bit vague and mostly based on modelling and estimations. However, even what little that we know indicates that there will be major reduction in food supply [23-26] and this is the main reason for a discussion on the future role of agricultural biodiversity in agriculture [27] under changing conditions brought about by climate change. Further, the impact of climate change on conservation and use of agricultural biodiversity is still vaguer and anything we can say on *in situ* conservation is only a scientific guess at this stage.

There is evidence that climate change is already affecting biodiversity and will continue to do so. The Millennium Ecosystem Assessment ranks climate change among the main direct drivers affecting ecosystems. Consequences of climate change on the species component of biodiversity include:

- Changes in distribution.
- Increased extinction rates.
- Changes in reproduction timings, and
- Changes in length of growing seasons for plants.
- Changes in plant community composition.
- Changes in ecosystems.

These changes will result significant changes in farming practices and genetic resources that we use now. All though still being debated, most researchers agree that there will be drastic changes in available water supply in different regions of the globe, which will have major effect of agricultural systems as we know as well as on total productivity. Current information available indicates that subtropical regions received less precipitation and were subjected to more frequent droughts, while the northern hemisphere received higher rainfall in recent past. Nevertheless, research to date suggests this trend is less predictable but at the same time, the degree of variation will be more pronounced [28,29]. All of these will have serious consequences on how we do agriculture, maintain agricultural biodiversity and crop improvement. However, we will focus here on its impact on *in situ* conservation of agrobiodiversity.

Climate change and in situ *conservation of agro-biodiversity*

From various climate change predictions made it is clear that many regions around the globe are going to change in various ways. Thus, a good question to ask is how these various changes will affect different *in situ*

conservation efforts of landraces and wild species. Although ecosystems have adapted to changing conditions in the past, current changes are occurring at rates not seen historically. In general, the faster the climate changes, the greater the impact on people and ecosystems. Reductions in greenhouse gas emissions can lessen these pressures, giving these systems more time to adapt [30]. In addition to mitigation, there is an urgent need to develop and implement climate change adaptation plans. There is a significant research gap in understanding the genetic capacity to adapt to climate change. An examination of available literature indicates that, while a broad range of studies examine the generic impacts of climate change on crop productivity, few studies examine varietal level changes in adaptation [31].

Changes in range and size of species distribution

Climate is one of the major factors governing the distribution of plant species and crops, impacting physiological and reproductive processes and through influencing ecological factors such as competition for resources [32]. Many instances, even relatively modest, climatic changes over the past century having significant impacts on the distribution, abundance, phenology and physiology of a wide range of species have been recorded and it is now possible to apply species distribution models and predict range shifts and assess extinction risks due to climate change [33-42]. Such models can lead us to better understanding if migration rates are known for particular plant species [43, 44].

Jarvis *et al.* [45] used current and projected future climate data for ~2055, and a climate envelope species distribution model to predict the impact of climate change on the wild relatives of groundnut (*Arachis*), potato (*Solanum*) and cowpea (*Vigna*). They reported that wild groundnut were the most affected group, with 24 to 31 (depending on the migration scenario) of 51 species projected to go extinct and their distribution area on average reduced by 85 to 94%, depending on the migration scenario, over the next 50 years. In terms of species extinction, *Vigna* was the least affected of the three groups crops studied. Their results suggest that there is an urgent need to identify and effectively conserve crop wild relatives that are at risk from climate change. While increased habitat conservation will be important to conserve most species, those that are predicted to undergo strong range size reductions should be a priority for collecting and inclusion in genebanks [45].

An additional factor that may have to be used for most such studies is to taking into consideration the capacity to adapt to changed conditions. Can the species that are shown to be at risk can adapt fast to changing climatic conditions or they have really run out of their time? I think this is one of the right questions to ask, even through the answer may not be within our grasp for while. Diversity conserved at the *in situ* areas will be interesting to monitor as rich biodiversity expected to buffer against unpredictable temperature and precipitation change than the areas with increased uniform farming system.

Protected areas (PA)

While considering the *in situ* conservation of useful wild plants and crop wild relatives it is important to consider the effects of climate change on protected areas. Although, as noted earlier, there is precious little empirical data, it can safely be assumed that significant amount of species and genetic diversity of related agricultural biodiversity occurs in protected areas (need survey and determination of distribution). Thus, the mitigation of negative effects of climate change on protected areas indirectly will help in conserving valuable agricultural biodiversity that is present in them. Reports available to date [46] indicate that protected areas can be an important conservation strategy in such a scenario, and that early action may be both more effective and less costly than inaction or delayed action. The costs may vary among regions and none of the three areas studied will fully meet all conservation targets, even under a moderate climate change scenario, which suggests that limiting climate change is an essential complement to adding protected areas for conservation of biodiversity.

