THEMATIC BACKGROUND STUDY

Managing Plant Genetic Resources in the Agro-ecosystem: Global Change, Crop-associated Biodiversity and Ecosystem Services

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EXECUTIVE SUMMARY

Many factors impact on plant genetic resources for food and agriculture and crop and crop-associated biodiversity (PGRFA-CCAB). Today, these include globalization, climate change, desertification, loss of biodiversity, food security, food prices, transboundary movement of pests and diseases, energy use and biofuel, land-use change, poverty and the economic imbalance between developing and industrialized countries.

The global challenges facing conservation of PGRFA-CCAB services is discussed in section 2. In responding to the challenges posed to agriculture by global change, one way forward could be to review existing options and strategies based on recent guidance and recommendations adopted in international forums. These include the principles of an ecosystems approach, integrated natural resource management and *in situ* conservation/management strategies.

The contribution of PGRFA-CCAB to ecosystem goods and services is discussed in section 3. The essential characteristic of PGRFA-CCAB to be conserved in the long term is diversity, which is an essential quality of the four types of value that can be delivered by ecosystem services, i.e. ***utilitarian, functional, intrinsic*** and ***serependic***. Managing these values and services provided by PGRFA-CCAB requires special attention because these resources provide the food we eat and essential livelihoods for subsistence farmers. This is discussed in section 4.

The management of PGRFA-CCAB goods and services in the agro-ecosystem is discussed in section 5. This highlights the challenge of applying an ecosystem approach to the conservation of both planned and associated biodiversity. The section also discusses differences in management of biodiversity at various spatial scales, from the field to the landscape, and over differing time scales. Recognition of these differences is important in developing programmes and strategies, including the identification of priorities and levels of funding.

The final section summarizes the issues laid out in previous sections and provides recommendations on agricultural practices and approaches to valuing ecosystem goods and services and providing incentives for their conservation. Recommendations focus on issues such as the need to integrate efforts and coordinate actions among technical fields of knowledge dealing with agriculture; and the need for incentives/options and opportunities for compensating farmers for their services in managing PGRFA-CCAB services. The discussion of the international process examines the possibility of addressing the issue of conserving PGRFA-CCAB goods and services at the global level. It is suggested that this might best be achieved through an intergovernmental process to update the existing technical and policy guidance and recommendations for eventual use at global, regional, national and local levels. It is argued that this initial intergovernmental process could be included in the revision of the rolling Global Plan of Action on PGRFA if the FAO Commission on Genetic Resources for Food and Agriculture (CGRFA) so decides.

1. INTRODUCTION

This study explores ecosystem goods and services provided by plant genetic resources for food and agriculture and crop and crop-associated biodiversity (PGRFA-CCAB), deployment of plant genetic resources in production and their interactions with crop and crop-associated biodiversity (e.g. pest and disease organisms and pollinators), with the objective of identifying ways to optimize the goods and services they provide. This is done within the context of current global changes and challenges facing agriculture. Section 2 gives an overview of the main issues associated with global change and presents some of the causes. Section 3 describes the role of PGRFA-CCAB in the ecosystem, focusing on the ecosystem services they provide. Section 4 analyses why managing PGRFA-CCAB needs special attention, while Section 5 illustrates how such management can be achieved. Finally, Section 6 summarizes the findings, with an analysis of the issues and available options, identifying challenges and providing recommendations.

2. GLOBAL CHANGE AND CHALLENGES

Many factors impact on PGRFA-CCAB. Today, these include globalization, climate change, desertification, loss of biodiversity, food security, food prices, voluntary and involuntary migration, transboundary movement of pests and diseases, energy use and biofuel, land-use change, poverty and the economic imbalance between developing and industrialized countries. Here we focus on climate change and food security.

Climate change, desertification and loss of biodiversity have attracted significant local, national and international attention over the past two decades. These three factors are the subject of several Multilateral Environmental Agreements (MEAs), such as the United Nations Framework Convention on Climate Change (UNFCCC), the United Nations Convention to Combat Desertification (UNCCD), and the Convention on Biological Diversity (CBD). These address some of the negative impacts of human activities, including:

- Over-cultivation of marginal land, combined with rural poverty;
- Environmental and developmental problems in the application of intensive agricultural practices;
- Environmental degradation through depletion of non-renewable resources.
- Policies and socio-economic obstacles that may affect the management of the environment, directly or indirectly, including:
  - lack of participation of local communities when developing large-scale, centrally planned plans, programmes and/or projects;
  - inappropriate rural development policies that harm the environment and society;
  - disregard for the environment in intensive agriculture; and
  - overuse of fertilizer and long-lived substances, including pesticides, causing environmental degradation.

