Role of On-farm/*In situ* Conservation and Underutilized Crops in the Wake of Climate Change[1]

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Abstract

Traditionally farmers use diverse crops, trees and wild plant species, livestock and aquatic species to sustain/enhance their livelihood. The use of diverse species and varieties enhances their adaptability and resilience capacity to changing environmental and economic conditions. Genetic diversity is a key element in farmers' livelihood strategies particularly in areas under high ecological, climatic and economic stresses and risks. Global food security has become increasingly dependent on a limited number of varieties of a few major crops and in the wake of climate change, such a situation makes farmers more vulnerable with regard to their nutrition and income security. This paper aims to discuss the conceptual framework of on-farm/in situ conservation in adapting and mitigating climate change through an integrated system of diversified food production and land use. The role of on-farm/in situ conservation of crops is discussed along with its complementary advantages over ex situ conservation. Empowerment of farming communities is essential for effective *in situ*/on-farm conservation as the process encourages local level decision making on management of genetic resources. The paper also highlights community-based biodiversity management as a methodology to realize in situ/on-farm conservation through strengthening farmer seed systems, and promoting climate resilient integrated home garden production systems, especially underutilized crop species and carbon rich farming that support climate change actions. Implementation of biodiversity management approaches will require conducive policy environment in order to be truly effective and sustainable. Some relevant recommendations on how to best proceed towards a viable *in situ/*on - farm conservation system are also proposed.

Key words: *In situ* conservation, on-farm conservation, agrobiodiversity, underutilized crops, climate change, farmers' seed system, community based biodiversity management, integrated farming system.

Introduction

The Convention on Biological Diversity (CBD) within its broader framework defines two conservation strategies: *ex situ* conservation and *in situ* conservation. UNEP (1992) defined *in situ* conservation as "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 and cultivated species, in the surroundings where they have developed their distinctive properties". These definitions and related strategies applied to the field of agricultural biodiversity require their blending with the use dimension in order to be translated into practices

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and realize the effective linking of conservation with farmers' livelihoods. *In situ/*on farm conservation (often just referred to as 'on farm conservation') refers to the maintenance of cultivated plants (often in association with their wild relatives that may be present in the same field) which are conserved in the very place where they developed their present-day characteristics (Altieri and Merrick, 1987; Brush, 1995; Jarvis and Hodgkin, 2000) and where they continue to evolve thanks to the work of farmers (Frankel *et al.*, 1995). On-farm conservation is thus a highly dynamic form of plant genetic resources (PGR) management, which allows the processes of both natural and human selection to continue to act in the production system. On-farm conservation is therefore generally used to describe the dynamic management process by which farmers maintain traditional crop varieties that were developed in their local conditions and that they continue to modify thanks to their management practices and crop selection efforts. Thus, the conservation of specific genotypes becomes a secondary objective to the continuation of the processes that allow the material to evolve and change over time (Jarvis and Hodgkin, 2000).

The potential threat that the loss of genetic diversity poses to the world's food fuelled the so called PGR conservation movement which started in the early 1970s with the establishment of IBPGR (now Bioversity International) and which has led insofar to the creation of 1740 *ex situ* storage collections (called also gene banks) around the world (Pistorius 1997, Fowler and Hodgkin 2004, Bioversity 2009; FAO 2010). While this form of conservation remains no doubt practical and useful, especially for immediate use in plant breeding, it has major drawbacks in terms of effectiveness with regard to the use of stored material (not easily accessible by farmers). Serious concerns are also arising from the fact that they freeze the natural evolutionary process and in so doing limit the adaptive capacities of genetic resources to climate change. Furthermore, *ex situ* collections are more vulnerable to mismanagement (e.g. cases of genetic shifts, genetic drifts during rejuvenation activities or the spread of seed-borne pathogens due to poor plant quarantine practices). But *ex situ* conservation is also an expensive endeavor whether we are dealing with seed (orthodox seed crops) in cold stores or with vegetative material (field genebanks necessary for crops with recalcitrant seeds and clonally propagated species). With regard to on farm conservation, apart from allowing evolution to continue, this method contributes as well to the conservation of diversity at all levels (landscape, ecosystem, among and within species) and it is therefore highly strategic. It does also contribute to empower the farmers to better exercise control over their crop genetic resources, major biological and livelihood assets. Another major advantage of on farm conservation is related to its conduciveness in safeguarding the traditional knowledge associated to biodiversity which is an integral part of peoples' social and cultural identity (CUBIC,2000), and which is fundamental for celebrating and appreciating crop diversity today and in the future. Lastly, on farm conservation is a powerful instrument to allow the implementation of benefit sharing as recommended by the CBD which has in fact recognized the continued maintenance of traditional varieties on-farm as an essential component of sustainable agricultural development (UNEP 1992).

