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Abstract

The role of agricultural biodiversity for sustaining ecosystem services crucial for food and agriculture becomes particularly relevant in the face of climate change, and has been widely recognised as a central part of climate-smart agriculture (CSA) since the concept was first launched in 2010. The utilisation of agricultural biodiversity in risk reduction and climate adaptation strategies has continued to attract attention, particularly as a component of micro-level strategies oriented towards diversification of production on farm, and land management measures aiming to improve resilience at landscape scale. Despite ample evidence of the value of agricultural biodiversity (including genetic resources) in climate change adaptation, the scalability of biodiversity-based measures is limited as they are often context specific and may have a lower relative value when compared to other options. Public policies can also play an important role in facilitating or hindering the adoption and spread of measures based on agricultural biodiversity.

Importance of agricultural biodiversity for agricultural production

Agricultural biodiversity includes all components of biological diversity of relevance to food and agriculture, encompassing animals, plants and micro-organisms that are necessary to sustain the structure, processes and key functions of agricultural ecosystems. Unlike biodiversity in the wild, agricultural biodiversity is largely the result of the evolution of diverse management practices of farmers, pastoralists, forest managers and other users of natural resources. However, there are also components that are not actively managed and used for production but that remain important as sources of genetic material and for their contribution to ecosystem services such as pollination, control of greenhouse gas emissions and soil dynamics.

A number of studies for both (non-agricultural) prairies ecosystems and for agricultural systems (Lin, 2011) demonstrate that more diverse ecosystems, with more species or more genetic diversity within species, often have higher overall agronomic productivity than simpler systems. Some of the overall yield increase associated with greater diversity is the result of the different functions performed by different species and the complementary niches that they occupy in the system (Yu *et al*, 2015).

The concepts of functions and niches are illustrated in crop pest and disease management from effective use of both inter- and intra-specific diversity providing enhanced resistance to outbreaks of pests and diseases as an important mechanism for increased yield and yield stability. Several mechanisms contribute to this effect, ranging from simple distance between susceptible host plants and physical barriers to transmission, to induced resistance from inoculum sources and competition among pathogen races that reduce disease severity. Studies have also shown that manipulating diversity to manage soil structure and fertility through the rotation and combination of cover crops and nitrogen-fixing crops increases the yield of the primary crop. Both tree-crop intercrops and planted tree fallows (in rotations) bring important but context-specific benefits in crop yields and in stabilising crop production (Sileshi *et al*, 2012). The combination of different species and breeds based on their niches and needs has been demonstrated to increase and stabilise production in livestock-based systems as well. Pastoralists often strive for a mix of productive and resilient individuals, a variety of lineages or animals with different feeding patterns in their herds in order to be prepared for all eventualities (Krätli, 2015).

Agricultural biodiversity in climate change adaptation strategies

Biodiversity can therefore contribute to the resilience of ecosystems, that is, their ability to respond to and recover from disturbance. In agricultural production systems this resilience may be manifested by relatively stable productivity levels over time and relatively more rapid recovery times following shocks. The careful management of agricultural biodiversity can therefore contribute to risk reduction and avoid heavy losses or total production failure.

Climate change considerably increases the risks involved in agricultural production and takes agricultural ecosystems' adaptation capacities to their limit. Large-scale variations in temperature and rain patterns limit land areas suitable for the cultivation of particular crops, requiring the introduction of other crops. Planting millet instead of maize is often presented as an example of crop substitution as a result of climate change (Schlenker & Lobell, 2010). Extreme climatic events take place in many parts of the world, more frequently and more dramatically, causing catastrophic effects in soil and water resources, and reducing arable land. Studies indicate a general trend towards the loss of cropping areas in sub-Saharan Africa, the Caribbean, India and northern Australia (Lobell *et al*, 2008). Climate change affects ecosystem dynamics in ways that are difficult to predict. Some of the possible consequences include: increased asynchrony between crop flowering and the presence of pollinators; the spread of favourable conditions for invasive alien species, pests and parasites; and changes in the presence and abundance of disease vectors.

