Biodiversity for Food and Agriculture

Contributing to food security and sustainability in a changing world

PLATFORM FOR AGROBIODIVERSITY RESEARCH

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Contributing to food security and sustainability in a changing world

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Table of contents

ACKNOWLEDGEMENTS iv
FOREWORD v
EXECUTIVE SUMMARY vii

Introduction 1

Biodiversity for food and agriculture as a basis for food security 3

Global challenges and change 7

Land availability 8
Water Scarcity 11
Overuse of nutrients 12
Climate change 14
Productivity and sustainability 15
Farming systems 16
Broader social demands for change 17

Biodiversity for food and agriculture as a basis for food security 18

Scales, links and connections 19
Overcoming scepticism 21

The use of biodiversity for food and agriculture in practice 23

The benefits of different types of diversity in agricultural landscapes 24
Using multiple species in agricultural landscapes 26
Soil fertility 26
Pest control 29
Increasing yield and functionality through niche complementarity 32
Agroforestry 32
Crop and livestock production 34
Crop and fish production 36
Pollination 37
Agriculture and nutritional diversity 38

Enabling and supporting the increased use of biodiversity for food and agriculture 40

International and national policies 40
Economic and market perspectives 43
Community based approaches 45
Nutrition and health 47
Awareness and education 48
Research needs and opportunities 49

Conclusions 51

REFERENCES 53
ANNEX 1 66

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FAO and the Platform for Agrobiodiversity Research (PAR)

have collaborated on an initiative to explore the contribution that biodiversity for food and agriculture can make to improving food security and agricultural sustainability and meeting the challenges of global change, particularly climate change. A major part of this collaboration was the organization of an Expert Workshop which was held at FAO Headquarters, Rome in April, 2010. This Workshop explored the different challenges that confronted agriculture and the options that existed or could be developed that would be needed to meet the challenges of feeding the world, coping with climate change and improving impact of agriculture on the environment.

This report reflects the conclusions of the Workshop and the analysis undertaken by FAO and PAR over the past year. Many people have contributed to the information compiled in this report and to the development of the ideas and proposals presented in it. The participants at the Expert Workshop are listed in Annex 1 and their continuing support and contribution is gratefully acknowledged as is the continuing support of FAO and of Bioversity International to the work of PAR. The Editors would also like to thank Sara Hutchinson and Giulia Baldinelli for their contribution to the Expert Workshop and to the compilation of this report.

Foreword

After two decades of neglect, and particularly since the recent global food crises, international attention has focused on the need to increase investment in agriculture. The outcomes of recent gatherings of global leaders, including heads of state, indicate a consensus on the need to increase food production to feed a still growing population, but also on the need to ensure sustainability of that increase. Numerous global challenges are affecting the way agricultural production needs to be addressed, today and in the future. Examples of such global challenges include population increases, urbanization, an increasingly degraded environment, an increasing trend towards consumption of animal protein, and of course climate change. Agricultural production systems need to focus more on the effective conservation and management of biodiversity and ecosystem services in order to address the twin objectives of environmental sustainability and food security.

Understanding and enhancing the role of biodiversity and the genetic resources and ecosystem functions it conveys is essential. Biodiversity underpins to food security, sustainable livelihoods, ecosystem resilience, coping strategies for climate change, adequate nutritional requirements, insurance for the future and the management of biological processes needed for sustainable agricultural production.

A basic challenge to improving food security by capitalizing on agricultural biodiversity over the next few decades, is to balance relevance and realism. While there are many possible ways in which agricultural biodiversity could improve food security, they may not all be feasible in all production systems or they may prove uneconomic or too labour intensive for adoption by farmers. New approaches based on increased reliance on biodiversity may fit uneasily with production practices based on continuing simplification of agro-ecosystems. Identifying what works in practice, taking into account regional differences and different scales of farming, as well as supporting change will therefore also be essential elements of using diversity to improve sustainability, and food security in the face of change. Successful approaches are likely to bring together positive aspects of sustainable intensification, to reflect the realities of small-scale farmers and to be supported by appropriate policy and economic frameworks.

Strategies, actions, agricultural practices and approaches, and an enabling environment that promote the conservation and the sustainable use of biodiversity for food and agriculture is of utmost importance. This was highlighted at the recent Conference of the Parties of the Convention on Biological Diversity, at its Tenth Meeting in October 2010, in Nagoya, Japan.

Specifically, in its Decision X/34 on Agricultural Biodiversity, the Tenth Conference of Parties

> "notes the importance of the issue of sustainable use of biodiversity to the programme of work on agricultural biodiversity and invites Parties and requests the Executive Secretary to ensure coherence between the programme of work

on agricultural biodiversity and Article 10 of the Convention, on sustainable use…; and requests the Executive Secretary and invites the Food and Agriculture Organization of the United Nations and Bioversity International, together with other relevant partners, including indigenous and local communities, subject to available resources, to provide further information on the nature of sustainable use of agricultural biodiversity and sustainable agriculture…".

Given the importance of the sustainable use of biodiversity for food and agriculture, and the critical role of biodiversity and ecosystems in sustainable intensification of agricultural production, this publication addresses these issues, and by doing so also contributes to furthering the implementation of the Convention on Biological Diversity's Programme of Work on Agricultural Biodiversity and of FAO's strategic framework on sustainability.

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Executive summary

Agriculture needs to change. It must become increasingly sustainable at the same time as meeting society's goal of providing sufficient, safe and nutritious food. Production practices based on a continuing and increasing dependence on external inputs such as chemical fertilizers, pesticides, herbicides and water for crop production and artificial feeds, supplements and antibiotics for livestock and aquaculture production need to be altered. They are not sustainable, damage the environment, undermine the nutritional and health value of foods, lead to reduced function of essential ecosystem services and result in the loss of biodiversity. At the same time, food production needs to make its contribution to reducing the number of people who are food insecure and malnourished which remains unacceptably high at nearly 1 billion.

There are already many well-established ways of improving both the sustainability of agriculture and its capacity to deliver safe, nutritious products for a healthy diet. Integrated pest management, conservation agriculture, ecoagriculture and organic agriculture are examples of approaches to agricultural production that improve sustainability in a variety of ways that are based on enhancing efficiencies of biological processes and agro-ecosystems, and that are being used over many millions of hectares around the world.

Changing agriculture and food production in ways that ensure improved sustainability and a healthier and more nutritious food supply involve the increased use of biodiversity for food and agriculture. If loss of biodiversity (including agricultural biodiversity) has been a feature of agricultural intensification, increased use of biodiversity is necessary to improve sustainability and to cope with climate change.

The challenges

Agricultural production will need to deal with major challenges over the next 40 years. Production will need to increase by about 70% (although at a declining rate over the period as populations begin to plateau) to cope with population increases and changed demands for meat, dairy and other products. There will be increased competition for land and water from growing urban populations and increased reluctance to see natural landscapes converted to agricultural uses. Phosphorus may well begin to run out by the end of the century and current levels of nitrogen pollution will become unacceptable.

Climate change is expected to cause substantial reductions in potential crop production in southern Africa (up to 30% by 2030 for maize production) and South Asia (up to 10% for staples such as rice; declines in millet and maize production could exceed 10%). While crops in mid- to high-latitudes may benefit from a small amount of warming (up to +2°C), greater temperature increases will cause declines in production here too. Localized extreme events and sudden pest and disease outbreaks are already resulting in greater unpredictability of production from season to season and year to year and require rapid and adaptable management responses.

Most of the food insecure people (70%) live and work in rural areas and small-scale farmers still constitute 50% of developing country rural populations. Improving food security, reducing poverty and improving sustainability over the next decades will be inextricably linked to the development of strategies that are relevant and appropriate to small-scale farmers. At the same time, production practices will need to reflect a growing awareness by consumers of the importance of producing food in socially, environmentally and ethically acceptable ways.

A new approach

"There are three reasons for needing to directly address the role of biodiversity for food and agricultural in improving food security and sustainability: first, because of the integrated nature of the contribution; second, because it involves thinking about agriculture in a different way, one that brings together the very positive elements of the various approaches such as sustainable intensification, multifunctionality and the importance of appropriate policy and economic frameworks; and third, because of the need to take account of the realities of small-scale farmers and communities who maintain the agricultural biodiversity that will be used."

Over the next 40 years agricultural practices will need to become increasingly flexible, reflecting the multifunctional nature of agriculture and the need to deal with change and uncertainty. Resilience and adaptability will become more important properties. To achieve this, production systems will need to have greater reliance on ecological processes that produce positive feedbacks on sustainability and production and ensure improved provision of all ecosystem services. These changes will involve the integrated use agricultural biodiversity, bringing together the contributions of crops, livestock, agroforestry species, soil organisms, pollinators and other components. Capitalizing on diversity-based dynamics will give agricultural systems improved capacity to achieve high levels of productivity and to be economically profitable with a reduced need for external inputs.

The sustainable use of agricultural biodiversity is likely to be particularly beneficial for small-scale farmers, who need to optimize the limited resources that are available to them and for whom the access to external inputs is lacking due to financial or infrastructural constraints. Benefits on a large-scale can also be achieved by focusing on improvements relevant to large commercial farmers and conservation agriculture has already been effective in this respect.

Inevitably, there is considerable scepticism over the practicality of the widespread adoption of agricultural production practices that embody a greater use of biodiversity for food and agriculture and a greater emphasis on ecosystem functions. Two major geopolitical realities have a constraining effect on peoples' thinking. Firstly, modern, intensive farming in developed countries receives very large levels of financial support and all sectors of the agricultural and food industries are linked in to this highly subsidized system to a greater or lesser extent. Secondly, there is a continuing commitment to ensuring that food prices remain low and that basic foodstuffs are affordable by all sectors of society including the poorest. These both tend to lead to a disinterest in the nature of agricultural production systems and present a very real barrier to the development of new approaches to production.

However, it is increasingly recognized that an appropriate policy framework can largely overcome these constraints and, indeed, must be developed.

A number of approaches have already been developed that use biodiversity for food and agriculture to achieve sustainable increases in productivity and provide a sounder ecological basis for agriculture. The use of multi-species and multi-breed herds and flocks is one strategy that many traditional livestock farmers use to maintain high diversity in on-farm niches and to buffer against climatic and economic adversities. Species combinations also enhance productivity and yields in aquatic systems. Crop rotations, intercropping and growing different varieties of a single crop have all been shown to have beneficial effects on crop performance, nutrient availability, pest and disease control and water management. Multi-cropping, intercropping, alley farming, rotations and cover cropping are all ways of combining crop species that have positive effects on productivity and yield stability.

Below-ground biodiversity is strongly influenced by management practices such as tillage, crop combinations, organic-matter inputs, application of fertilizers and pesticides. All management practices that use complex, ecologically-grounded approaches rather than applying off-farm inputs for achieving short-term outputs dedicate great care to nurturing soil biodiversity. In so doing, they benefit from positive cascading effects on the efficiency and productivity of the entire system, as in the case of conservation agriculture and organic agriculture.

Integrated pest management practices are well-established and have been adopted by millions of farmers throughout the world. Successful programmes have shown, for example, that conserving arthropod biodiversity by helping increase local understanding of how agro-ecosystems function is a key ingredient of effective pest management in rice production. These diversity-rich approaches, together with others such as increased use of agroforestry species, the further development of home gardens, the use of fish–rice systems and the improved maintenance of pollinator diversity, demonstrate the contribution that biodiversity for food and agriculture can make. At the same time a richer diversity of products from diverse production systems can make a significant contribution to improving the nutritional status and health of both the urban and rural poor around the world.

The way ahead

The shift in thinking and the changes in approach that will be needed encompass policy, social and economic aspects. They will need to involve and engage consumers and all other actors in the agricultural and food industries. The approaches needed will be particularly concerned with supporting small-scale farmers and in ensuring effective ecosystem function and diversity deployment at the landscape level. A number of actions can already be identified that are likely to have a significant effect and to create the framework for the redirection of agriculture that is needed. These include:

- ensuring that international instruments and agendas take adequate account of the contribution that agricultural biodiversity can make to their overall objectives;
- implementing changes at national level with respect to the support given to pesticides and fertilizers so as to favour biologically-based options;

- testing a range of economic instruments such as payment for ecosystem services in agricultural landscapes, internalizing environmental costs, and increasing the responsibility of the private sector;
- promoting approaches that reflect an overall ecosystem perspective, include socio-ecological considerations, and take account of agricultural, environmental and social policies, links and trade-offs;
- supporting and expanding the various research agendas that have already been developed by organizations and groups aiming to increase the effective use of biodiversity for food and agriculture;
- strengthening local institutions and the capacity to maintain and use biodiversity for food and agriculture at local levels through mechanisms such as farmer field schools, participatory crop and livestock improvement and locally-identified adaptation strategies; and
- making consumers aware of the benefits of having a sustainable diet, encompassing a high diversity of foods, for their own health and the health of ecosystems.

Underpinned by a framework that takes particular account of the needs and interests of small-scale farmers and of the rural poor and meets societal needs for a safe and healthy supply of food, these approaches will also make a real contribution to improving food security and to helping meet the challenges of climate change over the next 40 years.

Introduction

AGRICULTURAL PRODUCTION PRACTICES NEED TO CHANGE. They need to become increasingly sustainable at the same time as meeting societal goals of access to sufficient, safe and nutritious food (Baulcombe et al., 2009; IAASTD, 2008; World Bank, 2007; Nellemann et al., 2009). The Declaration of the World Food Summit on Food Security (FAO, 2009a) stated that not only should there be increased investment in agriculture to meet the challenge of achieving food security but that this investment should be directed more consistently towards sustainability. Production practices based on a continuing and increasing dependence on external inputs, such as chemical fertilizers, pesticides, herbicides and water for crop production and artificial feeds, supplements and antibiotics for livestock and aquaculture production, need to be altered. They are not sustainable, damage the environment, lead to reduced function of essential ecosystem services, result in the loss of biodiversity (MEA, 2005) and undermine the nutritional and health value of foods. While production and productivity of the major food crops continue to increase, the number of people who are food insecure and malnourished remains unacceptably high at nearly 1 billion and reached a record high in 2009. Over the last ten years there has been increasing evidence that production and productivity are increasingly influenced by the changing frequency and intensity of extreme weather events (IPCC, 2007). It has been argued that unless more sustainable management of food production is adopted prices will rise and become increasingly volatile and the damage to the environment will continue to increase (Nellemann, 2009).

There are already many well-established ways of improving both the sustainability of agriculture and its capacity to deliver safe, nutritious products for a healthy diet. Integrated pest management, improved soil and water management, conservation agriculture, ecoagriculture and organic agriculture are all examples of approaches to agricultural production that improve sustainability in variety of ways and that are being used, often on many millions of hectares, in various parts of the world and in a range of socio-economic contexts. These assorted approaches are based on enhancing the efficiency of biological processes in agro-ecosystems. Biological processes, such as nutrient cycling, can be undermined by continuous overuse of chemical inputs. In this context, agricultural systems can no longer be considered only as simplified input–output systems, but as systems that function best when the nature and interconnectedness of the various ecosystem components and functions are recognized and fully utilized as the basis of all forms of agriculture. There has also been an interest in the nature and quality of food produced, as indicated by the growth in popular civil society movements such as Slow Food and by changes such as increases in consumption of local vegetables in Nairobi following active efforts by government agencies, civil society organizations and others such as Bioversity International.

Changing agriculture and food production in ways that ensure improved sustainability and a healthier and more nutritious food supply involves the increased use of biodiversity for food and agriculture[1]. If loss of biodiversity (including biodiversity for food and agriculture) has been a feature of agricultural intensification (MEA, 2005), increased use of biodiversity is necessary to improve sustainability. The loss of significant biodiversity from many production systems has left them impoverished, vulnerable and dependent on continuous use of external inputs. This loss limits the future capacity of agriculture to respond or adapt to changes such as increased urbanization, reduced land, water and resource availability and climate change.

Much of the discussion on the potential use of biodiversity for food and agriculture to date has used a component-based approach, exploring the specific ways in which biodiversity for food and agriculture could contribute to improved production and sustainability (see, for example, Østergård et al., 2009, on crop diversity; Notter, 1999, on livestock diversity; Bartley et al., 2007, on living aquatic resources diversity; FAO, 2001, on forest resources; Swift, 2004, on soil biological diversity; and FAO, 2008b, on pollinator diversity). In reality, there are links and associations between the various components by which diversity in one component complements or interacts (positively or negatively) with that in other components. The contribution of biodiversity for food and agriculture to improving food security and sustainability needs to be considered not only in terms of the role of diversity in the various components but also in terms of how integrated systems that capitalize on interactions between components can strengthen productivity, resilience, adaptability and sustainability of agro-ecosystems at meaningful scales.

The development and widespread adoption of integrated, diversity-rich options for sustainable agriculture and food security will require a holistic, interdisciplinary, ecosystem and biologically-based approach that takes account of the social, economic and cultural aspects of agriculture (MAE, 2005; IAASTD, 2008). Such an approach involves recognizing the multifunctional nature of agriculture and the importance of considering the broad range of provisioning, regulating, supporting and socio-cultural services provided by agricultural biodiversity. It acknowledges the interconnectedness of biodiversity, food security and human and ecosystem health and in so doing indicates the requirement to involve a range of stakeholders (farmers, consumers, agricultural and food industries and researchers) in interdisciplinary interventions. It also recognizes the importance of smallholder farmers. About 50% of developing-country rural populations are smallholders (UNCTAD, 2010) and a further 20% are landless. Smallholder farms constitute about 85% of all farms (IFPRI, 2005). These smallholders (or small-scale farmers) include pastoralists and those dependent on artisanal fisheries and aquaculture. The farming systems are usually complex, diverse and risk prone and suffer in varying degrees from problems associated with low levels of technology and unpredictable exposure to markets (Chambers et al., 1989; Morton, 2007).

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1 Biodiversity for food and agriculture includes all the components of biological diversity of relevance to food and agriculture together with the 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, that sustain the functions, structure and processes of the agro-ecosystem. This diversity has been maintained by farmers and communities for millennia and remains a key element of the livelihood strategies of poor, small-scale farmers throughout the world. In this document it is used synonymously with agricultural biodiversity.

Climate change is likely to be a major driver of change in agriculture, requiring changes in production methods and in the crops and animals produced. Rising income and increased urbanization will be two other important drivers of change. By 2050 it is expected that 70% of the world's population will live in cities (UN-HABITAT, 2008). A further major driver is likely to be increasing population; it has been estimated that about 70% more food will need to be produced by 2050 than was produced in 2005 (Bruinsma, 2009) to meet the needs of a population that will have grown to over 9 billion (UN, 2008)[2]. However, an important feature of population growth over the next 40 years will be that it will occur at a declining rate. The Food and Agriculture Organization of the United Nations (FAO) has suggested that over the next 40 years world agriculture may be transiting to a future when global population growth will no longer be a major driving force for further growth in world food demand and production (FAO, 2006). Indeed, the expected slowdown in population growth together with the potential role of agricultural systems in mitigating and adapting to climate change offer unprecedented opportunities to redirect the drive for increasing yields towards developing more sustainable means of agricultural production adapted to change.

This paper considers what is involved in ensuring that biodiversity for food and agriculture contributes to improved food security and to feeding the world in the coming decades within a framework of enhanced agricultural efficiency and sustainability. Starting from the perspective of the World Food Summit held at FAO in November 2009[3], the paper summarizes some major changes (and their drivers) expected over the next 40 years that are likely to present the most pressing challenges to agricultural production, global food security and environmental quality. It considers the essential characteristics or properties needed by sustainable agriculture and presents examples of how biodiversity is contributing to low-input, sustainable *and* productive systems. It offers a perspective on the fundamental change in thinking needed that is already at least partly under way. Finally, it outlines a range of policy initiatives, market interventions and other actions that can facilitate wide adoption of the required approaches.

A basic challenge in describing the contributions that agricultural biodiversity can make to improving food security over the next few decades is one of relevance and realism. While there are many possible ways in which agricultural biodiversity can improve food security, they may not all be feasible in production systems or they may prove uneconomic or too labour intensive for adoption by farmers. New approaches based on increased use of biodiversity may fit uneasily with production practices based on continuing simplification of agro-ecosystems. Identifying what works in practice, taking into account regional differences and different scales of farming, as well as supporting change, will therefore also be essential if diversity is to be used to improve sustainability and food security in the face of change. Successful approaches are likely to bring together positive aspects of sustainable intensification and multifunctionality in agriculture, to reflect the realities of small-scale farmers and to be supported by appropriate policy and economic frameworks.

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2 http://esa.un.org/unpp/
3 http://www.fao.org/wsfs/world-summit/en/

Biodiversity for food and agriculture in the global political agenda for food security

SINCE THE GLOBAL FOOD CRISIS IN 2008, there has been a renewed recognition of the need to increase investment in agriculture. The outcomes of recent gatherings of world leaders[4] indicate a consensus both on the need to increase food production to feed a still growing population and on the need for enhanced sustainability.

The Declaration of the recent World Summit on Food Security (FAO, 2009a) highlighted the issue of investments in agriculture specifying that these should be directed more consistently towards sustainability, by increasing and supporting sustainable agricultural production and productivity, through development and implementation of practices aimed at conservation and improved use of the natural resource base, protection of the environment, and enhanced use of ecosystem services.

This acknowledgment of the importance of ecosystem services from agriculture constitutes a clear entry point for recognizing the specific contribution of biodiversity for food and agriculture to ecosystem function and to the ensuring the continued capacity of agricultural systems to providing food security in the face of global changes. A number of aspects of improving food security identified in the World Food Summit to which agricultural biodiversity is explicitly or implicitly relevant are listed in Box 1.

Programmes and activities that contribute to or support the enhanced use of biodiversity for food and agriculture are being implemented by international and national agencies and organizations. One of FAO's global goals is the sustainable management of natural resources for the benefit of present and future generations, which includes work on crops, livestock, fisheries and aquaculture resources, forests and trees, land, water and genetic resources. It also encompasses other related issues such as improved food security and better nutrition, improved quality and safety of food, and markets. Other UN agencies, including the United Nations Environment Programme (UNEP), the United Nations Educational, Scientific and

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4 Including the June 2008 Declaration of the High-Level Conference on World Food Security: the Challenges of Climate Change and Bioenergy (Rome, Italy); July 2008 UN High-Level Task Force on the Global Food Security Crisis – Comprehensive Framework for Action (CFA); January 2009 High Level Meeting on Food Security for All (Madrid, Spain); May 2009 17th Session of the Commission on Sustainable Development (New York, USA); and July 2009 G8 Summit Joint Statement on Global Food Security (L'Aquila, Italy).

