# Agrobiodiversity and climate change: what do students need to know?

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ABSTRACT

Agrobiodiversity sustains livelihoods in Africa but is threatened by, among others, habitat degradation, land use changes, agricultural intensification, climate change, over-harvesting and loss of useful wild species, invasive species, etc. Adaptation of production systems and society to climate change requires human capacity in agrobiodiversity but a 2007 survey in African universities showed that education in this area is weak or absent.

Scientists predict a warmer climate across Africa, with significantly less rainfall in some areas like Southern Africa, or more rainfall in pockets of Eastern Africa, leading to changing crop suitability patterns, loss of species, disappearance of marginal plant populations and altered distribution patterns of pests and diseases.

The role of agrobiodiversity in adaptation to climate change must be better understood and recognized. Areas of competence include, among others: Biophysical and socioeconomic drivers and change in major components of agrobiodiversity including crops, wild crop relatives, trees, animals, fish, microbes; *In situ* and *ex situ* conservation and on-farm management of agrobiodiversity; Breeding for resistance to abiotic and biotic stresses; Enhancing links between genebanks, breeders and farmers; Policy implementation, and the role of local knowledge. Agriculture extension will need to work with farmers on the substitution of species and varieties adapted to the emerging climate. Farmers need information on new pests and diseases, and how to prepare for long-term effects (e.g. gradually increasing temperature) and short-term effects (e.g. increasing frequency of extreme weather events) of climate change.

Universities should review curricula to include agrobiodiversity dimensions in teaching of climate change. Innovative, experiential teaching methods and active student participation would help institutionalize holistic and action-oriented learning. Education must be research-driven to incorporate a rapidly growing knowledge base on agrobiodiversity and climate change. Research capacity will need strengthening, including MSc and PhD theses opportunities.

**Key words:** agrobiodiversity, climate change, crop suitability, plant breeding, curriculum development

***Presented at: 2$^{ND}$ ANAFE International Symposium: Mainstreaming climate change into Agricultural Education: Tools, Experiences and challenge.***
***28th July-1st August, 200, Cross Roads Hotel, Lilongwe, Malawi***

## 1. INTRODUCTION

Agrobiodiversity – the sub-set of biodiversity important to food and agriculture – is a surprisingly recent concept. The Convention of Biological Diversity (CBD) for the first time specifically addressed agrobiodiversity in 1996 (CBD 1996). In consequence, universities and colleges have just began including agrobiodiversity in agriculture curricula. The recent surge in food prices and the threats of climate change to food and livelihood security have brought agrobiodiversity into focus, calling for accelerated mainstreaming of agrobiodiversity in Africa's universities and colleges.

Learning about agrobiodiversity in the context of climate change adaptation in Africa obviously requires that universities cover both areas. However, both agrobiodiversity and climate change currently get limited attention in most curricula. This paper therefore gives a broad review of agrobiodiversity as a preparation for its discussion on climate change adaptation. We suggest that competences to be developed in university programmes and courses might include, among others:

- Agrobiodiversity: what it is, how it has evolved, and its functions for livelihoods and landscapes
- Processes influencing land use change in agroecosystems, including human, economic, policy and environmental drivers
- Processes affecting the provision of ecosystem services and functions in agro-ecosystems
- Impact of land use change on agrobiodiversity at ecosystems, species and within-species levels
- Climate change and variability predictions for different sub-regions in Africa
- Impact of projected climate change on components of agrobiodiversity, including crop suitability projections
- Adaptation to climate change: agrobiodiversity options
- Approaches for putting adaptation strategies into practice in research, extension and policy implementation.

Reviewing curricula will not be enough to achieve this: teaching agrobiodiversity also calls for a critical look at the teaching and learning approaches in use. Because the topic is dynamic, system-oriented and multi-disciplinary, and because of uncertainty and a rapidly evolving knowledge base, traditional teacher-centered methods need to give way to more learner-oriented, participatory and innovative approaches to education.

## 1. WHAT IS AGRICULTURAL BIODIVERSITY AND HOW IS IT TAUGHT?

### What is agrobiodiversity?

Agricultural biodiversity is described as: ‘a broad term that includes all components of biological diversity of relevance to food and agriculture, and all components of biological diversity that constitute the agro-ecosystem: the variety and variability of animals, plants and micro-organisms, at the genetic, species and ecosystem levels, which are necessary to sustain key functions of the agro-ecosystem, its structure and processes’ (CBD 2000).