Challenges

Since the time that the Convention on Biological Diversity provided a general framework for *ex situ* and *in situ* conservation strategies, most agencies dealing with plant genetic resources conservation have been facing the dilemma of how to implement in practical terms *in situ* conservation of agricultural biodiversity. The major challenges faced to achieve this end are centered around the following:

i) lack of a clear understanding of the scientific basis of *in situ* conservation of agricultural biodiversity and how it can be practically implemented on the ground,
ii) difficulty in changing the mindset of current PGR institutional set up to work closer with farmers and communities,
iii) rationale of identifying the least cost conservation areas
iv) difficulties in identifying sustainable incentive mechanisms to support on farm conservation and
v) obstacles when trying to canvass policy support to empower the communities in diversity rich areas for community based management of agricultural biodiversity.

What makes these challenges particularly complex is the fact that they are highly interlinked and dependent upon a mix of socio-cultural, economic and political factors, making on- farm conservation not a purely technical intervention (as is the case in *ex situ* conservation) but a much more complex social and collective-action type of endeavour.

Central to these issues, is the recognition that if crop genetic resources (including landraces) are to be conserved successfully and sustainably on-farm, such an outcome should be the result of farmers' production activities directed to improve his/her livelihood ("*conservation through use"*). This means that on-farm conservation efforts must be carried out within the framework of farmers' livelihood needs, and for that reasons, the mobilization of support to on farm conservation need to be conceived and designed within the broader objective of creating a more enabling environment for agricultural development in its various aspects. So far, rich local crop diversity is maintained in those regions where the private value of local landraces and public value of genetic diversity are high (Smale *et al*., 2004). Given the current globalization trends and market environments, it would be difficult to maintain valuable local crop genetic resources unless these are made economically attractive and competitive in the market through consistent interventions along the value chain from the selection of improved varieties, to enhanced cultivation practices, value addition and marketing as well as socio-cultural, educational and public awareness efforts.

One of the often-cited disadvantages of on-farm conservation is the difficulty experienced by plant breeders in accessing material that is maintained by farmers. This is mainly because the on-farm conservation efforts to date have not been mainstreamed or linked to national PGR efforts. Although *ex situ* and *in situ*/on- farm conservation methods are highly complementary measures, their interdependency has only very rarely been put into practice. Depending upon the available resources and government commitment, selection of on-farm conservation sites should consider two broad guidelines: a) identification of the least cost conservation site, and b) potentiality of "win-win" situation in terms of livelihood gains and ecological costs for the site. The least cost on-farm conservation will occur in those sites that are most highly ranked in terms of public benefits (richness and evenness of genetic diversity) and where the private benefit that farmers obtain from growing genetically diverse varieties is the greatest. The economic concept that farmers' varieties embodies both (i) 'private' values in the harvest the farmer enjoys, either directly as food or feed, or indirectly through the cash obtained by selling the seed/grain and purchasing other items, and (ii) 'public' values in its contribution to the genetic diversity from which future generations of farmers and consumers will also benefit (Smale *et al.*, 2004). The crop genetic resources which have both low farmer utility (current private value) and public value will be difficult to conserve on-farm unless public interventions are made for adding benefits.

Those crop genetic resources important zones (CGR-IZs) which have both high private value (direct use) and high public value (rich genetic diversity of CGR) are considered potential sites for on-farm conservation of agricultural biodiversity. Since there is a trade-off between livelihood gains and ecological costs, on-farm conservation programmes should aim to achieve "win-win" situation by balancing livelihood gains with conservation costs (Umashaankar *et al.*, 2004). This requires community based approaches that empower farmers and rural institutions in better appreciating the value of on-farm conservation, take greatest advantage of genetic resources maintained on- farm and play a leading role in decision making in the management of this biodiversity at the local level. The actions such as public awareness, education, participatory plant breeding, value addition of local products and policy support through local institutions are very important for realizing on-farm conservation in a sustainable manner. Two options can be considered in providing benefits; the first through participatory plant breeding, and the second through public awareness, better marketing, and policy incentives (Gauchan *et al.*, 2003). The first option is to seek improved quality, disease resistance, high yield, better taste, and other preferred traits through breeding, seed networks and modified farming systems. The second option includes adding value to local crop genetic resources so that the demand for the material or some derived products may be increased. These diverse options will emerge when the communities, researchers, and developmental institutions are directly involved in the management of traditional knowledge and genetic resources for biodiversity-based livelihood and income generation. This is only possible if the local capacity of farming communities and institutions are strengthened for making appropriate decisions and for being able to take up effectively also important tasks including the documentation and monitoring of local crop diversity (Sthapit *et al.*, 2008).