Cultural Organization (UNESCO), the United Nations Development Programme (UNDP) and the International Fund for Agricultural Development (IFAD), also work on aspects of the improved use of biodiversity for food and agriculture.

A number of global and national reports have recognized to a greater or lesser extent the importance of diversity in agricultural production systems. The World Development Report 2008 (World Bank, 2007) acknowledges the importance of stewardship of natural resources but largely presents a conventional set of technology- and input-driven options for agriculture in the future. The recent International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD, 2008), which examined the role of agricultural science and technology in meeting development and sustainability goals, argued that acknowledging the multifunctionality of agriculture is of central importance. It also identified the challenge of simultaneously increasing agricultural production, reducing pressure on ecosystems and addressing competing uses for agricultural and other natural resources. UNEP's recent assessment on the role of the environment in averting future food crises (Nellemann et al., 2009) was concerned explicitly with the wider environmental cost of current agricultural production methods and argued that, unless more sustainable and intelligent management of production and consumption are undertaken, food could indeed

BOX 1

Key aspects of improving food security identified by the World Food Summit Declaration that particularly involve agricultural biodiversity

- Increase production including through access to improved seed and inputs; reduce pre- and post-harvest losses; pay special attention to smallholders.
- Implement sustainable practices, including responsible fisheries, improved resource use, protection of the environment, conservation of the natural resource base and enhanced use of ecosystem services.
- Ensure better management of the biodiversity associated with food and agriculture; support the conservation of and access to genetic resources and fair and equitable sharing of the benefits arising from their use.
- Recognize that increasing agricultural productivity is the main way to meet the increasing demand for food given the constraints on expanding the amount of land and water used for food production.
- Mobilize the resources needed to increase productivity, including research and the review, approval and adoption of biotechnology and other new technologies.
- Enable all farmers, particularly women and smallholder farmers from countries most vulnerable to climate change, to adapt to, and mitigate the impact of, climate change.
- Support national, regional and international programmes that contribute to improved food safety and animal and plant health.
- Encourage the consumption of foods, particularly those available locally, that contribute to diversified and balanced diets.
- Address the challenges and opportunities posed by biofuels.

become more expensive and prices more volatile as a result of escalating environmental degradation and climate change.

Many regional and national analyses and activities have complemented these international programmes and assessments, reflecting the increasing recognition that agricultural production systems need to change. Examples of these include the UK Royal Society Report, *Reaping the Benefits: Science and the sustainable intensification of global agriculture* (Baulcombe et al., 2009).

While these various initiatives are important and valuable, there is still a need to directly address the role of biodiversity for food and agricultural in improving food security and sustainability. This is necessary for three reasons: first, because of the integrated nature of the contribution; second, because it involves thinking about agriculture in a different way, one that brings together the very positive elements of the various approaches such as sustainable intensification, multifunctionality and the importance of appropriate policy and economic frameworks; and third, because of the need to take account of the realities of small-scale farmers and communities who maintain the agricultural biodiversity that will be used.

Global challenges and change

RECENT EVENTS HAVE SHOWN that there remains substantial volatility in global food provision and that the degree of food security around the world can change very rapidly. The 2008 food crisis was variously ascribed, *inter alia*, to reduced stocks as a result of several years of reduced yields caused by extreme weather events and plant diseases in major food crops, the global economic downturn and the transfer of land from crop production to biofuel production. Whatever the causes, the crisis demonstrated how far we are from achieving genuine food security.

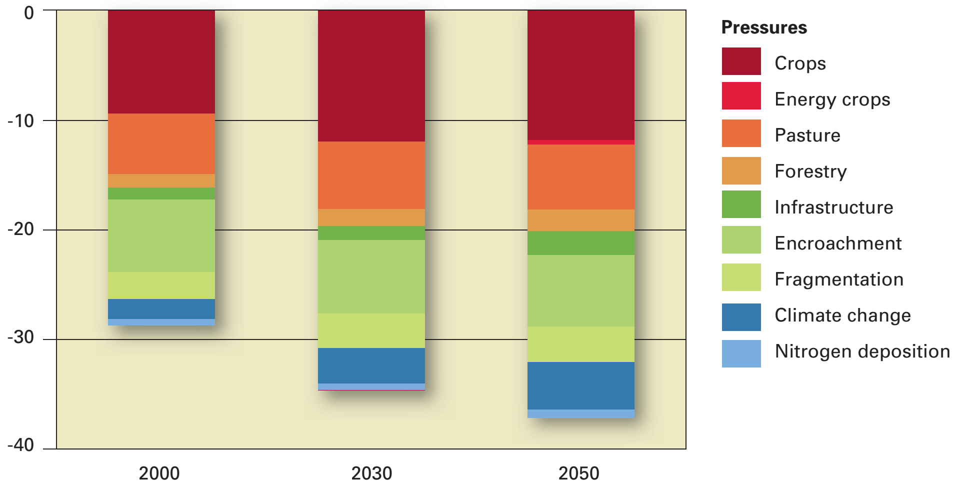
The world population is expected to grow by over a third, or about 2.3 billion people, between 2010 and 2050. Increases in agricultural productivity will be needed throughout this period, although probably at a declining pace as the rate of population increase slows. Increased demand for meat, dairy, vegetable oils and other products will accompany the need to feed a larger population. Taking all these factors into account, FAO has suggested that global food production will need to increase by about 70% by 2050 relative to production in 2005 (Bruinsma, 2009). Although globally the agricultural food system has the potential to cope with the expected demand from currently cultivated land, given sustainable management and adequate inputs (Fischer et al., 2002), meeting expected demand in particular countries (those with, for example, high population growth rates) or regions will present significant challenges.

While there is the potential to meet expected demand over the next 40 years, there is also a clear recognition that this needs to be done in ways that reduce the dependency of agriculture on external resources. It has been suggested that if current production practices continue, up to 10^9 hectares of natural ecosystems would have to be converted to agriculture. This would be accompanied by 2.4- to 2.7-fold increases in nitrogen- and phosphorus-driven eutrophication of terrestrial, freshwater, and near-shore marine ecosystems, and comparable increases in pesticide use (Tilman et al., 2001). Phosphorus will become a severely limiting constraint on production by the end of this century, when readily available stocks are expected to be running out (Vaccari, 2009). Demand for water (of which agriculture already accounts for 70% of global use) would increase to unsustainable levels. Unprecedented ecosystem simplification, loss of ecosystem services and species extinction (Loreau et al., 2002) would also occur as a result of the various pressures associated with unsustainable agricultural practices (see Figure 1).

Specific challenges for agricultural development over the next 20 to 40 years have been described in some detail in a number of recent reports and papers, including the FAO study,

FIGURE 1

Pressures driving biodiversity loss as Mean Species Abundance in the "business-as-usual" scenario over the next 40 years (NEEA, 2010)



World Agriculture: Towards 2015/30 (FAO, 2002), the 2006 interim report, *World Agriculture: Towards 2030/2050* (FAO, 2006) and other publications mentioned in the previous section. These often present particular perspectives that reflect their source but contain broadly convergent conclusions about agriculture and the environment (Kok et al., 2008). Some of the major challenges are summarized in the next sections.

Land availability

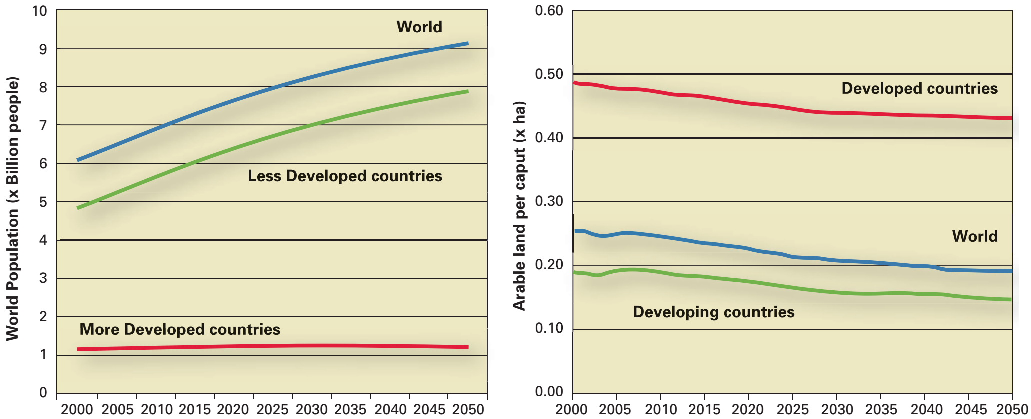
Over the last 30 years the world's crop area has expanded by some 5 million hectares annually, with Latin America alone accounting for 35% of this increase. The pool of unused, suitable cropland is unevenly distributed, with greatest current potential for arable land expansion in South America and, to a lesser extent, southern Africa (Fischer et al., 2002). While FAO projections (FAO, 2002) indicate that most gains in production (around 90%) will be achieved by raising productivity through increasing yields and cropping intensity, it is still expected that the area of arable land will be increased by around 70 million hectares globally. An increase of around 120 million hectares in developing countries (responsible for an expected 21% of growth in crop production in these areas between 2005 and 2050) will be partially offset by a decline in arable land of some 50 million hectares in developed countries, resulting in a lower per capita decline of arable land in developing countries, than would be expected when looking at the population growth alone (Figure 2) (Bruinsma, 2009).

Use of biomass has been the primary source of energy for the rural poor in developing countries. In recent years the use of biomass as an energy source has received increased attention, especially for its potential use as a biofuel for transportation. Whereas some projections indicate that biofuel crops could occupy 15–30% of any net expansion in cultivated land area in the period 2000-2030 (OFID, 2009), the effect that this will have

FIGURE 2

World population prospects (UN Population Division) and arable land per capita

(Bruinsma, 2009)



on biodiversity loss is relatively small by comparison with other factors (NEAA, 2010) (see Figure 1). The use of agricultural land and resources for energy purposes has opened a wide debate about the appropriate balance between food and fuel production. However, it can be expected that working with more advanced technologies, crop residues and cultivating the crops on areas that are too degraded for other purposes will lower the overall impact. Some biofuel production systems, such as Integrated Food Energy Systems (IFES), which can include liquid biofuel production, can also combine food production, energy production and adequate biodiversity on the same land (Bogdanski et al., 2010).

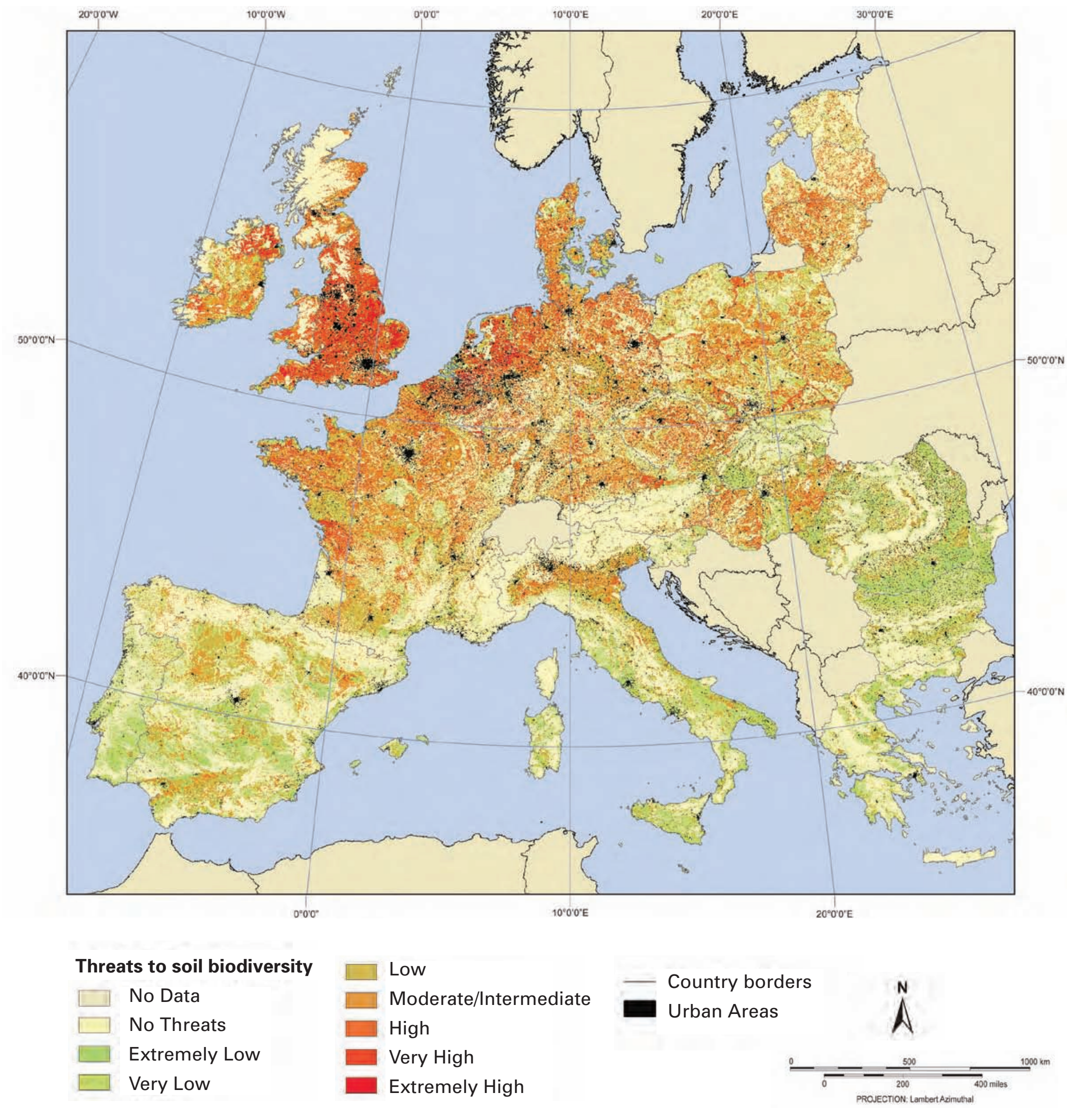
Food security concerns have seen a rapid increase in demand for land in many regions as some food insecure nations have sought to secure their own food supplies. Major actors involved in land acquisitions include governments and private companies from China, Japan, the Republic of Korea, Saudi Arabia and the United Arab Emirates (Borger, 2008); countries with limited natural resources and that are not in biodiversity hotspots. Countries in which land is being purchased, such as Indonesia, Lao People's Democratic Republic (PDR), Madagascar and Philippines are all located in such hotspots (Myers et al., 2000).

In direct contrast (and competition) with the demand for land for agriculture are the growing land requirements of urban populations. It is expected that 70% of the world's population will live in cities by 2050 (UN-HABITAT, 2008). In China alone, more than 2 million hectares of land have been already taken out of agriculture in the ten years to 1995. Current estimates suggest that by 2030 an additional 100 million hectares of land will be needed globally to satisfy the needs of urban populations (FAO, 2002). Urbanization creates additional challenges beyond the loss of agricultural land in and around cities: the number of people who are pure consumers of food produced elsewhere will more or less double; reductions in the rural labour force are likely to be significant; large urban populations create strong pressures for governments to maintain cheap food policies that relatively impoverish rural food producers.

Not all potential agricultural land is actually productive. The extent and seriousness of degraded lands is not known with much precision. The most comprehensive survey to date, the Global Assessment of Human Induced Soil Degradation (Oldeman et al., 1990), estimated that a total of 1964 million hectares were degraded, 910 million hectares were degraded to at least a moderate degree (with significantly reduced productivity) and 305 million hectares were strongly or extremely degraded (no longer suitable for agriculture). In developing countries, salt accumulation and waterlogging have reduced yields on 15 million hectares of land (Naylor, 1996). Continuous cropping and loss of nutrients through harvest,

FIGURE 3

Map of threats to soil biodiversity in Europe (Jeffery et al., 2010)



erosion, leaching or gaseous emissions deplete fertility and cause soil organic matter levels to decline, often to less than half the original levels (Matson et al., 1998). Soil degradation and loss of soil biodiversity are thus important components of land degradation. The *European Atlas of Soil Biodiversity* (Jeffery et al., 2010) shows high threats to soil biodiversity in areas where intensification has been greatest – a process likely to continue in other regions of the world (Figure 3).

This trend could be reversed by increasing the efficiency of the use of natural resources for agriculture. Carefully designed, integrated management practices, such as no-till and conservation agriculture, mixed crop–livestock systems with careful manure management, cropping systems with perennial and annual species, responsible use and storage of irrigation water and development of drought-tolerant crops are among the strategies that result in maintenance of year-round soil cover, increased organic matter, improved soil structure and thereby reduced erosion (FAO, 2002).

Water scarcity

Agriculture accounts for about 70% of all water use globally and physical water scarcity is already a problem for more than 1.6 billion people (IWMI, 2007). By 2025, 1.8 billion people will live in countries or regions with absolute water scarcity and two-thirds of the world's population could be under water-stress conditions (UN-Water, 2005[5]). Over-pumping of groundwater aquifers is a serious concern in many countries throughout the world, especially in China, India, Mexico, Pakistan, and most of the countries in North Africa and the Middle East (Seckler et al., 1999). It is estimated that already more than 60% of the world's rivers are fragmented by hydrological alterations, including dams (eFLowNet, 2010).

Urban and industrial water use, hydropower plants, restoration of streams for recreational use, freshwater fisheries and protection of natural ecosystems are all competing for water resources previously dedicated to agriculture and this competition will intensify. Over the next 40 years agriculture will have to become increasingly efficient in its use of water through improved management of irrigation, the development of cropping and livestock production systems that use water more efficiently, reductions in loss of water from agricultural systems and improved watershed management. Trade-offs in the use of water not only have a large influence on biodiversity on the sector-scale (industry, energy, drinking water, recreation, fisheries, agriculture and natural ecosystems), but within the agricultural sector itself there can also be substantial trade-offs. For example, paddy fields in Asia support a large aquatic biodiversity on which many people depend, but permanent flooded conditions have a negative impact on both methane emissions and environmental water flows needed to maintain healthy ecosystems, such as wetlands.

According to the Ramsar definition, wetlands are "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres" (Ramsar Convention Secretariat, 2006). Around half of the world's wetlands have disappeared since 1900 (Katz, 2006). Wetland agriculture has, over many

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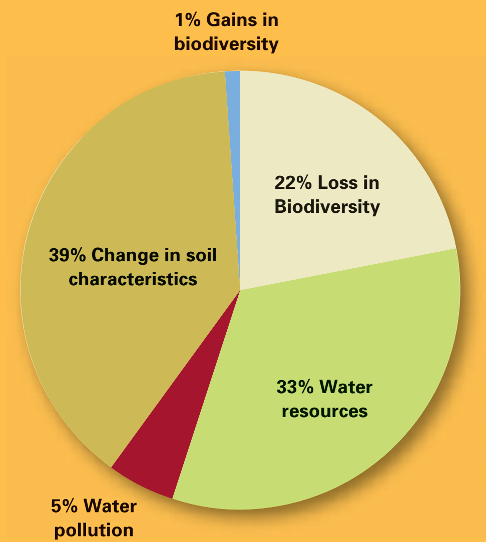
5 UN-Water Thematic Initiatives http://www.unwater.org/downloads/waterscarcity.pdf

BOX 2

Main pressures and state changes on wetland ecosystems in Africa

An FAO study (FAO, 2008a) on agriculture–wetland interactions in 90 cases examined driving forces, pressures, state changes, impacts and responses and concluded that the pressures are almost evenly distributed over agricultural expansion, agricultural intensification and water use. Loss of biodiversity is, with one-third, the second most commonly listed state change, after the change in water resources. In Africa, where pressures will continue to be large due to population growth, agricultural expansion and intensification, a related problem is change in soil characteristics. Increased irrigation that does not sufficiently consider relations with wetlands will thus not only result in biodiversity loss, but also in lower soil fertility.



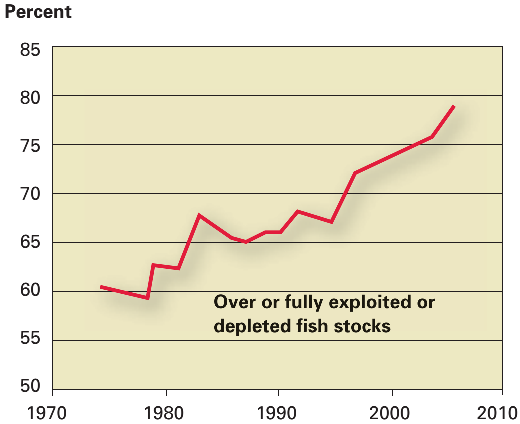
centuries, significantly contributed to societal well-being in many regions around the world. Wetlands provide a wide range of functions, including providing water for crop production and fisheries and aquaculture, water purification, groundwater recharge, nutrient cycling and flood protection.