The utilisation of agricultural biodiversity in risk reduction and climate adaptation strategies has been widely recognised, as illustrated by the multiple examples in the following section of this article. It has been a central part of CSA since the concept was first launched in 2010 (FAO, 2010) and has continued to attract attention since then, particularly as a component of micro-level strategies oriented towards diversification of production at the on-farm level and land management measures aiming to improve resilience at landscape scale.

On-farm actions

In recent years, a number of studies have documented how farmers and farming communities in different countries are adopting measures that rely on the use of agricultural biodiversity in response to climatic changes and their associated effects. These measures have been integrated in guides and sourcebooks supporting the adoption of CSA (FAO, 2013), and can be classified in three categories: cultivation of a larger number of species and farm diversification overall; introduction or increased cultivation of better adapted crops and varieties, and livestock animals and breeds; and integration of trees and shrubs into production systems.

Through the cultivation of more crops, farmers spread the risk of crop failure and increase yield stability overall. Different crops are affected differently by climate events, and this in turn gives some minimum assured returns for livelihood security. Crop diversification may take place spatially (*ie* more species cultivated at the same time) and temporally *(ie* crop rotation). Alternating cereal crops with legumes and broadleaf crops has been a common practice for maintaining soil nutrients, managing diseases and adapting crop production to climatic variations that has been widely successful (Yu *et al,* 2015). The cultivation of home gardens is another common strategy of crop diversification, particularly for domestic consumption in poor farming communities. Cover crops have been introduced to improve soil moisture and enhance seedling survival in areas which have recently started to suffer temporary drought. The introduction of poultry, small farm animals and other livestock has also been observed as a diversification strategy in response to climate change. In some regions of Africa, subject to long droughts, farmers tend to reduce their investment in crops, or even stop planting and focus instead on livestock management. Crop diversification and crop-livestock integration are often combined with adjustments in agricultural practices and adoption of low-input methods for soil fertility improvement, water conservation and weed management.

Another common climate change adaptation measure observed in farmers' fields is to grow crops and crop varieties that better cope with the new climatic conditions. Studies show that in several African countries, farmers are increasing cultivation of species that perform well in dry and hot seasons, such as finger millet, sorghum and fonio (*Digitaria* spp) for cereals, and cowpea for legumes (Schlenker & Lobell, 2010). A study documenting adaptation practices in Eastern Uttar Pradesh, in the foothills of the Nepal Himalayas, revealed that farmers have started to cultivate crops and varieties whose maturity cycles are not expected to be disturbed by possible flooding, in addition to anticipating or postponing the planting time. The substitution of traditional varieties with improved, early maturing ones has also been observed as part of adaptation strategies in places affected by drastic increases or decreases of temperature and rainfall (Dinar *et al*, 2008). The opposite is also observed: farmers stick to the cultivation of traditional varieties because of their capacity to respond and adapt to new climate patterns (Vigouroux, 2011) (Figure 1).

Figure 1. The Kyanika Women's Group in Kenya plays a role in conserving local farmer landraces of crops, such as sorghum, which grows in harsh environments where other crops do not grow well. (Photo: Y Wachira (Bioversity International))

As with crops, different animal species and breeds differ greatly in the extent to which they can tolerate climatic extremes. A number of farm animal species (and breeds within species) have revealed differences in heat tolerance. An example is the expansion of the distribution range of one-humped camels further south in Africa, replacing cattle, because of their better drought resistance (Faye, 2016).

Trees and shrubs on farms add structural complexity to production systems and can act as buffers against extreme effects. Planting trees has been observed in a number of countries as a way to protect crops from lower precipitation and reduced soil water availability (Sileshi *et al*, 2012). Agroforestry systems also protect crops from extreme storm events (*eg* hurricanes and tropical storms) in which high rainfall intensity and winds can cause landslides, flooding, and premature seed and fruit drop from crop plants (Lin, 2011). In addition, trees diversify the production within the farm, by providing fruits, nuts, essences, fibres and other products.