To date, the organizations engaged in the promotion of conservation of plant genetic resources for food and agriculture (PGRFA) are facing the dilemma of how to strengthen capacity of communities and rural institutions for best implementing *in situ* conservation on-farm. Since the farmers and their social networks play a key role in maintaining dynamic process of evolution, selection and adaptation of useful diversity in the changing climate, it is important to understand that on-farm conservation is a constantly changing complex system of relations between people, plants, animals, other organisms and the environment, continuously challenged by new problems. In such a condition, the broader is the diversity employed on- farm, the more resilient will be the production system (Jarvis *et al.,* 2007). And this statement is particularly meaningful within a climate changing context. To that respect, therefore, the deployment of *in situ/*on- farm sustainable conservation and use of neglected and underutilized species (NUS) represent a very strategic component of community-based adaptation strategies (Padulosi *et al.* 2009). Functional partnerships between multi-sectoral institutions and community based organizations will be then fundamental to pursue such a strategy (Rojas *et al.* 2009).

In response to these challenges, Bioversity International (formerly known as International Plant Genetic Resources Institute (IPGRI) and its national partners launched an international research effort, ‘Strengthening the scientific basis of on-farm conservation of agricultural biodiversity on-farm’ in eight countries in 1995 to understand four basic questions (Jarvis *et al.*, 2004, 2007):

- What is the amount and distribution of the genetic diversity maintained by farmers over space and time?
- What are the processes/methods used, consciously or unconsciously, to maintain the genetic diversity on-farm?
- Who maintains genetic diversity within a community and how?
- What factors influence farmers’ decisions on maintaining traditional varieties?

Understanding the above mentioned questions provides the scientific knowledge needed not only to manage crop genetic resources on-farm, but also to develop options for better livelihoods and income that provide incentive for conservation efforts.

Impact of climate change in agriculture and livelihoods

The Fourth Assessment (AR4) of the Intergovernmental Panel on Climate Change (IPCC) provides an overview of recent scientific understanding on climate change (IPCC, 2007). Climate models are only predictable means to predict global future climate. Although 21 global climate models (GCM) give different scenarios based upon atmospheric science, chemistry, physics, biology and astrology. In general, as per the IPCC predictions, the global temperatures are likely to increase by 1.1 - 6.4ºC from 1990 to 2100 though the speed at which the temperature will rise is still debated (IPCC, 2001; 2002). The water availability in humid tropics and high latitude areas will increase due to 20-30% increase predicted in annual precipitation whereas in sub-tropical regions, the water availability will decrease as the region will receive less rain and/or untimely rains and therefore will be subjected to more frequent droughts. Sea levels are likely to rise in the range of 22-34 cm between 1990 and 2080s, thereby affecting lives of communities in coastal countries. The IPCC also predicted that Hindu Kush Himalayan climate will undergo an increase of 5-6ºC in atmospheric temperature as well as 20-30 % increase in precipitation. This coupled with glacial retreat and loss of snow cover on mountains will lead to unpredictability of seasons and monsoons in South Asia. Suitability for grain production will decrease more rapidly in regions with sandy soils than in regions with clay or medium soils, as the temperature increases (Zullo Junior *et al.*, 2006). Furthermore, there is likelihood of higher frequency of extreme events such as cyclones, typhoons and hurricanes, floods and landslides, prolonged drought, etc.

Although there are lots of debates and disagreements in these predictions, the scientific community agree on the following common understanding: 1) climate change is already happening and will happen in future, 2) some regions will get hotter, some places dryer and others wetter, 3) there will be more variability and therefore, great uncertainties in agriculture, 4) the suitability of species/genotypes changes in both positive and negative directions, and finally 5) lack of knowledge on what will happen in some regions due to lack of data and information (Jarvis *et al.*, 2008ab).