Overuse of nutrients

Overuse and mismanagement of mineral fertilizers have polluted groundwater to different degrees in almost all developed countries and, increasingly, in many developing countries. This affects downstream agricultural and natural systems and results in high costs of purification to obtain drinking water. Since 1960, flows of biologically reactive nitrogen in terrestrial ecosystems have doubled (Figure 4), and flows of phosphorus have tripled, largely due to efforts to increase food production through fertilizer application (Vitousek et al., 1997; Bennett et al., 2001). Furthermore, it has been found that only 30–50% of applied nitrogen fertilizer (Smil, 1999) and around 45% of phosphorus fertilizer (Smil, 2000) is taken up by crops. The readily available global supply of essential minerals for fertilizers is declining rapidly. Production systems with a lesser dependency on these inputs and wiser management of these resources are needed if agricultural production is to continue to increase sustainably. The use of nitrogen fertilizer, based on the synthesis of ammonia by the Haber-Bosch process, currently represents the largest component of fossil fuel exploitation by agriculture (Glendining et al., 2009). Since agricultural systems have also been estimated

FIGURE 4

Summary of biodiversity indicators **(Butchart et al., 2010)**



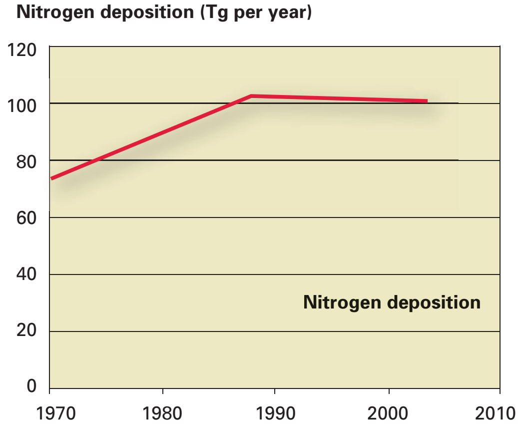
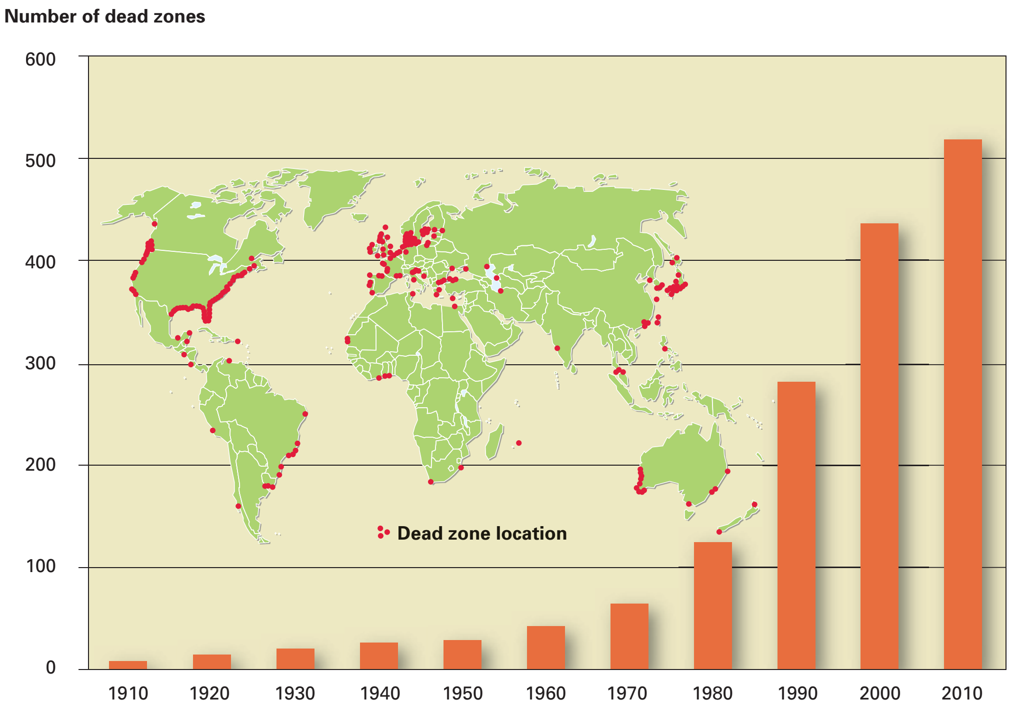


FIGURE 5

Marine "dead zones" **(Updated and adapted from Diaz and Rosenberg, 2008)**



to produce about 60% of global N_2O emissions (Smith et al., 2007) it would be desirable to find ways of significantly reducing synthetic nitrogen use.

Pollution of water by overuse of agrochemicals in cropping systems has negative impacts on a very large scale and can cause aquatic dead-zones that spread over large areas (Figure 5). International initiatives are being established to improve efficiency in the use of nutrients and thus to reduce their use. One example is the Global Partnership on Nutrient Management (GPNM), which was launched in 2010. The GPNM will be a key initiative to help implement the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities that addresses the links between watersheds and coastal systems using an ecosystem management approach (UNEP/GPA, 2006).

Climate change

Changes in global climate are expected to have considerable effects on agricultural production, although with significant differences across regions. The Fourth Assessment Report by the Intergovernmental Panel on Climate Change indicates that crop yield losses will occur with minimal warming in the tropics, due to decreased water availability and new or changed insect pest incidence (Easterling et al., 2007). Southern Africa could lose more than 30% of its main crop, maize, by 2030, while in South Asia losses of many regional staples, such as rice, millet and maize, could exceed 10% (Lobell et al., 2008). In contrast, crops in mid to high latitudes may benefit from a small amount of warming (up to +2°C) but plant health will eventually decline with additional warming. Fish resources and the fishing industry will also be severely affected, through greater incidence of diseases and algal blooms. Localized extreme events and sudden pest and disease outbreaks are already resulting in greater unpredictability of production from season to season and year to year and require rapid and adaptable management responses.

Changes in the availability and distribution of the various components of biodiversity associated with food and agriculture will affect local supplies of raw materials essential for enhancing productivity and ecosystem services. Changes in distribution of pollinators, crops and beneficial and harmful soil organisms may have a profound effect on production and productivity. At the same time the expected loss of cultivated lands due to increased salinization and sea level rise will make the need for more efficient production on remaining cropland ever more urgent.

Farmers will need to alter existing agronomic practices, both to adapt to and to mitigate the effects of climate change. Adjustments will involve changes in water use (irrigation), development and use of improved crop varieties and better adapted livestock breeds, alterations to cropping schedules and crop rotations and diversification of production strategies to improve capacity to face risk. There is already considerable evidence that small-scale farmers in traditional farming environments are adapting to climate change, particularly through the use of traditional varieties and the adaptation of traditional farming practices (PAR, 2010).

BOX 3

The recent report of the UK Royal Society, Reaping the Benefits, lists four principles for sustainability

Persistence – the capacity to continue to deliver desired outputs over long periods (human generations)

Resilience – the capacity to absorb, utilize or even benefit from perturbations, shocks and stresses

Autarchy – the capacity to deliver the required outputs from resources acquired within system boundaries

Benevolence – the capacity to produce desired outputs while sustaining the functioning of ecosystem services

Source: Baulcombe et al. (2009)

Among the ecosystem properties that will be increasingly important for helping agriculture to maintain production in the face of climate change are resilience – the ability to revert to a stable equilibrium following 'shocks' – and 'sustainagility' – the ability to adapt by meeting needs in new ways (Jackson et al., 2010). Diversity of crops, breeds and diversification of management strategies are the basis of both these ecosystem properties; diversity is traditionally used by farmers as an insurance against risks, including climate related ones (Altieri, 1987). In some cases adoption of alternative types of production may be the only option and the raw materials and resources for change will depend largely on the availability of genetic resources adapted to altered growing conditions and on adoption of practices that make use of these resources.

Productivity and sustainability

Over the next 40 years there will be a continuing need to develop crop and livestock varieties with innately higher levels of productivity in terms of harvestable and useful products (food, feed, fuels, medicines etc.). While the experience of the last 50 years suggests that this is technically possible, the need to combine productivity increases with improvements in the sustainability of agricultural systems will involve searching for different kinds of solutions; these may be completely new approaches or combinations of existing practices (see Box 3).

Elements that are likely to be of particular importance in achieving the sustainable increases in productivity required are the development of appropriate mixes of plant and livestock varieties, avoiding unnecessary use of external inputs, harnessing agro-ecological processes, minimizing use of harmful technologies and harnessing human capital to adapt and innovate and social capital to resolve common landscape-scale problems (Baulcombe et al., 2009).

Farming systems

Around half of the global population is found in the rural areas of developing countries (Anríquez and Stloukal, 2008). Most of the food insecure people in the world (about 70%) live and work in these rural areas. About 50% of developing-country rural populations are smallholders (UNCTAD, 2010) and a further 20% are landless. It is believed that smallholder farms constitute about 85% of all farms (IFPRI, 2005). These smallholders (or small-scale farmers) include pastoralists and those dependent on artisanal fisheries and aquaculture. As Morton (2007) notes, all suffer in varying degrees from similar problems associated with low levels of technology and unpredictable exposure to markets. The farming systems are usually complex, diverse and risk prone (Chambers et al., 1989). These small-scale farmers, more than 1 billion in total, play a central role in the management of agricultural landscapes and the maintenance of agricultural biodiversity in developing countries.

Improving food security and reducing poverty over the next decades are therefore inextricably linked. Improvements in farming practices will need to be relevant and appropriate for small-scale farmers if they are to make a genuine difference to the numbers of food insecure. Responses to challenges such as those of climate change, relative declines in rural populations and increased competition for water will need to be relevant to small-scale farmers and to their particular circumstances and concerns. In this context biodiversity for food and agriculture, which is already a central part of their livelihood strategies, is likely to play a key role.

Biodiversity is an important regulator of agro-ecosystem functions, not only in the strictly biological sense of impact on production but also in satisfying a variety of needs of the farmer and society at large. In particular it increases resilience of agro-ecosystems and is, as such, a means for risk reduction and adaptation to climate change. Agro-ecosystem managers, including farmers, can build upon, enhance and manage the essential ecosystem services provided by biodiversity in order to work towards sustainable agricultural production. This can be achieved though good farming practices that follow ecosystem-based approaches designed to improve sustainability of production systems. These should:

- maintain a high level of crop genetic diversity, both on farms and in seed banks, which will help to increase and sustain production levels and nutritional diversity throughout the full range of different agro-ecological conditions;
- integrate, through ecosystem-approach strategies, the planned biodiversity (crop sequences and associations) that is maintained with the associated diversity (for example, wild pollinators);
- adopt production system management strategies, such as not disturbing soil, maintaining mulch covers from crop residues and cover crops that increase the biological activity and diversity of the production system;
- consider the benefits of having fragmented land (riparian areas, forest land within the agricultural landscape) on the agricultural yield, through improved biological processes such as pollination;
- improve the adaptation of good farming practices (i.e. pest management strategies, etc.) that follow ecosystem-based approaches designed to improve the sustainability and agricultural biodiversity of production systems; and

- aim at producing commodities that meet the consumer needs for products that are of high quality, safe and produced in an environmentally and socially responsible way.

Broader social demands for change

There is a growing awareness and appreciation by consumers in many parts of the world of the importance of agricultural practices that produce what they perceive to be healthy and nutritious food. Awareness of how serious environmental degradation has become is far more widespread than in the past and there is a concern over the contribution of agriculture to this environmental damage. Concerns over risks related to the persistence of pesticide residues and antibiotics in food products have existed for many years and are now becoming more powerful, raising health concerns as well as ethical considerations on how food should be produced and agricultural systems managed. There are growing debates over the impact of agriculture on climate change and the ethics of genetically modified organisms (GMOs).

There is every reason to expect that the nutritional, health and ethical dimensions of food production will increase in importance over the next decades. Debates about use of agrochemicals, concerns about contamination of products by antibiotics or microorganisms and perceptions about appropriate livestock rearing conditions are all likely to become more rather than less significant and to affect production methods. The trend towards globalization and international trade in food is being increasingly challenged by strong civil society movements, some of which argue for the need to reconnect agriculture and food production to ethical and cultural dimensions to achieve food security with a long-term perspective.

The role of biodiversity for food and agriculture in this process is often seen as fundamental: diversity is recognized as the basis for local, possibly forgotten specialties and sustainable food systems that bear a strong connection to cultural diversity. For many rural communities, and particularly indigenous peoples, culture plays a central part in determining the characteristics of their food production systems. Strong local cultures and institutions play a significant role in strengthening both the resilience of local farming systems and their capacity to copy with change in ways that maintain or improve livelihoods. Local food systems are being promoted, in both developed and developing countries, for their capability to deliver environmental, nutritional and, if appropriately supported, economic benefits to communities. The concept of food sovereignty, defined as the right of each nation to maintain and develop its own capacity to produce the staple foods of its peoples, respecting their productive and cultural diversity (Menezes, 2001), often underlies or accompanies the promotion of regional and local food systems.

Biodiversity for food and agriculture as a basis for food security

OVER THE PAST DECADES, agriculture has achieved substantial increases in food production but these have been paralleled by serious overuse of non-renewable inputs and natural resources, loss of biodiversity and degradation of ecosystems, particularly with respect to their regulating and supporting services. While high-input industrial agriculture and long-distance transport have increased the availability and affordability of refined carbohydrates and edible oils, this has been accompanied by an overall simplification of diets and reliance on a limited number of energy-rich foods. Diets increasingly low in variation but high in calories contribute to increasing problems of obesity and non-communicable disease (Popkin, 2002) which can now be found coexisting with malnutrition or undernourishment in the same family or community. Reliance on a lesser number of crops can also result in erosion of plant genetic resources and increased risk of wide-spread disease when a variety is susceptible to a new plant disease, which results in food insecurity. From an analysis of 104 country reports it appears that genetic erosion may be greatest in cereals, followed by vegetables, fruits and nuts and food legumes (FAO, 2010).

Over the next 40 years some major changes will be needed in agricultural production systems if we are to achieve the desired objectives of improved productivity, environmental sustainability, equity and livelihood and health and nutrition. Systems will have to become increasingly flexible, multifunctional and option-rich, capable of providing multiple services and dealing with change and uncertainty. Resilience and adaptability will become increasingly important as the negative effects of climate change increase and the availability of non-renewable external inputs declines. Increases in production, which will have to be essentially increases in productivity, will need to be achieved with reduced water and chemical fertilizer use. To achieve this, production systems will need to have greater reliance on ecological processes that produce positive feedbacks on sustainability and production. Adaptation of agricultural systems will also be required to improve food security by ensuring reliable yields of nutritionally diverse foods in ways that contribute to improving human well-being and equity, particularly of poor rural communities.

Agricultural systems that are reliant on biological processes and on the natural properties of agro-ecosystems to provide provisioning, regulating, supporting and cultural services exist around the world. These are the characteristics of most traditional production systems. They are often (simplistically) associated with low levels of productivity, poor farming systems and practices unable to respond to modern demands. However, they are also characteristic of a range of different innovative approaches to agricultural production that seek to combine productivity and increased farmer incomes with long-term sustainability. Conservation agriculture, integrated pest and disease management and ecoagriculture are all examples of often successful attempts to achieve productivity comparable with that achieved with conventional intensive agriculture through the maximization of efficiency in agro-ecosystems' inherent biological functions rather than through an unconstrained application of external inputs. A growing number of agricultural production models focused on combinations and communities of plants, animals and soil organisms, rather than on one particular species at a time, have emerged over the past decades.

Greater integration in the management of various components of agro-ecosystems involves changes in the management of plants, soil, water and nutrients in ways that take account of interactions between these divers components, making use, for example, of the abundance and diversity of soil organisms to obtain higher yields and greater production efficiency through synergistic effects among these resources. Where animals are part of the farming system, they are additional resources to be managed in complementary ways. Such ecologically-oriented production models explicitly embrace multiple objectives, rather than directing all efforts toward single goals such as yield or profitability (Altieri, 1987).

The wider adoption of ecological approaches will depend on the capacity to develop a sound ecosystem-wide, integrated framework grounded on the maintenance of diversity in production systems, including the human component of diversity (biocultural diversity). Such a framework will emphasize flexible strategies that increase productivity at the total ecosystem level, as opposed to efficiencies within single commodities or isolated production systems. Some of the ways of looking at production that have developed over past decades will need to change. Total productivity of ecosystems and landscapes will become more important than yield per hectare of specific crops. The functioning of the system in terms of regulating and supporting services will need to be considered in addition to the volume of extractable products. Integrated approaches will be required that can take account of the associated production of crop, livestock, fish and agroforestry. New concepts will be needed that, for example, can adequately reflect the way a regional food system is capable of meeting total food and nutritional needs and supporting human health and well-being under increasingly unpredictable environmental conditions.

Past efforts to increase yields and productivity have been undertaken within a framework that has aimed to control conditions and make production environments uniform through more or less unconstrained use of inputs rather than building on, and making use of, the highly diversified, complex and sometimes limiting farming conditions occurring in various regions of the world. This has led to the development and promotion of a narrow set of crops, breeds and management practices suited to high-input farming. It has also led to the neglect of a greater wealth of diversity of genes, organisms and systems that perform better in terms of productivity, economic and environmental sustainability in the majority of farming contexts, especially in the developing world.

Scales, links and connections

To date, diversity-based management has tended to focus on localized interventions for single crops or animals or specific components such as enhanced soil management or pollinator availability, with consequent single, small-scale effects. In contrast, interventions involving or targeting agricultural biodiversity need to encompass a variety of components in an integrated manner: inter- and intraspecific diversity of plants and animals, ecological interactions between wild, cultivated, above-ground, below-ground and aquatic diversity and the resulting ecosystem services should be considered not as self-standing components but as interacting players in processes that ultimately sustain long-term production and food security. Capitalizing on diversity-based dynamics gives agricultural systems the capacity to achieve high levels of productivity and be economically profitable, with a lesser or no need for external, costly and increasingly scarce inputs.

When one makes the shift to this more holistic understanding of ecosystem efficiency concepts, a richer set of complementarities involving the maintenance and use of biodiversity for food and agriculture begins to emerge. This way of understanding production and productivity can be easily linked to questions of nutritional diversity and dietary health and to an acknowledgment that human and ecosystem health are linked to wider biological diversity issues. Ecologically-based food systems allow the production of safer food with lower risks of contamination with chemical residues and less fossil fuel input per unit of food. Greater diversity in the crops used for food leads to a greater variety of nutrients available in human diets. Sustainable food systems often involve closer connections between producer and consumer, meaning more direct marketing of foods to local consumers (through farmers' markets, community-supported farms, farmer cooperatives, etc.), less energy for food transport and increased income opportunities for small-scale farming communities.

Agricultural systems that use biodiversity and place greater reliance on biological processes to achieve productivity and sustainability objectives need to place increased emphasis on the links and connections that are present within the agro-ecosystem. Since there are different scales at which ecosystems provide services to people, production systems should be managed at scales large enough to encompass cultivated and natural elements, taking into account their interactions and the services they provide to agriculture, even in faraway fields (Sherr and McNeely, 2008). Land-use management decisions – too often focused on a few 'key-stone' species and local processes – will have to embrace this wider range of ecological processes and aim at maintaining structurally complex and dynamic agro-ecosystems. The necessary structural and functional complexity is most commonly achieved through the maintenance of diversity, which underpins a system's capacity for resilience or transformation while compensating for localized, high-intensity management and acting as a buffer against environmental and economic risk (Naeem and Li, 1997).

The ability to work across scales will be a necessary characteristic of a more biologically-based agriculture. Biodiversity-based options vary according to biome, soil, climate, the nature of the agro-ecosystem and the practices and traditions of rural communities. Developing relevant problem-solving approaches will need to take account of local knowledge and practices and adopt more grass-roots-based approaches that build on local community institutions and experiences as well as ecosystem properties. These should become part of a framework that takes account of landscape dimensions as well as of national needs and concerns.

The sustainable use of agricultural biodiversity is often stated to be mainly beneficial for small-scale farmers who need to optimize the limited resources that are available to them and for whom access to external inputs is lacking due to financial or infrastructural constraints. Whereas small-scale farmers can profit considerably from optimizing the use of agricultural biodiversity, the negative impacts that are caused by large-scale farmers (land clearing, run-off of agrochemicals and push towards monocultures) are much larger. Benefits on a large-scale can be reached by focusing on improvements relevant to large commercial farmers; conservation agriculture has already been effective in this respect.

Overcoming scepticism

Inevitably, there is considerable scepticism over the practicality of the widespread adoption of agricultural production practices that embody a greater use of biodiversity for food and agriculture and a greater emphasis on ecosystem function. Two major geopolitical realities have a constraining effect on peoples' thinking. Firstly, modern farming in developed countries receives very large levels of financial support and all sectors of the agricultural and food industries are linked in to this highly subsidized system to a greater or lesser extent. Secondly, there is a continuing commitment to ensuring that food prices remain low and that basic foodstuffs are affordable by all sectors of society, including the poorest. These both tend to lead to a disinterest in the nature of agricultural production systems and present a very real barrier to the development of new approaches to production, however necessary those changes might be.

A common criticism has been that adoption of ecological approaches to farming reflects a romantic and backward-looking perspective. Other criticisms have been that it is economically impractical when it comes to large-scale implementation and will require even larger subsidies, or that the required levels of production for an expanding world population could not be achieved. It has also been argued that the approach is labour and knowledge intensive and difficult for the farmer to manage and the consumer to understand. The further development of agriculture based on reduced inputs will involve innovation and the development of new approaches. As consumers get more access to information and control over consumption, they show great powers of discrimination in respect of, for example, food from GMOs, Fairtrade products or organically-produced foodstuffs.

While the use of diversity does require significant knowledge, the skills and capacity to maintain and use biodiversity optimally has been characteristic of high-quality farming systems throughout the world. More research will be needed and this will need to be oriented to solving production problems in biodiversity-rich systems in ways that save labour rather than to simplification of production systems and ever-increasing yields per hectare of major cereal crops. In the next section we present some of the ways in which agricultural practices are already changing and demonstrating how the criticisms of ecological approaches to agriculture can be confronted in a practical way.

Finally, it should be noted that most cost–benefit analyses, comparing high-input systems with sustainable agricultural systems, tend not to account for the wider range of societal benefits agricultural systems can provide, since these are considered externalities and are not factored into the prices paid by producers or consumers, prices that are often lower for products from high-input systems. Excluding externalities (both positive and negative) from prices distorts the market by encouraging activities that are costly to society but have high private benefits, such as agricultural systems based on a narrow, short-term understanding of yield and productivity. It discourages development of other systems that would deliver significant societal benefits (reducing expenditures in other sectors, such as health care, landscape restoration, water sanitation, etc.) but do not maximize private benefits. Low prices at the grocery store give us a false sense that our food comes cheap, but they do not include the cost of cleaning up farm pollution, for example, or the cost of vast government subsidies to agriculture. A growing proportion of consumers, especially in developed countries, have embraced sustainability and are willing to pay more for food produced by ecologically-oriented agricultural systems.

