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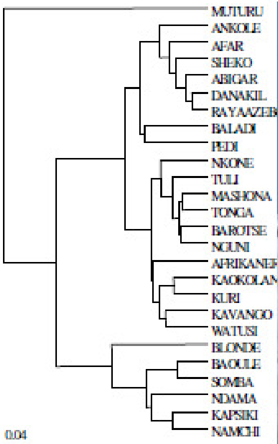
CeTSAF Centre for Tropical and Subtropical Agriculture and Forestry

Can agrobiodiversity enhance food security facing climate change? – The insurance function of biodiversity declined through all scales

Report from a workshop held in Göttingen, Germany, 10-11 March 2011



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Can agrobiodiversity enhance food security facing climate change?The insurance function of biodiversity declined through all scales- Report from a workshop held in Göttingen, Germany, 10.-11. March 2011

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GEORG-AUGUST-UNIVERSITÄT
GÖTTINGEN

Graphics courtesy of Padulosi, Simianer, Sharifi, and Gebauer

Mai 2011

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Motivation

Changing climate expressed as increased variability in temperature and precipitation (e.g. inundations, heat waves, droughts, shifts in rainy season) requires a high adaptive capacity of crop and animal breeds. Biodiversity at different scales is assigned an insurance function as it increases the probability that at least parts of the genepool, species, or ecosystems will match with changing environmental conditions. However, this insurance hypothesis deriving from ecological theory is far from being proven in the agricultural context, and also the challenges posed by a growing world population which is changing its diet toward a higher degree of meat pose trade-offs concerning the sustainability and stability of agricultural production.

Network-Forum on Biodiversity Research Germany (www.biodiversity.de) together with the Centre for Tropical and Subtropical Agriculture and Forestry, CeTSAF, invited an interdisciplinary and international group of participants to discuss the various mechanisms based on biodiversity that might ensure food security. Further possible trade-offs between high biodiversity and productivity, research needs as well as action demands should be analysed and discussed.

Introduction

Kerstin Wydra described the present challenges of a growing population, climate change, and demands of agricultural land for biofuels. At the same time, as described by the Millennium Ecosystem Assessment (2005), ecosystems and the goods and services humans can derive from them are degenerating. The FAO give warning of increasing hunger and malnutrition in the coming decades. Agricultural diversity may provide solutions, considering not only inter- but also intraspecific diversity of crops and livestock, and multiformity of beneficial organisms comprising soil biota. Biodiversity of pathogens though increases their environmental fitness and adaptation and their epidemic potential, it is therefore not regarded as 'beneficial'. On the other hand, the resistance of crops is a key factor which might be negatively influenced by climate change, resulting in higher susceptibility to a given or increased challenge. Here, microbial and chemical resistance inducers may play a role in increasing and stabilizing the tolerance of a plant to biotic and abiotic stress. Case studies along the scale of environmental interactions from the field - covering genotype x environment studies (G x E) -, to the greenhouse with host x pathotype interactions, to the single cell level with biochemical and molecular dissection of changes in the transcriptome and proteome after resistance induction revealed that deep understanding of the interactions across all scales is needed in order to develop measures to reduce the impact of climate change.

Johannes Kotschi pointed out that farmers over more then 10.000 years have tried to reduce the risk of production. An increased diversity of crops and animals have been main results. Since 150 years, however, this trend has reversed. The biological diversity is dwindling. Today, only three crops (rice, maize and wheat) account for 60% of global food supply, less and less varieties of one crop are used and varieties are getting increasingly uniform. This makes agriculture extremely vulnerable and deprives it of options that may be necessary to cope with climate change. Kotschi underlined the need to reinforce conservation efforts. He considers that ex-situ conservation in gene banks ("from the field to the fridge") is commendable but not sufficient. Gene banks have to be complemented by intensive efforts in in-situ conservation done by farmers and rural communities. Only then it will be possible to conserve a much wider range of plants with their manifold varieties and to expose crops to evolution and adaptation as part of the cropping cycle. Until today, in-situ conservation is largely neglected by governments, mainly NGOs are drivers of this activity.

As a second great challenge, Kotschi demanded that participatory evolutionary plant breeding be up-scaled as it is an important innovation in plant breeding. There is increasing evidence that composite cross populations can be superior to leading high-yielding commercial varieties because they perform better under various environmental conditions. Due to their genetic diversity, they have higher yield stability and can achieve a high yield. In doing so, agricultural intensification and biological diversity can be combined.