In spite of what has been published in the abundant recent literature on this topic, the implications of climate change in agriculture are still a bit vague as these are based upon modeling and predictions. Lobell *et al.* (2008) carried out an analysis of climate risks for crops in

12 food insecure regions to identify adaptation priorities, based upon statistical crop models and climate projections for 2030 from 20 GCM models. The results indicated that South Asia and Southern Africa are the two regions that, without sufficient adaptation measures, are likely to suffer with negative impacts on several crops that are important to large food insecure human populations. Using the A2 scenario of the IPCC's NCAR and CSIRO models, International Food Policy Research Institute (IFPRI) studied the impact of climate change in agriculture in the time frame of 2000 - 2050. The report also suggests that South Asia will be particularly hard hit by climate change as the crop productivity of almost all crops is predicted to face the greatest decline in that region (IPCC, 2007). Higher temperatures eventually reduce yields of desirable crops while encouraging weed and pest proliferation. Although there will be gains in some crops in some regions of the world, particularly in developed countries in the North, the overall impacts of climate change on agriculture are expected to be negative, thereby threatening the global food security.

There is established evidence that climate change is already affecting biodiversity and will continue to do so. The Millennium Ecosystem Assessment (2005) report estimated that by the end of this century, the climate change will be the driver of biodiversity loss. IPCC reports predicted that many species will be extinct from the ecosystems which will have profound impact on ecosystem functioning and services (i.e. provisioning, regulating, supporting and cultural) because of increase in global average temperature. There will also be an adverse effect on the species component of biodiversity (Rao, 2009) which include: i) changes in distribution pattern (Jarvis *et al*., 2008), ii) increased extinction rates, iii) changes in reproduction timings, iv) changes in length of growing seasons for plants, v) changes in plant community composition, and vi) changes in ecosystems. These factors will result in significant changes in farming practices and genetic resources that are currently being used. Coping with these new realities will involve the use of agricultural biodiversity in innovative ways to provide adaptability and resilience in the face of changing and variable environments.

Role of *in situ* conservation on-farm in the context of climate change

In the debate on climate change and agriculture, the role of *in situ* conservation and on-farm management of agricultural biodiversity is seldom discussed with the attention it deserves. The various climate change predictions made it clear that many regions around the globe are going to witness the change in various ways. In such a situation, it is important to consider whether such changes will affect on-farm management of cultivated landraces and their wild relatives. Jarvis *et al*.(2008ab) 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 hypogea*), potato (*Solanum tuberosum*) and cowpea (*Vigna unguiculata*). They reported that wild groundnuts were the most affected group, with 24 -31 (depending on the migration scenario) of 51 species projected to go extinct and their distribution area, on an average, expected to be reduced by 85-94 %, depending on the migration scenario, over the next 50 years. In terms of species extinction, cowpea appeared to be the least affected by the climate projections on these three crops studied, although, according to other studies almost half of the natural distribution area of wild *Vigna* species (that is, not just wild *Vigna unguiculata*) is also expected to be lost by the middle of this century due to climate change (Anonymous 2007). These results suggest that there is an urgent need to identify and effectively conserve crop wild relatives that are at risk due to climate change. On the other hand, there are many reports indicating that the new strains of pathogens and pests (e.g. Ug99 strain of stem rust in wheat; bacterial fire blight in apples; new strain rice blast, etc.) are emerging which need landraces and wild relatives as sources of resistance genes (Qualset and Shands, 2005). Due to climate change, it is difficult to predict which new pest or pathogen will develop or how will be the rainfall next year, but agricultural biodiversity can be used - as always farmers do-to have a set of crop varieties in farming systems to increase the options to buffer against unpredictable changes (Holger *et al.*, 2004). This requires access to a wide range of portfolio of local crop diversity at the hand of community for countering these threats. This explains why on-farm conservation can play critical role in future as well to solve emerging problems.