Agrobiodiversity has spatial, temporal and scale dimensions. There is a dynamic change of agroecosystems in time and space, shaped by interactions between genetic resources, the environment and people (FAO 1999). In Africa, communities traditionally used a very wide range of species and varieties for their food, nutritional and livelihood security, reflecting Africa’s extremely diverse environment and cultural heritage. These genetic resources include traditional plant and animal varieties – landraces – domesticated by farmers, wild species harvested from forests, rangelands, wetlands and aquatic/marine ecosystems, as well as wild crop relatives.

An estimated 7000 plant species have been used for food or animal feed globally at one time or other, and some 150 are commercialized at a global scale Thirty crops provide 95% of our food energy and only three crops – maize, wheat and rice – provide half of our calorie and protein intake (Wilson 1992). Meanwhile, hundreds of underutilized plant and animal species continue to be important locally or sub-regionally, in particular for poor communities in marginal areas. In Kenya alone, about 800 wild plants are recorded to be used for food (Maundu 1996). Such species tend to be neglected by scientists, policy makers and practitioners and their diversity is rapidly being lost along with farmers’ local knowledge about them.

Agriculture policies and institutions, including higher education institutions, have largely focused on major stable crops and a few animal species. Agriculture education in Africa has largely concentrated on cultivating these few species in agricultural systems based on modern cultivars, monocultures and high inputs. Universities and colleges have therefore paid relatively limited attention to agrobiodiversity, including its maintenance and use, agro-ecosystem properties and functions, the role of farmers' traditional varieties, and the socio-economic and cultural processes that shape agrobiodiversity. This is now starting to change. Some systems-oriented subjects that recently have been introduced in university curricula, such as integrated pest management, agroforestry and watershed management. Participatory approaches are increasingly taught. The mainstreaming of agrobiodiversity education can build on such experiences.

**How is agrobiodiversity taught: examples from Eastern and Southern Africa**

In 2007 Bioversity International commissioned a survey to evaluate how plant genetic resources and agrobiodiversity are being taught in universities in eastern and southern Africa (Muluvi et al 2008). The survey comprised of an electronic questionnaire distributed to 50 institutions, and in-depth interviews conducted during personal visits to nine universities in Kenya, Zimbabwe, Malawi, Zambia and Uganda. There was a very poor response rate for the electronic survey; the responding universities were those the consultant also visited. (The links between agrobiodiversity and climate change were not specifically addressed by the survey).

Master's programmes on plant genetic resources (PGR) are taught in several universities, including:

- MSc Biotechnology (Kenyatta University and Jomo Kenyatta University of Agriculture and Technology (JKUAT), both in Kenya)
- MSc Seed science (Moi University, Kenya and Makerere University, Uganda)
- MSc Horticulture (Kenyatta University, Egerton University and University of Nairobi, all in Kenya)
- Makerere University also offers an MSc in Crop science, with an option in plant genetic resources or plant breeding/genetics

All these programmes offer significant PGR content with courses on genetics, plant breeding and seed production, among others, but very little agrobiodiversity learning. A notable exception is Kenyatta University which offers an MSc in Ethnobothany, a programme which presumably includes significant socio-cultural aspects of agrobiodiversity.

In contrast, none of the nine surveyed universities offer a comprehensive agrobiodiversity programmes at undergraduate or graduate level. At BSc level, the study found limited agrobiodiversity content in only three programmes:

- Copperbelt University in Zambia incorporates a course on biodiversity conservation in its BSc Agroforestry programme
- JKUAT offers undergraduate students a course on ethnobothany in its Botany programme
- Egerton University in Kenya offers a course on traditional vegetables production with the BSc Horticulture programme

In six of the universities surveyed, the agrobiodiversity concept seems absent in their undergraduate programmes.

Most programmes, regardless of level, are oriented towards a specific discipline, e.g., seed science, crop protection, agricultural economics, horticulture, microbiology, and agronomy. At the postgraduate level, the universities' agricultural programmes are typically (though not exclusively) thematically focused and quite technical. This implies less scope for addressing the holistic and multidisciplinary elements of agrobiodiversity.