The ecological insurance hypothesis

Volkmar Wolters gave an introduction into the theoretical concept of the insurance hypothesis which based on works of Neam and Li (1997) and others. They stated that the biodiversity insures ecosystems against decline in overall functioning because a greater variety of species increases the probability that at least some will continue to provide functions. However, this is not always true, theoretical work showed that instability may increase with diversity. At least some non-random structures are needed according to Bascompte (2010) to ensure stability. Wolters provoked with the questions whether one should rather talk about an anti- or un-insurance hypothesis. Even high ranked biodiversity researchers state that the insurance argument is mainly applied because of gaps in our understanding of biodiversity (Mace et al. 2010). Maintaining all biodiversity is not only costly, it is impossible with regard to humans and their demands. Priority decisions have to be taken, which requires that the insurance function of biodiversity and its components have to be analysed context specific. This conclusion was debated, workshop participants stated that all biodiversity provides insurance as it increases options. However, enabling evolutionary potential is difficult to operationalize in current decision making. It also requires a decision what kind of ecosystem services are meant – mostly it is referred to agricultural production. Biodiversity is judged according to the usefulness for humans – as indicated in the introductory talk on the diversity of pathogens.

The genetic scale

Lothar Frese introduced the genepool concept of Harlan & de Wet (1971). The primary genepool (GP-1) includes the cultivated form and all wild species that cross easily. Between species within GP-1 generally no crossing barriers exist and gene transfer is easy. Hybrids between species of the secondary genepool (GP-2) and GP-1 species tend to be sterile but provided a plant breeder is willing to invest some efforts gene transfer is possible. The tertiary genepool (GP-3) defines the outer limits of the crop genepool. Species within this genepool must not necessarily belong to the crop genus. GP-3 includes all species producing hybrids with GP-1 species. Two criteria define the outer limit of GP-3: (i) the existence of a hybrid plant after artificial crossing and (ii) the availability of a functioning non-GMO gene transfer technique.

He then described the evolution of crop diversity and explained that genetic diversity is managed by plant breeders in breeding pools. If a breeding pool lacks genetic variation required to cope with a problem caused by a new pest or a new pathotype of a disease then plant breeders tap the gene pool to channel novel genetic variation into their breeding pool. Crop wild relatives are often the only source in which new traits or trait variation can be found. Hence, the protection of CWR in the natural habitat where novel variation evolves is a precondition for breeding progress and stability of agricultural production. Conditional for the evolution and maintenance of novel genetic variation is a functioning genetic system. The maintenance of these systems through appropriate measures ensures evolution (Namkoong et al. 1996).

Frese illustrated the relationship between the in situ, on farm and ex situ conservation techniques whereby the management of breeding pools can be understood as a part of the on farm technique. Plant Genetic Resources for Food and Agriculture (PGRFA) have to be managed ex situ and in situ on farm. Ex situ and in situ conservation strategies should complement each other. Depending on the responsibilities of ministries in individual European countries the development and implementation of complementary genetic resources conservation strategies may be more difficult if the responsibility is shared between ministries such as in Germany where three Federal Ministries contribute to genetic resources conservation, and moreover, the implementation of in situ and on farm measures falls into the responsibility of the Länder. If the competence is united within a single ministry such as in the United Kingdom the implementation of a complementary conservation strategy may be easier.

Frese stresses the responsibility of public institutions to monitor the state of genetic diversity within crops and CWR with the objective to maintain the insurance functions of gene and breeding pools.

Insurance is interpreted by Frese as "risk management primarily used to hedge against the risk of a contingent, uncertain loss" (Wikipedia 2011). Referring to the biodiversity value categories discussed by WBGU (1999) Frese said that the use and option value of species are the most relevant. As agriculture in industrialized countries is often understood as agricultural business, economic arguments are likely the most convincing if agriculture is to be convinced to undertake more actions in the field of crop and CWR genetic diversity conservation, i.e. actions required to protect an indispensible natural resource of breeding and agriculture. He explained that the economic value of a resistance gene found in a wild species, utilized by breeders, and used by farmers in form of an improved variety may change in time depending on the changing economic damage caused by a specific disease or pathotype. Despite this fact, methods suited to monetarize the insurance function of genetic diversity should be developed. He noted that information on the use value of a wild species or even a species' population containing unique resistance genes can considerably strengthen species protection programmes. The assessment of the value of gene pool components (alleles, genes, genotypes, populations, and species) with the objective to develop a gene pool portfolio guaranteeing the resilience of breeding remains a big challenge.