Genetic diversity which is currently underutilized may become more attractive to farmers as a result of climate change. Many neglected and underutilized species which are currently maintained through *in situ* conservation on-farm could be the important crops for the future. Their adaptability, plasticity and resilience to stresses provide farmers with needed coping strategies to confront with climate changes. Because of changes in shift in rainfall pattern and temperature deviations from normal, community based management of a wide portfolio of plant and animal genetic diversity is required to allow adaptive capacity. The suitability of current crop genotypes to local conditions will change in both positive and negative ways, depending upon the crop and region, but will affect many production systems. The processes of *in situ*/on-farm management of agricultural biodiversity carried out by millions of farmers in the world have developed a range of genetic diversity that helps to diversifying incomes and livelihoods of people in such changing situations. On-farm management of genetic diversity has traditionally allowed farmers to cope with adversity and this process will continue to serve that function in future too.

Climate variability and risk has always been a part of agriculture, and farmers have developed many ways of managing that risk. From farmers perspective, climate change is not seen in terms of major disasters such as floods or drought or hurricanes, but rather as increased uncertainty such as shift in onset of rain at planting time or end of rain at harvesting time; some years bring excessive rainfall while others are very dry, with a greater irregularity within and between two annual rainy seasons. Such uncertain weather is directly affecting crop production and income of farmers. It is difficult to assume that current research system has capacity to develop a set of technologies and suitable varieties that match the needs of changing climate scenario.

The maintenance and use of a wide diversity of crops, trees and livestock are the livelihoods and survival strategies of rural farming communities throughout the world but the speed of climate change is reported to be much higher than that required for landraces to evolve and adapt for changing climatic environments. Hence, the plasticity of genetic resources will remain important for such situations. Pigliucci (2001) defines phenotypic plasticity as a "property of a genotype to produce different phenotypes" as a response to different environments. There is already a lot of debate in the scientific community (Scheiner, 1993; Via, 1993; Via *et al.*, 1995; Pigliucci, 1996, 1998) about whether phenotypic plasticity (phenotypic variation due to environment) is an evolving trait, which can be adaptive, neutral or maladaptive (Alpert and Simms, 2002), or a by-product variation due to other plant responses. Regardless of the debate, it can be agreed that phenotypic plasticity can be a useful paradigm or framework to understand the interactions of genetics, development, ecology and evolution (DeWitt and Scheiner, 2004).

In order to understand the role of *in situ*/on-farm conservation of agricultural biodiversity in the wake of climate change, it is also important to understand how communities have been using diverse types of plants and animals in integrated production systems to adapt and cope with climate change effects. There are two ways: first, seed selection by farmers over seasons exerts selection pressure on populations of genotypes through the criteria used by the farmers to select the seeds and through the environment (Harlan, 1992). Second, new genetic diversity is introduced into the farmer's seed system through the introduction of new varieties or new selection and introgression of genes from hybridization with wild species or varieties. New varieties enter the farmer seed system through social seed network and exchange of seeds with other farmers, seed from local markets or from the project or commercial enterprises (Sthapit and Rao, 2009; Almekinders & Louwaars, 2002). This system is very dynamic and integrated to cope with all kinds of pressures. The common strategies used by farmers and communities to manage vulnerability caused by climate change are listed in following points:

- Maximize the use of NUS as genetic resource base (buffer) for managing adversity and to cope up with changing climate scenario
- Capitalize/ maximize the use of diversity-ecosystems', and species diversity integrated farming system (home gardens, livestock, aquaculture, perennials, bee keeping etc)
- Maintain intra-specific diversity to cope with environmental and economic adversity (e.g. maintain richness in staple crops to cope with vulnerability)
- Adopt farmer-to-farmer seed/planting materials exchange system (informal seed system) as a social seed networks to ensure local level community based adaptation strategies and enhance access to locally adapted genetic resources for unpredictable climatic situations
- Farmer selection from available or introduced or introgressed diversity to adapt local situation

Neglected and underutilized species as a buffer for climate change

Another interesting traditional practice is that indigenous farming communities in the most vulnerable areas such as Sub-Sahara Sahelian regions, Andean mountains, Himalayan high mountain ecosystem, maintain portfolios of species of neglected and underutilized species, animal breeds and farm trees as risk aversion or adversity management practices. Mixed farming and mixed cropping are common practices to address such uncertainties. In home gardens of East Java, a portfolio of emergency root crops (e.g. *Amorphophallus campanulatus*, *Colocacia* spp, *Dioscorea* spp, *Manihot* spp. etc.) is found to buffer food supply chain during climatic adversity. Many such examples were also reported in Chepang indigenous community of Nepal (Sthapit *et al.*, 2008; Aryal *et al.* 2009). Although policy makers and the media highlight the impact of extreme events such as hurricane, floods and drought, the farmers are worried from rainfall and temperature patterns moving outside the regular variability ranges. The impact of such local variation and uncertainty is the low farm productivity and income of farmers and there are not immediate technological solutions available to farmers as the speed of these changes is difficult to be controlled with the current research and development system.