All the universities surveyed – with the exception of the University of Zambia, and to a lesser degree Makerere University – expressed dissatisfaction with the way both agrobiodiversity and plant genetic resources are being taught. When asked about learning material dedicated to agrobiodiversity, all universities assessed their 'content quality' as inadequate.

The survey established that all responding universities engage in curricula review on a regular basis. Usually initiated by departmental staff as a response to industry and market demands, it involves a large number of stakeholders from academia, employers, farmers, government ministries, and research organizations. Draft documents are then tabled for university Senate approval. This suggests that with sufficient sensitization, staff might be encouraged to propose a curriculum review which incorporates an increased focus on agrobiodiversity.

However, it is unclear whether there is existing job market and employer demand for these new skills and knowledge. The job market is predominantly comprised of public sector institutions, including ministries of agriculture, forestry departments, national genebanks, and the wider national agricultural research system. Since universities offer programmes in disciplines for which there has traditionally been solid demand for graduate, courses tend to be fact-based, pragmatic and ‘hard sciences’ oriented. Without questioning the importance of these characteristics, this suggest that many programmes are not multi-disciplinary in scope, are reductionist as opposed to systems-oriented, and possibly lend themselves less to the development of ‘soft skills’. These are all additional capacities which are urgently required in today’s graduates in order to tackle emergent, complex and multi-stakeholder agricultural and environmental problems, such as the adaptation to climate change.

The survey recommends promoting agrobiodiversity learning using a three-pronged strategy: Introducing elements of agrobiodiversity in existing courses and programmes opportunistically, in a manner that does not always require a formal curriculum re-think. This pragmatic way of introducing new content quickly and efficiently requires training of teaching staff and availability of effective teaching materials on agrobiodiversity.

Secondly, universities could be supported to mainstream agrobiodiversity education in their range of BSc and MSc programmes in connection with the next cycle of curriculum reviews. Basic knowledge on agrobiodiversity should be acquired by all agriculture and forestry graduates.

Thirdly, in the medium term perspective, universities could consider developing tailor-made agrobiodiversity options or specializations within existing Masters degrees. On a more distant horizon, the possibility of a full-fledged postgraduate programme in agrobiodiversity – perhaps developed through university partnership and offered through a regional centre of excellence – remains an interesting possibility. Such programme must emphasize the economic, social and environmental importance of agrobiodiversity, and attempt to connect this to future employment opportunities.

## 2. WHAT IS HAPPENING TO AGROBIODIVERSITY IN AFRICA?

### Functions of agrobiodiversity

The contribution of agrobiodiversity towards food and livelihood security among poor African small-holders is increasingly recognized. Benefits of agrobiodiversity include, among others, risk mitigation, income generation, health and nutrition, ecosystems resilience, and cultural and aesthetical values.

Risk mitigation: Farmers, especially those using low-input farming systems, use plants, animal, fish and forestry diversity (both within and between species variation) to mitigate risks arising from droughts, pests and diseases or from volatile markets. Many resource-poor farmers plant genetically heterogeneous crops to minimize risk of crop failures (FAO 1996). Agrobiodiversity can therefore act as a ‘safety net’ in farmers livelihood strategies. For example, farmers may turn to forest ecosystems as a source of food and medicines in times of crisis.

Income generation: Traditional crop varieties, indigenous fruits, trees on farms, medicinal species, etc., can generate enhanced or new sources of income through their commercialization. The rapid growth of speciality crops and niche markets create new opportunities for farmers to gainfully participate in markets.

Health and nutrition: Agrobiodiversity contribute in many ways to health and nutrition by providing food and access to traditional medicines. A diet rich in iron and micro-nutrients is essential to avoid ‘hidden hunger’. The nutritional properties of traditional food is here gaining attention.

Ecosystems resilience: Agrobiodiversity is essential to functional agroecosystems and good soil and water management. Soil organisms contribute to nutrient cycling, soil carbon sequestration, soil physical structure and water regimes, and influence on plant life (e.g. nitrogen fixation and interactions in the soil of pests, predators and other organisms). Pollinators are essential for crop and fruit production and their number and diversity can profoundly affect crop production levels. Payment schemes for environmental services now start recognize such values.

