Linking Agricultural Biodiversity and Food Security: The Valuable Role of Sustainable Agriculture
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Linking agricultural biodiversity and food security: the valuable role of agrobiodiversity for sustainable agriculture

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There is a growing realization worldwide that biodiversity is fundamental to agricultural production and food security, as well as a valuable ingredient of environmental conservation. Yet predominant patterns of agricultural growth have eroded biodiversity in, for example, plant genetic resources, livestock, insects and soil organisms. This erosion has caused economic loss, jeopardizing productivity and food security, and leading to broader social costs. Equally alarming is the loss of biodiversity in 'natural' habitats from the expansion of agricultural production to frontier areas.

The conflicts between agriculture and biodiversity are by no means inevitable. With sustainable farming practices and changes in agricultural policies and institutions, they can be overcome. Historical evidence and current observation show that biodiversity maintenance must be integrated with agricultural practices—a strategy that can have multiple ecological and socio-economic benefits, particularly to ensure food security. Practices that conserve, sustainably use and enhance biodiversity are necessary at all levels in farming systems, and are of critical importance for food production, livelihood security, health and the maintenance of ecosystems.

This article summarizes the main conflicts and complementarities between biodiversity and agriculture, discusses the ecosystem services provided by agricultural biodiversity, and highlights principles, policies and practices that enhance diversity in agroecosystems.

* This article is extracted from a longer research report by L. A. Thrupp, *Cultivating diversity: agrobiodiversity and food security* (Washington DC: World Resources Institute, 1998). To order, please contact WRI at <www.wri.org>, or (00 1) 202 729 7600. Other recent WRI publications by the same author include *New partnerships for sustainable agriculture* and *Bittersweet harvests for global supermarkets: challenges in Latin America's agricultural export sector.*

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Agrobiodiversity as a basis for production and survival

Biodiversity and detailed knowledge about it have allowed farming systems to evolve since agriculture began some 12,000 years ago.[1] Although sometimes perceived as an enemy of biodiversity, agriculture is actually based on richly diverse biological resources. Likewise, agriculture comprises a variety of managed ecosystems, or *agroecosystems*, that benefit from resources in natural habitats.

Agricultural biodiversity (or *agrobiodiversity*) is a fundamental feature of farming systems around the world. It encompasses many types of biological resources tied to agriculture, including:

- genetic resources—the essential living materials of plants and animals;
- edible plants and crops, including traditional varieties, cultivars, hybrids and other genetic material developed by breeders;
- livestock (small and large, lineal breeds or thoroughbreds) and freshwater fish;
- soil organisms vital to soil fertility, structure, quality and health;
- naturally occurring insects, bacteria and fungi that control insect pests and diseases of domesticated plants and animals;
- agroecosystem components and types (polycultural/monocultural, small-/large-scale, rain-fed/irrigated, etc.) indispensable for nutrient cycling, stability and productivity; and
- 'wild' resources (species and other elements) of natural habitats and landscapes that can provide ecosystem functions and services (for example, pest control and stability) to agriculture.

Agrobiodiversity therefore includes not only a wide variety of species and genetic resources, but also the many ways in which farmers can exploit biological diversity to produce and manage crops, land, water, insects and biota.[2] The concept also includes habitats and species outside farming systems that benefit agriculture and enhance ecosystem functions.[3] One example is a source of host plants for natural enemies and predators of agricultural pests.

As recorded by Egyptian, Mesopotamian, Chinese and Andean civilizations, ancient agricultural settlements made use of a variety of plants, livestock and agroecosystems. Over many centuries, farmers have employed numerous practices to use, enhance and conserve this diversity in traditional farming systems. Many such practices continue today: the use of particular species for pest control and the integration of trees and woody shrubs into farming systems are two examples. Wild plant and animal species in surrounding habitats also provide services and value to the farming system. Such practices are a basis of survival and livelihood for millions of people.

1 Genetic Resources Action International, 'Biodiversity in agriculture: some policy issues', *IFOAM Ecology and Farming*, January 1994, p. 14.
2 H. Brookfield and C. Padoch, 'Appreciating agrodiversity: a look at the dynamism and diversity of indigenous farming practices', *Environment* 36: 5, 1994, pp. 7–44.
3 H. Brookfield, 'Postscript: the population–environment nexus', *Global Environmental Change* 5: 4, 1995, pp. 381–93.

The majority of staple crops cultivated and consumed across the world today originated in a few areas, mostly in Asia, Africa and Latin America, often called 'centres of diversity' centres, and crop diversity is still most concentrated in these regions, where it served as a basis for the growth of important civilizations.[4] From ancient times to the present day, plant collecting has also enhanced agrobiodiversity. Throughout the colonial period, the search for and collection of new plants and foods was a driving interest of European explorers and played an important role in colonial expansion.

