Training Module: Agriculture and Biodiversity

TO ENHANCE CAPACITIES OF KEY STAKEHOLDERS FOR BIODIVERSITY CONSERVATION

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1. INTRODUCTION

Biodiversity not only acts as an insurance for food availability under various predicted environmental stress like climate change, nutrient depletion, etc. but also it provides a marginal and poverty ridden societies with high nutritional variety in terms of vitamins, minerals and other micro nutrients.

Agricultural sector gains from biodiversity and at the same time contribute towards it. Diversity in agricultural-ecological systems provides many crop specific benefits and ecosystem services like biological pest protection, nutrient replenishing, erosion control, water quality, and many others. Since agricultural land covers a major portion of earth's surface, they are the prominent landscapes for *in-situ* biodiversity conservation. Changing socio-ecological systems needs shift in frameworks for better addressing biodiversity crisis using good governance and stewardship incentives at State level with effective inter-departmental cooperation/collaboration to serve greater goals.

Capacity development of the involved stakeholder and future decision makers with respect to agricultural biodiversity is important for sustainable agricultural development and at the same time maintaining environmental sustainability. Changes at the local scale are equally crucial, including farmers' traditional knowledge, land-use practices and decisions, livelihood systems, migration patterns, and the role of local institutions.

Such engagement should be based on the "co-construction" of knowledge, drawing on both scientific and local knowledge. Capacity building is then not just about transferring skills and technologies, but also about changing the wider system through the knowledge, skills and crucially, attitudes (values, mind-sets and behaviours) that the concerned stakeholders need. A key role in implementing the specifically chosen agrobiodiversity agenda, through capacity development and knowledge creation and sharing, lies with all the stakeholder involved in agricultural system including farmers, government officials, NGOs, research institutions and community organisations.

1.1 Biodiversity and Agriculture

Agriculture is the single largest land use, covering over a third of the world's land surface. It is the main source of livelihood for more than 75% of the population of Sikkim and contributes around 17% of the State Gross Domestic Product (GDP). In Sikkim Himalayas a globally unique indigenous farming system is practiced and is in the process of being recognized as an associate site of the Globally Important Agriculture Heritage Programme (GIAHS) under the United Nations Food and Agriculture Organization (Sharma et al., 2016). Sikkim encompasses a variety of agro-ecological zones, with varying dominant farming systems in different zones: pastoralism and agro-pastoralism in the alpine and trans-Himalayan zones (4,000–5,500 m); mixed farming (subsistence agriculture) in the temperate zone (2,500–4,000 m); traditional agroforestry systems in the subtropical to warm temperate zones (600–2,500 m); and terrace rice cultivation-based mixed farming in the subtropical zones (300–1,700 m). Local agrobiodiversity features more than 126 landraces of cereals, including rice (77), maize (26), and millet (7); 18 cultivars of oilseeds; 34 cultivars of pulses/beans; 132 species of vegetables; 38 species of spices/ condiments; 33 landraces of tubers/roots; and 64 species of fruit. Traditional farming systems of the Sikkim Himalaya are large repositories of biological diversity. These systems are represented in four different layers of vegetation by Sharma *et al., 2016*, listed below with specific characteristics:

i. **Top layer:** Multipurpose agroforestry trees important for timber, fuelwood, fodder, and Non-Timber Forest Products (including wild edible fruits); wind break around farms; soil binder on terraces.
ii. **Middle layer:** Species of fruit (papaya, guava, banana, peach, pear, litchi, citrus), vegetables (tree tomato, drumstick, cassava), and climbers (cowpea, bitter gourd, bottle gourd, cucumber, beans, yams, chayote, pumpkin, beans)
iii. **Lower layer:** Mostly vegetables (okra, chenopodium, spinach, amaranthus, leafy vegetables, chilies, cauliflower, pulses, taro), and potential crops like finger millet, buckwheat, Job's tear, and ground fodder (broom grass)
iv. **Ground layer:** Consists of creepers (sweet potatoetc.), root/tuber crops (radish, beetroot, turnip, carrot, onion, yams, taro), spices (coriander, ginger, turmeric, large cardamom), pulses, and medicinal herbs (tulasi, babari, mints, sesame) (Sharma *et al.*, 2016).