The use of biodiversity for food and agriculture in practice

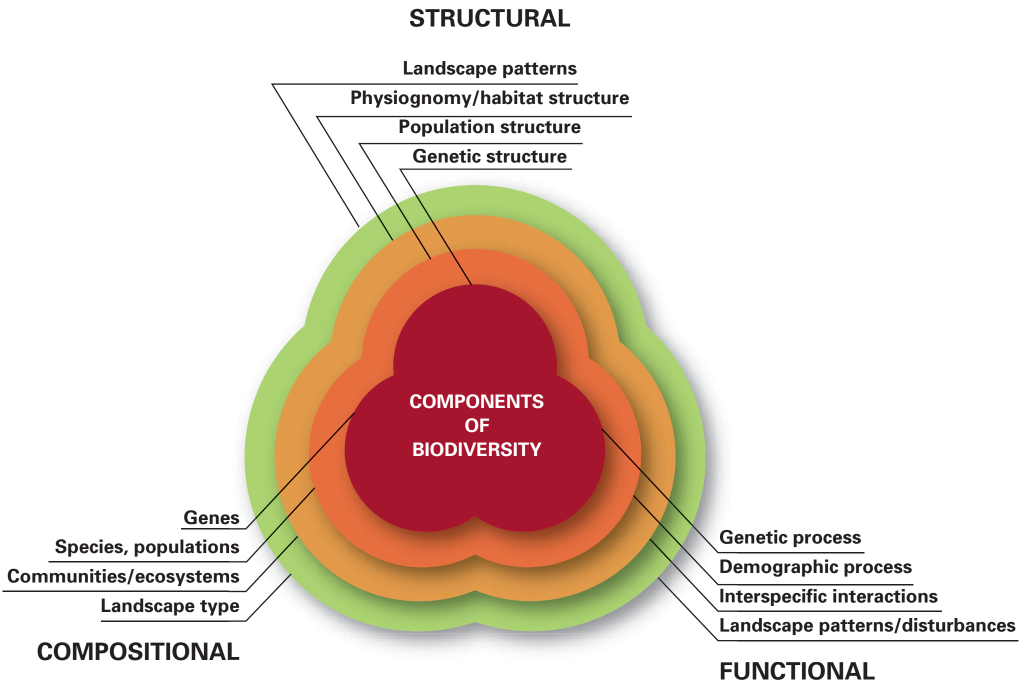
THERE IS A WIDE AND VARIED RANGE of agricultural practices that achieve the aim of improving system production in sustainable ways using biologically-based approaches. These usually involve improving the use of biodiversity for food and agriculture, combining inter- and intraspecific diversity in ways that increase production, resilience and ecosystem function. They generally deliver improved returns for farmers, better ecosystem services and, often, increased production of higher-quality products. They illustrate the potential value of agricultural biodiversity and suggest entry points for the development of further improvements. Ongoing research in some of these areas has already provided evidence of further potential sustainable production gains that can improve food security and help cope with climate change.

The dimensions of agricultural biodiversity are (a) genetic resources for food and agriculture; (b) components of biodiversity that support ecosystem services upon which agriculture is based; (c) abiotic factors and (d) socio-economic and cultural dimensions; and have numerous structural, compositional and functional components (see Figure 6). In this section a few of the ways in which biodiversity for food and agriculture is being used to improve agricultural production are described. The aim is not to provide an exhaustive description of all the possible ways in which biodiversity will need to be used to achieve the desired agricultural production and food security goals, rather to illustrate the possibilities, highlight some of approaches that already exist, provide a basis for exploring further possibilities and identify areas where research is likely to bring particular benefits.

The reservoir of practices that can be drawn on for sustainable agricultural models is based on knowledge and innovations that have often been developed through close collaboration among farmers, extension services, NGOs and researchers. These practices arose as a response to problems or constraints that farmers encountered when introducing high-input, modern agricultural methods to their specific ecological and socio-economic contexts. The innovations are responsive to variations in soil type, topography of landscape, size of holding, labour, cash or other limitations, pest and disease problems, market failures, etc. They tend to be more adaptive strategies and are often formulated inductively, being effective alternatives to the top-down introduction of solutions validated on a few (small) locations operating under near-ideal conditions, as is the case for much of contemporary research-driven innovation in agriculture.

FIGURE 6

Different scales of agricultural biodiversity that support ecosystem services upon which agriculture is based (Adapted from Noss, 1990)



The benefits of diversity and multi-species approaches

The crop and livestock systems that are often the focus of agricultural improvement are, in practice, parts of a larger landscape that includes a wide range of wild, weedy and feral species that can play key roles in ensuring agricultural production and ecosystem function. Wild species that are needed for agriculture include pollinator species, crop wild relatives and soil biota. Wildlife in the form of animals consumed as bushmeat, wild fruit species or other species occurring in and around agricultural fields can play an important role in feeding the population in various regions. Wild species may also have a devastating effect on production, either as pests and diseases or as competitors for resources.

The use of multi-species and multi-breed herds and flocks is one strategy that many traditional livestock farmers use to maintain high diversity in on-farm niches and to buffer against climatic and economic adversities (Hoffmann, 2003; FAO, 2009b). Different breeds and species make different contributions to livelihoods through provision of food, fibre, fertilizer, cash income, draught power and transportation. Generally, the more complex, diverse and risk-prone peasant livelihood systems are, the more they will need animal genetic resources that are flexible, resistant and diverse in order to perform the required functions. Further development of tolerance to abiotic stress can be achieved by using a range of adaptive strategies, both behavioural and physiological (Hall, 2004). Bedouin goats, for instance, are able to graze without need for shelter thanks to a greater ability to control their body temperature, whereas other breeds originating from northern climes loose appetite and body weight if not given shade (Mualem et al., 1990).

Species combinations enhance productivity and yields also in aquatic systems. The integration of small indigenous fish species into polyculture systems – for example, *Amblypharyngodon mola* with commercial carp species – can increase overall pond fish production (Roos et al., 2007) and since these small species command high prices (Ahmed, 2009; Saha, 2003) they provide a source of supplementary income to rural households. Self-recruiting species also contribute significantly to aquatic resource production. For example, three self-recruiting fish species (*Channa striata*, *Clarias brachatus* and *Anabas testudineus*) contributed more than 40% of total household catch by weight in Cambodia and Thailand (Amilhat, 2006). Diversification of fish species and breeds in aquaculture also enhances resource use efficiency and reduces waste. For this reason, four types of carp are commonly raised in the same pond in China: silver carp filter phytoplankton, grass carp feed on plant-eating microorganisms, the common carp is an omnivorous bottom feeder and bighead carp filters zooplankton (Naylor et al., 2000).

Maintenance of wild patches of vegetation in the farming landscape preserves useful wild or weedy species that can have a direct use in rural households and provides shelter and habitat for wild fauna that contribute to beneficial ecological processes, such as soil enrichment, pest control and pollination (Vandermeer et al., 2002). Traditional cacao and coffee systems (grown as polycultures with overstory and understory plants) are good habitats for migrant and resident forest birds (Robbins et al., 1993), which control populations of pest insects. Dairy farm pastures surveyed in the Monteverde area of Costa Rica included 190 plant species, over 90% of which are known to provide food for forest birds and other animals. Many other species were important locally for humans as sources of timber (37%), firewood (36%) or fence posts (20%).

In pollinator management, good practices occur at a variety of scales: field, farm and landscape. At the field scale, pollinator-friendly practices include minimizing the use of farm chemicals, through organic production, integrated pest management, sound application techniques, set-aside areas or finding alternatives to agrochemicals. A reduction in the use of herbicides and other pesticides at least in parts of the field is recognized as having benefits for keeping pollinators in the crop fields. At the farm level, the way farmers organize different land uses across their farm can influence pollination services. For example, pollinator populations can be encouraged by conserving diverse cropping patterns on farms, for example by combining mixed cropping, including cover crops, kitchen gardens and agroforestry systems and providing habitat for bees. At the landscape level, areas of natural vegetation in close proximity to farmland are beneficial for crop production; such habitat patches provide flowering resources and nesting sites that sustain pollinators.

Maintaining a diversity of crops (both temporally and spatially) is also an established part of good agronomic practice. Crop rotations, intercropping and growing different varieties of a single crop have all been shown to have beneficial effects on crop performance, nutrient availability, pest and disease control and water management. Agro-ecological studies have investigated the impact of regimes based on combining various species occupying different niches in time and space. Multicropping, intercropping, alley farming, rotation and cover crops are all ways of combining crop species in ways that have positive effects on productivity and yield stability. Species-rich communities also deliver other ecosystem benefits, such as greater water retention in the upper soil (Caldeira et al., 2001), greater diversity amongst complementary and associated species (including pest-controlling organisms above and below ground) and overall greater resource use efficiency than in species-poor communities (Loreau et al., 2002).

This intrinsic efficiency in resource use can be maximized by sustainable intensification approaches, based on careful combinations of species and functional groups, each occupying a definite niche in time and space and providing specific services, such as nitrogen fertilization. In West Africa's dry savannah, where conditions are not suited to high-input agriculture, cereal and legume rotations have been successfully developed: maize and promiscuous soybean rotations combine high nitrogen fixation and the ability to kill large numbers of *Striga hermonthica* seeds in the soil; millet and dual-purpose cowpea allow for an efficient supply and uptake of nitrogen, with no need for external inputs.

Intraspecies diversity can also be directly beneficial in cropping systems. Traditional farmers often return to genetically heterogeneous local varieties to help recover from extreme weather events, such as flooding, droughts and storms and to cope with specific additional stresses such as climate change (PAR, 2010) or civil conflict (Richards and Ruivenkamp, 1997). Under stress conditions, the risk of crop failures is lower with landraces than with modern varieties; for example, yield under stress of barley landraces was between 25 and 61% higher than non-landraces (Ceccarelli, 1996). This leads farmers to perceive landraces and intraspecific diversity as an additional instrument for ensuring stability and productivity under unpredictable climatic conditions. Modern varietal mixtures of many crops can also out yield the mean of their monocultures: wheat mixtures, for instance, have proven to have a yield advantage of 19% over monocultures (Burdon and Jarosz, 1990). Whereas scientific evidence is available for the benefits (both in yield and in preventing disease) of spatial and temporal mixtures of a wide range of crop species, the evidence from large-scale testing is limited (Li et al., 2009).

Soil fertility

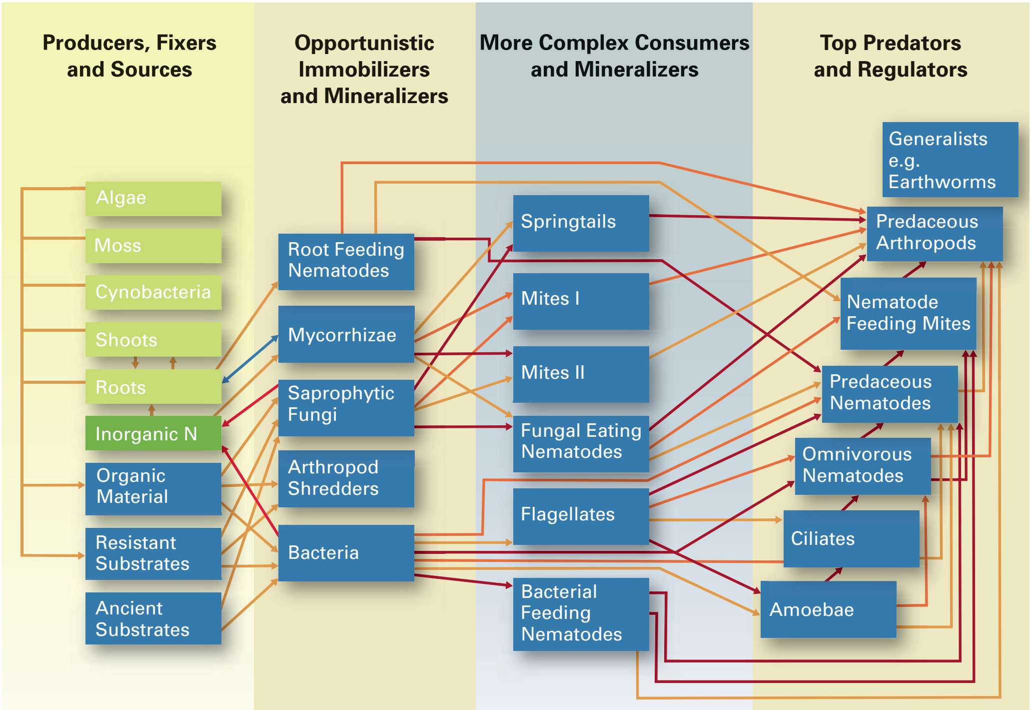
There is increasing appreciation of the importance of soil biodiversity in biochemical and nutrient flow processes on a landscape scale. Soil food webs are extremely intricate and ramified, involving plant roots, organic matter micro- and macrofaunal diversity (Figure 7). Below-ground communities are involved in complex ecological processes and interactions with above-ground organisms. The abundance of species in these communities and their functions are strongly influenced by management practices such as tillage, crop combinations, organic-matter inputs and application of fertilizers and pesticides. All management practices that use complex, ecologically-based approaches dedicate great care to nurturing soil biodiversity. In so doing, they benefit from positive cascading effects on the efficiency and productivity of the entire system.

Organic agriculture relies on the concept of 'feeding the soil, not the crop.' Decomposition of plant residues provides nutrients for soil flora and fauna, which in turn increase nutrient

FIGURE 7

Different levels of the soil food web

(Modified from Soil and Water Conservation Society - SWCS, 2000)



availability to plants through mineralization, solubilization, physical transport (in the case of mycorrhizal fungi and siderophores) and other processes. In soils under organic agriculture, Mäder et al. (2002) documented a 40% increase in biomass and in mycorrhizal symbioses; 130–320% increase in microbial and earthworm decomposition; and 200% increase in biodiversity and arthropod abundance. Although a 20% decrease in yield was associated with organic practice, 30–54% reductions in nutrient inputs and 97% reduction in pesticide use were recorded. Organic plots exhibited increases of 10–60% in nutrient-use efficiency, soil fertility, phosphorus cycling and aggregate stability. Under stressful conditions, organic crops tend to react better than those under high-input management. In 1999, during one of the worst droughts on record, organic soybeans in the USA yielded 2 t/ha, compared with only 1.07 t/ha from conventionally grown soybeans (Rodale Institute, 1999).

The System of Rice Intensification (SRI) is becoming widely adopted in many African and Asian countries because, compared with standard rice management (SRM), it consistently achieves increases in output alongside reductions in inputs of seeds, agrochemicals, water, energy and labour. SRI uses specific crop and water management practices that favour aerobic soil environment, root growth and tillering, soil biodiversity and more efficient soil and plant biological activity – which results in a higher impact of all levels of nitrogen

FIGURE 8

Animal traction no-till direct planting in CA in a mixed cropping system in Nicaragua

application on yields in SRI than in SRM fields (Lin et al., 2009). SRI was introduced in India in 2000 and it is now practiced by as many as 600,000 farmers on about 1 million hectares. The average increase in income from SRI in eight countries (Bangladesh, Cambodia, China, India, Indonesia, Nepal, Sri-Lanka and Vietnam) has been shown to be around 68% , with yield increases of 17-105% and decreases in water requirement between 24% and 50% (Africare, Oxfam America, WWF-ICRISAT Project, 2010).

Conservation agriculture aims at maximising the functions of soil biodiversity through maintenance of year-round organic cover, minimal soil disturbance (for example by direct seeding – Figure 8) and use of diversified crop rotations, including appropriate nitrogen-fixing legumes. Rotations contribute to maintaining biodiversity above and below the ground, contribute nitrogen to the soil/plant system and help avoid the build-up of pest populations (Kassam et al., 2009). It is estimated that there are now some 117 million hectares of arable and permanent crops under conservation agriculture worldwide. Rainfed rice yields in the range of 8–9 tonnes per hectare, well above usual irrigated yields, are being achieved in Brazil within four to five years of using conservation agriculture methods; yields of maize and soybeans have been increased by about 50% with half the cost of production (Machado and Silva, 2001). In Paraguay, even small farmers have been able to successfully grow crops that initially were thought not to be appropriate for no-till systems, such as cassava. Planting cassava under conservation agriculture in combination with cover crops has resulted in yields sometimes double those obtained from conventional farming systems (Derpsch and Friedrich, 2009) and has enhanced the system's diversity.

Three decades of successes in large-scale implementation of conservation agriculture practices demonstrate that a system of agriculture that 'imitates' nature and nurtures soil biodiversity can in fact be productive and profitable. An economic evaluation of conservation agriculture in Brazil clearly shows that, besides direct benefits to farmers (26% of the total), the principal indirect-use benefits come from reductions in public spending. These derive from the value of the reduced clearing of native vegetation (57% of the total); reduced off-farm effects of soil erosion; lower emissions of greenhouse gases; carbon sequestration; and enhanced aquifer recharge (due to increased rainfall infiltration) (Landers, 2007).

Although conservation agriculture is not intrinsically organic, recent advances show that it offers great potential for weed and pest control using non-chemical means. Crop rotation and short-term green-manure cover crops reduced the use and cost of herbicides drastically in trials conducted with farmers in Paraguay (Kliewer et al., 1998) and Brazil (Sorrenson and Montoya, 1984) and it has been suggested that conservation agriculture has great potential for smallholders in Africa given adequate resources and institutional support.

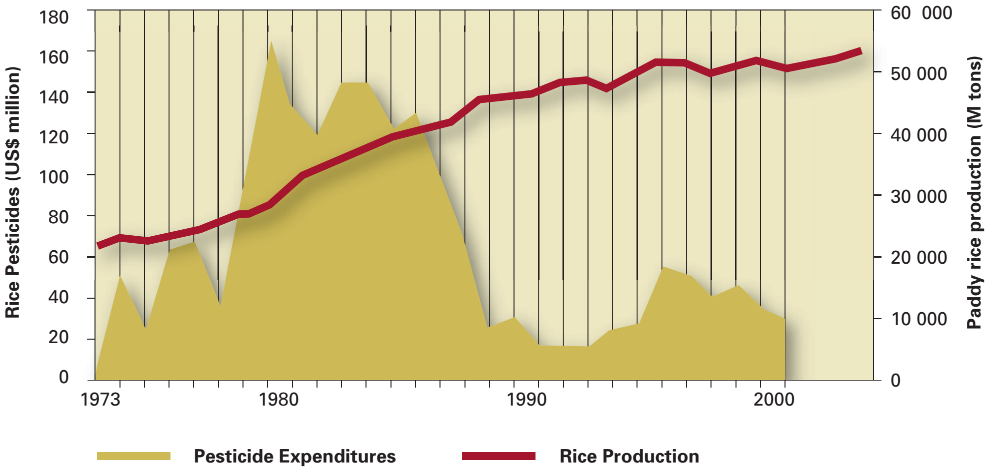
Pest control

Diversity in the form of intraspecific genetic diversity, mixed cropping systems and – at larger scale – landscape heterogeneity, increases resilience of the agro-ecosystem, contributes to more effective control pests and diseases and offers considerable promise for improving production and productivity sustainably. Growing various species and varieties with different resistance characteristics mitigates the risk of infection and damage (Hajjar et al., 2008). The validity of this approach has been tested through numerous studies that have compared simplified and diversity-rich agro-ecosystems; these have indicated that pest populations are dramatically lower in mixed-species than in single-species plantings. Stemming from these research findings, interventions aimed at controlling or preventing pest and disease outbreaks through sound management of landscape- and field-level diversity have been developed, many of which have been implemented on a large scale (Gurr et al., 2004). Global epidemics of wheat yellow rust in the 1980s and 1990s were the result of the evolution of a new race of the pathogen able to overcome the resistance gene, Yr9, and its spread from East Africa to the Near East and Central and South Asia (Singh et al., 2004).

Successful integrated pest management (IPM) programmes in Asia have shown that conserving arthropod biodiversity by helping increase local understanding of how agro-ecosystems function is a key ingredient of effective pest management in rice production. In Bangladesh, IPM initiatives have invested in maximizing natural diversity in rice paddies, with the integration of fish into rice paddies and the adoption of agro-ecological methods to restore the natural balance between insects and other fauna. This approach has increased rice yields while consuming less pesticide and has provided valuable new sources of food. In Indonesia's national IPM programme, thousands of farmers have adopted IPM methods, including measures to enhance local biodiversity and restore natural pest–predator balance.

FIGURE 9

Rice production and pesticide expenditures in Indonesia from 1973-2001 (FAO, 2009c)



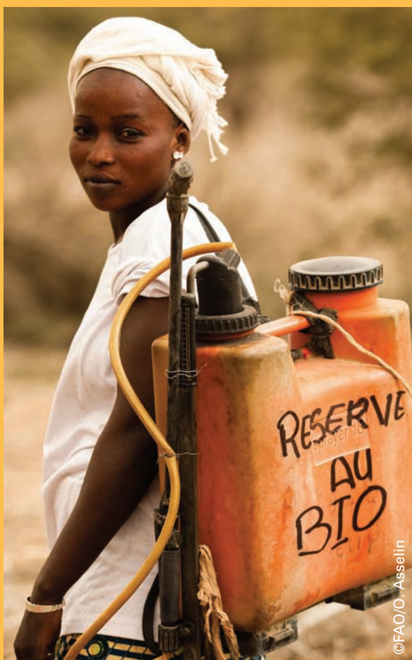
As a result, the expenditure on pesticide used on rice fell by over 75% while yields increased by 25% from the start of the programme in 1986 to 2001 (Figure 9), thanks in part to a supportive policy environment.