It is likely that the only solution to the environmental and poverty challenges facing food security will be to address these issues through a combination of the MEAs, efforts to achieve the Millennium Development Goals (MDGs) (top-down approach) and bottom-up approaches involving action at the local and community levels.

2.1 Food security

The World Bank (2007) estimated that it will be necessary to produce nearly 50% more cereal and about 80% more meat in 2030 compared with 2000 production levels. Thus, the world is facing a major challenge to meet the food requirements of a growing population at a time when other factors, including climate change and land shortages, are constraining agricultural production.

Food price also has a marked effect on food security. Starting in 2005, prices rose abruptly after more than 50 years of declining prices. FAO identified several factors that contributed to this:

- low levels of world stocks (especially wheat and maize) following two years of below-average harvests in Europe and crop failures in major producing countries such as Australia, in 2006 and 2007;
- rapidly growing demand for grain-based biofuel production supported by subsidies; and
- gradual changes in agricultural policies member countries of the Organization of Economic Co-operation and Development, where reductions in subsidies reduced production of surpluses.

In addition to these challenges to food security, rapid urbanization and market expansion for crops and livestock in developing countries is encouraging a shift from subsistence to market-oriented farming. This is increasing migration of poor farmers to urban and suburban areas, but is also opening new opportunities for improving the income of the rural poor.

2.2 Climate change

FAO's High-Level Conference on World Food Security: the Challenges of Climate Change and Bioenergy, held in 2008 (see the conference website at http://www.fao.org/foodclimate/expert/en/; accessed 6 January 2010) highlighted the essential contribution of ecosystem services provided by PGRFA-CCAB to sustainable intensification of agricultural production in the face of climate change. The conference concluded that national, regional and international programmes should account for the effects of climate change when developing strategies for the conservation and sustainable use of PGRFA-CCAB both *ex situ* and *in situ*, and recommended more emphasis on the latter.

Both the Intergovernmental Panel on Climate Change Report (IPPC 2007) and the FAO Conference noted the disparity of information on the effects of climate change between developed and developing countries. For example, almost no data are available on the impact of climate change on the majority of centres of crop diversification that are located in developing countries.

Assessments and models suggest that the impact of climate change will be particularly large in the Middle East and Central Asia, where drought is expected to increase, and South-East Asia, where both droughts and floods are expected to increase. These regions are important centres of diversity of PGRFA-CCAB and where such diversity still provides much of the livelihoods of subsistence farmers. Unfortunately, such assessments and models have not been specifically targeted at regions considered centres of diversity of PGRFA-CCAB.

Information on the effects of climate change on centres of diversity is needed to enable development of long-term policies, actions and measures at the local, national and international levels. Crop gene pools will need to be exposed to the abiotic and biotic impacts of climate change through *in situ* conservation will help ensure they continue to adapt to high temperatures, droughts and new diseases and will complement *ex situ* conservation efforts. More research is needed into, for example, genetic control of the physiology of water balance, mechanisms for adapting PGRFA-CCAB to high temperatures and sources of new genes for resistance to diseases that may develop as a result of climate change.

3. CONTRIBUTION OF PGRFA-CCAB TO ECOSYSTEM GOODS AND SERVICES[1]

The goods and services provided by ecosystems depend on the diversity of the systems' biological components. These include invertebrates, protista, bacteria and fungi, both aboveground and belowground, and not only the vertebrates and plants that are commonly the main focus of biodiversity conservation efforts.

The value of biological diversity can be defined in a number of ways, including that needed for functioning of ecosystem services. Broadly speaking there are four types of value that can be delivered by ecosystem services: ***utilitarian, functional, intrinsic*** and ***serependic*** (Swift *et al*. 2004). Table 1 groups the services provided by PGRFA and CCAB according to these four categories. This list of uses to which PGRFA-CCAB are put is not exhaustive but does indicate the breadth of uses.

Utilitarian value refers to the benefits derived directly by society from use of species or their genes as inputs into consumption and production processes.

Functional value refers to the contribution made by diversity to supporting ecosystem functions and preserving of ecological structure and integrity. These functions are also referred to as "regulating services" (MEA 2005a). This category of services is now recognized as important in the economic literature (Evenson *et al*. 1998; Smale 2006; SOFA 2007), and partly overlaps with the concept of 'indirect use' value (Kerry-Turner 1999). Functional services may result in the production of goods and services that can be priced, but are mainly services that are not recognized as delivering direct utilitarian benefits.