It is generally found around the world that agriculture is the largest driver of biodiversity loss and the ways in which it affects species are complex, including conversion of natural ecosystems into farms and ranches; intensification of management in long-established cultural landscapes; release of pollutants, including greenhouse gases and associated value chain impacts, including energy and transport use and food waste. Recent assessments of trends and challenges driving change in food systems in the early 21st century agree that major drivers are as follows:

a) Demographic changes

The global population will grow from the present 7.4 billion to about 9.3 billion people by 2050. The global middle class is expected to be more than double in size to almost 5 billion by 2030, and two out of three people will live in a city. Higher incomes, urbanization, a growing population and changing dietary patterns are driving intensified demand for increased production of food. This puts pressure on natural resources, promoting high production mono-cropping system, exacerbated by growing demand for more homogenous western diets and for processed convenience foods. Sustained investment in producing more high-yielding starchy staples has led to a situation where of the 5,000–70,000 plant species documented as human food, only three – rice, wheat and maize – provide half the world's plant-derived calories.

b) Agricultural intensification

The breeding of new plant and animal varieties in high-input agricultural systems has dramatically increased yields (in what is often referred to as the 'Green Revolution'), and this agricultural intensification has been critical to meeting the needs of growing populations. However, this success has come at high environmental costs, and our food basket is increasingly based on a very limited number of species of crops and animals (globally, 90%

of the energy and protein in our food comes from only 15 plant and eight animal species). This intensification has had an alarming impact on many traditional agricultural systems, leading to a loss of genetic resources.

c) Climate Change

Diversity (genetic, species and ecosystem) in production systems can improve adaptability and resilience and is an essential part of adaptation to changing production conditions. The Intergovernmental Panel on Climate Change estimates total average global warming of over 1.3°C by 2040. Climate change leads to changes in temperature, rainfall patterns and increases in extreme weather events across time and geography. The demand for water for irrigation is projected to rise in a warmer climate, which will increase evaporation from the soil and accelerate transpiration in the plants, bringing increased competition between agriculture and urban as well as industrial users. In many of the poorest regions of the world, climate change will reduce crop yields and increase the incidence of animal diseases, leading to higher food prices, and insecurity for farmers. Climate is a significant driver of pest range extension and population dynamics; especially temperature has a strong and direct influence on insect development, reproduction, and survival. No doubt climate change will require adaptive management strategies to cope with the altered status of pests and pathogens.

d) Depletion of natural resources

Natural resources include land, soil, water and biodiversity. Agriculture covers up to 38% of the Earth's surface but 33% of the world's farmland is degraded. Agriculture accounts for 70% of all freshwater withdrawn and drives 80% of deforestation worldwide.

e) Food and nutrition changes

Food simplification has had a detrimental impact on health and nutrition. Changing food habits in both urban and rural households has led to an overdependence on energy-rich but nutrient-poor staple crops. Westernized diets put more pressure on natural resources; for e.g. the production of 1kg of beef uses 12 times as much water as compared to 1kg of wheat, and five times as much land. Modern diets are also linked to the triple burden of under-nutrition, malnutrition and obesity. Intakeof pulses, fruits and vegetables are declining around the globe alongside a rising predominance of starches, meat and dairy. (Rudebjer, 2011)

1.2 Biodiversity for farmers

Biodiversity is the basis of agriculture and shares historical bond with farmers. It has enabled farming systems to evolve ever since agriculture was first developed some 10,000 years ago. Biodiversity is the origin of all species of crops and domesticated livestock and the variety within them. It is also the foundation of ecosystem services essential to sustain agriculture and human well-being. Today's crop and livestock biodiversity are the result of many thousand years of human intervention. Biodiversity and agriculture are strongly interrelated because while biodiversity is critical for agriculture, agriculture can also contribute to conservation and sustainable use of biodiversity. Maintenance of biodiversity in every scale of farms is essential for the sustainable production of food and other agricultural products and the benefits these provide to humanity, including food security, nutrition and livelihoods.

Farmers realize the importance of biodiversity, which refers to the variety of plants, animals and micro-organisms above and below the soil within an ecosystem. Farms are ecosystems in themselves. Each part, from the soil to the animals that live there to the crops themselves, has an important role to play. The biodiversity in farms is, however, under threat. Despite the many benefits it provides, it is being lost as:

- Farming production systems have shifted to more intensive production practices which rely on fewer varieties, genes or species
- Traditional agricultural practices and knowledge are displaced (by intensive, external input-based management practices) and undervalued
- Climate change and land-use changes accelerated degradation
- Value chains are under pressure to provide standard products year-round in all seasons.