Diversification of the farming landscape by favouring species mixtures over monocultures is one of the best ways of achieving results in pest and disease control. For example, mung beans or sweet potatoes grown together with maize discourage weed growth because of their shading effect. Farmer participatory trials in Africa testing various crop combinations found that intercropping maize with the fodder legumes *Desmodium uncinatum* (silver leaf) and *D. intortum* (green leaf) reduced infestation of the parasitic weed, *Striga hermonthica* by a factor of 40 (Pretty, 1999). Similarly, growing *Brachiaria* species as a cover crop in bean fields reduced *Rhizoctonia, Sclerotinia* and *Fusarium* infections by 75%. This has revolutionized rainfed and irrigated production of *Phaseolus* bean; planting *Phaseolus* into desiccated *Brachiaria* has led to farm yields of over 3 t/ha (corroborated by Kluthcouski et al., 2003). Human management of insect biodiversity through controlled release of natural predators has also yielded some positive results, especially for pest control in crops such as cassava. A study of the economic benefits of cassava mealybug control over 40 years estimated a cost–benefit ratio of 200 at world market prices (Zeddies et al., 2001). Water hyacinth (*Eichhornia crassipes*) is readily controlled by *Neochetina eichhorniae*, a weevil occurring in the natural vegetation.

Intraspecific diversity is another valuable tool for preventing pest outbreaks. Zhu et al. (2000) observed that growing a simple mixture of rice (*Oryza sativa*) varieties across thousands of farms in China significantly restricted development of rice blast. In Yunnan Province, China, blast-susceptible rice varieties grown in mixtures with resistant varieties yielded 89% more grain and suffered 94% less severely from blast than when grown in monoculture. The experiment was so successful that fungicidal sprays were no longer

BOX 4
Farmer field schools promote use of ecofriendly ways to fight pests

Strategies for integrated pest management are generally different for each crop, depending on local varieties used, local agronomic practices and crop protection options available. IPM is thus best understood as a local process of experimentation and adaptation by farmers prior to adoption. Designing and practising effective IPM systems are about learning and continuously finding solutions to changing field situations and problems. There are a number of practices that contribute to elimination or suppression harmful organisms. These include: crop rotations and intercropping; growing pest-resistant or tolerant cultivars from certified seeds; integrated weed management; applying field sanitation and hygiene measures; and enhancing habitat for beneficial organisms. Pesticides should be used only as a last resort.



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There are a number of alternatives to chemical pesticides that should be evaluated before farmers decide to use chemical pesticides. These include biological pest control agents and botanical pesticides; these alternatives are being promoted by farmer field schools. The picture shows a farmer in Senegal spraying bio-pesticides.

applied by the end of the 2-year programme. This approach constitutes a calculated and effective reversal of the trend towards monoculture. This experience strongly supports the view that intraspecific crop diversification provides an ecological approach to disease control that can be highly effective over large areas and contribute to the sustainability of crop production.

Control of disease and pests in target crops is linked to the ways in which other components of the agro-ecosystem are managed. A healthy and diverse soil community contributes to healthy crops through a complex food web that keeps weeds and pests under control through competition, predation and parasitism (Susilo et al., 2004). In northern Cameroon, for example, maize and sorghum inoculated with arbuscular mycorrhizal fungi and grown in *Striga* infested soil was effective in reducing *Striga hermonthica* emergence by 30–50% and biomass by 40–63% (Lendzemo et al., 2005). Other studies have found differences in phosphorous uptake and supply among mycorrhizal species (Marshner, 1995), supporting the need to conserve diverse soil genetic resources.

BOX 5
Weed management in West Africa

Striga hermonthica is a noxious weed affecting cereal production in West Africa and other regions. It parasitizes cereal crops (maize, sorghum, millet and upland rice), commonly causing yield losses up to 60–90% (Gbèhounou et al., 1991). Crop diversity helps manage this parasitic weed. Non-cereal crops can function as false hosts or "trap crops" in intercropping systems, such as maize with cowpea. Leguminous crops, including cover crops such as velvet bean (mucuna), are preferred as they help to improve soil fertility by fixing atmospheric nitrogen, protect soils from erosion and provide good-quality livestock feed (Gbèhounou and Adango, 2003).

Increasing yield and functionality through niche complementarity

Agroforestry

Agroforestry is the use of trees and shrubs in crop or animal production and land management systems. It is estimated that trees occur on 46% of all agricultural lands and support 30% of all rural populations (Zomer et al., 2009). Trees are used in many traditional and modern farming and rangeland systems. Trees on farms are particularly prevalent in South-East Asia and Central and South America. Agroforestry systems and practices come in many forms, including improved fallows, taungya (growing annual agricultural crops during the establishment of a forest plantation), home gardens, growing multi-purpose trees and shrubs, boundary planting, farm woodlots, orchards, plantation/crop combinations, shelterbelts, windbreaks, conservation hedges, fodder banks, live fences, trees on pasture and apiculture with trees (Nair, 1993; Sinclair, 1999).

The multi-species composition of home gardens contributes to efficient nutrient cycling and resource use and conserves biodiversity while providing relatively secure livelihood support through product diversification (Kumar and Nair, 2004). Alley cropping involves the cultivation of fast-growing legume trees in rows, usually 4–5 metres apart within the fields where food crops are grown. Many local, underutilized and neglected tree species are used for this purpose, having proved highly adapted to local ecological conditions and efficient reclaiming lost nutrients from deeper layers of soil and supplying nitrogen-rich foliage. Many are leguminous, with the added benefit of fixing atmospheric nitrogen. The tree–crop combination enhances the efficiency of land use and reduces the need for fallow periods, making continuous cultivation possible and sustainable.

A 4-year trial in Nigeria consistently measured greater maize yields under alley cropping with native leucaena *(Leucaena leucocephala)* than under conventional cropping without trees. The addition of fallow periods and sheep in the system further enhanced the nutrient cycling process, as fallow vegetation was grazed and returned to the soil as manure. Farmers in Malawi intercropping maize with *Gliricidia* bushes have seen their maize yields increase threefold while also being provided with fuel for their kitchens (World Agroforestry Centre, 2009). In Indonesia, agroforests with rubber trees produce a variety of other products from local biodiversity, such as durian fruits, cinnamon and timber. These agroforestry patches, often scattered across a rice field landscape, account for 50–80% of the total agricultural income of villagers in certain provinces. In Nicaragua, maintaining trees within fields is economically advantageous since it provides a number of products, including medicinal products from ipecac (*Cephaelis ipecaucuana*), fuelwood, fencing material and water regulation services.

Important cash crops such as cacao and coffee are cultivated in a variety of management systems ranging from shaded, multi-strata agroforests to open monocultures, the former being rich in diversity and providing beneficial ecological functions and services. Shaded coffee plantations in Ethiopia have been found to harbour 19 dominant shade tree species belonging to 14 plant families. The soil is rich in arbuscular mycorrhizal fungi, especially under leguminous shade trees, and spore counts are significantly positively correlated with coffee counts and available soil phosphorus content (Muleta et al., 2007). In contrast, more open and homogeneous coffee growing systems suffer from the loss of fertilization and nutrient supply services provided by the shade trees and experience a serious decline in pollination services, which reduces coffee yields by up to 18% and net revenues per hectare by up to 14% according to simulations over two decades starting from 2001. Establishing and maintaining a minimum threshold of forest cover provides a compromise solution by preserving both ecological and economic values (Priess et al., 2007). More sustainable approaches to the intensification of cacao systems are also possible through carefully balancing trade-offs. Reduction in shade tree cover from 80% to 40% combined with increased land-use intensity caused only minor quantitative changes in biodiversity and maintained high levels of ecosystem functioning while doubling farmers' net income. Greater reductions in tree cover further increased short-term income gains but degraded ecosystem functions, depressing productivity in the long run. Low-shade agroforestry therefore provides the best available compromise between economic forces and ecological needs.

Agroforestry systems are important sources of timber and fuelwood throughout the world in both developing and developed countries. For example, intercropping of trees and crops is practised on 3 million hectares in China (Sen, 1991). In the United Kingdom, a range of timber/cereal and timber/pasture systems has been profitable to farmers (McAdam et al., 1999). Trees produced on farm are major sources of timber in Asia (e.g. China, India and Pakistan), East Africa (e.g. Tanzania) and southern Africa (e.g. Zambia). Increasing wood production on farms can take pressure off forests, which would otherwise suffer degradation.

The use of trees and shrubs in agricultural systems helps to tackle the triple challenge of securing food security, reducing the vulnerability and increasing the adaptability of agricultural systems to climate change, and mitigating climate change. Trees in the farming system can help increase farm incomes and can help diversify production and thus spread risk against agricultural production or market failures; this will be increasingly important as impacts of climate change become more pronounced. Trees and shrubs can diminish the effects of extreme weather events, such as heavy rains, droughts and wind storms. They prevent erosion, stabilize soils, raise infiltration rates and halt land degradation. They can enrich biodiversity in the landscape, increasing ecosystem stability. They can improve soil fertility and soil moisture through increasing soil organic matter content.

Agroforestry systems tend to sequester much greater quantities of carbon than agricultural systems without trees. Planting trees in agricultural lands is relatively efficient and cost effective compared with other mitigation strategies, and provides a range of co-benefits important for improved farm family livelihoods and climate change adaptation. There are several examples of private companies supporting agroforestry in exchange for carbon benefits. Agroforestry is therefore important for climate change adaptation through reducing vulnerability, increasing long-term land and food crop productivity, diversifying income sources and building the capacity of smallholders to adapt to climate change.

Crop and livestock production

In modern farming, crop and livestock production systems have become increasingly specialized (Entz et al., 2005) and often separate large-scale, specialized, energy-intensive farming operations (Kirschenmann, 2007). The recent concern over environmental quality of agricultural production has led to a renewed interest in crop–livestock systems, primarily because they provide opportunities for diversification, nutrient cycling and greater energy efficiency (Entz et al., 2005). Mixed systems enable the integration of different enterprises on the farm; livestock provide draught power and manure, while crop residues are fed to livestock. Deriving income from multiple sources (livestock and crops) offers farmers options for buffering crop failures or animal disease outbreaks (Carvalho de Faccio et al., 2007).

The efficiency of mixed crop–livestock systems can be enhanced through the adoption of well-designed crop rotations, especially those incorporating a range of appropriate dual-purpose crops. These provide both food for humans and fodder for animals, often increasing

BOX 6
Benefits of livestock in Ethiopia

Integrating livestock in crop production systems is not only beneficial for cycling nutrients and providing draught power, but also acts as a risk management strategy. Since livestock can reproduce, they constitute an asset that can appreciate even when prices are stable. The timing of realizing the asset value is more f exible than for many other agricultural products. Another important characteristic of livestock for risk management is that they are better able to deal with environmental shocks than are crops. Their mobility increases their survival rate. Livestock are herbivorous and omnivorous animals, and can survive on a wide range of feedstuff.


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overall farm productivity. In India, improved dual-purpose varieties of sorghum and millet have allowed smallholders to increase the milk production of buffalos and cows by up to 50% without reducing the grain output from their crops. Integrated crop–livestock zero tillage systems developed and implemented in Brazil are based on carefully planned crop and livestock combinations, resulting in increased yields while arresting further deforestation (Landers, 2007).

In the upland areas of the midlands of Sri Lanka, monoculture coconut systems were replaced by a diversified system combining tree crops (coconut and fruits), root crops and herbs with dairy cattle, goats and poultry, with the main goal of increasing farm income. The integrated system was economically viable compared with coconut monoculture, with dairy production and biogas covering domestic needs and contributing most to the total profits. The introduction of a mixed pasture, based on easily manageable *Brachiaria subquadripara* and *Pueraria phaseoloides* and the multi-purpose trees *Gliricidia sepium* and *Leucaena leucocephala* resulted in increases of 17% and 11% in nut and copra yield respectively. The system produced enough forage to maintain animal growth and production and the manure produced significantly improved soil fertility, reducing the cost of fertilizing the coconuts by 69%.

In Bali, the three-strata forage system combines forage crops, shrub legumes and fodder trees, food crops (maize, soybean and cassava) and livestock. A study by Pretty and Hineb (2000) found that although the system reduced the yield of food crops because of reductions in the cropped area, forage yield was increased by 91% and composition of livestock feed benefited from a 13% increase in protein content. As a result, liveweight gains of steers increased and egg production and hatchability increased by 56% and 22% respectively. Soil erosion decreased by 57% while soil organic matter content increased by 11%. Fuelwood supply increased to meet 64% of annual needs. A project of a similar kind involving numerous farmers in India introduced trees, fodder and livestock in a previously homogeneous cropping system; the positive effects of diversification on soil and water retention turned an unproductive season into a productive one, resulting in a sharp decrease in seasonal out-migration (Pretty and Hineb, 2000).

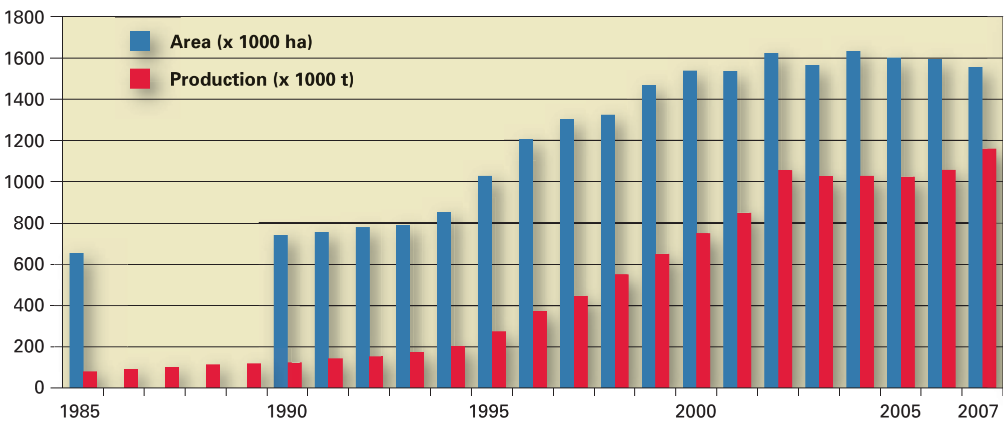
Crop and fish production

Cultivating rice and fish together is a 2000-year-old tradition in some parts of South-East Asia. However, the practice was gradually abandoned due to population pressures and the widespread introduction of high-input monoculture with high-yield rice varieties and the use of pesticides and herbicides that decreased fish stocks due to their toxicity. During the 1980s and early 1990s, rice–fish culture as managed cultivation systems experienced a revival. From an IPM point of view, fish culture and rice farming are complementary activities: fish not only play a direct role in regulating pest populations but also provide additional income which raises the economic threshold for chemical control of rice pests to a higher level than would be considered critical in rice monocultures. Indigenous fish species and breeds, such as *dhela* (*Rohtee cotio*) and *thai sarpunti* (*Barbonymus gonionotus*) in Bangladesh, respond better in mixed culture than commonly cultured breeds.

Integrated culture not only yields a variety of products from the same unit of land but also increases rice yields (both grain and straw), particularly on poorer soils and unfertilized crops (Dewan et al., 2003). The area and production of rice–fish systems in China has increased dramatically since the mid 1980s: production of finfish and other aquatic animals in these systems increased from around 81 000 tonnes in 1985 to 1.16 million tonnes in 2007 (Figure 10), while the area increased from about 650 000 hectares to about 1.55 million hectares over

FIGURE 10

Area and production of rice–fish systems in China



SOURCE: Miao (2010)

the same period. These increases were mainly the result of supportive government policies at the local and national levels aimed at increasing the income of rural farmers (Miao Weimin, 2010). Rice yields from mixed systems in China have also increased by 10–15%. With savings on pesticides and earnings from fish sales, increases in net income on rice–fish farms are reportedly 7–65% higher than on rice monoculture farms (Halwart, 1998).

Diversity of the rice crop is also important in determining the efficiency and productivity of the integrated system: the use of long-stemmed, late-maturing traditional varieties allows a higher water table and an extended period for fish farming, although the use of modern rice varieties is not a constraint for rice–fish farming. The possibility of mixing different varieties with different adaptability and productivity potential provides options for enhancing diversity and contributing to the overall resilience of the system (Halwart, 1998).

Pollination

Animal pollination provides a highly effective pollination service for better seed set and fruit quality and quantity, particularly pollination by wild bees and honey bees. Pollinators contribute to the yield and quality of output of at least 70% of the major crops used directly by humans for food and these crops contribute about 35% of the total amount of food produced (Klein et al. 2007). The economic value of the pollination services was estimated at €153 billion worldwide in 2005 (Gallai et al. 2009). Crop pollination is both an ecosystem service (Myers, 1996 ; Balvanera et al., 2001, Kremen et al., 2007) and a practice used by farmers in their overall production scheme (Delaplane and Mayer, 2000; Stokstad 2007). It is an ecosystem service in that wild pollinators – especially wild bees (Apiformes) of which there are 20,000 species in the world – contribute to the pollination of many crops (Kremen et al., 2002; Klein et al., 2007 ; Winfree et al., 2007). It is also a production practice in that farmers commonly bring colonies of honey bees (*Apis mellifera*) or purchase colonies of bumble bees (e.g., *Bombus terrestris* in Europe) to ensure the pollination of their crops (Carreck et al., 1997, Velthuis and Van Doorn, 2006).

Recent studies show the interaction between different species of pollinators can enhance pollination efficiency and be an essential element for achieving optimal pollination. In some instances pollinator diversity may be even more important than pollinator density as has been reported for almond (Dag et al., 2006), coffee (Klein et al., 2003), pumpkin (Hoehn et al., 2008), and sunflower grown for hybrid seed production (Greenleaf and Kremen, 2006). In this last study, the pollination efficiency of honey bee foragers was enhanced up to 5 times by the presence of wild bees.

The spread of *Varroa destructor* throughout the world in the 1980s has led to the disappearance of nearly all feral colonies of honey bees as well as a considerable drop in the number of beekeepers and managed colonies in all temperate areas where it still remains a very significant problem (Yang and Cox-Foster, 2005). New pathogens such as *Nosema ceranae* (Higes et al., 2007) and parasites such as the small hive beetle *Aethina tumida* (Lounsberry et al., 2010) are further contributing to the weakening and loss of colonies. The recent Colony Collapse Disorder (CCD) syndrome and the recurrent colony losses faced by beekeepers in many countries (Cox-Foster et al., 2007, Stokstad, 2007) have clearly exposed the vulnerability of relying solely on honey bees to pollinate field crops.

A number of crops depend to a significant extent on species other than domesticated bees for satisfactory pollination. Today there are over one million colonies of bumble bees raised on a worldwide basis to pollinate mainly tomatoes and other greenhouse crops (Velthuis and Van Doorn, 2006). Similarly, passion fruit is pollinated mainly by wild carpenter bees *Xylocopa* spp. (Nicodemo, 2004). Modern methods of plant breeding and the use of hybrid seeds in a growing number of crop species require access to a growing panel of pollinators. For example, recurrent selection of beans *Phaseolus vulgaris* is undertaken using bumble bees (Wells et al., 1988) as is the production of true seeds in potatoes *Solanum tuberosum* (Batra, 1993). Currently, one of the obstacles to the development of hybrid seed production in lettuce is the availability of an effective pollinator as its flowers are visited neither by honey bees nor bumble bees (Curtis et al., 1996).

Agriculture and nutritional diversity

The recognition of the value of nutritional and dietary diversity is becoming an important entry point for exploring more ecologically sustainable food systems. The causes and consequences of the impoverishment in food diversity and simplification of diets span culture, health, agriculture, markets and environment and are complex to address. However, it seems likely that agricultural biodiversity can play a role in moderating nutritional problems (Johns and Eyzaguirre, 2006). The combination of various crops and animals in agro-ecosystems permits not only the more-efficient utilization of ecological niches, it also increases locally available nutrients for human diets or improves household income, allowing the purchase of alternative food items on the market.

In south-west Ethiopia some 12 500 farm households have been assisted in the adoption of sustainable agriculture on about 5000 hectares of land, introducing vegetables and trees (fruit and forest), using manure and natural pest control strategies (Pretty, 1999). Along with a 60% increase in crop yields, this resulted in a 70% improvement of overall nutrition levels within the project area. An area once reliant entirely on emergency food aid has now become able to feed itself through sustainable agriculture and surplus to build up reserves. Elsewhere, the fish component in rice–fish integrated systems secures the protein and fatty acid intake of farming populations, and provides essential micronutrients that are not found (or are at inadequate levels) in rice, particularly calcium, iron, zinc and vitamin A. In some areas of Cambodia the wild fish found in rice fields, canals, ponds and rivers provide an estimated 70% of total protein intake (Halwart, 2006). In poor rural households in Kishoreganj, Bangladesh, small indigenous fish species contributed 40% and 31% of the total recommended intakes of vitamin A and calcium, respectively (Roos et al., 2003).

Indigenous species are important to health besides having an important role in ecologically-based production systems. In many crops, the difference between one variety and another can make the difference between micronutrient deficiency and micronutrient adequacy. Projects implementing an integrated approach to sustainable agriculture and improved nutrition have successfully built upon locally available biodiversity to revitalize local or regional food products and systems and have had a positive impact on communities' livelihoods and health. Across many southern African countries, progressive substitution of what had become 'shameful' local vegetable species with 'modern' cabbage caused a decrease in vitamin and micronutrient intake (Bioversity International, 2010). In response to this, local underutilized leafy vegetables have been reintroduced in Kenyan supermarkets through a campaign based on nutritional and agronomic studies, distribution of seeds to farmers and dissemination of local recipes. Production of leafy vegetables in peri-urban Nairobi has grown more than tenfold since 1997 (Bioversity International, 2007) and incomes have increased, particularly where farmers have been successfully linked to markets. Composition analyses can provide information on the micronutrient content of varieties, including lesser-known cultivars and wild varieties. Recent analyses of crops have shown that beta-carotene content can differ by a factor 60 between sweet potato cultivars and the pro-vitamin A carotenoid of banana cultivars can range between 1 μg and 8500 μg/100 grams (Lutaladio et al., 2010).

BOX 7
Benefits of local banana varieties in Pohnpei (Federated States of Micronesia)

Consumption of local traditional foods by the people of Pohnpei has been steadily declining, and their diets have shifted towards increased consumption of imported food. An increasingly large share of the population now has serious nutrition-related problems, including vitamin A deficiency, obesity and diet-related non-communicable diseases. Programmes aimed at introducing leafy vegetables into people's diets did not show significant results, since these vegetables were neither indigenous nor well-liked.

Composition analysis of traditional banana varieties (*Karat* and *utin iap*) showed high pro-vitamin A content and very high levels of beta-carotene.