Despite the general notion that NUS are neglected for specific socioeconomic reasons, the role of these species traditionally used by indigenous farming communities, becomes extremely important to reduce risks and adapt to adversities caused by climate changes. The neglected and underutilized crop genetic resources are very vital for sustainable agriculture (Eyzaguirre *et al.*

1999; Bhag Mal, 2007). Traditionally, these species contribute significantly to the well being and livelihoods of the rural households. Many of these species are well adapted to stress conditions of extreme environments and hence form part of the sustenance farming systems. Many underutilized species occupy important niches, adapted to risky and fragile conditions of rural communities and have a comparative advantage in marginal lands as they can withstand stress. They also contribute to the diversity and stability of agro-ecosystems and are potential crops for the diversification of agriculture. These species often play a strategic role in fragile ecosystems such as those of arid and semi-arid lands, mountains, steppes and tropical forests. Most of the these crops do not require high inputs and can be successfully grown in marginal, degraded and wastelands with minimal inputs and at the same time can contribute to increased agricultural production, enhanced crop diversification and improved environment and have the potential to contribute useful genes to breed better varieties capable of withstanding and sustain the climate change scenario (Bhag Mal and Joshi, 1991; Bhag Mal, 1993, 1994, 2007, Padulosi *et al.* 2009).

The genetic resources of many of these important species are being lost through rapid destruction of natural habitats especially in the tropics. The State of the World Report II on PGRFA (FAO 2009) depicted a very worrying situation with regard to conservation and use of agricultural biodiversity and highlighted that very limited efforts are on record to curb the genetic and cultural erosion taking place on-farm and severely affecting the sustenance of local crops and varieties. Furthermore, the international policy instruments such as the Global Crop Diversity Trust are currently focusing on crops of Annex. 1 of the International Treaty on Plant Genetic resources, thus excluding *de facto* a large number of other important species including potential underutilized crops from being properly safeguarded, conserved and promoted for effective use. Hence, more and concerted efforts are needed to support *in situ*/on-farm conservation and sustainable use of neglected and underutilized species.

An integrated faming system to climate change adaptation

It is a fact that agricultural biodiversity is an important part of the climate change management strategies being developed by indigenous people and rural communities but is not adequately recognized and the knowledge of how, when and what agricultural biodiversity has been used to cope with climate change is scattered and not well documented. Most rural areas have always experienced climate variability, and farmers have always had to cope with a degree of uncertainty in relation to the local weather. They maximize the wide range of ecosystem available in the landscape they live, their production systems are integrated with crops, animals, fisheries, perennial fruits and trees around homestead or at the vicinity to rivers, lakes and forests and maintain portfolios of varieties of staple crops for managing adversity. There is interdependence within the system which is designed to spread risk and vulnerability to stochastic events. In the past, the production system with greater diversity, or which was successfully integrated with livestock or orchard, was often less vulnerable to sudden changes, and showed higher levels of resilience. Farming systems with perennial fruit trees for example, coconut, mango, mangosteen, durian, jackfruit, etc. not only provide options for household food supply but also constantly maintain and develop their root and biomass and associated carbon (Scherr and Sthapit, 2009) while providing vegetative cover for soils whereas livestock provide cash to meet emergency needs. Livestock was never really mentioned in the climate change debate until 2007, when FAO reported that livestock produces 14.5% of all greenhouse gases. If the livestock are effectively integrated into ecological farming by small holder farmers, they have potential to mitigate some of the adverse effects of climate change and also offer options for coping strategies to farmers.

Similar to carbon credits, agrobiodiversity conservation credits (ACC) could be awarded to farmers who nurture wild and cultivated agrobiodiversity in their fields, who adopt agrobiodiversity or carbon friendly farming practices, such as no-tillage, using higher residue cover crops and rotations, decrease the use of fossil based fertilizer or pesticides, convert marginal crop land to trees or grass residue management, high-biomass crop rotation and cover crops or integrated home garden system, perennial grasses for pastures, rotational grazing, etc. In order to meet the restrictions on greenhouse gas emissions, industries need to buy "carbon credits," essentially paying another for storing carbon to offset the excess it is releasing to the air. This requires strong policy support to implement such incentives.