Traditional farming methods that maximize diversity include the small-scale polycultural systems, sometimes called 'home gardens', that are still found today in many regions, including Central America, South-East Asia, sub-Saharan Africa and even some parts of Europe. Numerous studies show that shifting cultivation systems, especially in traditional forms, are agroecologically diverse and contain numerous plant species. These can also be relatively sustainable in certain areas of the world, especially where economic and demographic pressures for growth are low.[5]

Other methods that support high biodiversity are traditional agroforestry systems, such as the shaded coffee plantations common throughout Central and South America,[6] which commonly contain well over 100 annual and perennial plant species per field.[7] Farmers often integrate leguminous trees, fruit trees, trees for fuelwood and types that provide fodder on their coffee farms. The trees also provide habitat for birds and animals that benefit the farms. For example, a shaded coffee plantation in Mexico supports up to 180 species of birds that help control insect pests and disperse seeds.[8] Ethnobotanical studies show that the Tzeltal Mayans of Mexico can recognize more than 1,200 species of plants, while the P'urepechas recognize more than 900 species and Yucatan Mayans some 500.[9] Such knowledge is used to make production decisions in various circumstances, for example to select species that are suited for diverse soil types, to expand options of crops to cultivate and/or for conservation purposes.

Another important dimension of traditional agrobiodiversity is the use of so-called 'folk varieties', also known as *landraces*. Defined as 'geographically or ecologically distinctive populations [of plants and animals] which are conspicuously diverse in their genetic composition',[10] landraces are products selected by local

4 P. Raeburn, *The last harvest: the genetic gamble that threatens to destroy American agriculture* (New York: Simon & Schuster, 1995), p. 40.

5 For extensive discussion and review of diverse shifting cultivation systems, see S. Hecht, L. A. Thrupp and J. Browder, 'Diversity and dynamics of shifting cultivation: myths, realities, and human dimensions', draft paper (Washington DC: World Resources Institute, 1996); also H. Brookfield and C. Padoch, 'Appreciating agrodiversity: a look at the dynamism and diversity of indigenous farming practices', *Environment* 36: 5, 1994; and literature from the Sustainable Agriculture Program of the International Institute for Environment and Development (IIED).

6 R. Greenburg, 'Phenomena, comment and notes', *Smithsonian* 25: 8, 1994, pp. 24–7.

7 M. Altieri, 'Traditional farming in Latin America', *The Ecologist* 21: 2, 1991, p. 93.

8 Greenburg, 'Phenomena, comment and notes'.

9 Altieri, 'Traditional farming in Latin America'.

10 A. H. D. Brown, 'Isozymes, plant population genetic structure, and genetic conservation', *Theoretical Applied Genetics* 52, 1978, pp. 145–57, cited in D. Cleveland *et al.*, 'Do folk crop varieties have a role in sustainable agriculture?', *Bioscience* 44: 11, 1994, pp. 740–51.

farmers over time for their various production benefits.[11] In some areas in the Andean region, for example, farmers have developed complex techniques to select, store and propagate the seeds of landraces.

The numerous practices used for enhancing biodiversity are tied to the rich cultural diversity and local knowledge that support the livelihood of agricultural communities. In many societies, rural women are particularly knowledgeable about plant and tree species and about their uses for health care, fuel and fodder, as well as food.[12] Many principles from traditional systems, as well as intuitive knowledge, are applied today in both large- and small-scale production. In fact, 'traditional multiple cropping systems still provide as much as 20 per cent of the world food supply'.[13]

These components of agrobiodiversity therefore yield an array of benefits. They contribute to productivity, resilience in farming systems, income generation, nutritional values, and food and livelihood security for numerous societies. Agricultural biodiversity also provides ecosystem services on farms, such as pollination, fertility and nutrient enhancement, insect and disease management, and water retention.

Moreover, agrobiodiversity has great value for science and technological discovery in crop production. Starting in the late nineteenth and early twentieth centuries, scientists who recognized the value of diverse crop varieties discovered plant breeding methods that have boosted crop productivity. The innovative use of plant genetic resources has continued to be important for scientific advances in plant and livestock breeding and seed improvements up to the present day. Access to germplasm is vital for modern agriculture, and for the development of medicinal products, fibres and foods. In the United States, for example, for two major crops—soybeans and maize—exotic germplasm adds a value of $3.2 billion to the nation's $1 billion annual soybean production and $7 billion to its $18 billion annual maize crop.[14] Agrobiodiversity therefore contributes to industrial agribusiness as well as to traditional small-scale farming and livelihoods.

[11] Cleveland *et al.*, 'Do folk crop varieties have a role?'. See also National Research Council, *Alternative agriculture* (Washington DC: National Academy Press, 1989).

[12] For documentation on women's local knowledge, see publications from the ECOGEN (Ecology and Gender) programme, Department of Geology, Clark University, Worcester, MA. See also J. Abramowitz and R. Nichols, 'Women and agrobiodiversity', *Society for International Development Journal on Development*, 1993; and L. A. Thrupp, 'Women, wood, and work: in Kenya and beyond', *Unasylva: FAO Journal of Forestry*, December 1984.

[13] UNDP, *Agroecology: creating the synergisms for sustainable agriculture* (New York: United Nations, 1995), p. 7, citing C. A. Francis, ed., *Multiple cropping systems* (New York: Macmillan, 1986).

[14] H. Shand, *Human nature: agricultural biodiversity and farm based food security* (Ottawa: Rural Advancement Foundation International, 1997).

Agrobiodiversity losses

Agrobiodiversity losses and global food insecurity

Developments in agriculture over the last 30 years have brought significant increases in global production, partly as a result of expansion of cropland, partly through changes in technologies over time. However, at the same time, the model and patterns of industrial agriculture and the 'Green Revolution' have exacted significant biophysical and socio-economic costs and disadvantages in many parts of the world, in both North and South. One of the main concerns has been the serious degradation of natural resources, including soils, water and biodiversity, in and around agricultural land. These trends not only do social harm, but also can undermine productivity. This in turn contributes to food insecurity, which affects some 800 million to 1 billion people worldwide. At the same time, natural resources (including diverse plant genetic resources) are distributed unequally within nations, in regions and across the world. These trends pose tremendous challenges to efforts to meet growing demand for food while conserving resources—one of the most important being the need to address the threat from the erosion of agrobiodiversity.