2. What is Agriculture Biodiversity?

Agricultural biodiversity, also called agrobiodiversity, is an important sub-set of biodiversity. Agrobiodiversity is that part of biodiversity related to agriculture and the production of food and non-food natural resources. It is the outcome of the interactions among genetic resources, the environment and the management systems and practices used by farmers. This is the result of both natural selection and human interventions developed over millennia. The Convention on Biological Diversity defines agro-biodiversity as a “broad term that includes all components of biological diversity of relevance to food and agriculture, and all components of biological diversity that constitute the agricultural ecosystems, also named agroecosystems: the variety and variability of animals, plants and micro-organisms, at the genetic, species and ecosystem levels, which are necessary to sustain key functions of the agroecosystems, its structure and processes”(CBD,2014). Agrobiodiversity is the result of the interaction between the environment, genetic resources and management systems and practices used by culturally diverse peoples, and therefore land and water resources are used for production in different ways. Figure 2.1 shows different levels involved in agro-biodiversity.

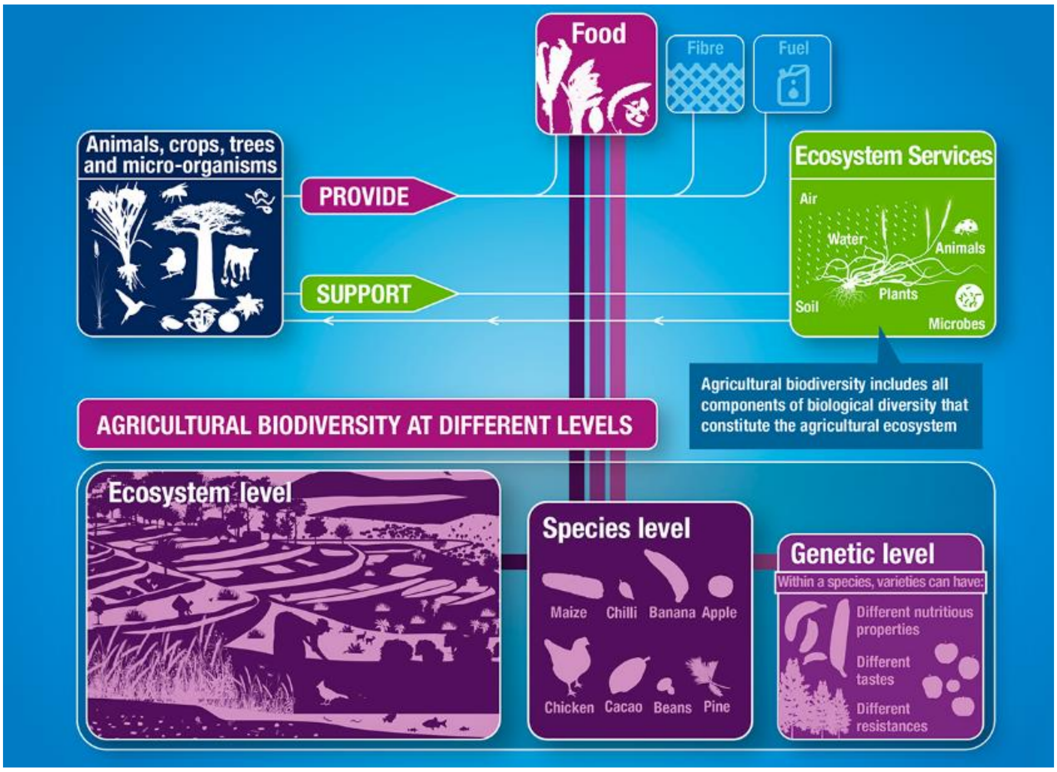


Figure 2.1: Agriculture Biodiversity (adapted from: Biodiversity International)

The following dimensions of agricultural biodiversity can be identified:

1) **Genetic resources** for food and agriculture
   - Plant genetic resources, including crops, wild plants harvested and managed for food, trees on farms, pasture and rangeland species (Table 2.1 shows major crops with number of landraces in Sikkim),
   - Animal genetic resources, including domesticated animals, wild animals hunted for food, wild and farmed fish and other aquatic organisms,
   - Microbial and fungal genetic resources.

These constitute the main units of production in agriculture, and include cultivated and domesticated species, managed wild plants and animals, as well as wild relatives of cultivated and domesticated species. It also includes soil micro-diversity as shown in figure 2.2.