Similar to the concept of reducing emissions from deforestation (REDD) and Avoided Deforestation (AD) for developing countries, agrobiodiversity conservation could potentially seek to be compensated through agrobiodiversity conservation credits (ACC) for saving genetic diversity for current and future food security and for providing valuable ecosystem services. Potentially, it can be used both as an adaptation and mitigation tool that will earn back money for the people who nurture and care for it.

Agrobiodiversity conservation credits might be just the answer to addressing pressing conservation challenges faced by farmers and scientists alike. The concept of agrobiodiversity conservation credits (ACC) has to demonstrate the full costs and benefits of the maintenance and use of agrobiodiversity in agricultural landscapes to the different stakeholders involved. This valuation must go beyond the present and future financial benefits of the marketable products of biological resources to include those of the ecosystem services that they provide. These credits could be traded or paid for maintenance.

Farmer seed system

The traditional knowledge/practices and local genetic resources play a key role in farmers and community's capacity to adapt to climate change. Farmers' ability to cope with impact of climate change will be strengthened if the research and development institutions can build upon the traditional knowledge and practices of farmer seed and germplasm management systems. This requires strengthening their social seed networks and policy supports that promote farmer-to-farmer seed exchange system. Traditional or social or informal seed systems are maintained through the interactions of economic, social and cultural institutions that ensure availability of planting materials. Individual farmers search, select and keep their own locally adapted seeds and breeding stocks but practice social forms of exchange, including gifts, barter and sales that deploy agricultural biodiversity across landscapes and communities. In the context of climate variability and risk of crop failure in a local condition, communities with strong social seed networks are better equipped to cope with the effect of climate change compared to communities with weak and disturbed social seed networks (Subedi *et al.,* 2003; Paudel *et al.,* 2008). In many traditionally managed agro-ecosystems, local populations of domesticated crops maintain a high level of genetic diversity by the function of migration and re-colonization (sink-source) of meta-populations (van Dusen, 2003, Hastings and Harrison, 1994). It was observed that local varieties suffered from climate variability can re-colonize their populations (in terms of area and number of growers) by simple way of seed/planting materials flow that takes place from farmer to farmer networks. Commercially and centrally planned seed companies and government institutions have difficulty to predict climatic unpredictability and plan for seed provision that needed for diverse types of small farmers. In fact, on-farm conservation/management of wide range of crops, trees and animals play key role to buffer such situation and provide access to locally adaptive materials and sustain livelihoods. Farmer seed system allows the dynamic change that characterized crop landrace systems-open, decentralized genetic systems that are constantly evolving to fit farmers' needs and environmental changes-could help in coping with the uncertainty generated by climate change in agriculture (Bellon, 2010).

Strengthening farmers' capacity through R&D to cope with climate change

In order to strengthen the capacity of farmers, it is essential to consolidate the roles of farmers as conservers, promoters of diversity and dynamic innovators by enabling policy environment for on-farm management, farmer innovation and strengthening farmers' seed systems coupled with scientific capacity building of these communities. The community biodiversity management (CBM) approach integrates knowledge and practices with social systems; local rules of institutions drive it (Sthapit *et al.*, 2006; Sthapit *et al.*, 2008ab). This approach can be realized by empowering communities and their institutions from the outset, building upon an analysis of sustainable livelihood assets for reducing poverty and social injustice. The key element is to institutionalize local level decision-making. As an integrated conservation and development approach, CBM reinforces the capacity of farming or user communities and their institutions. The focus is on increasing decision-making power and securing community access to and control over the resources required for community biodiversity management. The key elements of CBM include: (i) knowledge about biodiversity and associated landscapes, (ii) social systems facilitating maintenance and exchange of their genetic resources, (iii) local institutions that support and govern local management and access to biodiversity, (iv) technologies, processes and practices that add value to local genetic resources, (v) local financial resources such as group savings and credits to ensure continuity, and (vi) necessary linkages to appropriate institutions which will sustain the access to livelihood assets.