Intrinsic value (sometimes called 'non-use' value) refers to the value that biodiversity has in its own right, and comprises cultural, social, aesthetic and ethical benefits of biodiversity. PGRFA-CCAB also provide recreational services in such sectors as gardens, sport turfs and agrotourism (MEA 2005a; Eyzaguirre 2006).

Serependic value refers to possible future, but unknown, value of biodiversity. This includes, for example, the presence of genes or other characteristics with an undiscovered potential for utilitarian, functional or intrinsic service. The serependic value PGRFA-CCAB is particularly high, especially in face of climate change. Biotechnology has broadened serependic value to include to genes beyond PGRFA-CCAB that could be incorporated into crops and CCAB.

TABLE 1

Services provided by plant genetic resources for food and agriculture and crop and crop-associated biodiversity, by value category[1]

Value category/service	The contribution of PGRFA-CCAB
Utilitarian	
Food	Provide options of sustainable intensification of production and resilience
Fibre	Provide raw material for production
Fuel	Provide options for feedstocks
Medicinal	Provide raw materials and new molecules for pharmaceutical uses. Traditional knowledge plays a strong role
Feed	Provide options for improving animal feed and for sustainable management of animal production, contributing also to agricultural diversification
Shelter	Provide windbreaks or shade for other crops, material for housing and/or animal protection
Dyes	Mainly used by indigenous people and local communities, rarely used for commercial purposes
Crop calendar	Provide for crop diversification over the year
Climate regulation	Provide both resilience and resources for the development of adaptation and mitigation strategies
Functional	
Water regulation	Management and availability can be improved
Erosion regulation	Provide options for diversification, including green mulches and rotations, to reduce soil degradation due to intensive monoculture; provide options for alternative food, feed and forage crops etc
Water purification	Contributes to maintaining/improving water quality – for example, contrasting degraded water quality due to intensive use of fertilizer (particularly nitrogen-based)
Pest regulation	Natural control of pests
Pollination	Provide food and habitat for pollinators
Soil fertility	Increased fertility when appropriately managed
Carbon regulation	Increased soil organic matter
Intrinsic	
Organoleptic characteristics	Food diversity
Cultural and religious values	Consolidate cultural values
Recreation	Agro-ecotourism
Serependic	
Varieties, local varieties and crop wild relatives	Provide options for adaptation to climate change and meeting unforeseen future opportunities

[1] See also MEA (2005a: p. 17).

The conservation and sustainable management of PGRFA and associated biodiversity is essential to achieving food security. However, management of agro-ecosystems to meet specific production purposes often negatively affects goods and services that previously were considered free and abundant. This must be taken into account when planning interventions to optimise exploitation of agro-ecosystems.

In conclusion, the role of PGRFA-CCAB services goes beyond the utilitarian and includes other essential services. Biodiversity is essential for provision of these services, providing the basis for ensuring the adapting capacity of agriculture to present and future needs.

[1] Sections 3 and 4 draw extensively on the work of Swift et al. (2004).

4. WHY DOES MANAGING PGRFA-CCAB NEED SPECIAL ATTENTION?

The ecosystem services provided by PGRFA-CCAB result from human interactions with biological processes. Consequently special attention needs to be paid to ensure the resilience of these services and to the drivers, including farmers, responsible for conserving these processes. MEA (2005a) states that:

"Even food grown in what appear to be the most unnatural conditions, however, is still a product of the biological processes of nature. Whether it is in the genetic material from which seeds or livestock are bred (or, with biotechnology, altered), the soils in which crops are grown, or the water that makes the land fertile: human nourish-ment depends on a natural infrastructure underlying the skills and technology of farmers around the world."

Farmers play a central role in the relationship between biodiversity and ecosystem services. In particular, their actions influence which organisms are present and regulate the populations of specific organisms, such as 'weeds', 'pests', 'diseases' and their vectors.

The management of the ecosystem services provided by PGRFA-CCAB can also be seen as managing biodiversity feedback capacity to ensure the resilience of the services in agricultural systems. The links between biodiversity and ecosystem function can be described the following three ways (Vandermeer *et al*. 1998):

- Biodiversity enhances ecosystem services because different species or genotypes perform slightly different functions.
- Biodiversity is neutral or negative, in that there are many more species than there are services and thus redundancy is built into the system. This assumes that the differences between members of an ecological community are 'neutral', or irrelevant to their success (Hubbell 2001).
- Biodiversity enhances ecosystem function because those components that appear redundant at one point in time may become important when the environment changes.