At the same time, it is important to note that key risks associated with projected climate trends for the 21st century include the prospects of future climate states unlike the current states (novel states) and the disappearance of some extant climates. Williams et al. [47] conclude that there is a close correspondence between regions with globally disappearing climates and previously identified biodiversity hotspots; for these regions, standard conservation solutions (e.g., assisted migration and networked reserves) may be insufficient to preserve biodiversity. By extrapolation, we can assume that this applies to agricultural biodiversity found in areas affected by climate change. This further strengthens earlier statement that there is as large gap in research to make correct conservation decisions.

Concluding remarks

In situ conservation or on-farm conservation of crop genetic diversity is feasible and a component of an integrated approach to conservation of germplasm. Efforts are underway to collect, conserve and use the crop genetic diversity in many countries in the region. Currently *ex situ* approach is the main focus of many national programmes. There is a need to focus on *in situ* approach, as together these two approaches would help us effectively conserve and access maximum crop genetic diversity. On-farm conservation will assist the researchers to work towards the development goals of the conservation efforts, i.e. the well being of our main partners, the farmers.

Scientific basis for on-farm conservation/*in situ* conservation is reasonably well understood. Since much of the basis for this conservation approach is human influenced, it is not exact science and appropriate adjustments have to be made as we go along. Although there is a large gap in research that can help us to visualize the impact of climate change on agricultural biodiversity in general and *in situ* conservation in particular, some decisions can be made that will probably hold true in any situation. Any effort in this direction would only lead to a win-win situation, i.e. conserving and using crop genetic diversity for the benefit of those who depend on it, in addition to contributing to environmental health through its contribution to ecosystem functions in general.

To set off in this new direction, we need

1) Collection of all available information on *in situ* conservation/on-farm conservation efforts in the country to date

2) Identify national partners who wish to integrate *in situ* conservation of crops

3) Discuss and develop the process of *in situ* conservation with participation of grass roots stakeholders

4) Identify resources that supports community based conservation actions

5) Follow “Next Steps” (see above)

In relation to climate change we need to focus immediate efforts on:

1) Highlight the need for paying increased attention and enhancing public awareness on problems and opportunities created by the climate change.

2) Agro-biodiversity conservation should be the basic component of adaptation strategies to climate change.

3) Public sector will have to take the lead in implementing such a comprehensive approach

4) We need more studies on modelling and prediction of change in distribution of crops/plants and crop wild relatives (endemic to India) in protected and forested areas.

It is also clear that we are in early stages of understanding the changing rules of the game, but I believe there is sufficient experience and diverse resources available to deal with satiations. However, complacency should be out and we need to be strategic and need to involve several stakeholders and plan early and systematically. Some amount of crystal gazing and innovation (that may or may not seem right, right now). That means we need to be flexible and be able to change fast when situation demands.

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References

1. **Altieri M. A. and Merrick L. C.** 1987. *In situ* conservation of crop genetic resources through maintenance of traditional farming systems. Economic Botany, **41**: 86-96.
2. **Ledig F. T.** 1988. The conservation of diversity in forest trees. BioScience, **38**: 471-479.
3. **Ledig F.T.** 1992. Human impacts on genetic diversity in forest ecosystems. OIKOS, **63**: 87-108.
4. **Brush S. B.** 1989. Rethinking crop genetic resource conservation. Conservation Biology, **3**: 19-29.
5. **Brush S. B.** 1993. *In situ* conservation of landraces in centres of crop diversity. Symposium on Global Implications of Germplasm Conservation and Utilization at the 85th Annual Meetings of the American Society of Agronomy, Cincinnati, Ohio, USA.
6. **Hodgkin T.** 1993. Managing the populations - some general considerations. A workshop organized by the Council of Europe in cooperation with Swiss Authorities and Neuchâtel University - Conservation of the Wild relatives of European Cultivated Plants: Developing Integrated Strategies, Neuchâtel University, Switzerland, 14-17 October 1993.
7. **Jarvis D. I., Sthapit B. and Sears L.** 2000. Conserving agricultural biodiversity in situ: A scientific basis for sustainable agriculture. International Plant Genetic Resources Institute, Rome, Italy.