The erosion of agrobiodiversity is manifested in many different ways and on many different levels, both within farming systems and off farms, in natural habitats and in communities around the world. The various threats to biodiversity emanate from common root causes, linked to prevailing assumptions, conflicting policies and inappropriate production practices, as explained below.

Genetic diversity Although people consume approximately 7,000 species of plants, only 150 species are commercially important, and about 103 species account for 90 per cent of the world's food crops. Just three crops—rice, wheat, and maize—account for about 60 per cent of the calories and 56 per cent of the protein people derive from plants. Reduction in diversity often increases vulnerability to climatic and other stresses, raises risks for individual farmers, and can undermine the stability of agriculture.

In Bangladesh, for example, 'promotion of HYV [high-yield varieties] rice monoculture has decreased diversity, including nearly 7,000 traditional rice varieties and many fish species. The production of HYV rice per acre in 1986 dropped by 10 per cent from 1972, in spite of a 300 per cent increase in agrochemical use per acre.'[15] In the Philippines, HYVs have displaced more than 300 traditional rice varieties that had been the principal source of food for generations. In India, by 1968 the so-called 'miracle' HYV seed had replaced half of the native varieties; but these seeds were not high-yielding unless cultivated on irrigated land with high inputs of fertilizer, which poor farmers cannot afford.[16] As a consequence, in many areas the expected production increases were not realized.

[15] Mian Hussein, 'Regional focus news: Bangladesh', *Ecology and Farming: Global Monitor, International Federation of Organic Agricultural Movements (IFOAM)*, January 1994, p. 20.
[16] V. Shiva, 'The Green Revolution in the Punjab', *The Ecologist* 21: 2, 1991, pp. 57–60.

Table 1: Extent of genetic uniformity in selected crops

Crop	Country	Number of varieties
Rice	Sri Lanka	From 2,000 in 1959 to fewer than 100 today; 75% descend from a common stock
Rice	Bangladesh	62% of varieties descend from a common stock
Rice	Indonesia	74% of varieties descend from a common stock
Wheat	United States	50% of crop in 9 varieties
Potatoes	United States	75% of crop in 4 varieties
Soybeans	United States	50% of crop in 6 varieties

Source: World Conservation Monitoring Centre, 1992; Brian Groombridge, ed., *Global diversity: status of the earth's living resources* (London: Chapman & Hall, 1992).

In Africa, the introduction of Green Revolution technologies has also reduced diversity. In Senegal, for example, a traditional cereal called fonio (*Panicum laetum*), which is highly nutritious as well as robust in lateritic soils, has been threatened with extinction because of its replacement by modern crop varieties.[17] In the Sahel, too, reports confirm that traditional systems of polyculture are being replaced with monocultures that cause further food instability.[18] (For a summary of the extent of genetic uniformity in certain key crops, see table 1.)

Homogenization also occurs in high-value export crops. Nearly all the coffee trees in South America, for example, are descended from a single tree in a botanical garden in the Netherlands. *Coffea arabica* was first obtained from forests of south-west Ethiopia that have virtually disappeared.[19] Uniform varieties are also common in export crops of bananas, cacao and cotton, replacing traditional diverse varieties.[20] Such changes have increased productivity, but the risks of narrowing varietal selection have become clear over time.

In the North, similar losses in crop diversity have occurred (see table 2). Many fruit and vegetable varieties listed by the US Department of Agriculture in 1903 are now extinct. Of more than 7,000 apple varieties grown in the United States between 1804 and 1904, 86 per cent are no longer cultivated, and 88 per cent of 2,683 pear varieties are no longer available.[21] Evidence from Europe shows similar trends. Thousands of varieties of flax and wheat vanished after HYVs were introduced.[22] Similarly, varieties of oats and rye are also declining

[17] IFOAM, 'Biodiversity: crop resources at risk in Africa', *Ecology and Farming: Global Monitor*, January 1994, p. 5.

[18] R. D. Mann, 'Time running out: the urgent need for tree planting in Africa', *The Ecologist* 20: 2, 1990, pp. 48–53.

[19] Cary Fowler and Pat Mooney, *Shattering: food, politics, and the loss of genetic diversity* (Tucson: University of Arizona Press, 1990), p. 104.

[20] Ibid., p. 63.

[21] Ibid.

[22] J. Harlan and Bennett, quoted in Pat Mooney, *Seeds of the earth: a private or public resource?* (Ann Arbor: Canadian Council for International Cooperation, 1979), p. 12.

Table 2: Reduction of diversity in fruits and vegetables, 1903–1983[a]

Vegetable	Taxonomic name	No. in 1903	No. in 1983	Loss (%)
Asparagus	*Asparagus officinalis*	46	1	97.8
Bean	*Phaseolus vulgaris*	578	32	94.5
Beet	*Beta vulgaris*	288	17	94.1
Carrot	*Daucus carota*	287	21	92.7
Leek	*Allium ampeloprasum*	39	5	87.2
Lettuce	*Lactuta sativa*	497	36	92.8
Onion	*Allium cepa*	357	21	94.1
Parsnip	*Pastinaca sativa*	75	5	93.3
Pea	*Pisam sativum*	408	25	93.9
Radish	*Raphanus sativus*	463	27	94.2
Spinach	*Spinacia oleracea*	109	7	93.6
Squash	*Cucurbita spp.*	341	40	88.3
Turnip	*Brassica rapa*	237	24	89.9

[a] Varieties in NSSL Collection.