The third of these is particularly pertinent to the level of biodiversity needed to maintain ecosystem goods and services in the face of agricultural intensification and other changes facing agriculture. Swift *et al*. (2004) note that there is extensive evidence that many key services can be maintained by small numbers of species within a particular functional group. They cite the example of the effectiveness of cover provided by single species of perennial plants being as effective as a diverse community in controlling soil erosion, and the fact that only a minority of the hundreds of species of fungi, bacteria and invertebrates present in soil participate in decomposition at a given time and place.

In conclusion, ecosystems have extensive feedback mechanisms to maintain their resilience. Human activities, particularly those of farmers, are responsible for sustainably managing these feedbacks for preserving the diversity of genes, species and ecosystems as well as landraces, local varieties and traits. However, loss of biodiversity is seriously affecting livelihoods of poor farmers and food sources for future generations. There have been numerous international instruments and treaties focused on diverse aspects of this serious problem. They have recommended actions that should be taken as soon as possible for achieving a sustainable management of ecosystem services, including those provided by PGRFA-CCAB.

5. MANAGING OF PGRFA-CCAB GOODS AND SERVICES IN THE AGRO-ECOSYSTEM

Managing agro-ecosystems to limit land degradation and loss of agrobiodiversity is complex and requires holistic and integrative approaches. The failure of earlier efforts has principally been due to narrow targeting of a particular component problem, or viewing agricultural production systems in isolation from the many ecosystem factors that confront farmers.

An integrated ecosystem approach (also called integrated natural resources management) is proposed as a way to tackle the complexity of managing PGRFA-CCAB in the agro-ecosystems and to shift from the narrow agricultural research-for-development approaches or unidisciplinary/sectoral approaches (Table 2).

TABLE 2
Comparison between conventional and integrated ecosystem approach

Aspect	Conventional approach	Integrated ecosystem approach
Perspective	Natural ecosystems viewed as free input suppliers (land, fertility, etc.) for current or future commodity production	Natural and managed ecosystems viewed as part of an interdependent whole, providing a wide range of valued goods and services
Products	A few commodities or products	A wide array of both managed and natural goods and services
Strategy	Maximize yield, production and net present value by intensifying the use of land, labour and capital	Optimize total output of ecosystem goods and services over time
Methodology	Reductionist: high-resolution measurement of a small number of factors	System-oriented, including both quantitative and qualitative assessments with close attention to interactions, flows, asset balances and tradeoffs
Approach to diversity	Reduce diversity for more predictable results, more targeted interventions and greater economies of scale	Take advantage of diversity to exploit niche potential, meet a wider range of needs, preserve future options and reduce total system risk
Scales of work	Political and ownership boundaries	Ecosystem, landscape, societal and biophysical
Role of science	Applied science focused on biophysical resources, geared towards specific technology outputs	Combine biophysical with social analysis, include policy and social context and create prototypes and models of development processes for local adaptation

Source: Richard Thomas, ICARDA (personal communication, 2007).

These integrated approaches are under development and being tested by many research/development teams and projects and by several ecological System-wide Programmes launched or implemented by centres of the Consultative Group on International Agricultural Research (CGIAR) (i.e. the System-wide Genetic Resources Programme; Participatory Research and Gender Analysis; African Highlands Initiative; Sustainable Development of Inland Valley Agro-ecosystems in sub-Saharan Africa; Partnership for the Tropical Forest Margins; Integrated Pest Management; Desert Margins Program; Global Mountain Program; and Sustainable Agricultural Development in Central Asia and the Caucasus). The approaches combine technical, socio-economic, institutional and policy options, all directed to improve the livelihoods of local communities while preventing more degradation of natural resources.

The community-driven *in situ* conservation approach was recently developed and tested by several projects aiming at conserving agrobiodiversity at the farm level or in natural habitats. The project on 'Conservation and sustainable use of dryland agrobiodiversity in Jordan, Lebanon, Palestine and Syria', funded by the Global Environment Facility and coordinated by ICARDA, developed a holistic approach for conserving landraces and wild relatives of crops of global importance originating from the West Asia centre of diversity. This project focused on increased productivity, better integration of crops, range and livestock, diversification of crops and incomes and more incentives to sustain livelihoods of the main custodians of agrobiodiversity.