2) Components of biodiversity that support **ecosystem services** upon which agriculture is based. These include a diverse range of organisms that contribute, at various scales to, *inter alia*, nutrient cycling, pest and disease regulation, pollination, pollution and sediment regulation, maintenance of the hydrological cycle, erosion control, and climate regulation and carbon sequestration.

Table 2.1 On-farm agricultural crops and landraces/cultivars/species commonly grown in the diverse (adapted from Sharma *et al.*, 2016)

Crop (scientific name)	**Local name**	**Number of species/ landraces/cultivars**
Rice *(Oryza sativa)*	Dhan	>77
Maize *(Zea mays)*	Makai	26

Ragi (Eleusine coracana)	Ragi	7
Taro or cocoyam (*Colocasia esculenta*)	Pindalu	7
Yams (*Dioscorea spp*.)	Tarul	15
Common French bean (*Phaseolus vulgaris*)	Simbi	14
Rice bean (*Vigna umballata*)	Masyam	7
Pumpkin *(Cucurbita pepo)*	Pharsi	8
Cherry pepper and local chillies *(Capsicum spp.)*	Khorsani	>20
Chayote squash *(Sechium edule)*	Ishkush	>55
Large cardamom *(Amomum subulatum)*	Alainchi	18
Ginger *(Zingiber officinale)*	Aaduwa	5
Banana *(Musa spp.)*	Kera	>9
Citrus *(Citrus spp.)*	Suntola	12

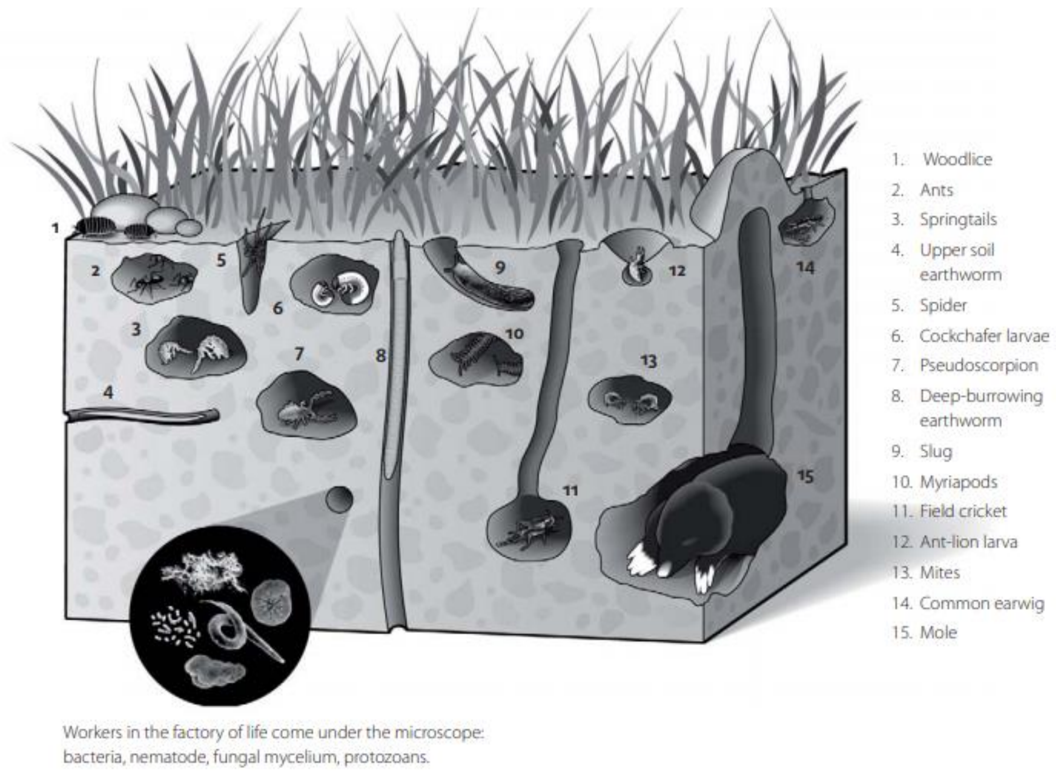


Figure 2.2 Glimpse of Soil Biodiversity (European Union, 2010)

3) **Abiotic factors**, such as local climatic and chemical factors and the physical structure and functioning of ecosystems, which have a determining effect on agricultural biodiversity.
4) **Socio-economic and cultural dimensions**, as agricultural biodiversity is largely shaped and maintained by human activities and management practices, and a large number of people depend on agricultural biodiversity for sustainable livelihoods. These dimensions include traditional and local knowledge of agricultural biodiversity,

cultural factors and participatory processes, as well as tourism associated with agricultural landscapes (source: URL 1).