Source: Cary Fowler and Pat Mooney, *The threatened gene: food, politics and the loss of genetic diversity* (Cambridge: Lutworth Press, 1990).

in Europe.[23] In Spain and Portugal, various legumes that had been an important part of the local diet are being replaced by homogeneous crops, and in the Netherlands, four crops are grown on 80 per cent of Dutch farmlands.[24]

Livestock is also suffering genetic erosion. The FAO estimates that at least one traditional breed of livestock dies out somewhere in the world every week. Many traditional strains have disappeared as farmers focus on new breeds of cattle, pigs, sheep and chickens.[25] Of the 3,831 breeds of cattle, water buffalo, goats, pigs, sheep, horses and donkeys believed to have existed at the beginning of the twentieth century, 16 per cent have become extinct, and a further 15 per cent are rare.[26] Some '474 extant [livestock] breeds can be regarded as rare. A further 617 have become extinct since 1892.'[27] Over 80 breeds of cattle are found in Africa, and some are being replaced by exotic breeds.[28] These losses weaken breeding programmes that could improve hardiness of livestock, and also reduce the resources available for future adaptation.

[23] Renne Vallve, 'The decline of diversity in European agriculture', *The Ecologist* 23: 2, pp. 64–9.
[24] Ibid.
[25] D. Plucknett, and M. E. Horne, 'Conservation of genetic resources', *Agriculture, Ecosystems, and the Environment* 42, 1992, pp. 75–92, cited in N. Smith. 'The impact of land use systems on the use and conservation of biodiversity', draft paper (Washington DC: World Bank, 1996), p. 23.
[26] S. J. G. Hall and J. Ruane, 'Livestock breeds and their conservation: a global overview', *Conservation Biology* 7: 4, 1993, pp. 815–25, cited in Smith, 'The impact of land use systems', p. 43.
[27] S. J. G. Hall, cited in Brian Groombridge, ed., *Global biodiversity* (London: Chapman & Hall, 1992), p. 397.
[28] J. E. O. Rege, 'International livestock center preserves Africa's declining wealth of animal biodiversity', *Diversity* 10: 3, 1994, pp. 21–5, cited in Smith, 'The impact of land use systems', p. 43.

Table 3: Past crop failures due to genetic uniformity

Date	Location	Crop	Effects
1846	Ireland	Potato	Famine
1800s	Sri Lanka	Coffee	Farms destroyed
1940s	United States	Various	Crop loss to insects doubled
1943	India	Rice	Famine
1960s	United States	Wheat	Rust epidemic
1970	United States	Maize	$1 billion loss
1970	Philippines, Indonesia	Rice	Tungo virus epidemic
1974	Indonesia	Rice	3 million tons destroyed
1984	Florida, US	Citrus fruits	18 million trees destroyed

Source: World Conservation Monitoring Centre, 1992; Brian Groombridge, ed., *Global diversity: status of the earth's living resources* (London: Chapman & Hall, 1992).

Increased vulnerability to pests and diseases The homogenization of species and of farming systems increases vulnerability to insect pests and diseases. Purely monocultural systems are highly susceptible to attack, which can devastate a uniform crop, especially on large plantations. History offers many examples of serious economic loss and suffering arising from reliance on monocultural systems (see table 3). Among the best known are the potato famine of Ireland during the nineteenth century, a wine-grape blight that wiped out valuable vines in both France in the nineteenth century and the United States in California in the 1970s and 1980s, a virulent disease (Sigatoka) that damaged extensive banana plantations in Central America in recent decades and a devastating mould that infested hybrid maize in Zambia.

In addition, there has been a serious decline in soil organisms and soil nutrients. Beneficial insects and fungi suffer under agriculture that involves heavy pesticide inputs and uniform stock, again making crops more susceptible to pest problems. The consequent losses can reduce productivity. In addition, many insects and fungi commonly seen as enemies of food production are actually valuable—for pollination, as contributions to biomass, in natural nutrient production and cycling, and as natural enemies to insect pests and crop diseases. Mycorrhizae, the fungi that live in symbiosis with plant roots, are essential for nutrient and water uptake.[29] But agrochemicals frequently kill natural enemies and beneficial insects, as well as the 'target' pest. 'Pesticides [especially when overused] destroy a wide array of susceptible species in the ecosystem while also changing the normal structure and function of the

[29] D. Tillman, D. Wedline and J. Knops, 'Productivity and sustainability influenced by biodiversity in grassland ecosystems', *Nature* 379: 22, 1996, pp. 718–20.

ecosystem.'[30] The disruption in the agroecosystem balance caused by heavy use of agrochemicals can lead to perpetual resurgences of pests and outbreaks of new pests, as well as provoking resistance to pesticides. This disturbing cycle often leads farmers to apply increasing amounts of pesticides or to change products—a strategy that is not only ineffective, but further disrupts the ecosystem services and elevates costs. This 'pesticide treadmill' has occurred in countless locations.[31] Reliance on monocultural species and the decline of natural habitat around farms also reduces or eliminates beneficial insects in the agricultural ecosystem.