8. **Jarvis D. I., Myer L., Klemick H., Guarino L., Smale M., Brown A. H. D., Sadiki M., Sthapit B. and Hodgkin T.** 2000. A Training Guide for *in situ* Conservation On-farm. Rome, Italy, International Plant Genetic Resources Institute. 161 p.

9. **Sthapit B. R. and Joshi K. D**. 1996. *In situ* conservation possibilities through participatory plant breeding and selection approach: A case study from Nepal. Paper presented in Expert Meeting on Agricultural Biodiversity, 11-12 June 1990, Chinese Academy of Sciences, Chengdu, China.

10. **Jarvis D. I.** 1999. Strengthening the scientific basis of *in situ* conservation of agricultural biodiversity on-farm. Botanica Lithuanica Suppl., **2**: 79-90.

11. **Ramanatha Rao V., D. Jarvis and B. Sthapit** 2000. Towards *in situ* conservation of coconut genetic resources. Paper presented at the 9th COGENT Steering Committee Meeting, 20-12 July 2000, Chennai, India.

12. **Ramanatha Rao V. and B. Sthapit.** 2002. *In situ* conservation - a component of complementary conservation strategy. Pp. 123-135 *in* Asian Network for Sweetpotato Genetic Resources (ANSWER): Workshop on Exploring the Potential of *In Situ* (On-Farm) Conservation of Sweetpotato Genetic Resources in Asia, 2-4 October 2001. Denpasar, Bali. (V. Ramanatha Rao and D. Campilan, eds.). IPGRI and CIP, Serdang Malaysia.

13. **Maxted N., B. Ford-Lloyd and J. G. Hawkes**. 1997. Plant genetic conservation: the in situ approach. Chapman and Hall, London.

14. **Brush S. B.** 1991. A Farmer-based approach to conserving crop germplasm Journal Economic Botany, **45**: 153-165.

15. **Grum M., E. A. Gyasi, C. Osei, Kranjac-Berisavljevic**. 2003. Evaluation of best practices for landrace conservation: farmer evaluation. Unpublished donor report

16. **Adhikari A., R. B. Rana, B. R. Sthapit, A. Subedi, P. K. Shrestha, M. P. Upadhayay, K. P. Baral, D. K. Rijal and S. Gyawali.** 2005. Effectiveness of diversity fair in raising awareness on agrobiodiversity management. *in* On-farm conservation of agricultural biodiversity in Nepal. Vol II Managing diversity and promoting its benefits. Proc of the second national workshop, 25-27 August Nagarkot, Nepal. (B.R. Sthapit, M.P. Upadhyay, P.K. Shrestha and D. Jarvis, eds.).

17. **Joshi K. D., M. Subedi, R. Rana, K. B. Kadayat, B. R. Sthapit.** 1997. Enhancing on-farm varietal diversity through participatory varietal selection: A case study for Chaite rice in Nepal. Experimental Agriculture, **33**: 335-344.

18. **Shrestha P., B. R. Sthapit, A. Subedi, D. Paudel, P. K. Shrestha, M. P. Upadhyay and B. K. Joshi.** 2006. Community Seed Bank: A Good Practice for On-Farm Conservation of Agricultural Biodiversity. Paper presented at the "Incentives for supporting on-farm conservation, and augmentation of agro-biodiversity through farmers' innovations and community participation: An international policy consultation for learning from grassroots initiatives and institutional interventions", May 27-29, 2006 in Indian Institute of Management, Ahmadabad, India

19. **Bellon M., J. L. Pham and M. T. Jackson**. 1997. Genetic conservation: a role for rice farmers. Pp. 263-289 in Plant genetic conservation. Chapman & Hall, London.

20. **Brush S. B.** 2000. Genes in the Field: On-Farm Conservation of Crop Diversity. Lewis Publishers/ IDRC/IPGRI, Boca Raton/Ottawa/Rome.

21. **Biggs S. D**. 1988. Resource poor farmer participation in research: a synthesis of experiences in nine national research systems. On-farm Client Oriented Research Comparative Study Paper No. 3, ISNAR, The Hague.

22. **Friis-Hansen E. and Sthapit B**. 2000. Participatory approaches to the conservation and use of plant genetic resources. IPGRI, Rome.

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

24. **Hijmans R. J.** 2003. The effect of climate change on global potato production. Amer. J. Potato Res., **80**: 271-280.

25. **Hijmans R. J. and Graham C. H.** 2006. The ability of climate envelope models to predict the effect of climate change on species distributions. Glob. Change Biol., **12**: 2272-2281.