While these approaches aim to increase productivity of whole agro-ecosystems in a sustainable manner, more needs to be done to assess and include the conservation of crop-associated biodiversity.

5.1 Natural and cultivated environments

Agro-ecosystems consist of both 'planned' and 'associated' diversity (Conway 1993; Swift *et al*. 1996; GCTE 1997). Planned diversity comprises those plants and animals deliberately retained, imported and managed by the farmer. Associated diversity comprises those plants, animals and microbes that are part of the ecosystem but not directly 'managed' by the farmer, but that are nonetheless influenced by changes in planned diversity. The challenge is to manage the planned biodiversity in such a way as to also preserve the associated diversity.

The management of ecosystem services provided by biodiversity is complex but can be achieved by using appropriate ecosystem management practices. Farmers and farming communities can adopt practices that conserve and strengthen linkages between different elements of agrobiodiversity and contribute to long-term stability in the face of climate change. For example, they might implement measures to promote beneficial insects that help to reduce crop pests or to promote pollinators, including providing more non-crop flowering plants in fields, such as cover crops, strip crops or hedgerows.

Ecosystem services build important measures of resilience and risk mitigation into agriculture – elements of increasing importance with changing climates. As conditions change, different groups of organisms are favoured to continue providing ecosystem services, and this resilience is enhanced by having a large number of facilitative interactions in an ecosystem – any ecosystem, but particularly in a simplified farming system. Farming communities may best adapt to climate change impacts on pollinators by, for example, giving consideration to the season-long resources needed by pollinators, both before and after crop flowering (often provided by wild or semi-wild areas of habitat in agricultural landscapes); ensuring connectivity of natural habitats in farming areas, so that pollinators can more easily disperse; and making needed range shifts in response to changing climates. Many possible mitigation measures, taken together, contribute to long-term stability of agro-ecosystems by contributing greater and more continuous biomass cover on-farm. These same practices, retaining large quantities of biomass and soil organic matter, may enhance the ability of agricultural systems to sequester carbon.

5.2 Level of scale of intervention

PGRFA-CCAB diversity is managed at various spatial and temporal scales.

At field level, the natural ecosystem services are substituted and supplemented by human labour and other inputs, mainly by farmers. While substitutions may buffer some services, they also run the risk of damaging others. Adjusting such interventions could provide the means to reduce the risk of losing ecosystem services and reducing ecosystem resilience. For example, farmers could avoid disease-control measures that also harm non-target organisms that provide other services such as pollination or soil fertility enhancement.

At the landscape level, agricultural intensification tends to reduce crop and livestock diversity and simplify ecosystems and rotations. Farmers substitute diversity by increasing use of pesticides and changing the varieties they grow frequently to stay ahead of the evolutionary race with pests and diseases. Such practices substitute and supplement ecosystems services and may affect evolution of natural systems, because they narrow the diversity of the gene pool in the ecosystem. While intensive agriculture depends on a rapid turnover of new traits and varieties, extensive agricultural systems are characterized by the preservation of perennial and annual crops (local varieties and landraces) and trees. They avoid the need for rapid turnover of varieties by maintaining diversity as a risk management strategy (Conway 1993).

Another level of scale of intervention, specific to intensive agriculture, is availability of new varieties as an external service to the agro-ecosystem (i.e. maintaining genetic diversity in gene banks) and on the mechanisms of rapid seed multiplication and transfer of such varieties. This is beyond field level and depends on external services at national, regional and/or international levels.

The analysis of human intervention for conserving ecosystem services in agriculture according to spatial or temporal scale helps national and international policy-makers in developing policies and strategies for managing PGRFA-CCAB. It assists in identifying the needs of each level of intervention and their timing and is also very useful in deciding on priorities and levels of funding.

5.3 Farming practices

Managing PGRFA-CCAB depends on local farming practices, which are highly heterogeneous even within a given ecosystem. However, any farming system, from subsistence through to systems for production of high-yielding crops, can be sustainably managed. PGRFA-CCAB biodiversity, together with soil biodiversity and water, are essential tools enabling sustainability through diversification of agriculture practices.