Additional losses—farming systems, habitats, nutrition, and cultural diversity/knowledge
Diverse farming systems have also been displaced, eroded and eliminated, in many areas, as monocultural models have become predominant. For example, there has been a decline in traditional agroforestry, polycultural home gardens, indigenous shifting cultivation systems and other mixed farming practices. These changes affect the broad agricultural landscape, transforming the countryside from a rich mosaic of crops and plants to a monotonous uniformity.

Agricultural expansion has also reduced the overall biodiversity of natural habitats, including tropical forests, grasslands and wetland areas, through the process of land conversion. The loss of biodiversity in habitats surrounding agricultural areas results in the disruption of the ecosystem services provided by that biodiversity, such as pollination, water retention, nutrient cycling and decomposition. These disturbances in turn can result in productivity declines both on and off farms. Likely future trends of cropland expansion will tend to aggravate these losses and ecosystem disruptions.

Evidence from some areas also suggests that a decline in diversity of food varieties also adversely affects nutrition.[32] In many cases where 'modern' food markets and development technologies have been introduced, people have stopped growing and consuming highly nutritious and diverse native foods, such as pulses, legumes and/or high-protein traditional grains, and have replaced them with 'modern' monoculture cereals, such as uniform wheat and maize varieties, which are less nutritious.[33] In the process, local knowledge and cultural traditions related to use of diverse plant resources have been lost as uniform industrial agricultural technologies predominate.[34]

In sum, the loss of agrobiodiversity has immediate risks and costs—financial and social—for producers, communities and nations, and long-term effects on agricultural productivity, as well as jeopardizing food security. Evidence indicates that such changes can decrease sustainability and productivity in farming systems.[35]

[30] D. Pimentel *et al.*, 'Conserving biological diversity in agricultural/forestry systems', *Bioscience* 42: 5, 1992, p. 360.
[31] S. Swezey, *Breaking the circle of poison* (San Francisco, CA: Food First, 1985).
[32] IIED, *Hidden harvests project overview: sustainable agriculture programme* (London: IIED, 1995).
[33] Shiva, 'The Green Revolution in the Punjab'.
[34] Miguel Altieri, *Agroecology: the scientific basis of sustainable agriculture* (Boulder: Westview, 1987); UNDP, *Benefits of diversity* (New York: UNDP, 1992); and UNDP, *Agroecology.*
[35] These examples are largely from Miguel Altieri, 'Traditional farming in Latin America', and Altieri, *Agroecology.*

Win–win approaches to biodiversity and agriculture

The need to overcome conflicts and build complementarities between agriculture and biodiversity poses a major challenge to humanity. Changes are needed at all levels, ranging from major policy reforms by governments and institutions to implementation of new practices at the local level by communities and farmers. Experience on the ground—literally—provides promising examples and opportunities for conserving diversity in agriculture, but such efforts must be strongly supported and widely multiplied.

Confronting the causes of agrobiodiversity loss

In addressing the reasons for agrobiodiversity loss it is helpful first to understand the proximate causes, which are often tied to the use of unsustainable technologies and degrading land-use practices, such as reliance on uniform varieties and the heavy use of agrochemicals. Yet if we look beyond these we see that there are more deeply rooted factors underlying the erosion of agricultural biodiversity that determine the farmers' use of particular technologies and practices (see table 4). These are often based on disparities in resource distribution, the dominance of industrial agricultural policies and institutions that support and contribute to inappropriate farming practices and technologies, and pressures from businesses that promote uniform monocultures and chemicals.

Moreover, institutions and companies from developed countries have gained control of intellectual property rights (patents) of seeds and other genetic resources. This predominant pattern of ownership of intellectual property rights tends to give transnational companies unfair advantages in exploiting the diverse biological resources of the tropics, while at the same time it often constrains indigenous people's and local farmers' access. Related causes of agrobiodiversity loss include the depreciation and devaluation of diversity and accumulated local knowledge, and market and consumer demands for standardized products. Demographic pressures may also contribute to the losses, but addressing these often requires consideration of broader socioeconomic structures, ways of overcoming inequities, and the provision of economic and educational opportunities for the rural poor. These longer-term challenges need concerted attention over time.

Diversity through sustainable agriculture principles and practices

Effective approaches to the conservation and enhancement of agrobiodiversity fit within a general framework of sustainable agriculture, merging the goals of productivity, food security, social equity and ecological soundness. A shift to sustainable agriculture requires changes in production methods, models and policies, as well as the full participation of local people. Scientific advance in genetics can have a significant role in this approach, but need to be re-oriented towards using and enhancing diversity in farming systems.