Cultural and aesthetic values: Rural landscapes have important cultural and aesthetic values, both for local people and for society at large, values that are threatened by rapid changes of agroecosystems. On the other hand, the growth of eco-tourism is a fast increasing source of income from agroecosystems.

**Threats to agrobiodiversity**

The loss of agrobiodiversity and associated local knowledge is rampant. The public debate on biodiversity loss tends to focus on 'wild' biodiversity: the threats to ecosystems, such as the reduction of forest areas, wetlands or coral reefs; or the loss of species, as reported in the IUCN Red List of Threatened Species (IUCN 2008). There is much less concern with the loss of genetic diversity within agroecosystems: the loss of genetic diversity that can occur when farmers substitute modern cultivars for traditional varieties, when crop wild relatives are being threatened, or when marginal populations of a species are lost. Although genebanks play an important part in conserving much of the crop diversity as well as that of crop wild relatives, they too can suffer problems of genetic erosion through inadequate resources and poor maintenance conditions. The recent opening, in February 2008, of the Svalbard Global Seed Vault brought these issues to global attention (Global Crop Diversity Trust 2008).

While much of the discussion in this paper focus on crops, it is important to emphasize that similar patterns apply also to other types of agrobiodiversity. For example, according to FAO estimates, around 20 percent of reported livestock breeds are classified as at risk, and 62 breeds became extinct during a 6-year period (FAO 2007).

Many threats to agroecosystems and agrobiodiversity are well-known; others are more recent and less recognized. Climate change will accelerate many of these processes. Key drivers of change in agrobiodiversity in SSA include:

- Population growth: The population in SSA will increase from 769 million in 2005, to between 1,518 and 2,022 in 2050, according to forecasts by the United Nations (2006). Given no change in consumption patterns, the demand for agrobiodiversity products and services will double, or more, in the next 45 years. This will put tremendous pressure on agroecosystems to producing more and better food, while sustaining the environment.
- Land conversion: Urban expansion causes wide-spread loss of agricultural land. The loss of forests and other wooded land in Africa continues at a rate of 4,4 million hectares, or 0.62 % per year (FAO 2005). The promotion and expansion of biofuel production, such as *Jatropha curcas*, across Africa is also fast converting land from other uses (Henning 200x)

- Land degradation and desertification results in the loss of agricultural area and productivity. In Africa, the degradation and loss of forest and bush land was found to be a main cause of loss of genetic resources (FAO 1996).
- Changing agricultural practices associated with intensification of production, the introduction of mechanization and the use of agro-chemicals, leading to marginalization of traditional production systems (FAO 2007). Promotion of a single approach to agricultural development, – e.g. the Green Revolution approach – is one of the most fundamental causes of agrobiodiversity loss (FAO 1999). 'Neglected and underutilized crops' and traditional varieties are now getting more recognition, but much more research, resources and capacity is needed to enhance their conservation, use and commercialization.
- The rise of supermarkets in Africa is having profound impact on agricultural production systems. Supermarkets use specialized wholesalers in their procurement and demand tough quality and safety standards (Weatherspoon and Reardon 2003). This may exclude many small-scale farmers who trade small quantities of variable produce. On the other hand, supermarkets can also be a new opportunity for adding value to agrobiodiversity, as in the successful Africa Leafy Vegetable project (Oniang'o et al 2006).
- Changing food habits have far-reaching implications on what farmers produce, such as the on-going shift from traditional food to carbohydrate-rich fast food, and increased meat consumption among a growing African middle class.

These trends can be devastating for small-scale farmers in Africa because loss of agrobiodiversity results in the loss of many products (food, fuel, medicines, building materials, living fences and so on) which are used as part of farmers' livelihood strategies as well affecting ecosystem function. Loss of agrobiodiversity can also result in a substantial decrease in the **resilience** (the capacity to absorb shocks while maintaining function) of farmers' agroecosystems and consequently increase in farmers' vulnerability. When change occurs, resilience provides the components for renewal and reorganization. When ecosystem loses its resilience, adaptation to change is not possible and therefore, change inevitably has potentially disastrous consequences. Inability to cope with risks, stresses and shocks, substantially undermines livelihoods of small-scale farmers. It is worth noting that the recent IPCC report particularly noted loss of ecosystem resilience as likely consequence of climate change (IPCC 2007).