There have been many assessments of farming practices, but these have used variety of approaches and the information generated has not been synthesized in a systematic way. There is thus a need at the global level to develop systematized information that enables comparison and development of sustainable practices. A useful recent published example of this approach summarized the assessment of management practices used for 27 crops in local communities of eight countries (Jarvis *et al*. 2008). This utilized a network of local researchers coordinated by Bioversity International with the active and full cooperation of farmers, farmer organizations, NGOs and experts on farming practices from CGIAR centres, universities and national institutes for agriculture research. This is an example of integrating knowledge of local farmers and communities with that of other stakeholders, by assessing and exchanging information and experience on management practices of local crop varieties to improve farming practices.

As illustrated by Jarvis *et al*. (2008), a network of farmers and farming communities can be very useful, particularly in regions with widely varying climatic conditions. Assessment of effects of climate change could be carried out by coordinated networks of scientists and farmers growing local varieties. Marginal areas identified by the IPCC (2007) as likely to suffer most from climate change could be chosen as priorities, i.e. regions located in lower to medium latitudes, including the Middle East, sub-Saharan Africa and Central Asia. These contributions could be the building blocks towards a global system of information on community practices for sustainable farming that would help the global community in planning *in situ* conservation and responding to climate change, *inter alia*.

As mentioned above, farming practices are mainly developed through interactions between the farmer and field-level biological processes and vary even between farmers of the same community. This characteristic makes the collection and exchange of information on farming practices particularly difficult. However, information and experience on farming practices is becoming an important tool for sustainably intensifying agriculture in the face of global change. In 2008, a very positive step towards this end was adopted at the intergovernmental level by the request to the Executive Secretary of the Convention on Biological Diversity (CBD), in consultation with FAO, to collate and disseminate information on best practices for on-farm and *in situ* conservation of agricultural biodiversity (UNEP/CBD/COP/9/1/Add.2, paragraph 11).

5.4 Crop wild relatives

There is growing consensus at the global level that specific action is needed for conservation of crop wild relatives (CWR) both *ex situ* and *in situ*. Maxted *et al*. (2008) provide a considerable number of examples of CWR that contain genes that provide goods and services to ecosystems and make technical and policy recommendations that could guide national, regional and international policy-makers on this matter.

There are growing calls for the assessment and conservation of CWR as a source of new gene pools to respond to global change. One concern is that natural populations of these species are found in developing countries where they are faced with habitat loss and potential negative impacts of climate change. Developing countries need funding to build local capacity for assessing and managing the conservation needs, including capacity in taxonomy, plant ecology and population management. Farmers need new options and opportunities to benefit from managing CWR populations. Strengthening long-term policies, including capacity building programmes, could be the way to contribute locally to this global need.

6. CONCLUSIONS AND RECOMMENDATIONS

This section discusses strategies for managing PGRFA-CCAB and makes recommendations in three sets. The first deals with management of PGRFA-CCAB in the context of ***agricultural practices***. The second focuses on farmer interventions through ***valuing ecosystem goods and services including incentives***. The third set addresses the ***international process*** through which these discussions and recommendations could contribute to developing strategies for conserving PGRFA-CCAB goods and services in the context of global change.

6.1 Agricultural practices

The goods and services provided by PGRFA-CCAB underpin sustainable agriculture practices such as reduced tillage, nutrient management, rotations, integrated pest/disease management, weed management, improving water use efficiency, management of pollinators and use of appropriate crop landraces/varieties for farming diversification. Applying these practices in turn contributes to the conservation of PGRFA-CCAB, in particular through *in situ* conservation and sustainable utilization. While *ex situ* conservation is essential for enhancing goods provided by PGRFA, *in situ* conservation is more focused on maintaining ecosystem services within and beyond farms.

Turner *et al*. (2003) state that:

"Future research effort should include complementary research on multiple ecosystem services that seeks to capture the temporal disturbance profile and its causal factors. The explicit recognition of it would serve to transform the practice of research in this sub-field via the *a priori* assumption of multiple (and inter-dependent) use, instead of independent single use."

This integrated approach should provide managerial tools aiming to maintain the resilience of ecosystem services, including those provided by PGRFA-CCAB. Utilization of PGRFA-CCAB is key to achieving agricultural intensification and reducing the extensification of agriculture at the expense of natural ecosystems. On this issue, there is a strong agreement in the recommendations of recent reports (MEA 2005b: p. 459; IPPC 2007; World Bank 2007), which highlight the underlying need for increasing scientific efforts by both the public and private sectors for ensuring food security by maintaining ecosystem resilience.