26. **Jones P. G. and Thornton P. K.** 2003. The potential impacts of climate change on maize production in Africa and Latin America in 2055. Glob. Environ. Change, **13**: 51-59.

27. **Kotschi J.** 2007. Agricultural Biodiversity is Essential for Adapting to Climate Change. GAIA, **16**: 98–101.

28. **IPCC (Intergovernmental Panel on Climate Change)**. 2001. Climate change: The scientific basis. Cambridge: Cambridge University Press.

29. **IPCC (Intergovernmental Panel on Climate Change).** 2002. Climate change and biodiversity. Technical Paper V. Geneva: IPCC.

30. **CBD**. 2007. Biodiversity and Climate Change. Booklet produced on the occasion of International Day for Biological Diversity.

31. **Jarvis A., Upadhyaya H., Gowda C. L., Aggerwal P. K. and Fujisaka S.** 2008. Climate Change and its effect on conservation and use of plant genetic resources for food and agriculture and associated biodiversity for food security. Thematic study for the SoW Report on PGRFA, FAO, Rome.

32. **Shao G. and Halpin P. N.** 1995. Climatic controls of eastern North American coastal tree and shrub distributions. J Biogeogr 22, 1083-1089.

33. **Walther G. R., Post E., Convey P., Menzel A., Parmesan C., Beebee T. J. C., Jean- Fromentin M., Hoegh-Guldbergand O. and Bairlein F.** 2002. Ecological responses to recent climate change. Nature, **416**: 389-395.

34. **Parmesan, C. and G. Yohe**. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature, 421(6918): 37–42.

35. **Root T. L., J. T. Price, K. R. Hall, S. H. Schneider, C. Rosenzweig and J. A. Pounds.** 2003. Fingerprints of global warming on wild animals and plants. Nature, **421**: 57–60.

36. **Parmesan C.** 2006. Ecological and Evolutionary Responses to Recent Climate Change. Annu. Rev. Ecol. Syst., **37**: 637-669.

37. **Thomas C. D., Cameron A., Green R. E., Bakkenes M., Beaumont L. J., Collingham Y. C., Erasmus B. F. N., Ferreira De Siqeira M., Grainger A., Hannah L., Hughes L., Huntley B., Van Jaarsveld A. S., Midgley G. F., Miles L., Ortega-Huertas M. A., Peterson A. T., Phillips O. L. and Williams S. E.** 2004. Extinction risk from climate change. Nature, **427**: 145-148.

38. **IPCC.** 2007. IPCC Fourth Assessment Report: Climate Change 2007 (AR4). IPCC.

39. **Araújo M. B. and Rahbek C.** 2006. How Does Climate Change Affect Biodiversity? Science, **313**: 1396-1397.

40. **Hijmans R. J. and Graham C. H.** 2006. The ability of climate envelope models to predict the effect of climate change on species distributions. Glob. Change Biol., **12**: 2272-2281.

41. **Howden S. M., J-F. Soussana, F. N. Tubiello, N. Chhetri, M. Dunlop and H. Meinke.** 2007. Climate Change and Food Security Special Feature: Adapting agriculture to climate change. PNAS, **104**: 19691-19696.

42. **Lawler J., Whit D., Nelson R. and Blaustein A. R.** 2006. Predicting climate-induced range shifts: model differences and model reliability. Glob. Chang. Biol., **12**: 1568-1584.

43. **Menendez R., Gonzalez A., Hill J. K., Braschler B., Willis S., Collinghan Y., Fox R., Roy D. and Thomas C. D.** 2006. Species richness changes lag behind climate change. Proc Biol Sci., **273**: 1465-1470.

44. **Midgley G. F., Hughes G. O., Thuiller W. and Rebelo A. G**. 2006. Migration rate limitations on climate change-induced range shifts in Cape Proteaceae. Divers. Distrib., **12**: 555-562.

45. **Jarvis J., Lane and Hijmans R. J.** 2008. The effect of climate change on crop wild relatives. Agriculture, Ecosystems and Environment, **126**: 13-23.

46. **Hannah L., Midgley G., Andelman S., Araújo M., Hughes G., Martinez-Meyer E., Pearson R. and Williams P.** 2007. Protected area needs in a changing climate. Frontiers in Ecology and the Environment, **5**: 131-138.

47. **Williams J. W., Jackson S. T. and Kutzbach J. E.** 2007. Projected distributions of novel and disappearing climates by 2100 AD. PNAS, **104**: 5738-5742.