Table 4: Addressing causes of biodiversity losses linked to agriculture

Problems	Proximate causes	Underlying causes (for all problems)
Erosion of genetic resources (livestock and crops/plants — threatens good security — increases risks — prevents future discoveries	Dominance of uniform HYVs and monocultures, biases in breeding methods, weak conservation efforts	• Industrial/Green Revolution paradigm that stresses uniform monoculture • Inequitable distribution of land and resources • Policies that support uniform HYVs and chemicals (e.g. subsidies, credit policies, and market standards) • Pressures and influence of seed/agrochemical companies and extension systems • Trade liberalization and market expansion policies that neglect social and ecological factors • Lack of awareness of agro-ecology in R&D and in education institutions • Disrespect for local knowledge • Democraphic pressures
Erosion of insect diversity — increases susceptibility — ruins pollination and biocontrol	Heavy use of pesticides, use of monocultures/uniform species, degrading habitats harbouring insects.	
Erosion of soil diversity — leads to fertility loss — reduces productivity	Heavy use of agrochemicals, degrading tillage practices, use of monocultures	
Loss of habitat diversity including wild crop relatives	Extensification in marginal lands, drift/contamination from chemicals	
Loss of indigenous methods and knowledge of biodiversity	Spread of uniform 'modern' varieties and technologies	

The following elements are of critical importance in any strategy designed to achieve such change:

- application of agroecological principles that can conserve, use and enhance biodiversity on farms, maintain or increase productivity and enable sustainable intensification;
- participation and empowerment of farmers and indigenous peoples, protection of their rights, and respect and use of their knowledge on biodiversity and resources, to help conserve agrobiodiversity in research and development processes;
- building upon existing successful methods and local knowledge about biodiversity and genetic resources in farming, and adapting sustainable practices (e.g. integrated pest management, integrated crop management) to local situations;
- conservation of plant and animal genetic resources—especially *in situ* and community-based efforts—to protect biodiversity for current livelihood security as well as future needs and ecosystem functions;

- creating a supportive policy environment—including eliminating incentives for uniform varieties and for agrochemicals such as tax discounts and subsidies for certain HYV seeds and for pesticides and extension programmes that promote technology packages, and implementing policies for secure tenure and local rights to plant genetic resources—and prioritizing agrobiodiversity enhancement in research and development programmes.

Applying these basic principles can generate considerable public and private benefits. At the farm level, more specific practices for agrobiodiversity enhancement have been discovered and adapted in many areas of the world. Building upon the knowledge of rural people has proven to be effective in many contexts, both in making scientific advances and in helping to ensure that agrobiodiversity innovations are adopted and the benefits appreciated.

Ecologically oriented integrated pest management (IPM) methods, for example, illustrate well the use and benefits of biodiversity. IPM approaches usually highlight diversity as a key feature. Examples of best practices that are effective for insect and disease management include the following:[36]

- multiple cropping and/or crop rotations, used to prevent build-up of pests;
- intercropping of plants that house predators of insect pests;
- use of certain plants as natural pesticides;
- use of weeds to repel insects;
- use of biocontrol agents, including various parasites, animals and fish that consume insect pests (e.g. ducks and fish in rice paddies in Asia);
- elimination or reduction of pesticide use to avoid adverse agroecological effects on diversity;
- mixed crop stands that slow down the spread of diseases by altering the micro-environment;
- use of non-host plants as 'decoy' crops, to attract fungus (or nematodes).

Successful IPM programmes in Asia show that building up agrobiodiversity—particularly using beneficial insects—is a key ingredient of effective pest management in rice production. These initiatives, coordinated by the FAO along with government and non-governmental organizations, have resulted in remarkable reductions of pesticide use and increased rice yields. For example, in Indonesia's national IPM programme, thousands of farmers have adopted IPM methods, including measures to enhance insect diversity and restore natural pest-predator interactions. In addition, many farmers, extension staff and scientists have been given participatory hands-on training ('farmer-field schools') in agroecological principles. As a result, the volume of pesticide used on rice has fallen while yields have increased.

This successful IPM approach, building on natural diversity in rice paddies, has been extended and adapted throughout South and South-East Asia. In

[36] World Bank, 'Integrated pest management: strategy and options for promoting effective implementation', draft document (Washington DC: World Bank, 1996); see also L. A. Thrupp, ed., *New partnerships for sustainable agriculture* (Washington DC: World Resources Institute, 1996).

Bangladesh, for example, thousands of farmers involved in IPM projects have integrated fish into rice paddies, adopted agroecological methods to restore the natural balance between insects and other fauna, and planted vegetables on the dykes around the edges. This approach has increased rice yields and provided new sources of nutrition, and has made hazardous chemical use unnecessary. For example, farmers in the pilot IPM programme achieved an 11 per cent increase in rice production while eliminating pesticides.[37]

Practices to support soil fertility and nutrient cycling also make use of agrobiodiversity. Examples include:[38]

- use of compost from crop residues, tree litter, and other plant/organic residues;
- use of intercropping and cover crops, particularly legumes, which add nutrients, fix nitrogen, and 'pump' nutrients to the soil surface;
- use of mulch and green manures through collection and spreading of crop residues, litter from surrounding areas and organic materials, on and/or under crop;
- integration of earthworms (vermiculture) or other beneficial organisms and biota into the soil to enhance fertility, organic matter and nutrient recycling; and
- elimination or reduction of agrochemicals—especially toxic nematicides—that destroy diverse soil biota, organic material and valuable soil organisms.

These kinds of soil management practices have proved effective and profitable in a variety of farming systems.[39] The benefits include improvement of soil nutrient cycles and soil quality; added economic value; increase in sustainability of systems; and alleviation of pressures on habitats.