CBM is a process-led approach and builds on farming/user communities' existing capacities and committed policy support. Empowerment of farmer communities is a precondition for effective *in situ* conservation of PGRFA. The experiences under Bioversity's global on-farm project amply demonstrated that community based biodiversity management facilitates the process of community empowerment and local decision making for collective action and therefore, the process that supports farmers decision making in management of genetic diversity is considered as a proxy methodology to realize *in situ/*on-farm conservation of PGRFA and this can be achieved by consolidating the role and capacity of farmers and their rural institutions. This approach is not easy for those people who work in genebank as they are used to control all decisions as per the need of *ex situ* system. In contrast, this mindset has to be changed in case of implementing on-farm work and many researchers find this challenging for current PGR conservation organizations as the institutions have to develop new kind of partnership with key and legitimate actors of on-farm management. PGR institutions that worked with community based organizations had been able to do this effectively by defining clear roles and responsibilities of different actors. During CBM process, all actors can find their respective role to cultivate partnership in research and development.

CBM is a methodology comprised of a number of steps and a set of practices that suit to the particular context (Sthapit *et al*., 2006). These include: i) enhancing community awareness, ii) understanding local biodiversity, social networks and institutions, iii) capacity building of community institutions, iv) setting up of institutional working modalities, v) consolidating community roles in planning and implementation, vi) establishing a CBM Trust Fund (payment system for community conservation efforts), vii) community monitoring and evaluation, and viii) social learning and scaling up for community collective action

This process allows farmers to gain scientific insights of knowledge related to climate change scenarios, access to new varieties and technologies and blend or integrate into their own traditional knowledge and farming system to cope with new problems and always finding new ways to deal with them. This allows the communities to be prepared against unpredictable nature of climate and socioeconomic environments.

Conclusion

Climate change represents a major threat to agrobiodiversity. However, agricultural biodiversity should be a key component of climate change adaptation strategies. One of the ways in which climate change negatively affects agriculture is to change the growing conditions and thus making the current practices and varieties ill-suited in the changed context.

Farmers may not have the capacity and facility to predict climatic variability before crop seasons or which new pest or pathogen will develop or how the rain will fall during the crop season. However, they can and do use a set of crop varieties in agricultural production systems to increase options to buffer against an unpredictable change. In this context, agricultural biodiversity has the potential to provide immediate cropping alternatives as well as genetic materials for the further development of stress tolerant varieties. The role of NUS as a buffer for climate change should be further strengthened and promoted. Crop diversification integrated with livestock/fisheries/forestry in a landscape for carbon rich farming and to cope with livelihood vulnerability needs to be also adequately supported.

Strengthening farmer seed systems of ranges of neglected crop species and other associated biodiversity promote open, dynamic and integrated genetic system to cope with climate change at the local level through: i) Community based conservation actions (e.g. seed fairs, diversity kits, community based register (CBR), community seed banks, community based seed production schemes) to improve access of materials and knowledge and their exchange, and ii) grassroots breeding, participatory variety selection and participatory plant breeding to develop farmer’s skill and capacity in selection in the changing context. This is only possible if farmer’s role as conserver and promoter of diversity and dynamic innovator is consolidated by strengthening farmer’s seed system and agronomic practices and compensated/rewarded for the services of conservation.

Farmer’s ability to search for new adaptive diversity, selection of new traits and exchange of selected materials with friends and relatives are key adaptive strategies for climatic adversity. While the international community is responding to climate change threat by lending increased support to *ex situ* conservation, very little is done to support evolutionary breeding process i.e. on-farm /*in situ* conservation where the largest amount of the world's local crop diversity is maintained for immediate use. Therefore, it is extremely important to understand the (very poorly known) situation regarding the *in situ*/on farm conservation of agrobiodiversity (including NUS), mapping out species distribution and their threats, documenting who maintains/ exchanges both diversity and associated traditional knowledge and how these materials and knowledge flows from farmer-to-farmer. All these data will be essential to guide local institutions and governments to develop suitable strategies for monitoring the impact of climate change over time and act in time to reduce negative impact on agrobiodiversity and livelihood of the people depending on it. It is therefore of utmost importance that greater research thrust is given on:

- Strengthening capacity of the community to maximize use of genetic diversity to adapt to climate change
- Integrating diverse crops, trees, livestock and aquatic species (including NUS) to enhance adaptability and resilience capacity to changing environmental conditions
- Establish monitoring and early warning systems for NUS in the context of greater interventions in support of in situ/on- farm conservation of local biodiversity (including the introduction of 'Red Lists' for cultivated crops);
- Promote greater access and exchange of diversity of underutilized (including expansion of Annex I list of the Treaty on PGRFA) as a critical element in support of crop diversification strategies.

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