## 3. HOW IS A CHANGING CLIMATE EXPECTED TO INFLUENCE AGRICULTURAL BIODIVERSITY?

### Climate change and variability

The Fourth Assessment IPCC report (2007) predicts widespread increases in temperature across the globe, along with changes in rainfall regimes over the next 100 years and beyond. Models suggest both a change in the baseline, along with a change in the variability within years and between years, although varying levels of uncertainty should be attributed to predictions. Specifically for Africa, mean annual temperature is expected to increase 3-4oC to 2080-2099 (Christensen et al 2007). Rainfall is predicted to increase (with high agreement between models) in Eastern Africa by around +7%, specifically around the highlands in Kenya, Uganda and Rwanda, and there is growing consensus that Southern Africa will become significantly dryer with predicted 30% decreases in the winter period (Christensen et al 2007). There is no agreement between models as to the future of the Sahel, with both increases and decreases in rainfall predicted by the different models (Boko et al 2007).

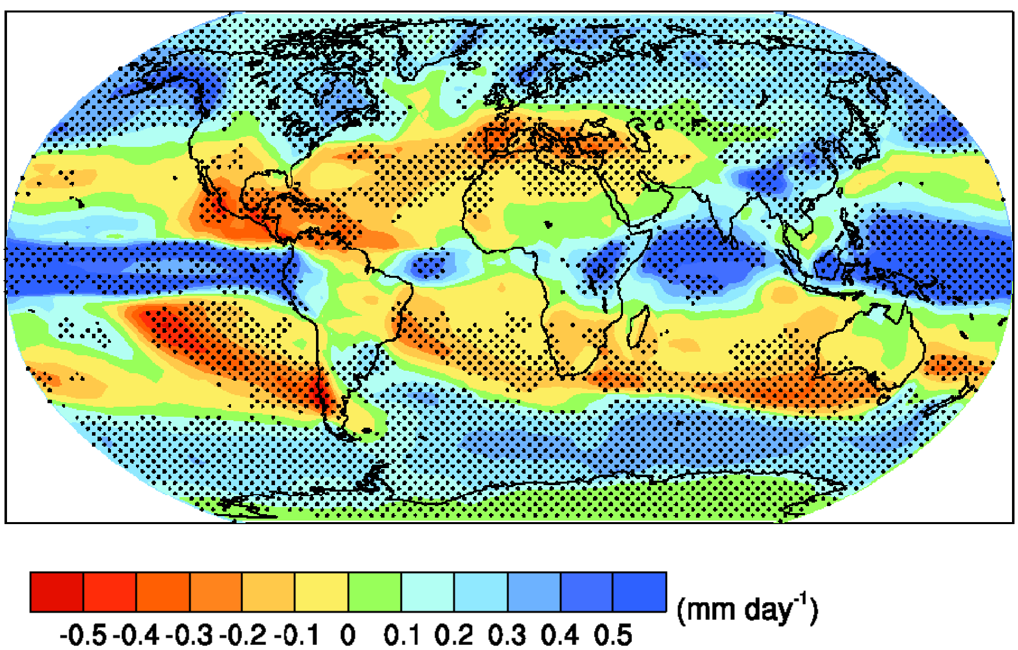

FIGURE 1. Change in rainfall climate according to the IPCC 4th Assessment (2007).

Climate variability is also expected to increase, resulting in more frequent incidence of extreme events, including droughts, floods and storms (mainly from tropical cyclones) and wild fires (brought about by increased temperatures and dryer environments).

The implications of these changes in climate offer both challenges and opportunities to agriculture in Africa. Systems are already vulnerable, and heavily exposed to climate risk, and so those areas with predicted drying are likely to suffer greatly from droughts. However, those areas where rainfall is predicted to increase could indeed capitalize on such opportunities if farming communities adapt.

**Impact on agrobiodiversity**

Climatic changes, in combination with other drivers, are expected to substantially alter agricultural biodiversity. Ecosystems will change with the climate, and drylands are particularly vulnerable because small climatic changes can have serious impacts on biodiversity, and because drylands are already under stress (CBD 2007). Crop suitability models predict that Sub-Saharan Africa and the Caribbean will be most affected in terms of reduction of suitable area for a range of crops (Lane and Jarvis 2007). The magnitude of change can be such that existing crop varieties are no longer suitable in a particular location. This will influence overall distribution of agroecosystems in Africa and will have a profound impact on the livelihood systems of people inhabiting them.