Agroforestry offers an excellent way to use agrobiodiversity that has multiple benefits.[40] The integration of trees into farming systems has various purposes in many contexts, such as providing fuel, fodder, shade, nutrients and timber for construction, as well as aiding soil conservation and water retention. (In West Sumatra, agroforestry gardens occupy 50–85 per cent of the total agricultural land.[41]) Complex forms of agroforestry exhibit forest-like structures, as well as a remarkable degree of plant and animal diversity, combining conservation and natural resource use. (In Indonesia, for example, small-holder 'jungle rubber' gardens incorporate numerous tree species.) Agroforestry systems in traditional forms also shelter hundreds of plant species, constituting valuable forms of *in situ* conservation.[42]

[37] Thrupp, ed., *New partnerships for sustainable agriculture.*

[38] These examples are mainly from Altieri, 'Traditional farming in Latin America'. See also Pimentel *et al.*, 'Conserving biological diversity in agricultural/forestry systems'; and Brookfield and Padoch, 1994.

[39] K. E. Lee, 'The diversity of soil organisms', in D. K. Hawksworth, ed., *The biodiversity of microorganisms and invertebrates: its role in sustainable agriculture* (London: CAB International, 1990).

[40] UNDP, *Benefits of diversity: an incentive toward sustainable agriculture* (New York: UNDP, 1992), pp. 98–102.

[41] UNDP, *Benefits of diversity*, pp. 120–4.

[42] G. Michon and H. de Foresta, 'Complex agroforestry systems and the conservation of biological diversity', in *Harmony with nature: proceedings of international conference on tropical biodiversity* (Kuala Lumpur: SEAMEO-BIOTROP, 1990).

Many of the practices noted above serve multiple purposes. For example, intercropping contributes to pest and soil management as well as enhancing income. In South America an estimated 70–90 per cent of beans and 60 per cent of maize are intercropped with other crops.[43] Farmers in many other parts of the world have recognized that such diversity provides valuable sources of soil nutrients, improved nutrition and reduced risk—all essential elements of a soundly based agricultural livelihood.

A common misperception is that agrobiodiversity enhancement is feasible only on small-scale farms. In fact, there is ample evidence to refute this notion. Experience shows that large production systems also benefit from incorporating these principles and practices. Crop rotations, intercropping, cover crops, IPM techniques and green manures are the most common methods being used profitably in larger commercial systems, in both North and South.[44] Illustrations of such sustainable approaches to intensification are found in tea and coffee plantations in the tropics, and in vineyards and orchards in temperate zones. In most large-scale settings, the change from monocultural to diverse systems and practices entails transition costs, and sometimes trade-offs or lower profits for the first two or three years. However, after the initial transition period, producers have found that agroecological changes are profitable as well as ecologically sound for commercial production and that they present new valuable opportunities.

Using participatory approaches The incorporation of farmers' local knowledge, practices and experimentation is advantageous in efforts to encourage agrobiodiversity and sustainable agriculture. Experience has shown that full involvement of local farming practices in agricultural R&D, through the participation and indeed leadership of local people, has had beneficial outcomes and should be adopted widely. A farmer-friendly approach is essential to the successful implementation of change. An understanding of farmers' knowledge and incorporation of their strategies for agrobiodiversity enhancement increase the chances of success, for example helping to make proposed innovations more relevant by drawing upon their informal methods of experimenting with unfamiliar cultivars and practices.[45] At the same time, the involvement of farmers as partners in R&D helps to ensure the adoption of agroecological methods and can help to empower local people.

In Mexico, for example, researchers worked with the local people to re-create *chinampas*—multicropped, species-diverse gardens developed from reclaimed lakes—which were native to the Tabasco region and part of Mexico's pre-

[43] UNDP, *Agroecology*.
[44] C. V. Finch and C. W. Sharp, *Cover crops in California orchards and vineyards* (Washington DC: USDA Soil Conservation Service, 1976), cited in UNDP, *Agroecology*.
[45] B. Rajasekaran *et al.*, 'A framework for incorporating indigenous knowledge systems into agricultural extension', *Indigenous Knowledge and Development Monitor* 1: 3, 1993, pp. 21–4.

Hispanic tradition.[46] A similar project conducted in Veracruz also incorporated the traditional Asiatic system of mixed farming, mixing *chinampas* with animal husbandry and aquaculture. These gardens also made more productive use of local resources, and integrated plant and animal waste as fertilizers. Yields of such systems equalled or surpassed these of conventional systems.[47]

In Burkina Faso, a soil-conservation and integrated cropping project in Yatenga province was based largely on an indigenous technology of Dogon farmers in Mali: building rock bunds for preventing water run-off. The project added innovatory elements—positioning bunds along contour lines—and revived an indigenous technique called *zai*, which is adding compost to holes in which seeds of millet, sorghum and peanut are planted. These crops are in a multicropping system, and animals are incorporated for their manure. In the fields using these techniques, yields were consistently higher than in fields using conventional practices; the increases ranged from 12 per cent in 1982 to 91 per cent in 1984. Yields in the *zai* method reached 1,000–1,200 kg/ha, compared to conventional yields of 700 kg/ha. Water management was enhanced, and food security, a priority for local people, was also improved. The techniques have been widely adopted, covering 3,500 hectares by the end of 1988.[48]

In such efforts, the full participation of women has significant benefits. As managers of biodiversity in and around farming systems in many areas of the world, women can make important contributions and have a promising role in research, development and conservation of agrobiodiversity. In Rwanda, for example, in a plant-breeding project of CIAT (International Centre for Tropical Agriculture), scientists worked with women farmers from the early stages of a project on breeding new varieties of beans to suit local people's needs.[49] Together they identified the characteristics needed to improve the beans, ran experiments, managed and evaluated trials, and made decisions on the basis of the trial results. The experiments resulted in stunning outcomes: the varieties selected and tested by women farmers over four seasons 'performed better than the scientists' own local mixtures 64–89 per cent of the time'. The women's selections also produced substantially more beans, with average production increases as high as 38 per cent.[50]