These varieties are now being systematically promoted for consumption on the island.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Enabling and supporting the increased use of biodiversity for food and agriculture

THE WIDER ADOPTION OF PRACTICES that make fuller use of biodiversity and strengthen ecological functionality in agriculture is limited by a number of factors. These include inappropriate policies, economic and market barriers, difficulties faced particularly by small-scale farmers and rural communities in adapting practices developed elsewhere to their realities with their participation and involvement, and a failure to adequately reflect nutritional and health perspectives in agricultural production. In addition, there is a widespread lack of awareness among everyone from policymakers to consumers of the importance of and need to adopt agricultural practices that enhance biological processes. Agricultural research over the last decades has not only generally ignored the potential value of biodiversity but has also been largely concerned with exploring approaches that simplify production systems and remove complexity and diversity; there is thus a need for substantial new research.

This section explores some of the ways in which increased use of biodiversity for food and agriculture might be favoured. Additional possibilities will undoubtedly be identified as the cross-sectoral and multi-scale aspects are explored and the linkages across health, environmental services, economics, landscape management and cultural benefits are explored and socio-ecological perspectives adopted (Ostrom, 1990).

International and national policies

A number of international mechanisms that provide a framework for the increased use of biodiversity for food and agriculture are already in place. For instance, under FAO's Strategic Framework, a number of Strategic Objectives, such as those on crops, livestock, fisheries, forestry and environment and natural resources, deal with sustainability in production systems. A specific example is Strategic Objective A, which is on the Sustainable Intensification of Crop Production[6], and includes the management of biodiversity for food and agriculture and the related ecosystem services. Strategic Objective A also takes account of a number of global and regional instruments, treaties, conventions and codes (e.g. the International Plant Protection Convention, the International Treaty on Plant Genetic Resources for Food and Agriculture, the International Code of Conduct on the Distribution

[6] http://www.fao.org/agriculture/crops/core-themes/theme/sustainable-crop-production-intensification

and Use of Pesticides) that embody international cooperation for enhancing and sustainably using natural resources and reducing risks from, and improving management of, transboundary threats to agricultural production, the environment and human health. For instance, the Emergency Prevention System for Transboundary Animal and Plant Pests and Diseases (EMPRES) Plant Health programme monitors transboundary pests and diseases that are a potential constraint to sustainable crop production intensification and the local agricultural biodiversity.

Other existing international mechanisms provide, *inter alia*:

- limitations on pollution especially nitrogen runoff;
- internationally enforceable safety regulations in respect of agrochemicals; and
- improved access to and movement of crop varieties needed to cope with change and enhance diversity in production systems within an agreed access and benefit-sharing regime that recognizes farmers' rights.

There are a number of other international mechanisms that could be strengthened, for example:

- a REDD+ framework that reflects the potential contribution of biodiversity for food and agriculture;
- appropriate international agreements that support and protect land and water rights of the maintainers of diversity, which include indigenous and rural communities and small-scale farmers; and
- the Global Plans of Action on Plant and Animal Genetic Resources, which deal with the conservation and sustainable utilization of these resources.

Encouraging policy signals in this direction have come from the EU seed regulation system, which has recently allowed the inclusion in national seed catalogues of landraces or conservation varieties and therefore legalized their commercialization. Directive 62/2008[7] states that "landraces and varieties which are naturally adapted to local and regional conditions and threatened by genetic erosion (conservation varieties) can be grown and marketed even where they do not comply with the general requirements", providing derogations as regards to their uniformity and distinctness. Recognizing regional and local differences in agricultural systems throughout member states, the EC also authorizes each State to adopt their own provisions as regards distinctness, uniformity and stability.

The work programmes of international and regional organizations can also have a significant effect on the adoption of biodiversity-friendly approaches. FAO's own programmes on the sustainable production of crops, livestock, fish and forest resources, as well as its work on environment and natural resources, are examples of programmes that should be given increased support and visibility. UN agencies such as FAO, UNEP, UNDP and UNESCO also carry out important relevant work and a number of valuable agricultural biodiversity projects have been supported, *inter alia*, by the Global Environment Facility. However, much of the work takes the form of individual initiatives and would produce greater benefit with the development of linkages and collaboration.

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7 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:162:0013:0019:EN:PDF

National policies and economic practices are of primary importance in respect of the possibilities of increasing the use of biodiversity for food and agriculture. The full implementation by countries of the international agreements that contribute to increased use of biodiversity for food and agriculture is an essential first step that needs to be combined with revising those agreements that have a constraining effect (e.g. as in the case of some agreements and regulations adopted by EU member countries and those trading with them). National policy can have a significant effect at many levels. Relevant entry points that can influence the use of biodiversity include:

- land management policies that permit or limit production practices or, for example, permit or limit sale of large areas of land to producers likely to engage in monocropping;
- pollution regulations that act to limit nitrogen or phosphorus use and use of agrochemicals;
- safety regulations, especially with regard to specific agrochemicals;
- subsidies that favour or limit use of particular production practices;
- land and water rights, especially for small-scale farmers, rural communities and indigenous peoples;
- research-support policies that encourage research into particular kinds of agricultural practices; and
- legislation in respect of seed sales, product type and identity, all of which can have positive or negative effects on the ability to use diversity to achieve production objectives.

An important way of supporting the increased use of agricultural biodiversity is through the formal recognition that can be given to the use of traditional crop varieties and livestock breeds. The increasing domination of a few seed companies in providing seeds of major crops has led to concern at loss of diversity and to continuing pressure on farmers to abandon traditional varieties. Livestock policies have also encouraged short-term solutions, e.g. promotion of 'exotic' breeds and their crosses through centralized provision of exotic x local F1 animals to farmers and neglect of local, adapted animal genetic resources (ILRI, 1999). At the farm level though, these planned mating schemes may not function as intended due to poor extension services or high transaction costs and following livestock generations often express poor adaptation to real-world, low-input and high-stress environments.

Alternatives are possible. In Nepal, the Variety Approval, Registration and Release Committee gave its approval to a rice variety called 'Pokhareli Jethobudho' in 2006. The official recognition of what is essentially a landrace constituted by a mixture of six diverse lines not only opens the possibility of greater acceptance of diversity within a commercial product but also gives farmers in a community intellectual ownership of their variety, setting an important precedent for Nepal and other countries (Gyawali et al., 2010). Important ingredients seem to be the maintenance of strong public sector plant breeding programmes, involvement of farmers and communities using participatory approaches and deliberate development of programmes that target multiple environments and meet multiple preferences of farmers, communities and consumers (Ceccarelli and Grando, 2007). Policies supportive of plant biodiversity in agriculture need to ensure that informal seed supply systems remain dynamic and effective ways for farmers to access new materials just as they need to relax the stringent requirements for uniformity in the informal seed sector, in order to allow wider commercialization of diverse breeding and growing material.

Economic and market perspectives

The powerful effect of economic subsidies and taxes in posing barriers to or promoting adoption of sustainable solutions is evident in the following three examples.

1. Heavy subsidies awarded to rubber production distort rubber prices by making them unrealistically low. If the subsidies were lifted, returns to labour from rubber production in extensive agroforestry systems would exceed those from plantation production by 30% (Tomich et al., 2001), with extensively managed agroforests providing additional ecosystem services through greater levels of biodiversity.

2. Policies that reduced land taxes and subsidized feed production determined the growth of otherwise marginally profitable ranching operations in South America in the 1970s, with consequent increases in deforestation. When this support was removed, the operations stopped being profitable and much of the land reverted to forest (Kaimowitz, 1996).

3. In Indonesia, the government's commitment to IPM strategies for rice culminated in the establishment of a ban on a number of pesticides. This resulted in a 75% reduction in the use of chemical control methods for rice although yields continued to rise by 25% over the same period (FAO, 2009c).

As well as discouraging unsustainable practices, governments can invest in the maintenance (or improvement) of ecosystem regulating and supporting services that derive from the maintenance of diversity in the agricultural landscape. Payments for environmental services (PES) are a mechanism for translating external, non-market values of the environment into real financial incentives. The money for these investments can come from charging beneficiaries (consumers of various kinds) through taxes or market mechanisms for the use of ecosystem services. In the first years of such a scheme the funds can be used either to compensate those whose livelihoods may be diminished by conservation efforts or to support the transition to alternative, ecologically-based agricultural models. In most large-scale settings the change from monoculture to diversified, multifunctional systems and practices entails transition costs (often mostly in terms of labour) with sometimes lower profits for the first two or three years. However, after the initial transition period, producers have found that changes are profitable as well as ecologically sound and that they present valuable income opportunities. Using tax or market revenues for payments for ecosystem services could play a crucial role in making the transition possible and demonstrating its profitability. More generally, perhaps payments to farmers should be such as to ensure that they have the necessary incentives to maintain and enhance all the different ecosystem services.

Examples of payments for environmental services include national-scale PES programmes in Costa Rica (Pagiola, 2008) and Mexico (Muñoz-Piña et al., 2008), agri-environmental schemes in Europe and the USA (Claassen et al., 2008; Dobbs and Pretty, 2008; Baylis et al., 2008), conservation concessions and easements (Niesten et al., 2004; Hardner and Rice, 2002) and forest-carbon plantations (Smith and Scherr, 2002). Careful planning of these schemes is needed to avoid some recurrent problems such as the lack of additionality (i.e. paying for activities that would have been conducted anyway) and leakage (i.e. shifting environmentally-damaging activities elsewhere).

In a world increasingly dominated by market values and transactions, market incentives have to be found to support use of biodiversity and increased sustainability. Market creation for products or services provided by ecological agriculture may be important in ensuring long-term adoption of sustainable practices, substituting public financial support after an initial phase. Consumers' demand for sustainability and diversification in food and non-food products is a powerful instrument to motivate private corporations also to move towards sustainable means of production. For example, Chiquita has invested heavily in certification, reducing its pesticide use by 80% to maintain access to the European market for certified bananas. In Italy interventions at national and regional scales have created successful niche markets for landraces and local breeds, leveraging their traditional, cultural value and supporting small-scale farmers who are usually in charge of their maintenance in low-input agricultural systems (Negri, 2003).

BOX 8

Limitations placed on diverse systems by processing and cultivation techniques

An issue that has to be tackled by markets in order to promote the use of more biodiversity in food production is the current limitations that are placed on the more diverse systems. It is generally more difficult to work with large farm machinery on polycultures than monocultures of crops, and, due to the market demand for homogenous products, processing machinery is designed to handle uniform products. Removing this uniformity in processing equipment may result in a higher cost of the final product, since more machinery and manual selection may be required.

The annual cost of environmental damage of the world's 3,000 largest publicly listed companies in 2008 has been estimated at over US$ 2 trillion (UNPRI, 2010). Efforts to develop policies that ensure economic costs of damage to ecosystems and biodiversity are fully recognized are therefore increasing as is work on the total value of ecosystems and biodiversity. The Economics of Ecosystems and Biodiversity (TEEB, 2010) study has recommended that 'ecosystem conservation should be regarded as a viable investment option in support of a range of policy goals including food security, urban development, water purification and wastewater treatment, regional development, as well as climate change mitigation and adaptation'.

In many countries, consumers are already willing to pay more for products that come from sustainable agricultural systems and traditional landscapes because of health and environmental concerns. Product certification is one of the most commonly used instruments to identify such products and can provide a price premium for producers. The market for certified organic products has been growing by 20% a year since the early 1990s, a lot faster than the rest of the food industry both in developed and developing nations. Estimates of future growth range from 10% to 50% annually depending on the country[8]. Certification is used not only for organic products (estimated at over 35 million hectares in 2008; Willer and Kilcher, 2010), but also for those obtained through the use of a wide range of practices that conserve soil resources, wild habitats, endangered species or forest land. The Rainforest Alliance runs a certification programme for coffee from shaded plantations that maintain forest cover and prevent soil erosion. The Salmon-Safe Agricultural Products programme in the USA awards a label to farmers who protect salmon habitat. Fairtrade labelling embraces a concept of sustainability that goes beyond natural and environmental values to include social equity in securing livelihoods and adequate income for producers, especially from developing countries.

There is great potential to develop markets for underutilized or wild species, given the wide availability of crops, livestock and fish that have not been (fully) domesticated or commercially exploited. Such developments would support the conservation through use of a wider range of genetic resources while providing farmers with opportunities to diversify livelihood options and increase their incomes, which is particularly relevant in dealing with global changes. The development of totally new markets, however, needs to take into account possible modifications along the entire supply chain, including measures to ensure stable supply of planting or breeding stocks, to adapt processing technologies and to set quality standards.

Community-based approaches

An essential element of the successful development and long-term adoption of ecologically sound, sustainable systems is the involvement of farming communities and small-scale farmers and the integration of socio-cultural and socio-ecological dimensions and local knowledge into any decision about food security and sustainability. The importance of integrating traditional knowledge and modern technologies has been widely recognized, as has the importance of participatory approaches in mainstreaming innovations towards sustainability (e.g. IAASTD, 2008).

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8 http://en.wikipedia.org/wiki/Organic_food#Facts_and_statistics

BOX 9

Training on integrated pest management at a farmer field school in Lao PDR

Farmer field schools are helping farmers to better understand sustainable production and protection techniques. In Lao PDR, farmers are making drawings insects in the field and are later examining these in the school to know which are beneficial and harmful for the crops. This enhances the capacity of farmers to identify insects they see in the field.

Since many farmers have a mobile phone, these are increasingly used to help farmers identify organisms in remote areas. This helps farmers to prevent diseases without applying pesticides when this is unnecessary.


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The improved use of biodiversity for food and agriculture has been successfully achieved in many developing countries through projects using community-based approaches. Under the auspices of the Global Environmental Facility (GEF) over 34 countries have undertaken projects aimed at maintaining and using agricultural biodiversity in various ways and over US$122 million have been invested by GEF in multi-country global or regional projects, covering about 1.25 million hectares. Similar successes have been described for the adoption of sustainable agricultural practices in Ethiopia (Pretty, 1999) and for the multifunctional Machobane Farming System in Lesotho, which is based on intercropping, row-rotations, organic fertilizers and the preservation of natural enemies (UNEP, 2010). The entry points of these projects are specific components (crops, livestock, soils, pollinators, etc.) and been relatively local in respect of the target areas. Scaling up to landscape levels and integrating across components are necessary next steps.

The potential for large-scale adoption of participatory community and farmer-based approaches has been demonstrated by farmer field schools (FFS), which have allowed a wide adoption of IPM strategies throughout the world. FFS were started in 1989 in Indonesia to reduce farmer reliance on pesticides in rice systems. Given their immediate success and rapid spread (more than 1 million farmers have been trained in Indonesia alone), programmes centred on rice were carried out in another 12 Asian countries where over 2 million rice farmers participated in IPM schools throughout the 1990s. Over a period of ten years, farmers and agriculture extension workers took part in over 75 000 schools (Pontius et al., 2002). IPM FFS programmes have been conducted in over 30 countries worldwide (Van den Berg, 2004). Farmers who have participated in field schools have reduced their use of pesticides, improved their use of inputs such as water and fertilizer, realized enhanced yields and obtained increased incomes (Pontius et al., 2002).

An important element in the maintenance or adoption of diversity-rich approaches will be the recognition of the importance of local institutions and the development of ways of strengthening them (Van Oudenhoven et al., 2010). These institutions, which include local seed supply systems, community networks and local social organizations of various kinds, play a significant part in providing the framework in which local communities organize and manage local production strategies in ways that support the use of agricultural biodiversity.

Nutrition and health

Food security encompasses the need to have access to not only sufficient energy intake but also to nutritious food that can meet dietary requirements. Agricultural biodiversity can deliver a diversified range of nutrients from local, adapted plant and animal species that perform well in low-input farming systems. The relationship between biodiversity and nutrition is highlighted in the Millennium Ecosystem Assessment itself (Wood et al., 2005). A further opportunity for developing comprehensive approaches to food security and sustainability comes from ensuring synergies between agricultural and nutritional policies at international, national and local scales. International initiatives include the adoption by the Conference of the Parties to the Convention on Biological Diversity (CBD) of a cross-cutting initiative on biodiversity for food and nutrition[9] with implementation activities undertaken by Parties to the Convention with the support of both FAO and Bioversity International. There have also been a number of local projects and initiatives that have shown remarkable success, such as the increased consumption in Kenya of local vegetables as a result of collaboration between government agencies, local NGOs and Bioversity International.

More activities are needed at national and regional levels. For example, national agricultural policies and investments should move away from an almost exclusive emphasis on primary agricultural production and include a more decisive effort to increase consumption of fruits and vegetables, including local species and varieties, through awareness campaigns and market interventions.

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9 Biodiversity for Food and Nutrition, http://www.cbd.int/agro/food-nutrition/

BOX 10
Defining sustainable diets

One of the outcomes of the International Scientific Symposium on Biodiversity and Sustainable Diets: United against Hunger, held in Rome in 2010, was a consensus on a definition of 'sustainable diets':

"Sustainable diets are those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing use of natural and human resources."


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Awareness and education

The widespread adoption of biodiversity-friendly agricultural practices must be supported by education and awareness aimed at highlighting the multifunctionality of agriculture and the interconnectedness of biodiversity, ecosystem functioning and human health. The world's increasingly urban population will need to become more aware of the importance of maintaining the link with the rural world which still produces their food and supporting sustainable ways of producing food. There is already a growing international movement (Slow Food) that seeks to link consumers, caterers and producers in ways that recognize and value food quality and local products and supports farmers and communities who pursue alternative approaches to production. There are also a growing number of national and international NGOs and consumer groups active in the area of food politics that are developing radical critiques of current narrowly-based agricultural production systems.

Education of all the actors involved in production, marketing and consumption of agricultural products will be an important part of the process of changing agricultural production practices. In the case of farmers, there is already considerable experience in this area. The success of farmer field schools in the adoption of IPM illustrates the kind of approach needed and how it could work. Seed diversity fairs are another tool that has helped to fill knowledge gaps about agricultural diversity, especially when farmers in village settings did not have access to all the information they wanted on the crop diversity available (Jarvis et al., in press).

Research needs and opportunities

Although there have been important and interesting exceptions, much of the agricultural research conducted over the last decades has been concerned with increasing productivity through increased control of inputs and management of the production environment in ways that render it simpler and more uniform. Optimizing biological processes and ecosystem function requires an alternative approach, in which the diversity of organisms in the production system plays a central part in achieving production objectives previously achieved by external inputs and control. This will require a radically different research agenda that covers all aspects of agricultural production. It will be concerned with the multifunctionality of agriculture, involve closer collaboration with farmers and rural communities, be multidisciplinary and concerned with linkages, trade-offs and the management of complex systems. Landscape perspectives and the ways in which farmers can implement research results under their specific local conditions will become increasingly important.

An example of the kind of changes that will be needed is provided by research strategies in breeding. Most large-scale crop and animal breeding programmes to date have resulted in the development of a relatively small number of genetically uniform crop varieties and animal breeds that are specifically adapted to rather narrowly-defined environmental conditions created through extensive use of external inputs (fertilizers, feeds, pesticides, etc.). Breeding for maintenance of diversity in crop and animal populations, either as part of improved ecosystem function or to provide products and nutritional diversity, will require different approaches. In crops, population improvement strategies will probably become more important as will the way in which genotype by environment interaction is handled in breeding programmes (see, for example, Cooper et al., 2001 for further discussion and examples for crop plants). Crops bred in this manner are likely to exploit a broader diversity of available resources and deliver yield advances with a reasonable use of available inputs (Lammerts van Bueren et al., 2002). Molecular genetic and other biotechnological methods will make an important contribution to maximizing the effectiveness of these approaches, providing effective ways of ensuring that the desired diversity is retained and optimally managed in breeding programmes.

Alternative research agendas are already being developed or have been advocated in various areas of agricultural research, including soil management, pest and disease control and water use (Jackson et al., 2005). Implementing these research agendas and diverting resources to them will be an important task for both national and international research managers. It will also be important to ensure that the necessary linkages are developed between research on different aspects and to adopt research approaches that can explore trade-offs and functionality in complex systems. The research agenda will also need to include studies of the ways in which biological diversity in production systems can optimally contribute to essential system properties such as resilience and adaptability (or 'sustainagility', *pace* Jackson et al., 2010) as well as to climate change mitigation and adaptation.

Although the concern here is primarily with the use of biodiversity for food and agriculture, projects that use ecosystem services to simultaneously address environmental protection and human well-being in other areas would also benefit from improved scientific understanding of key issues related to ecosystem services dependant on agricultural biodiversity (Tallis et al., 2008). Indicators of biodiversity in agricultural production systems will be needed to monitor changes (see, for example, Sachs et al., 2010). An evaluation of ecosystem services is needed to identify their separate contributions to productivity, the most suitable scale for management, context dependency (a service in one agricultural context can become a disservice in another) and to design incentives for maintaining ecosystem service.

An area of research that merits particular attention is the contribution that diversity-rich farming can make to health and nutrition. Further investigation is needed of the ways in which society can benefit through the elimination of 'hidden hunger' (Johns and Eyzaguirre, 2006) and from the positive benefits to health from dietary diversity. For example, for most of the minor crops the nutritional differences and possible advantages of one variety over another are not known (Burlingame, 2000) although some experiences (see previous section) clearly show their advantage in securing a healthy supply of specific nutrients.

Another important focus for research is economic. A more comprehensive understanding and more complete description of the values of diversity in terms of both current and future uses is needed. The total value of ecosystem systems can be divided into social, environmental and economic costs and benefits, many of which are difficult to convert to monetary units. A better appreciation of these different values would have the power of directing policy decisions about the allocation of resources to promote and develop genetic resources. Economic evaluation of the trade-offs between ecosystem services and cost–benefit analyses of ecologically-based agricultural measures are possibly the most effective ways to deliver a policy message that can mobilize change. Evaluating the monetary value of ecosystem services requires well-designed research and collaboration between economists and ecologists to determine how services flow from one region to another, what human groups benefit from ecosystem services and what groups or populations would need to be compensated for protecting those services (Tallis et al., 2008).