At species level, biodiversity which is already endangered or vulnerable will face an increased extinction rate. There will also be a loss of intraspecific diversity and disappearance of marginal plant populations. This can be particularly serious for wild relatives of crops, which may contain valuable genes for plant breeding programmes for increasing heat and drought resistance or resistance to pests and diseases.

Threat patterns of insects and pathogens will also likely change, increasing risks of crop failure to smallholder farmers. CBD also cites a number of other impacts on plant growth and production including: increased exposure to heat stress, leaching of nutrients in areas with more intensive rains, erosion due to strong winds, and wild fires. (CBD 2007). There is already abundant evidence of change in patterns on insect distribution that affect both beneficial (e.g. pollinators) and harmful insects (Menéndez 2007). However, at present, the data come largely from studies undertaken in developing countries. Of the significant changes in biological systems analysed by IPCC that may be attributable to climate change from 1970 to 2004 some 28 115 changes were recorded in Europe, but only 2 for Africa**.**

It is likely that there will need to be significant movements of crop and livestock species and varieties as production environments change. Many major crops are widely adapted to a range of environments but the specific varieties may need to changed to meet new conditions. New varieties of many crops will also be needed to match new combinations of temperature, water availability and photoperiod.

In contrast to annual crops and many livestock types which can be transferred and adapted to changing conditions, soils are not mobile and adaptation of soil diversity will depend on having sufficiently large population and species diversity to allow adaptation. In some cases the present 'fit' between currently adapted crops, soils and other agrobiodiversity components will be markedly altered in unpredictable ways.

## 4. HOW COULD MANAGEMENT OF AGROBIODIVERSITY HELP ADAPTATION TO CLIMATE CHANGE?

Broad efforts to help reduce climate vulnerability of production systems will be required in agriculture, forestry and agroforestry systems, including fisheries and animal husbandry. At a given location, three basic options for adapting cropping systems to climate change are at hand:

- Migration of crop varieties to fit a new climate zone
- Adaptation of varieties through selection and breeding
- Substitution of new crop species for the old ones

These options are discussed below (of course, one can also think of scenarios of shifting away from crop production to other types of production, such as intensive horticulture, or forestry-based production, or shift to non-agriculture livelihood strategies, or migration to urban areas, but these will not be discussed here).

In this section the discussion is focused on crops; similar discussions could also be held for other elements of agrobiodiversity.

**Migration of crop varieties to fit a new climate zone**

Because of the changing temperature and rainfall climate and increased climate variability, farmers may need different varieties of a particular crops, compared to the ones they presently use. These varieties, whether landraces or modern improved varieties, would currently be grown or conserved elsewhere, including in other countries. A range of mechanisms will be needed to ensure that farmers can access these varieties:

- Information on existing variation: This requires that varieties in genebanks and in-situ collections are characterized, according to descriptor lists, and that this information is organized in databases which are available to users. However, this system would only cover the formal seed system. The informal seed systems, which dominate in marginal areas and among resource-poor farmers, would need other information mechanisms. Participatory tools such as ‘seed diversity fairs’ or community seed banks can serve this need of information sharing.
- Improved seed systems: Both formal and informal seed systems must to take into account increased need for migration of varieties. In the formal seed systems, better links between genebanks and breeders are needed, and competence in international exchange of seeds will need strengthening. Informal seed systems might need new institutional mechanisms, because the transfer of varieties in future will need to cover longer distances. For example, long-distance exchange among farmers may be required.
- Material transfer agreements: Cross-national exchange of seeds is likely to increase, because a useful variety may currently be grown or conserved in a different country. The International Treaty on Plant Genetic Resources for Food and Agriculture (FAO 2002) makes provision for such sharing, but not all crops are covered and not all countries have signed. And even in countries which have signed, a lot of awareness raising and capacity building will be required for material transfer to become effective.