The turn-over of the global market for sugar beet seed is about 0.75 billion USD, just to mention one example (http://www2.syngenta.com/de/media/mediareleases/de_100527.html). This could be seen as the insurance value of the crop. If we take the total annual costs incurred globally for the maintenance of the global germplasm holding of that crop we get an idea of how much insurance fee we are willing to pay. Whether this annual investment is sufficient or insufficient from the risk management perspective is to be investigated and answered.

In the discussion it was argued that traditional knowledge plays an important role, too, although it remains unclear in what relation it is to the insurance function. Closest relation might be to ethical values of biodiversity as "it is not possible to compensate everything with money". Frese shared this view and added that with the shut down of each breeding programme within the public research sector and within the sector of small and medium sized breeding companies there is not only the risk of loosing breeding pools but also the breeder's crop specific knowledge.

Reza Sharifi came from the other direction so to say. He described the development of the last decades in poultry breeding especially in hot countries (USA, Brazil,..). Due to this dynamic growth in poultry production in hot countries, an intensive immigration of high-yielding genotypes, commonly developed in temperate countries, has taken place over the last decades. In the last few decades, substantial genetic progress has been made in broiler growth and feed efficiency (1.66 kg food -> 1.00 kg meet gain), resulting in broiler lines with higher potential for growth rate, but being more sensitive to suboptimal ambient temperature, particularly to heat. In general this genetic progress is combined by a narrower of optimal environmental condition and the continual need to provide expensive management facilities to control the ambient temperature in poultry houses. Especially in poor countries this causes problems as environmental conditions are more difficult to control (e.g. power blackout). Native fowl can use as reservoir for genomes and major genes with direct or indirect effects on adaptability. Particular major genes such as the frizzled plumage (F), naked neck (Na), and sex-linked slow-feathering (K) gene have been identified to have positive effects on heat tolerance. Breeding perspectives and breeding plans for the integration of local gene complexes and major gene like feather restricting genes into tropical oriented breeding strategies are presented. In the discussion it was pointed out that this kind of industrial breeding is contrary to participatory and decentralized breeding. It was questioned whether poultry breeding in general should be reduced as it is mainly used as animal feed and does not directly serve human nutrition. But poultry on the other hand has an economic insurance function for small farmers

The species scale

Jens Gebauer focussed on the significance of unterutilized fruit tree species with regard to food security during famines – but also food quality (vitamins etc.). A large number of products from fruit trees are available at the markets in Sudan, and also the species themselves, for example the baobabs, show a high variability in plant functional traits. Some species such as the tamarind seem to be suitable for reforestation of degraded saline soils. The observed large collection of fruits by the rural people leads to the extraction of seeds from the natural forests which lead further to a lack of regeneration. In Sudan most of the natural baobabs stands are overage. Furthermore, missing wildlife for breaking seed dormancy seems to be another aspect for the lack of seedlings. In the discussion it became clear that the insurance function of wild fruit trees is neglected in horticultural programs of the Sudan government which is focussing on exotic fruit species such as mango.

Marius Ekué talked about the enormous contribution agroforestry germplasm (AG) is providing to food security and how this can be improved. He gave an overview of the great diversity and life forms (roots, tubers, aromatic and medicinal plants, vegetables, grains, fruits, nuts, flowers etc) of neglected and underutilized species (NUS). NUS play a crucial role in the food security, nutrition, health, income generation and food culture of the rural poor; and are often of local or regional importance. In addition, they are particularly well adapted to their natural environment, have the potential to withstand climate changes and contribute to ecosystem stability. He mentioned 3 complementary ways in which agroforestry germplasm can contribute to enhance food security. The first is by promoting the domestication, uses and conservation of superior germplasm of priority species. The participatory tree domestication process illustrated by case study of ackee (Blighia sapida) in Benin was presented. The improvement of AG products marketing and extension as well as the maximization of their on-farm productivity are further ways to enhance their contribution to food security. The lack and or inadequacy of funding to work on such species should also be addressed. Finally, in light of the growing decentralization process and subsequent transfer of power to local authorities (especially in many sub-Saharan African countries), such stakeholders should be involved in any development project concerning AG.