The private sector is often seen as having a negative effect on sustainability because it focused more on short-term profits than on the possible long-term negative consequences and the impact on the poor. This picture is still in many cases partly true, but improvements are being made by a range of companies, many of which are leading agro-businesses. This shift will be very important for the total amount of money that will be invested in sustainable technologies, since companies invest much more in research and development than is available to most of national research institutes.

Conclusions

OVER THE NEXT FEW DECADES, agricultural production practices need to change, reducing the negative impact of agriculture on the environment while continuing to increase productivity and improve sustainability. This will be an essential part of improving food security and responding to the challenge of climate change. It will require increased emphasis on ecosystem function within agro-ecosystems and the enhanced use of biodiversity for food and agriculture.

There is sufficient evidence that agriculture can meet this challenge and that appropriate ways can be found to achieve the sustainable intensification needed. Biodiversity for food and agriculture will play an essential part in this process. Ways in which agricultural biodiversity can contribute to improved pest and disease control, nutrient availability and water use and to increased yields and the production of food with better nutritional content have all been described and are already part of production systems at various scales and in a variety of situations. However, a much more substantial change in approach is needed to ensure that agricultural biodiversity can fulfil its full potential in contributing to food security and adapting to climate change.

The shift in thinking and the changes in approach that will be needed encompass policy, social and economic aspects. They will need to involve and engage consumers and all other actors in the agricultural and food industries. The approaches needed will be particularly concerned with supporting small-scale farmers and in ensuring effective ecosystem function and diversity deployment at the landscape level. A number of actions can already be identified that are likely to have a significant effect and to create the framework for the redirection of agriculture that is needed. These include:

- ensuring that international instruments and agendas take adequate account of the contribution that agricultural biodiversity can make to their overall objectives (as in the case of the UNFCCC's mitigation and adaptation aims);
- implementing changes at national level with respect to the support given to pesticides and fertilizers so as to favour biologically-based options (as in Indonesia in the 1980s);
- testing a range of economic instruments (such as payment for ecosystem services in agricultural landscapes), internalizing environmental costs and increasing the responsibility of the private sector;
- promoting approaches that reflect an overall ecosystem perspective and that reflect socio-ecological considerations when considering agricultural, environmental and social policies; links and trade-offs should be sufficiently understood;

- supporting the various research agendas that have already been developed by organizations and groups aiming to increase the effective use of biodiversity for food and agriculture;
- strengthening local institutions and the capacity to maintain and use biodiversity for food and agriculture at local levels through mechanisms such as farmer field schools, participatory crop and livestock improvement and locally-identified adaptation strategies; and
- making consumers aware of the benefits of having a sustainable diet, encompassing a high diversity of foods, for their own health and the health of ecosystems.

Other actions and approaches will undoubtedly be identified as work is undertaken to transform agriculture and food production systems in ways that will ensure greater sustainability and more biological approaches to production. Underpinned by a framework that takes particular account of the needs and interests of small-scale farmers and of the rural poor and meets societal needs for a safe and healthy supply of food, these approaches will also make a real contribution to improving food security and to helping meet the challenges presented by climate change over the next 40 years.

References

Africare, Oxfam America, WWF-ICRISAT Project. 2010. *More Rice for People, More Water for the Planet*. WWF-ICRISAT Project, Hyderabad, India. Available at: http://www.sri-india.net/documents/More_Water_For_The_Planet.pdf.

Ahmed, N. 2009. The sustainable livelihoods approach to the development of fish farming in rural Bangladesh. *Journal of International Farm Management*, 4(4). 18 pp.

Altieri, M.A. 1987. *Agroecology: The scientific basis of alternative agriculture*. Westview Press, Boulder, CO, USA.

Amilhat, E. 2006. *Fisheries Ecology of Rice Farming Landscapes: Self-recruiting Species in Farmer Managed Aquatic Systems*. A thesis submitted for the degree of Doctor of Philosophy and Diploma of Imperial College in the Faculty of Science of the University of London. Biology Division, Imperial College of Science, Technology and Medicine. London, UK.

Anríquez, G. and Stloukal, L. 2008. *Rural Population Change in Developing Countries: Lessons for Policymaking*. ESA Working Paper No. 08-09. Agricultural Development Economics Division, Food and Agriculture Organization of the United Nations, Rome, Italy. Available at: ftp://ftp.fao.org/docrep/fao/011/aj981e/aj981e00.pdf.

Balvanera, P., Daily, G.C., Ehrlich, P.R., Ricketts, T.H., Bailey, S.A., Kark, S., Kremen, C., Pereira, H. 2001. Conserving biodiversity and ecosystem services. *Science* 291: 2047.

Bartley, D.M., Harvey, B.J. and Pullin, R.S.V. (eds.). 2007. *Workshop on Status and Trends in Aquatic Genetic Resources: A Basis for International Policy*. FAO Fisheries Proceedings 5. Food and Agriculture Organization of the United Nations, Rome, Italy.

Batra, S.W.T. 1993. Male-fertile potato flowers are selectively buzz-pollinated only by *Bombus terricola* Kirby in upstate New York. J. Kans. Entomol. Soc. 66 :252-254.

Baulcombe, D., Crute, I., Davies, B., Dunwell, J., Gale, M., Jones, J., et al. 2009. *Reaping the Benefits: Science and the Sustainable Intensification of Global Agriculture*. Royal Society, London, UK.

Baylis, K., Peplow, S., Rausser, G. and Simon, L. 2008. Agri-environmental policies in the EU and United States: a comparison. *Ecological Economics*, 65: 753-764.

Bennett, E.M., Carpenter, S.R. and Caraco, N.F. 2001. Human impact on erodable phosphorus and eutrophication: a global perspective. *BioScience*, 51: 227-234.

Bioversity International. 2007. Back by popular demand. In: *Annual Report 2007*. Bioversity International, Rome, Italy. pp. 14-16.

Bioversity International. 2010. *Annual Report 2009. Sustainable Agriculture for Food and Nutrition Security*. Bioversity International, Rome, Italy.

Bogdanski, A., Dubois, O., Jamieson, C. and Krell R. 2010. *Making Integrated Food-Energy Systems Work for People and Climate. An Overview.* FAO Green Paper Series, Food and Agriculture Organization of the United Nations, Rome, Italy.

Borger, J. 2008. Rich countries launch great land grab to safeguard food supply. *The Guardian*, 22 November 2008. Available at: http://www.guardian.co.uk/environment/2008/nov/22/food-biofuels-land-grab

Bruinsma, J. 2009. The resource outlook to 2050: By how much do land, water and crop yields need to increase by 2050? Paper presented at the FAO Expert Meeting, 24–26 June 2009, Rome, on How to Feed the World in 2050. Food and Agriculture Organization of the United Nations, Rome, Italy. Available at: ftp://ftp.fao.org/docrep/fao/012/ak971e/ak971e00.pdf

Burdon, J.J. and Jarosz, A.M. 1990. Disease in mixed cultivars, composites, and natural plant populations: Some epidemiological and evolutionary consequences. In: Brown, H.D., Clegg, M.T., Kahler, A.L. and Weir, B.S. (eds.). *Plant Population Genetics, Breeding and Genetic Resources*. Sinauer Associates Inc., Massachusetts, USA. pp. 215–228.

Burlingame, B. 2000. Wild nutrition. *Journal of Food Composition and Analysis*, 13: 99-100.

Butchart, S. H. M., Walpole, M., et.al. 2010 Global Biodiversity: Indicators of Recent Declines. *Science* (in press), 328 (5982): 1164-1168.

Caldeira, M.C., Ryel, R.R., Lawton, J.H. and Pereira, J.S. 2001. Mechanisms of positive biodiversity–production relationships: insights provided by D13c analysis in experimental Mediterranean grassland plots. *Ecology Letters*, 4: 439-443.

Carreck, N.L., Williams, I.H., Little, D.J. 1997. The movement of honey bee colonies for crop pollination and honey production by beekeepers in Great Britain. *Bee World* 78: 67-77.

Carvalho de Faccio, P.C., Anghinoni, I., de Moraes, A., Damacena de Souza, E., Sulc, R.M., Reisdorfer Lang, C., Cassol Flores, J.P., Lazzarotto Terra Lopes, M. and Silva da Silva, J.L., Conte, O., Lima Wesp, C., Levien, R., Serena Fontaneli, R., Bayer, C. 2010 Managing grazing animals to achieve nutrient cycling and soil improvement in no-till integrated systems. *Nutrient Cycling in Agroecosystems*, 88:2, 259-273.

Ceccarelli, S. 1996. Positive Interpretation of Genotype by Environment Interactions in Relation to Sustainability and Biodiversity. The International Center for Agricultural Research in the Dry Areas (ICARDA). P.O. Box 5466 Aleppo, Syria. (mimeo)

Ceccarelli, S. and Grando, S. 2007. Decentralized-participatory plant breeding: an example of demand driven research. *Euphytica*, 155(3): 349-360.

Chambers, R., Pacey, A. and Thrupp, L. A. (eds.) 1989. *Farmer First: Farmer Innovation and Agricultural Research*. Intermediate Technology Publications, London, UK.

Claassen, R., Cattaneo, R. and Johansson, R. 2008. Cost-effective design of agri-environmental payment programs: U.S. experience in theory and practice. *Ecological Economics*, 65: 737-752.

Cooper, H.D., Spillane, C. and Hodgkin, T. (eds.). 2001. *Broadening the Genetic Base of Crop Production*. International Plant Genetic Resource Institute (IPGRI) and Food and Agriculture Organization of the United Nations, Rome, Italy.

Cox-Foster, D.L., Conlan, S., Holmes, E.C., Palacios, G., Evans, J.D., Moran, N.A., Quan, P.L., Briese, T., Hornig, M., Geiser, D.M., Martinson, V., van Engelsdorp, D., Kalkstein, A.L., Drysdale, A., Hui, J., Zhai, J., Cui, L., Hutchinson, S.K., Simons, J.F., Egholm, M., Pettis, J.S., Lipkin, W.I. 2007. A metagenomic survey of microbes in honey bee colony collapse disorder. *Science* 318: 283-287.

Curtis, I.S., He, H., Scott, R., Power, J.B., Davey, M.R. 1996. Genomic male sterility in lettuce, a baseline for the production of F1 hybrids. *Plant Science*. 113: 113-119.

Dag, A., Zipori, I., Pleser, Y. 2006. Using bumblebees to improve almond pollination by the honeybee. *J. Apic. Res.* 45: 215-216.

Delaplane, K.S. and Mayer, D.F. 2000. *Crop pollination by bees.* CABI Publishing, New York, USA. 332 pp.

Derpsch, R. and Friedrich T. 2009. Global overview of conservation agriculture adoption. Invited Paper, 4th World Congress on Conservation Agriculture: Innovations for Improving Efficiency, Equity and Environment, 4-7 February. Indian Council for Agricultural Research, New Delhi, India. Available at: http://www.fao.org/ag/ca.

Dewan, S., Chowdhury, M.T.H., Mondal, S. and Das B.C. 2003. Monoculture of *Amblypharyngodon mola* and *Osteobrama cotio cotio* in rice fields and their polyculture with *Barbodes gonionotus* and *Cyprinus carpio*. In: Wahab, A., Thilsted, S.H. and Hoq, E. (eds.). *Small Indigenous Species of Fish in Bangladesh: Culture Potentials for Improved Nutrition and Livelihood*. Bangladesh Agricultural University, Mymensingh, Bangladesh.

Diaz, R. J., and Rosenberg, R. 2008 Spreading Dead Zones and Consequences for Marine Ecosystems. *Science*, 321(5891).

Dobbs, T.L. and Pretty, J. 2008. Case study of agri-environmental payments: the United Kingdom. *Ecological Economics*, 65: 765-775.

Easterling, W.E., Aggarwal, P.K., Batima, P., Brander, K.M., Erda, L., Howden, S.M., Kirilenko, A., Morton, J., Soussana, J.-F., Schmidhuber, J. and Tubiello, F.N. 2007. Food, fibre and forest products. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (eds.). *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

eFlowNet. 2010. About environmental flows [online]. Available at: http://www.eflownet.org/viewinfo.cfm?linkcategoryid=4&siteid=1&FuseAction=display

Entz, M.H., Bellotti, W.D., Powell, J.M., Angadi, S.V., Chen, W., Ominski, K.H. and Boelt, B. 2005. Evolution of integrated crop–livestock production systems. In: McGilloway, D.A. (ed.). *Grassland: A Global Resource*. Wageningen Academic Publishers, Wageningen, the Netherlands. pp. 137-148.

FAO.2001. International Action in the Management of Forest Genetic Resources: status and challenges. Paper prepared by Christel Palmberg-Lerche, September 2000. Forest Genetic Resources Working Papers, Working Paper FGR/1. Forest Resources Development Service, Forest Resources Division. FAO, Rome (unpublished). ftp://ftp.fao.org/docrep/fao/004/X9818E/X9818E00.pdf

FAO. 2002. *World Agriculture: towards 2015/2030. Summary Report*. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO. 2006. *World Agriculture: towards 2030/2050, Interim Report. Prospects for Food, Nutrition, Agriculture and Major Commodity Groups*. Global Perspective Studies Unit, Food and Agriculture Organization of the United Nations, Rome, Italy.

FA0, 2008a. *FAO Water Reports 33: Scoping agriculture - wetland interactions: Towards a sustainable multiple-response strategy* Coordinated and edited by Adrian Wood and Gerardo E. van Halsema

FAO. 2008b. *Tools for Conservation and Use of Pollination Services. Initial Survey of Good Pollination Practices*. Global Action on Pollination Services for Sustainable Agriculture. Food and Agriculture Organization of the United Nations, Rome, Italy. Available at: http://www.fao.org/fileadmin/templates/agphome/documents/Biodiversity-pollination/SURVEY_DEC_08_Small.pdf

FAO. 2009a. *Declaration of the World Summit on Food, Rome, 16-18 November 2009*. Food and Agriculture Organization of the United Nations. Rome, Italy. Available at: http://www.fao.org/fileadmin/templates/wsfs/Summit/Docs/Final_Declaration/WSFS09_Declaration.pdf

FAO 2009b. *Contributions of Smallholder Farmers and Pastoralists to the Development, Use and Conservation of Animal Genetic Resources*. Commission on Genetic Resources for Food and Agriculture, Working Group Animal Genetic Resources, 5/09/Inf.4. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO. 2009c. *Increasing Crop Production Sustainably - the Perspective of Biological Processes*. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO. 2010. *Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture*. Commission on Genetic Resources for Food and Agriculture. Food and Agriculture Organization of the United Nations, Rome, Italy.

Fischer, G., van Velthuizen, H., Shah, M. and Nachtergaele, F. 2002. *Global Agro-ecological Assessment for Agriculture in the 21st Century: Methodology and Results*. International Institute for Applied Systems Analysis, Laxenburg, Austria, and Food and Agriculture Organization of the United Nations, Rome, Italy. Available at: http://www.iiasa.ac.at/Research/LUC/SAEZ/pdf/gaez2002.pdf

Gallai, N., Salles, J.-M., Settele, J., Vaissière, B.E. 2009. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecol. Econ.* 68: 810-821.

Gbèhounou, G., Egbers, W.S., Verkleij, J.A.C. and Pieterse, AH. 1991. A survey on Striga infestation in Borgou and Atacora Provinces in Bénin. In: Ransom, J.K., Musselman, L.J., Worsham, A.D., Parker, C. (eds) *Proceedings of the Fifth International Symposium of Parasitic Weeds.* CIMMYT, Nairobi, pp.484.

Gbèhounou, G. and Adango, E. 2003. Trap crops of *Striga hermonthica*: in vitro identification and effectiveness in situ. *Crop Protection* 22: 395-404.

Glendining, M.J., Dailey, A.G., Williams, A.G., van Evert, F.K., Goulding, K.W.T. and Whitmore, A.P. 2009. Is it possible to increase the sustainability of arable and ruminant agriculture by reducing inputs? *Agricultural Systems*, 99: 117-125.

Greenleaf, S.S. and Kremen, C. 2006. Wild bees enhance honey bees' pollination of hybrid sunflower. *Proc. Nat. Acad. Sci.* USA 103 :13890-13895.

Gurr, G.M., Wratten, S.D. and Altieri, M.A. 2004. Genetic engineering and ecological engineering: a clash of paradigms or scope for synergy? In: Gurr, G.M. Wratten, S.D. and Altieri, M.A. (eds.). *Ecological Engineering for Pest Management: Advances in Habitat Manipulation for Arthropods*. CSIRO Publishing, Australia.

Gyawali, S., Sthapit, B.R., Bhandari, B., Bajracharya, J., Shrestha, P.K., Upadhyay, M.P. and Jarvis, D.I. 2010. Participatory crop improvement and formal release of Jethobudho rice landrace in Nepal. *Euphytica*, DOI: 10.1007/s10681-010-0213-0.

Hajjar, R., Jarvis, D.I. and Gemmill-Herren, B. 2008. The utility of crop genetic diversity in maintaining ecosystem services. *Agriculture, Ecosystems and Environment*, 123: 261-270.

Hall, S.J.G. 2004. Ecological adaptation of breeds. In: Hall, J. (ed.). *Livestock Biodiversity*. Blackwell Science, Oxford, UK. pp. 45-71.

Halwart, M. 1998. Trends in rice–fish farming. *The FAO Aquaculture Newsletter*, April 1998, No. 18. ISSN 1020-3443.

Halwart, M. 2006. Biodiversity and nutrition in rice-based aquatic ecosystems. *Journal of Food Composition and Analysis*, 19: 747-751.

Hardner, J. and Rice, R. 2002. Rethinking green consumerism. *Scientific American*, May 2002, pp. 88-95.

Higes, M., Pilar, G.P., Raquel, M.H., Aránzazu, M. 2007. Experimental infection of *Apis mellifera* honeybees with *Nosema ceranae* (Microsporidia). *J. Invert. Pathol.* 94 :211-217.

Hoehn, P., Tscharntke, T., Tylianakis, J.M., Steffan-Dewenter, I. 2008. Functional group diversity of bee pollinators increases crop yield. *Proc. R. Soc. B.* 275: 2283-2291.

Hoffmann, I. 2003. Spatial distribution of cattle herds as a response to natural and social environments. a case study from the Zamfara Reserve, northwest Nigeria. *Nomadic Peoples*, 6: 6-23.

IAASTD. 2008. *Agriculture at a Cross-roads. Global Report*. Island Press, Washington, DC, USA.

IFPRI (International Food Policy Research Institute). 2005. *The future of small farms: Proceedings of a research workshop*, Wye, UK, June 26-29, 2005. Washington, DC.

ILRI. 1999. *Making the Livestock Revolution Work for the Poor*. International Livestock Research Institute, Nairobi, Kenya.

IPCC. 2007. *Climate Change 2007, Systhesis Report*. An Assessment of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland.

IWMI, 2007. *Water for Food, Water for Life: A Comprehensive Assessment of Water management in Agriculture*. London: Earthscan, and Colombo: Jackson, L., Bawa, K., Pascual, U. and Perrings, C. 2005. *AgroBIODIVERSITY: A New Science Agenda for Biodiversity in Support of Sustainable Agroecosystems*. Diversitas Report No. 4.

Jackson, L., van Noordwijk, M., Bengtsson, J., Foster, W., Lipper, L., Said, M., Snaddon, J. and Vodouhe, R. 2010. Biodiversity and agricultural sustainagility: from assessment to adaptive management. *Current Opinion in Environmental Sustainability*, 2: 80-87.

Jarvis, D., Hodgkin, T., Bhuwon, S., Fadda, C. and Lopez Noriega, I. (in press). A heuristic framework for identifying multiple ways of supporting the conservation and use of traditional crop varieties within the agricultural production systems. *Critical Reviews in Plant Sciences.*

Jeffery, S., Gardi, C., Jones, A., Montanarella, L., Marmo, L., Miko, L., Ritz, K., Peres, G., Römbke, J. and van der Putten, W. H. (eds.). 2010. *European Atlas of Soil Biodiversity*. European Commission, Publications Office of the European Union, Luxembourg. Available at: http://eusoils.jrc.ec.europa.eu/library/maps/biodiversity_atlas/Documents/Biodiversity_Altas.pdf

Johns, T. and Eyzaguirre, P.B. 2006. Linking biodiversity, diet and health in policy and practice. *Proceedings of the Nutrition Society*, 65: 182-189.

Kaimowitz, D. 1996. *Livestock and Deforestation in Central America in the 1980s and 1990s: A Policy Perspective*. Centre for International Forestry Research, Jakarta, Indonesia.

Kassam, A., Friedrich, T., Shaxson, F. and Pretty, J. 2009. The spread of conservation agriculture: justification, sustainability and uptake. *International Journal of Agricultural Sustainability*, 7(4): 292-320.

Katz, D. 2006. Going with the flow: preserving and restoring instream water allocations. In: Gleick, P.H. (ed.). *The World's Water 2006–2007: The Biennial Report on Freshwater Resources*. Island Press, Washington, DC, USA. pp. 29-39.

Kirschenmann, F.L. 2007. Potential for a new generation of biodiversity in agro-ecosystems of the future. *Agronomy Journal*, 99: 373376.

Klein, A., Steffan Dewenter, I. and Tscharntke, T. 2003. Fruit set of highland coffee increases with the diversity of pollinating bees. *Proceedings of the Royal Society*, 270: 955-961.

Klein, A.M., Vaissière, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C., Tscharntke, T. 2007. Importance of pollinators in changing landscapes for world crops. *Proc. Roy. Soc. B*. 274: 303-313.

Kliewer, L., Casaccia, J. and Vallejos, F. 1998. *Viabilidad da Reducão do Uso de Herbicidas e Custos no Controle de Plantas Daninhas nas Culturas de Trigo e Soja no Sistema de Plantio Directo, através do Emprego de Adubos Verdes de Curto Periodo*. Resumo de Palestras: I Seminario Nacional Sobre Manejo e Controle de Plantas Daninhas em Plantio Direto, 10-12 August 1998, RS. Editora Aldeia Norte, Passo Fundo. pp. 120-123.

Kluthcouski, J., Stone, L.F. and Aidar, H. 2003. *Integração Lavoura-pecuária*. Embrapa-CNPAF, EMBRAPA, Brazil. 569 pp.