Conservation of PGRFA-CCAB goods and services and their diversity in the face of climate change will be a major challenge. Howden *et al*. (2007) provides a list of recommendations that could provide guidance for adapting agricultural systems to the effects of global change, including the enhancing the contribution of PGRFA-CCAB services to climate change adaptation and mitigation. The following recommendations were modified for this study:

- Alter varieties/species grown to those with more appropriate thermal time and vernalization requirements and/or with increased resistance to heat shock and drought. Alter fertilizer rates to maintain grain or fruit quality consistent with the prevailing climate. Adjust amounts and timing of irrigation and other water management techniques.
- Make wider use of technologies to harvest water and conserve soil moisture (e.g. crop residue retention) and use and transport water more effectively where rainfall decreases.
- Manage water to prevent waterlogging, erosion and nutrient leaching where rainfall increases.
- Alter the timing or location of cropping activities.
- Conserve soil biodiversity through agricultural practices such as conservation agriculture, crop rotation, non-tillage, intercropping and grassland and pasture management.
- Diversify income through altering integration with other farming activities such as livestock raising.
- Promote the development and commercialization of under-utilized crops and species.
- Improve the effectiveness of pest, disease and weed management practices through wider use of integrated pest and pathogen management, development and use of varieties and species resistant to pests and diseases and maintaining or improving quarantine capabilities and monitoring programmes.
- Conserve habitat and food provision for ensuring the services of pollinators.
- Use climate forecasting to reduce production risk.

The recommendations described below are also relevant for low-input agriculture, including subsistence agriculture and traditional farming systems:

- When possible, develop *ex situ* conservation projects that are fully integrated with *in situ* conservation activities.
- Develop low-cost technologies with minimum input application and use of integrated pest management, including rotations.
- Establish programmes for improvement of productivity and quality of landraces and local varieties, with full participation of the farming community and utilizing their traditional knowledge.
- Conduct more research on improvement of rangelands through an integrated approach ensuring better crop–range–livestock integration by introducing herbaceous and tree forages and alternative feed resources into feeding calendars.

6.2 Valuing PGRFA-CCAB goods and services

The short- and long-term values of PGRFA-CCAB goods and services for agricultural improvement and food security are recognized and supported by policy-makers and society in general. However, in the new global change scenario more funding is needed, in particular for conserving PGRFA-CCAB *in situ*. Conserving PGRFA-CCAB *in situ* has the advantage of ensuring that gene pools and ecosystem and agro-ecosystem interactions continue to be exposed to selection pressures and stresses from abiotic and biotic factors (e.g. droughts, floods, soil erosion, greenhouse gases and contamination with pollutants) and biotic factors (e.g. invasions of new weeds and pests and diseases). However, *in situ* conservation requires the provision of incentives to farmers and other stakeholders to maintain these genetic resources in their native environment. This is not an easy task because these resources are mainly located in developing countries and under the management of subsistence farmers, whose primary objective is to ensure food security for themselves and their families.

One option to provide incentives to farmers is to enhance access to markets. Enlarging the market for diverse agriculture products will enable subsistence farmers, especially those living in a centre of crop diversity, to generate benefits for managing ecosystem services from which they obtain these products.

Another approach to paying for conserving PGRFA-CCAB services is to account for ecosystem services as part of the national economic wealth. However, methodologies for assigning economic value to ecosystem services are still not fully developed. This could be one way to attract more local and international funds for activities that manage services provided by PGRFA-CCAB, but more coordination of funding strategies at the global level would be necessary for achieve this. Case studies for services provided by PGRFA-CCAB, similar to that designed for accounting for services provided by wild pollinators to cash crops, could guide the accounting of PGRFA-CCAB services (Mäler *et al*. 2008). The purpose would be to determine in accounting terms the percentage that PGRFA-CCAB contributes to the final product as well as to determine the method needed for calculation. Developing case studies along this line could be also useful to implement payment for ecosystem services (PES) from PGRFA-CCAB (Wunder 2005; FAO 2007). Valuing PGRFA-CCAB services would allow creation of a wider funding portfolio including PES, environmental subsidies, donations, preferential credits and a carbon market and the priorities for allocating these funds. Elements for paying for PGRFA-CCA services should also be included in the processes of developing funding strategies for preparing and responding to the effects of global change, including climate change.