Stefano Padulosi analysed the role of on-farm conservation of underutilized crops in the wake of climate change. He reminded of the impressive situation regarding the dominance of major crops in today's agricultural production: just 20 crops are cultivated over 82% of the global agricultural area in 2008. This is an astonishing figure if compared with the 7,000 food crops used by people at the local level for food alone. The increased marginalization of local crop diversity ultimately results in reduced options for the poor in addressing climate change. Efforts to promote local crops (also defined as neglected and underutilized/NUS) are also challenged by the fact that too often these resources are wrongly perceived as being "food of the poor". Within the global efforts aimed at enhancing adaptation and resilience of production systems in the face of climate change, local crops/NUS have much to offer in view of their comparative advantage to thrive with less inputs and in difficult terrains when compared with major crops. For instance, in the case of minor millets, which are less demanding in terms of water, farmers in India are able to get reasonable yields using only 1/10 of the water requirement needed for growing rice. Such a characteristic coupled with very good nutritional profiles, make minor millets strategic for areas predicted to suffer from rainfall shortages in south Asia. Another point of great concern shared by Padulosi was the ongoing loss of traditional knowledge, no longer transmitted to the younger generations. Its rescuing and documentation calls for urgent attention. The highly strategic role of on farm conservation as complementary measure to ex situ was particularly emphasized and greater attention for its promotion advocated. On farm conservation was presented in its various contributions, technical (viz. maintaining a diversity of ecological conditions), social (viz. the safeguarding and/or re-establishment of traditional knowledge and social networks), political (viz. increasing the farmers' control over genetic resources and support global sustainability). Developing the proper trade-offs between marketing a NUS crop (which may lead to genetic uniformity within the species) and conservation of its genetic diversity was also mentioned as an area requiring more attention by research.

The ecosystem scale

Devra Jarvis provided arguments how crop biodiversity has the potential to reduce risks within the agricultural production system. She applied the concept of using the crop biodiversity within the agricultural ecosystems as a provider of ecosystem regulating services, such as disease and pest control, pollination efficiency and buffering of extremes and unpredictable changes in temperature and precipitation. However, this insurance portfolio should at the time be combined with increasing productivity in the agricultural production system. Some case studies showing evidence for mechanisms of risk management were provided. For example, the damage per household due to pests or weather extremes decreases with increasing the diversity portfolio. Here diversity is measured both in terms of the number of varieties grown by farmers and the evenness of frequencies of the different varieties grown. What is more striking, however, was the reduction in variance of disease average as diversity increases, i.e. an indication that some of the uniform farms may be fine in some cases, if they happen to be growing a winning variety, but if not, then these farms get hit far worse in terms of crop damage when there is a change in pathogen or pest biotype. Minimising risk while maintaining productivity, requires not only better management of agricultural biodiversity, but also linking this management with improved soil and water management. These methods only become sustainable when they go hand in hand with interventions that empower and strengthen the capacity and leadership abilities of local communities and institutions.

Teja Tscharntke emphasized that local and landscape-wide agricultural intensification is the major driver of biodiversity losses and associated ecosystem services. Agricultural intensification and yield increases are negatively related to biodiversity and associated functions in Europe (with pesticides playing a major role), but not in tropical smallholder systems, opening opportunities for win-win approaches (Clough et al. 2011). Higher diversity of pollinators and of biological-control agents are often associated with improved functional success, for example with respect to pollination success and fruit set and pest predation reducing pest density. Imagine a world without functional groups such as pollinators and natural enemies! This would cause dramatic economic problems because one third of the global food production is influenced by pollinators (Klein et al. 2007) and natural enemies hinder many notorious pest insects and potential pest insects from outbreaks. Broadening the view from local to landscape scales is needed, because the spillover across managed and natural habitats decreases the probability of the extinction of species and their ecosystem services (Tscharntke et al. 2005). Beta diversity (showing the role of the dissimilarity of local communities) is the driver of landscape-wide biodiversity, providing so-called response diversity to disturbances and changing environments. High biodiversity on a landscape scale may cause resilience, i.e. the capacity of the agroecosystem to reorganize after disturbance.