The development of participatory approaches requires deliberate measures, training and time to change the conventional approaches to agricultural R&D.[50]

[46] M. Altieri and L. Merrick, 'Agroecology and *in situ* conservation of native crop diversity in the third world', in *Biodiversity* (Washington DC: National Academy Press, 1988); and H. L. Morales, 'Chinampas and integrated farms: learning from the rural traditional experience', in F. De Castri, G. Baker and M. Hadley, eds, *Ecology and Practice*, vol. 1: *Ecosystem management* (Dublin: Tycooly, 1984).

[47] From UNDP, *Benefits of diversity.*

[48] CGIAR, *Partners in selection* (Washington DC: Consultative Group on International Agricultural Research, 1994).

[49] Ibid.

[50] See e.g. R. Chambers, A. Pacey and L. A. Thrupp, *Farmer first: farmer innovation and agricultural research* (London: IT Publications, 1987); I. Scoones and J. Thompson, *Beyond farmer first* (London: IT Publications, 1995); J. Alcorn, 'Making use of traditional farmers' knowledge', in *Common futures, proceedings of an international forum on sustainable development* (Toronto: Pollution Probe, 1989).

Nevertheless, the benefits are substantial: the application of such two-way approaches improves the likelihood of adoption and success of agrobiodiversity efforts. Basic principles of participatory rural appraisal in agroecological R&D include:[51]

- joint problem-solving among farmers and scientists, and responsiveness to local needs;
- mutual listening/learning between farmers and scientists;
- understanding of complexity;
- flexibility in selecting methods and timing;
- adoption of an interdisciplinary and holistic perspective;
- inclusive and equitable representation (in gender, class, ethnicity).

In sum, the use of these participatory approaches can help planners and communities to identify and develop 'best practices' in sustainable production, i.e. practices that are adapted to diverse local conditions and that bring agriculture and biodiversity into convergence, as well as creating socio-economic opportunities.

Merging agrobiodiversity and habitat conservation Efforts to conserve and enhance agrobiodiversity must also address the underlying policies that accelerate its loss. Broader policies and institutional structures focused on agrobiodiversity conservation drive practical, field-level changes. Many policy initiatives and institutions have already been established to address these issues. For example, several international institutions influence and regulate the use of plant genetic resources. Among the key players are the Consultative Group on International Agricultural Research, the International Plant Genetic Resources Institute, the Food and Agriculture Organization, the Commission on Plant Genetic Resources and the United Nations Food and Agriculture Organization. Recent important international conventions and agreements, particularly the Convention on Biological Diversity and the latest round of the General Agreement on Tariffs and Trade, are also influential in setting guidelines that affect agrobiodiversity and use of genetic resources.

Concerns about the control of plant genetic resources have led to many intellectual property regulations that govern the activities of public institutions and private companies and are intended to protect farmers' legal access to genetic resources. Gene banks conserve a remarkable diversity of plant genetic resources, and increasing numbers of agricultural research institutes have begun *in situ* conservation projects as well. Along with these large formal institutions, many NGOs and local organizations are also increasingly involved in promoting the conservation and equitable distribution of benefits from agrobiodiversity.

[51] Adapted from information provided by Centre for International Development and Environment/African Centre for Technological Studies. See *Participatory rural appraisal handbook* (Washington DC: WRI, 1990).

Policy and institutional changes Although many institutions are already actively involved, more coordination and work is needed at all levels to ensure effective reforms and agrobiodiversity conservation policies that benefit the public, especially the poor. Policy changes that attack the roots of problems and protect people's rights are needed. Issues and areas that require further attention include:[52]

- ensuring public participation in the development of agricultural and resource use policies;
- eliminating subsidies and credit policies for uniform high-yield varieties, fertilizers and pesticides, so as to encourage the use of more diverse seed types and farming methods;
- providing policy support and incentives for effective agroecological methods that make sustainable intensification possible;
- reforming tenure and property systems that affect the use of biological resources to ensure that local people have rights and access to necessary resources;
- implementing regulations and incentives to make seed and agrochemical industries more socially and environmentally responsible;
- developing markets and business opportunities for diverse organic agricultural products;
- developing legal systems and regulations to ensure the protection of intellectual property rights of indigenous peoples and farmers in developing countries in relation to genetic resources.

Building complementarity between agriculture and biodiversity will also require changes in approaches to agricultural research and development, land use and breeding. The types of practices and policies outlined here constitute potential solutions and promising opportunities. Such changes are urgently needed to overcome threats from the continuing erosion of genetic resources and biodiversity. Experience shows that enhancing and sustainably using agricultural biodiversity has benefits for both small- and large-scale farmers, while at the same time serving the broader social interests of ecosystem health and food security.

[52] Discussion of similar policy issues can be found, for example, in UNDP, *Benefits of diversity*; Thrupp, ed., *New partnerships for sustainable agriculture*; and Grupo Interamericano de Agricultura Sostenible, 'Semillas para el futuro' (San José, Costa Rica: Instituto de Cooperación Agricola).