In conclusion, the challenge of global change puts the onus on the management of PGRFA-CCAB goods and services to achieve sustainable agriculture practices in farming systems. Policies, technologies and financial measures must be developed to provide incentives to farmers, who are the largest group of natural resource managers. Coincidently growing interest in ecosystem approaches and climate change, in particular, has focused economists on trying to value ecosystem services, including those provided by PGRFA-CCAB (Nijkamp *et al*. 2008; Sarr et. al. 2008). These efforts could be oriented to also explore the growing interest in directing funds from carbon markets to biodiversity initiatives supporting the services provided by PGRFA-CCAB (Bekessy and Wintle 2008).

Recommendations relating to valuing PGRFA-CCAB goods and services are organized in three sets: 1. Assessment for development of strategies; 2. Management, integration and use of information; and 3. Capacity building and advocacy.

1. Assessment for development of strategies, including models for accounting ecosystem values for paying for ecosystem management services
    - Assess all types of incentives available for paying farmers for the services they provide, including PES.
    - Develop methodologies for assessing, monitoring and valuing ecosystem services. Establish indicators by integrating the multiple variables and their interdependency for valuing ecosystem services in a problem-oriented approach through learning-by-doing.
    - Develop guidance and learning material on managing PGRFA-CCAB services based on case studies and local experiences.
    - Develop methodology for accounting for PGRFA-CCAB services, including the development of validated models. The model developed by Mäler *et al*. (2008) for pollinators and the methodology used could guide this approach.

2. Management, integration and use of information
    - Collect, document and disseminate traditional knowledge, information and experiences on farming practices that value PGRFA-CCAB goods and services relevant for developing compensation and incentives to stakeholders, including farmers who conserve these goods and services.
    - Integrate information on the value of crop and crop-associated biodiversity and its services (e.g. managing pollinators) into existing information systems (e.g. early warning systems) for compensating farmers.

3. Capacity building and advocacy
    - Include the experience and traditional knowledge for managing PGRFA-CCAB services in Farmer Field School programmes and in agendas of farmers' associations.
    - Include guidance and incentives to reduce the consump¬tion that threatens ecosystem services at primary and secondary public education levels.
    - Give consumers access to information about ecosystems and decisions affecting their services.

6.3 International process

There is a need to strengthen the existing political processes to encourage policy-makers and funding managers to agree on a strategy for paying farmers to conserve PGRFA-CCAB. International agreements and institutions, including recent reports (IPPC 2007; World Bank 2007) and the MDGs already identify this new challenge from a variety angles but with the same target, i.e. fighting farmers' poverty. However, they still lack the political understanding and agreement that subsistence farmers can provide unique environmental services towards the conservation of PGRFA-CCAB if they are provided with options and opportunities. Fortunately these international efforts are accompanied, but to a lesser extent, by a bottom-up approach at the national and local level with processes for fighting poverty and conserving environmental health. These include the implementation of international agreements, the development of national strategies, NGOs' activities involving particularly farmer organizations and bilateral and regional cooperation that incorporates activities developed by national and international institutions such as universities and agricultural research organizations.

At the international level, fighting poverty has been a matter of discussions in the FAO's Commission on Genetic Resources for Food and Agriculture (CGRFA), the International Treaty on Plant Genetic Resources for Food and Agriculture, the CBD, the UNFCCC, the UNCCD, the MDGs and in recent reports of the World Bank (2007), the IPCC (2007) and the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). However, linking this issue with discussions on policies and strategic measures to recognize the potential capacity of small and subsistence farmers for conserving the services provided by PGRFA-CCAB and compensating them for these services need to be spelled out and packaged for ready action. To reach agreement on this matter, member countries to these forums would like to better understand these possibilities. They seek guidance and recommendations on options and opportunities for developing policies and strategies for seeking cooperation and compensating for the services of these farmers to remediate the damage done to PGRFA-CCAB services and to prepare them for increasing demand for food and agricultural products.

Although this is a national responsibility, it is of global concern since it affects future food security. As a global concern, the guidance and recommendations accounting for all these elements should be agreed by an intergovernmental technical process. The guidance and recommendations will be used to develop strategies and policies to be implemented at the global, regional, national and local levels.

To avoid duplications and to use existing international technical knowledge in this specific area, the technical intergovernmental forums for discussing this matter could be the CGRFA when revising the on-going Global Plan of Action for the Conservation and Utilization of PGRFA. This plan is the only agreed intergovernmental strategy to guide international cooperation on PGRFA-CCAB and it has the mandate and flexibility to link all existing relevant national, regional and international instruments and agreements and national and international relevant reports including the SoW on PGRFA-CCAB Report and provides updated internationally agreed guidance on this matter.

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