**Adaptation of varieties through selection and breeding**

Climate change and variability will influence plant breeders' work in several ways: New varieties need to be developed more quickly for traits such as drought and heat tolerance, shorter period from sowing to maturity, resistance to a new set of pathogens, tolerance to extreme weather events, etc. Genes with particular characteristics can be sources from the entire genepool, including from crop wild relatives. The accelerated erosion of the genepool in many species including in their wild relatives, is a serious concern, however, as genes that useful to breeding for adaptation to climate change might be lost forever. Species which are propagated clonally, such as banana, require molecular tools.

Genes valuable to breeders may currently not be accessible because genebank accessions are not characterized. Promising genes may therefore not yet be identified. Pre-breeding could enhance the value of collections by mapping and sharing information on the genepool of a species.

Increased attention to farmers' traditional knowledge on biodiversity for food and agriculture is also very important, particularly in marginal areas and among resource-poor farmers. Participatory varietal selection can serve the function of identifying varieties adapted to climate variability, for example. Participatory plant breeding can help overcoming agronomic or market constrains associated with the selected landraces. It important to also recognize farmers' rights and benefit sharing arrangements in this process. Attention to farmers' seed systems will be required.

The development or maintenance of a diversity of varieties, both new and traditional, with variable properties can help spread risks. Plant breeders may benefit from paying increased attention to existing traditional risk management strategies and enhancing the diversity available both in terms of numbers of varieties with a broader genetic base and in developing varieties which are multi-lines or mixtures (Cooper et al 2000).

**Substitution of crop species**

A third option to address changing crop suitability is to substitute new crops, which have previously not been grown in an area, for the ones farmers currently use, such as shifting from maize to sorghum and millet instead as the climate gets dryer. Such changes requires capacity and resources in the entire agriculture sector, from research to extension, from supply of agriculture inputs to farmers' agronomic practices, including pest management and post-harvest handling.

The issue of resilience of production systems will be critical. This calls for a broader portfolio of crops, and an increased emphasis in the farming systems on diversity within and among species. Putting more emphasis on neglected and underutilized crops is one such opportunity.

Market influences are likely to play an increasing role in all of the above scenarios. In particular, the increasing role of supermarkets will have a profound influence on what crops and varieties farmers' grow. A particular challenge is to match small-scale farmers' production systems to the modern supermarkets' demand for quality, quantity, packaging, sanitation etc. This calls for a much better integration between, and participation of, farmers, breeders and market specialists in the adaptation to climate change.

Much can also be learned from farmers' current strategies for coping with climatic stress, such as continuous introduction and trial of new materials that target specific climatic stresses, or maintaining a repertoire containing a wide diversity of planting material (i.e. varieties of same plant) or a mix of different plants from which farmers select planting materials depending on their perception of the cropping season.

## 5. LEARNING TO ADAPT TO CLIMATE CHANGE AND VARIABILITY

How can better conservation and use of agrobiodiversity contribute to adaptation to climate change? What knowledge, skills and attitudes will be required? What teaching and learning strategies could develop such competencies, in a situation with a rapidly evolving knowledge base? These are questions universities and colleges need to ask as they review curricula in coming years.

Because agrobiodiversity is shaped by interactions between genetic resources, the environment and people, the study of change in species and ecosystems is not enough. One also need to understand the underlying causes of change and loss in agrobiodiversity, including the various social, economic and policy processes that influence land use.

Many topics required for understanding agrobiodiversity and the processes that shape it – described earlier in this paper – are already taught in various subjects, such as integrated pest management, watershed management, soil and water conservation, agroforestry, integrated natural resources management, etc. These topics have in common that they require participatory approaches, a focus on farmer's realities through relevant practical learning experiences, and a combination scientific and traditional knowledge. Such tools are available, but may need to be adapted to the study of agrobiodiversity, especially taking into account that climate change will accelerate these processes. Other topics to be taught will be specific to the conservation and use of agrobiodiversity, in the context of adaptation to climate change.

Agrobiodiversity need to be understood at three levels: diversity of agroecosystems, diversity of species and variation within species, including the ecological and socio-economic processes that connect these levels. Especially, the study of population patterns and intraspecific genetic variation needs strengthening. Understanding the functions of fragmented landscapes and how they change in space and time will be increasingly important. Pollinator diversity, central to functioning landscapes, needs particular attention. The CBD therefore launched, in 2002 a cross-cutting initiative on the conservation and sustainable use of pollinators (CBD 2008). Much progress has been made in recent years in the study of multi-functional landscape mosaics by initiatives such as Alternatives to Slash-And-Burn (ASB) , or Rewarding Upland Poor for Environmental Services (RUPES). Again, learning resources available from these initiatives can be re-used and adapted.