Landscape level actions

A number of studies show that climate change has encouraged farmers to make greater use of the natural resources and the spatial diversity of their landscapes, often acquiring new land and moving their farms to more promising areas. Dual farming systems are becoming common in areas where seasonal fluctuations have been exacerbated by climate change. For example, in the Limpopo basin in Mozambique, farmers use fertile lowlands during droughts and higher dryland fields if floodplain lowlands are flooded (Thomas *et al*, 2007). Forests and bushland within the landscape become an important source of food and other products when farm production fails and during lean periods between crop harvesting.

The use of agricultural biodiversity has also been documented in landscape-scale actions oriented to the restoration of natural resources which have been negatively affected by human exploitation and dramatic climatic events. Examples include: maintaining landscape diversity by preserving a mosaic of agricultural land and natural habitat; conserving and restoring riparian areas; establishing agroforestry and silvo-pastoral systems; and conserving and restoring wetlands.

Genetic diversity for climate change adaptation

Crop breeding programmes around the world have been breeding improved materials in response to climate-related stresses for a long time. In recent years, breeders have identified new breeding priorities responding to environmental constraints that are directly linked to climate change, such as increased drought, more extreme temperatures, more widespread flooding, higher levels of salinity and greater shifts in patterns of pest and disease occurrence. Climate change has fostered the use of new technologies, such as molecular breeding, crop modelling methods and localised participatory breeding approaches, to make genetic improvement more targeted and efficient.

These efforts have produced new varieties better suited to particular climatic patterns. However, crop breeding still faces important limitations. In the first place, public and private investments in crop research and innovation concentrate on a relatively small number of staple crops of international importance, neglecting a wide range of plants which have the potential to make agricultural production more resilient to climate change because of their adaptation to harsh and/or varied climatic conditions. Particularly in the developing world, very little private funding is directed to cereal crops such as sorghum, barley and millet; legumes such as beans, chick pea, pigeon pea, lentil, bambara groundnut and vetches; and roots and tubers such as potato, sweet potato, yams, and cassava.

It has been argued that both public and private crop development communities need to better target stability and resilience of crops to respond to climate variation, described by some authors as the 'robustness' of crops (Smit & Skinner, 2002). It is still common for breeders to see an anomalous climatic season (*eg* due to drought) as an inconvenience in field testing, and discard the results, rather than taking this as an opportunity to assess and retain the robustness features of varieties that do well under such conditions. Making crops more adaptive and responsive to variability and change may involve broadening their genetic base, and relaxing the uniformity and stability criteria that are usually applied to improved varieties.

In animal breeding, it is pastoralists that have developed a large diversity of drought-adapted breeds, and also breeds that can cope with increasing rainfall amounts. An example of the latter is the *Deccani* sheep in India, which is the only breed that can cope with extended and intensified precipitation periods in the Western Ghats. While scientific animal breeding has until recently been oriented almost entirely at increasing production, interest in adaptive traits is now growing.

In tree breeding, the issue of climate change adaption is particularly acute because of the longevity of tree species. Climate might change significantly within the actual lifespan of individual trees with commensurate problems of tree diseases (for example, alien invasive fungal diseases) that have received much attention recently in the global media (Alfaro *et al*, 2014).

Clearly, breeders rely on the availability and accessibility of the necessary genetic diversity. Current *in situ* and *ex situ* programmes for the conservation of genetic resources of domesticated species and their wild relatives require considerable improvements, including investments in knowledge generation and data management. The international community has made considerable progress to facilitate the exchange and accessibility of genetic resources for food and agriculture for the purposes of research and breeding. The *International Treaty on Plant Genetic Resources for Food and Agriculture* and its *Multilateral System of Access and Benefit-Sharing* is the most salient result of this progress. However, although both the *Treaty* and the recently adopted *Nagoya Protocol on Access and Benefit-sharing* support farmers and pastoralists to assert rights over crop varieties and animal breeds which they have developed and maintained over long periods of time, very few countries have put in place mechanisms to effectively recognise and protect these rights and ensure that the benefits derived from the use of traditional varieties and breeds are shared with those who have originated or maintained them.