The economic dimension

In addition to arable land, grasslands substantially contribute to the food security in many regions of the planet. Many of insights into the ecosystem level phenomena of the insurance hypothesis were gained from grassland plots – including results on the drought resistance of grassland biomass production in relation to grass species richness. Securing the ability of grasslands to contribute to food security in the face of still unpredictable climatic and other global changes is an issue not only to farmers but also to society at large. Against this background, Jan Barkmann provided results on the willingness of the general public to pay for the insurance services of species-rich temperate grasslands (choice experiment study). Even non-expert respondents understood the insurance service concept well. A substantial annual willingness-to-pay (WTP) was documented. The results suggest, however, that WTP for protection against concrete risks or against certain disimprovements tend to be higher than for the rather abstract insurance services provided by species-rich grasslands.

Henner Simianer provided insight into priority setting and decision making in livestock conservation. Farm animal species as such are not endangered but livestock breeds. Threats are for example uncoordinated cross-breeding. To assess the extinction probability, the breeds are evaluated applying a scoring system. Not the threat is judged relevant but the expected future options of the whole species, manifested by genetic diversity of the set of conserved breeds. An algorithm based on general diversity theory of Martin L. Weitzmann, Harvard University, allowed the calculation of the optimal number and identity of conserved lines under limited (financial) resources, based on the maximum likelihood analysis of distances within a phylogenetic tree. This approach is distinct to the red list approach which mainly looks after the exposure of single breeds and not the overall diversity.

Roland Olschewski focused in his talk on the trade-offs between current income and future options. He judged the Millennium Ecosystem Assessment as a useful basis although it had some inherent problems: no scales, no unequivocal thresholds. The public insurance function as e.g. provided by many ecosystem functions conflicts with private opportunity costs. He provided the pollination function of bees as an example. Under the assumption of weak sustainability, replacing natural bee habitats by, e.g., renting private bee hives does not necessarily lead to a trade-off between sustainability and efficiency. Under strong sustainability such a substitution is not allowed. The preservation of natural habitats generates option values for future generations. However, providing this public insurance function causes private opportunity costs today. Rewarding landowners for the provision of this service would give incentives to reduce pressure on natural landscapes.

Some reflections

The insurance function of agro-biodiversity according to the insurance hypothesis, meaning the provision of different options under changing environmental conditions, was mainly applied in the context of resistance against pests and diseases, and to nature as "backing up" system to agriculture under increasing abiotic stress. From the conceptual view the insurance hypothesis overlaps with the "portfolio" approach and the risk management approach.

The insurance function of biodiversity depends highly on a specific context, or more precisely, on one or a bundle of ecosystem services. To judge the contribution of biodiversity to food insurance, scale is extremely important. With regard to the spatial scale, landscape heterogeneity plays an important role as reservoir of biodiversity. In temporal scales, wild crop relatives and genetically distinct animal breeds are important to maintain adaptive capacity of crop and livestock species. To understand the interacting networks and influences, and to develop solutions the scales from ecosystem and landscape to single plant and cell biology need to be considered.

Trade-offs mainly refer to the height of yields per area. For the global scale this might imply a lower amount of food available (neglecting other factors such as the share of vegetarian diet, wasted food, food quality etc.). Facing shortages with regard to phosphorous and other nutrients farming strategies that maintain biodiversity will be more sustainable on the long term than high input strategies relying on the high provision of energy and nutrients.

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Acknowledgement

We thank the participants of the workshop for their contribution to the workshop and the resulting report. The workshop was organised together with CETSAF in the frame of the Netzwerk-Forum Biodiversity Research Germany, funded by the Federal Ministry of Education and Research (BMBF grant 01 LC 0831 C).

Netzwerk-Forum zur Biodiversitätsforschung Deutschland (NEFO) ist eine Kommunikationsplattform für Wissenschaftlerinnen und Wissenschaftler und Anwenderinnen und Anwender von Wissen zur biologischen Vielfalt. NeFo ist ein Projekt im Rahmen von DIVERSITAS-Deutschland e.V. (www.diversitas-deutschland.de). Ein wichtiges Ziel von NeFo ist es, die Forschung unterschiedlicher Disziplinen, die sich mit gesellschaftlich relevanten Fragestellungen zur Biodiversität befasst, in öffentliche Diskussionen zu Themen der biologischen Vielfalt einzubinden.
Projektpartner sind das Museum für Naturkunde Berlin, die Universität Potsdam und das Helmholz-Zentrum für Umweltforschung - UFZ. NEFO wird gefördert durch das Bundesministerium für Bildung und Forschung. Weitere Informationen finden Sie unter: www.biodiversity.de