Biodiversity is essential for food security and nutrition and offers key options for sustainable livelihoods (CBD 2008b). Food and nutritional security can be enhanced by making better use of a plant, tree and animal diversity, through participatory breeding of local varieties, or a commercialization of neglected and underutilized crops. However, there is a lack of nutrient information for many food species.

Plant breeding is already taught in most programmes, but in addition to 'classic' plant breeding, courses also need to cover alternative approaches to plant breeding which integrate: a perspective of agrobiodiversity and agro-ecosystem maintenance and use. This is important because breeding to meet low input and sustainable approaches may involve additional or different concerns from those that have been reflected in plant breeding curricula to date. Examples of topics which needs enhancement include participatory varietal selection and participatory plant breeding, base broadening and the development of multi-lines and variety mixtures as deliberate breeding strategies. Knowledge of both formal and informal seed systems will also be important.

Plant breeding can also enhance nutrition. Harvest Plus, a broad research programme, is aiming at reducing micronutrient malnutrition , or 'hidden hunger' by breeding staple food crops that are rich in micronutrients (Harvest Plus 2007). Many education programmes need to strengthen their interface between agriculture and health and nutrition.

Soil biodiversity provides very important environmental services through their role in the regulation of the water and nutrient cycles, nitrogen fixation, etc. Soil biodiversity is particularly sensitive to climate change, because it moves slowly.

Students will also need to know the rapidly changing international policy framework of relevance to agrobiodiversity, especially the three conventions on biodiversity, climate change and desertification, and their relevant programmes on agrobiodiversity. It is also critical to know about the International Treaty on Plant Genetic Resources for Food and Agriculture, adopted in 2001 and entered into force in 2004. The Treaty has contributed to the creation of a multi-lateral system of access and benefit sharing of the 64 most important crops and fodders species (FAO 2002). This has far-reaching implications for the sharing of germplasm among countries, for the global public good. As climate change will lead to increased movement of germplasm, such knowledge is essential in many agriculture professions.

Capacity is also urgent needed in Africa on interpreting and using outputs of climate models. Also urgent is capacity building on the issue of delivery of climate information to the agricultural sector.

Agriculture extension will need to work with farmers on the substitution of species and varieties adapted to the emerging climate. Farmers need information on new pests and diseases, and how to prepare for long-term effects (e.g. gradually increasing temperature) and short-term effects (e.g. increasing frequency of extreme weather events) of climate change.

## CONCLUSIONS

Adapting learning on agriculture to climate change is no easy task and many of the challenges involves is connected with a paradigm shift from a 'blueprint approach' to agriculture development, towards a 'learning-process approach'. Universities should review curricula to include agrobiodiversity dimensions in teaching of climate change. Innovative, experiential teaching methods and active student participation would help institutionalize holistic and action-oriented learning with a strong element of 'soft skills'. Education must be research-driven to incorporate a rapidly growing knowledge base on agrobiodiversity and climate change. Research capacity will need strengthening, including dramatically increasing MSc and PhD theses opportunities, for example on neglected and underutilized species, or on farmers' risk mitigation strategies.

A particular challenge is how to teach in a situation with uncertainty and lack of data. Teachers will not have the right answers, and so they will need to use innovative learner-oriented methods, rather than teacher-centered ones. They need to facilitate learning, rather than lecture. There is need to develop and use more interactive methods, questioning, discussion, etc. There is need to develop skills of seeking out new information which can support 'life-long learning', for example via web-based tools such as the Global Platform on Agrobiodiversity Research (PAR), endorsed by the CBD in 2004 http://www.agrobiodiversityplatform.org. PAR will become a valuable repository for learning resources and curriculum development tools on agrobiodiversity, and a vehicle for networking and knowledge sharing. Bioversity International is also currently developing a set of Learning Cases on agrobiodiversity, designed to stimulate class room discussion on key topics. These will gradually become available on-line to enhance problem-based learning on agrobiodiversity and climate change.

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