Kok, M.T.J., Bakkes, J.A., Eickhout, B., Manders, A.J.G., van Oorschot, M.M.P., van Vuuren, D.P., van Wees, M. and Westhoek, H.J. 2008. *Lessons from Global Environmental Assessments*. Netherlands Environmental Assessment Agency, Bilthoven, the Netherlands.

Kremen, C., Williams, N.M., Aizen, M.A., Gemmill-Herren, B., LeBuhn, G., Minckley, R., Packer, L., Potts, S.G., Roulston, T., Steffan-Dewenter, I., Vazquez, D.P., Winfree, R., Adams, L., Crone, E.E., Greenleaf, S.S., Keitt, T.H., Klein, A.M., Regetz, J., Ricketts, T.H. 2007. Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change. *Ecol. Letters* 10 :299-314.

Kremen, C., Williams, N.M., Thorp, R.W. 2002. Crop pollination from native bees at risk from agricultural intensification. *Proc. Nat. Acad. Sci. USA* 99: 16812-16816.

Kumar, B.M. and Nair, P.K.R. 2004. The enigma of tropical homegardens. In: Nair, P.K.R., Rao, M.R. and Buck, L.E. (eds.). *New Vistas in Agroforestry*. Kluwer, Dordrecht, Netherlands. pp. 135-152.

Lammerts van Bueren, E.T., Struik, P.C., Jacobsen, E. 2002. Ecological aspects in organic farming and its consequences for an organic crop ideotype. *Neth J Agr Sci* 50: 1-26.

Landers, J.N. (ed.). 2007. Sustainable agriculture and policy considerations. In: *Tropical Crop-livestock Systems in Conservation Agriculture – the Brazilian Experience*. Food and Agriculture Organization of the United Nations, Rome, Italy. pp. 75-85.

Lendzemo, V.W., Kuyper, T.W., Kropff, M.J. and van Ast, A. 2005. Field inoculation with arbuscular mycorrhizal fungi reduces *Striga hermonthica* performance on cereal crops and has the potential to contribute to integrated *Striga* management. *Field Crops Research*, 91(1): 51-61.

Li, C., He, X., Zhu, S., Zhou, H., Wang, Y., Li, Y., Yang, J., Fan, J., Yang, J., Wang, G., Long, Y., Xu, J., Tang, Y., Zhao, G., Yang, J., Liu, L., Sun, Y., Xie, Y., Wang, H. and Zhu, Y. 2009. Crop diversity for yield increase. *PLoS ONE* 4(11): e8049.

Lobell, D.B., Burke, M.B., Tebaldi, C., Mastrandrea, M.D., Falcon, W.P. and Naylor, R.L. 2008. Prioritizing climate change adaptation needs for food security in 2030. *Science*, 319 (5863): 607-610.

Loreau, M., Naeem, S., Inchausti, P., Bengtsson, J., Grime, J.P., Hector, A., Hooper, D.U., Huston, M.A., Raffaeli, D., Schmid, B., Tilman, D. and Wardle, D.A. 2002. Biodiversity and ecosystem functioning: current knowledge and future challenges. *Science*, 294: 804-808.

Lounsberry, Z., Spiewok, S., Pernal, S.F., Sonstegard, T.S., Hood, W.M., Pettis, J., Neumann, P., Evans, J.D. 2010. Worldwide diaspora of /Aethina /tumida (Coleoptera: Nitidulidae), a nest parasite of honey bees. *Ann. Entomol. Soc. Am.* 103 : 671-677.

Lutaladio, N., Burlingame, B. and Crews, J. 2010. Horticulture, biodiversity and nutrition. *Journal of Food Composition and Analysis*, 23(6): 481-485.

Machado, P.L.O. and Silva, C.A. 2001. Soil management under no-tillage systems in the tropics with special reference to Brazil. *Nutrient Cycling in Agroecosystems*, 61: 119-130.

Mäder, P., Fliessbach, A., Dubois, D. and Gunst, L. 2002. Soil fertility and biodiversity in organic farming. *Science*, 296: 1694-1697.

Marshner, H. 1995. *Mineral Nutrition of Higher Plants*. Second Edition. Academic Press, London, UK.

Matson, P.A., Naylor, R. and Ortiz-Monasterio, I. 1998. Integration of environmental, agronomic, and economic aspects of fertilizer management. *Science*, 280: 112-115.

McAdam, J.H., Thomas, T.H. and Willis, R.W. 1999. The economics of agroforestry systems in the United Kingdom and their future prospects. *Scottish Forestry*, 53(1): 37-11.

MEA. 2005. *Ecosystems and Human Well-being*. Millennium Ecosystem Assessment. Island Press, Washington DC, USA.

Menezes, F. 2001. Food sovereignty: a vital requirement for food security in the context of globalization. *Development*, 44(4): 29–33.

Miao Weimin in S.S. De Silva and F.B. Davy (eds.), *Success Stories in Asian Aquaculture*, Springer Science+Business Media B.V. 2009

Michener CD. 2007. *The bees of the world*. 2nd ed. John Hopkins Univ. Press, Baltimore, Maryland, USA. 913 pp.

Morton, J.F. 2007. The impact of climate change on smallholder and subsistence agriculture. *PNAS*, 104(50): 19680–19685.

Mualem, R., Chosniak, I. and Shkolnik, A. 1990. Environmental heat load, bioenergetics and water economy in two breeds of goats. *World Review of Animal Production*, 15 (3): 92-95.

Muleta, D., Assefa, F., Nemomissa, S. and Granhall, U. 2007. Composition of coffee shade tree species and density of indigenous arbuscular mycorrhizal fungi (AMF) spores in Bonga Natural Coffee Forest, southwestern Ethiopia. *Forest Ecology and Management*, 241(1-3): 145-154.

Muñoz-Piña, C., Guevara, A., Torres, J.M. and Braña, J. 2008. Paying for the hydrological services of Mexico's forests: analysis, negotiations and results. *Ecological Economics*, 65: 725-736.

Myers, N. 1996. Environmental services of biodiversity. *Proc. Nat. Acad. Sci. USA* 93 :2764-2769.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B. and Kent, J. 2000. Biodiversity hotspots for conservation priorities. *Nature*, 403: 853–858. Available at: http://www.nature.com/nature/journal/v403/n6772/pdf/403853a0.pdf.

Naeem, S. and Li, S. 1997. Biodiversity enhances ecosystem reliability. *Nature*, 390: 507-509.

Nair, P.K.R. 1993. *An Introduction to Agroforestry*. Kluwer Academic Publishers, Dordrecht, the Netherlands.

Naylor, R.L. 1996. Energy and resource constraints on intensive agricultural production. *Annual Review of Energy and the Environment*, 21: 99-123.

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney, H. and Troell, M. 2000. Effect of aquaculture on world fish supplies. *Nature*, 405: 1017-1024.

Negri, V. 2003. Landraces in central Italy: where and why they are conserved and perspectives for their on-farm conservation. *Genetic Resources and Crop Evolution*, 50: 871-885.

Nellemann, C., MacDevette, M., Manders, T., Eickhout, B., Svihus, B., Prins, A.G. and Kaltenborn, B.P. (eds). 2009. *The Environmental Food Crisis – The Environment's Role in Averting Future Food Crises*. A UNEP Rapid Response Assessment. United Nations Environment Programme, GRID-Arendal, Norway.

NEAA.2010. *Rethinking Global Biodiversity Strategies: Exploring Structural Changes in Production and Consumption to Reduce Biodiversity Loss*. Netherlands Environmental Assessment Agency, The Hague, the Netherlands. Available at: http://www.rivm.nl/bibliotheek/rapporten/500197001.pdf

Niesten, E.T., Rice, R.E., Ratay, S.M. and Paratore, K. (eds.) 2004. *Commodities and Conservation: the Need for Greater Habitat Protection in the Tropics*. Conservation International, Washington, DC, USA.

Nicodemo. D., Nogueira Couto, R.H. 2004. Use of repellents for honeybees (*Apis mellifera* L.) in vitro in the yellow passion-fruit (*Passiflora edulis* Deg.) crop and in confined beef cattle feeders. *J. Venom. Anim. Toxins* 10:77-85.

Noss, D. 1990. Indicators for monitoring biodiversity: A hierarchical approach. *Conservation Biology*, 4:355 - 364.

Notter, D.R. 1999. The importance of genetic diversity in livestock populations of the future. *Journal of Animal Science*, 77:61-69.

OFID. 2009. *Biofuels and Food Security. Implications of an Accelerated Biofuels Production*. Summary of the OFID Study Prepared by IIASA. OFID Pamphlet Series 38. OPEC Fund for International Development, Vienna, Austria.

Oldeman, L.R., Hakkeling, R.T.A. and Sombroek, W.G. 1990. *World Map of the Status of Human Induced Soil Degradation*. ISRIC/UNEP, Wageningen, the Netherlands.

Østergård, H., Finckh, M.R., Fontaine, L., Goldringer, I., Hoad, S.P., Kristensen, K., Lammerts van Bueren, E.T., Mascher, F., Munk, L. and Wolfe, M.S. 2009. Time for a shift in crop production: embracing complexity through diversity at all levels. *Journal of the Science of Food and Agriculture*, 89(9): 1439-1445.

Ostrom, E. 1990. *Governing the commons*. Cambridge University Press, Cambridge, U.K.

Pagiola, S. 2008. Payments for environmental services in Costa Rica. *Ecological Economics*, 65: 712-724.

PAR. 2010. *The Use of Agrobiodiversity by Indigenous Peoples and Rural Communities in Adapting to Climate Change*. A Discussion Paper Prepared by the Platform for Agrobiodiversity Research. Available at: http://www.agrobiodiversityplatform.org/blog/wp-content/uploads/2010/05/PAR-Synthesis_low_FINAL.pdf

Pontius, J., Dilts, R. and Bartlett, A. (eds.) 2002. *Ten Years of IPM Training in Asia - From Farmer Field School to Community IPM*. Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific, Bangkok, Thailand.

Popkin, B.M. 2002. An overview of the nutrition transition and its health implications: the Bellagio Meeting. *Public Health Nutrition*, 5: 93-103.

Pretty, J. 1999. Can sustainable agriculture feed Africa? New evidence on progress, processes and impacts. *Environment, Development and Sustainability*, 1: 253-274.

Pretty, J. and Hineb, R. 2000. The promising spread of sustainable agriculture in Asia. *Natural Resources Forum*, 24: 107-121.

Priess, J. A., Mimler, M., Klein, A.M., Schwarze, S., Tscharntke, T. and Steffan-Dewenter, I. 2007. Linking deforestation scenarios to pollination services and economic returns in coffee agroforestry systems. *Ecological Applications*, 17:407-417.

Ramsar Convention Secretariat. 2006. The *Ramsar Convention Manual: a guide to the Convention on Wetlands* (Ramsar, Iran, 1971), 4th ed. Ramsar Convention Secretariat, Gland, Switzerland.

Richards, P. and Ruivenkamp, G. 1997. *Seeds and Survival: Crop Genetic Resources in War and Reconstruction in Africa*. International Plant Genetic Resources Institute, Rome, Italy. 61 pp.

Robbins, C.S., Sauer, J.R. and Peterjohn, B.G. 1993. Population trends and management opportunities for neotropical migrants. In: Finch, D.M. and Stangel, P.W. (eds). *Status and Mangement of Neotropical Migratory Birds*. General Technical Report. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, USA.

Rodale Institute. 1999. *100-Year Drought Is No Match for Organic Soybeans*. Rodale Institute, Kutztown, Pennsylvania, USA. Available at: http://www.rodaleinstitute.org/19991109/fst.

Roos, N., Wahab, A., Hossain, M.A.R. and Thilsted, S.H. 2007. Linking human nutrition and fisheries: incorporating micronutrient-dense, small indigenous fish species in carp polyculture production in Bangladesh. *Food and Nutrition Bulletin*, 28(2): S280-S293.

Roos, N., Islam, M.M. and Thilsted, S.H. 2003. Small indigenous fish species in Bangladesh: contribution to vitamin A, calcium and iron intakes. *Journal of Nutrition*, 133: 4021S-4026S.

Sachs, J., Remans, R., Smukler, S., Winowiecki, L., Andelman, S.J., Cassman, K.G., Castle D., DeFries, R., Denning, G., Fanzo, J., Jackson, L.E., Leemans, R., Lehmann, J., Milder, J.C., Naeem, S., Nziguheba, G., Palm, C.A., Pingali, P.A., Reganold, J.P., Richter, D.D., Scherr, S.J., Sircely, J., Sullivan, C., Tomich, T.P. and Sanchez, P.A. 2010. Monitoring the world's agriculture. *Nature*, 466: 558-560.

Saha, D. 2003. Conserving fish biodiversity in Sundarban villages of India. In: *Conservation and Sustainable Use of Agricultural Biodiversity*. CIP-UPWARD in collaboration with GTZ, IDRC, IPGRI and SEARICE. pp. 131-157.

Seckler, D., Barker, R. and Amarasinghe, U. 1999. Water scarcity in the twenty-first century. *International Journal of Water Resources Development*, 15: 29-42. Available at: http://pdf.dec.org/pdf_docs/Pnach595.pdf

Sen, W. 1991. *Agroforestry in China*. Ministry of Foreign Affairs, Beijing, China.

Sherr, S. and McNeely, J.A. 2008. Biodiversity conservation and agricultural sustainability: towards a new paradigm of 'ecoagriculture' landscapes. *Philosophical Transactions of The Royal Society of London Series B-Biological Sciences*, 363(1491): 477-494.

Sinclair, F.L. 1999. A general classification of agroforestry practice. *Agroforestry Systems*, 46: 161-180.

Singh, R.P., William, H.M., Huerta-Espino, J. and Rosewarne, G. 2004 Wheat Rust in Asia: Meeting the Challenges with Old and New Technologies. New directions for a diverse planet. *Proceedings of the 4th International Crop Science Congress*. Brisbane, Australia, 26 Sep - 1 Oct 2004. Available at: www.cropscience.org.au.

Smil, V. 1999. Nitrogen in crop production: an account of global flows. *Global Biogeochemical Cycles*, 13: 647-662.

Smil, V. 2000. Phosphorus in the environment: natural flows and human interferences. *Annual Review of Energy and the Environment*, 25: 53-88.

Smith, J. and Scherr, S.J. 2002. *Forest Carbon and Local Livelihoods: Assessment of Opportunities and Policy Recommendations*. CIFOR Occasional Paper No. 37. Center for International Forestry Research, Bogor, Indonesia.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B. and Sirotenko, O. 2007. Agriculture. In: Metz, B., Davidson, O.R., Bosch, P.R., Dave, R. and Meyer, L.A. (eds.). *Climate Change 2007: Mitigation*. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

Sorrenson, W.J. and Montoya, L.J. 1984. *Implicacões Econõmicas da Erosão do Solo e de Prátcas Conservacionistas no Paraná, Brasil, IAPAR, Londrina*. GTZ, Eschborn, Germany.

Soil and Water Conservation Society (SWCS). 2000. *Soil Biology Primer*. Rev. ed. Ankeny, Iowa: Soil and Water Conservation Society.

Stokstad, E. 2007. The case of the empty hives. *Science* 316 :970-972.

Susilo, F.X., Neutel, A.M., van Noordwijk, M., Hairiah, K., Brown, G. and Swift, M.J. 2004. Soil biodiversity and food webs. In: van Noordwijk, M., Cadisch, G. and Ong, C.K. (eds.). *Below-ground Interactions in Tropical Agroecosystems*. CAB International, Wallingford, UK. pp. 285-302.

Swift, M.J. 2004. Soil biodiversity and food webs. In: van Noordwijk, M., Cadisch, G. and Ong, C.K. (eds.). *Below-ground Interactions in Tropical Agroecosystems*. CAB International, Wallingford, UK. pp. 285-302.

TEEB. 2010. *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB.* Available at: http://www.teebweb.org/TEEBSynthesisReport/tabid/29410/Default.aspx

Tallis, H., Kareiva, P., Marvier, M. and Chang, A. 2008. An ecosystem services framework to support both practical conservation and economic development. *Proceedings of the National Academy of Sciences*, 105(28): 9457-9464.

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W.H., Simberloff, D., Swackhamer, D. 2001. Forecasting Agriculturally Driven Global Environmental Change. *Science* 292: 281-284.

Tomich, T.P., van Noordwijk, M., Budidarsono, S., Gillison, A., Kusumanto, T., Murdiyarso, D., Stolle, F. and Fagi, A.M. 2001. Agricultural intensification, deforestation, and the environment: assessing tradeoffs in Sumatra, Indonesia. In: Lee, D.R. and Barrett, C.B. (eds.). *Tradeoffs or Synergies? Agricultural Intensification, Economic Development and The Environment*. CAB International, Wallingford, UK. pp. 221-244.

UN-HABITAT. 2008. *State of the World's Cities 2008/2009. Harmonious Cities*. United Nations Human Settlements Programme (UN-HABITAT), Nairobi, Kenya.

UN. 2008. *World Population Prospects: The 2008 Revision Population Database*. United Nations Population Division, New York, USA. Available at: http://esa.un.org/unpp/

UNCTAD. 2010. *Technology and Innovation Report 2010: Enhancing food security in Africa through science, technology and innovation.* United Nations Conference on Trade and Development, Geneva, Switzerland. USA

UNEP. 2010. *Securing Sustainability through the Conservation and Use of Agricultural Biodiversity, the UNEP-GEF Contribution*. United Nations Environment Programme, UNEP Division for the Global Environment Facility (DGEF), Nairobi, Kenya.

UNEP/GPA. 2006. *Ecosystem-based Management: Markers for Assessing Progress*. United Nations Environment Programme, Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA), The Hague, the Netherlands.

UNPRI/UNEP FI. 2010. *Universal Ownership: Why environmental externalities matter to institutional investors*. United Nations Environment Programme Finance Initiative (UNEP FI) and The Principles for Responsible Investment (PRI). Available at: http://www.unpri.org/files/6728_ES_report_environmental_externalities.pdf

UN-Water. 2006. *Coping with Water Scarcity, A Strategic Issue and Priority for System-wide Action*. UN-Water Thematic Initiatives. Available at: http://www.unwater.org/downloads/waterscarcity.pdf

Vaccari, D.A. 2009. Phosphorus famine: the threat to our food supply. *Scientific American Magazine*, 300: 54-59. Available at: http://www.scientificamerican.com/article.cfm?id=phosphorus-a-looming-crisis

Van den Berg, H. 2004. *IPM Farmer Field Schools. A Synthesis of 25 Impact Evaluations*. Wageningen University for the Global IPM Facility.

Van Oudenhoven, F.J.W., Mijatović, D. and Eyzaguirre, P.B. 2010. Bridging managed and natural landscapes, the role of traditional (agri)culture in maintaining the diversity and resilience of social-ecological systems. In: Bélair C., Ichikawa K., Wong B.Y.L. and Mulongoy K.J. (eds.). *Sustainable Use of Biological Diversity in Socio-ecological Production Landscapes. Background to the 'Satoyama Initiative for the Benefit of Biodiversity and Human Well-being.'* Technical Series no. 52. Secretariat of the Convention on Biological Diversity, Montreal, Canada. pp. 8-21.

Vandermeer, J., Lawrence, D., Symstad, A. and Hobbie, S. 2002. Effects of biodiversity on ecosystem functioning in managed ecosystems. In: Loreau, M., Naeem, S. and Inchausti, P. (eds.). *Biodiversity and Ecosystem Functioning*. Oxford University Press, Oxford, UK. pp. 157-168.

Velthuis, H.H.W., Doorn, A. van. 2006. A century of advances in bumblebee domestication and the economic and environmental aspects of its commercialization for pollination. *Apidologie* 37: 421-451.

Vitousek, P.M., Aber, J.D., Howarth, R.W., Likens, G.E., Matson, P.A., Schindler, D.W., Schlesinger, W.H. and Tilman, D.G. 1997. Human alteration of the global nitrogen cycle: sources and consequences. *Ecological Applications*, 7: 737-750.

Wells, W.C., Isom, W.H., Waines, J.G. 1988. Outcrossing rates of six common bean lines. *Crop Sci*. 28: 177-178.

Willer, H. and Kilcher, L. (eds.) 2010. *The World of Organic Agriculture – Statistics and Emerging Trends 2010*. IFOAM, Bonn, Germany, and FiBL, Frick, Switzerland.

Wood, S., Ehui, S., Alder, J., Benin, S., Cassman, K.G., Cooper, H.D., Johns, T., Gaskell, J., Grainger, R., Kadungure, S., Otte, J., Rola, A., Watson, R., Wijkstrom, U. and Devendra, C. 2005. Food. In: *Ecosystems and Human Well-being, Vol. 1, Current State and Trends*. Island Press, Washington, DC, USA. pp. 209-241.

World Agroforestry Centre. 2009. *Annual Report 2008-2009: Agroforestry - a Global Land Use*. World Agroforestry Centre, Nairobi, Kenya. Available at: www.millenniumassessment.org/en/products.aspx.

World Bank. 2007. *Agriculture for Development. World Development Report 2008*. The World Bank, Washington, DC, USA.

Yang, X., Cox-Foster, D.L. 2005. Impact of an ectoparasite on the immunity and pathology of an invertebrate: Evidence for host immunosuppression and viral amplification. *Proc. Nat. Acad. Sci. USA* 102 :7470-7475.

Zeddies, J., Schaab, R.P., Neuenschwander, P. and Herren, H.R. 2001. Economics of biological control of cassava mealybug in Africa. *Agricultural Economics*, 24(2): 209-219.

Zhu, Y.Y., Chen, H., Fan, J., Wang, Y., Li, Y., Chen, J., Fan, J., Yang, S., Hu, L., Leung, H., Mew, T.W., Teng, P.S., Wang, Z. and Mundt, C.C. 2000. Genetic diversity and disease control in rice. *Nature*, 406: 718-722.

Zomer, R.J., Trabucco, A., Coe, R. and Place, F. 2009. *Trees on Farm: Analysis of Global Extent and Geographical Patterns of Agroforestry.* ICRAF Working Paper no. 89. World Agroforestry Centre, Nairobi, Kenya.

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