The role of policies in promoting or hindering the conservation and use of agricultural biodiversity for climate change adaptation

Public policies can play an important role in facilitating adaptation to climate change, with significant implications for the adoption/adaptation options considered at the farm, landscape and national levels, and for the weight given to agricultural biodiversity under each option.

Intergovernmental processes and decisions within the *United Nations Framework Convention on Climate Change (UNFCCC)* have encouraged and facilitated national efforts to develop the necessary institutional setting and plans for climate change adaptation. An example of these are the *National Adaptation Programmes of Action (NAPAs)*, which were meant to be instruments for Least Developed Countries (LDCs) to access funds for implementing climate change adaptation activities. To date, 50 LDCs have developed NAPAs. A recent review of their content reveals that 11 nations included a relatively wide range of activities relying on the utilisation of agricultural biodiversity, while 10 included very few activities (Bedmar Villanueva *et al*, 2014). In the majority of the NAPAs, agricultural biodiversity was not incorporated in a comprehensive or systematic manner.

In the last few years, academia has increased its attention to the role of agricultural biodiversity in sustainable intensification. Similarly, intergovernmental policy fora such as the Commission on Genetic Resources for Food and Agriculture of the United Nations Organization for Food and Agriculture (FAO) have included biodiversity as a central element in their discussions around agriculture intensification. However, this increased international interest has barely been reflected in public policy measures at the national level. Agricultural public policies tend to favour streamlined and simplified production systems oriented to satisfy a reduced number of market chains, and often with aspirations to supply goods in international commodity markets. Traditional farming systems, and the agricultural diversity that they generate and maintain, are affected by these agricultural policies. Subsidy programmes and credit schemes focusing on particular crops and varieties, and animal farms and breeds, are a common example of public policies that create disincentives for the diversification of agricultural production. An illustrative case can be found in Malawi, where for the past decade, the Government has run an agricultural subsidy programme oriented towards the production of improved varieties of maize, including hybrid varieties. As a result, the climate adaptation programme in-country based on crop diversification had only very modest success. This was due in part to the loans and insurance programmes that farmers had with seed companies providing almost exclusively hybrid maize varieties (Chisinga *et al*, 2011).

So far, only a very few countries have developed agrobiodiversity policies, which, among other things, underscore the contributions of that diversity for climate change adaptation. A welcome exception is Nepal, whose *Agrobiodiversity Policy* links conservation, characterisation and sustainable use of biological diversity with climate change adaptation, acknowledging that it will be necessary to strengthen ties between farming communities, the national agricultural research administration, and both community and national genebanks.

Conclusions

There is ample evidence of the value of agricultural biodiversity in climate change adaptation in specific settings, but the importance of context limits generalisation: what allows one particular crop, farm animal, tree species or agricultural system to cope with particular climatic conditions may not work for other species or in other systems and climates. This means that the adoption of CSA practices based on biodiversity can be knowledge intensive, both at the research stage and during adoption, and must consider gender-specific perspectives on diversity. Culture plays an important role and may render socially invalid an option that from an agronomic perspective appears at first sight very promising. The scalability of practices based on agricultural biodiversity is also very much influenced by their relative value when compared to other viable options for climate change adaptation. It is important to take into consideration that significant trade-offs are often involved in balancing the maintenance of agricultural biodiversity within a production system with available management practices.

National policies need to integrate agricultural diversification (in terms of species, varieties, breeds and also types of production) in agricultural development programmes, and eliminate the barriers and disincentives that currently prevent a wide range of actors from using agricultural biodiversity more widely and strategically for climate change adaptation.

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