Using agricultural biodiversity can take many forms. It can mean identifying which plant species or varieties contain important traits, such as salinity resistance or nutrient density, and using them to breed new varieties. At the farm level, it can refer to farming practices in which genetically distinct varieties of the same species are planted together as a mixture to increase resistance to diseases, or planting different varieties in different areas of the same farm to respond to different microenvironments. Using agricultural biodiversity might entail integrated farming systems where animals, crops and trees interact, with benefits of increased yields, lower fertilizer requirements and more food groups available for healthy diets.

At a landscape level, using agricultural biodiversity refers to creating a mosaic of different land uses – managed forest, cultivated fields, waterways, hedges and copses – to create beneficial synergies, such as water capture, pest control or pollinator habitat. It often involves matching land use to land form and soil type in order to tailor production to land capability, and in so doing reduce land degradation such as soil erosion (Biodiversity International, 2017). Different dimensions or themes in which agro-diversity is integrated can be seen in Figure 2.3, as a framework developed by Zimmerer *et al.*, 2019. Each theme has distinct knowledge assemblages (disciplinary, interdisciplinary, and transdisciplinary modes) and corresponding management and policy. Escalating interest in agrobiodiversity among diverse social and scientific sectors put forward the need to examine potential compatibility of diverse valuations as well as conflicts and frequent contestation. These themes are assembled to construct the proposed Agrobiodiversity Knowledge Framework as cross-theme integration for agro-biodiversity inclusion.

Figure 2.3 Agro-diversity knowledge framework: Themes and Values (adapted from Zimmerer et al., 2019)

Box 1: Agriculture diversity facts around the world (adapted from Ament *et al.*, 2008)

FAO estimates that about 75% of the genetic diversity of agricultural crops has been lost during the last century. A survey of 75 US crop species, carried out by the Rural Advancement Fund International (RAFI), found that 97% of the varieties listed in old United States Department of Agriculture catalogues are extinct. Equally dramatic losses have been recorded in Europe: in Germany about 90% of the historical diversity of crops has been lost and in Southern Italy about 75% of crop varieties have disappeared. Even the genetic diversity within these species has declined dramatically. For example, 75% of rice varieties grown in Sri Lanka are descended from one maternal parent, along with 62% in Bangladesh, and 74% in Indonesia.

3. Perspective on Agroecosystem

Any definition of sustainable agriculture must include how we examine the production system as an agroecosystem. We need to look at the entire system, or the entire "stream" focusing on various dimension of agricultural biodiversity as explained in previous section. Its definition is beyond the narrow view of agriculture that focuses primarily on the development of practices or technologies designed to increase yields and improve profit margins. Such practices and technologies must be evaluated on their contributions to the overall sustainability of the farm system. A primary foundation of agroecology is the concept of the ecosystem, defined as a functional system of complementary relations between living organisms and their environment. When we expand the ecosystem concept to agriculture, and consider farm systems as agroecosystems, we have a basis for looking beyond a primary focus on traditional and easily measured system outputs (yield or economic return). Agroecosystems are often more difficult to study than natural ecosystems because they are complicated by human management which alters normal ecosystem structures and functions. An agroecosystem is created when human manipulation and alteration of an ecosystem take place for the purpose of establishing agricultural production. This introduces several changes in the structure and function of the natural ecosystem, and as a result, changes in a number of key system level qualities. These same qualities can also serve as indicators of agroecosystem sustainability. Some of the key emergent qualities of ecosystems, and how they are altered as they are converted to agroecosystems, are as follows: energy flow, nutrient cycling and population dynamics (Source: URL 4).

3.1 Increasing Monoculture and intensive farming: Implications to farmers

Monoculture is essentially the opposite of multicultural. In modern agricultural terms it's the emphasis of crop specialization. Monoculture in agriculture involves the growing of a single crop using the majority or whole of the land. It is important to know that it is still called monoculture even if this single crop species is replaced by a different crop in the next growing season. The reason why that is still monoculture farming is that there is only one species of genetically uniform plants present on the field at one time. This strategy benefits farmers as it allows reduced costs, but when a single variety of species is grown it can also endanger the farm to widespread crop failure and biodiversity loss. But monoculture isn't connected only with crop cultivation, it is applied even in animal agriculture to higher production. A few advantages of monoculture includes:

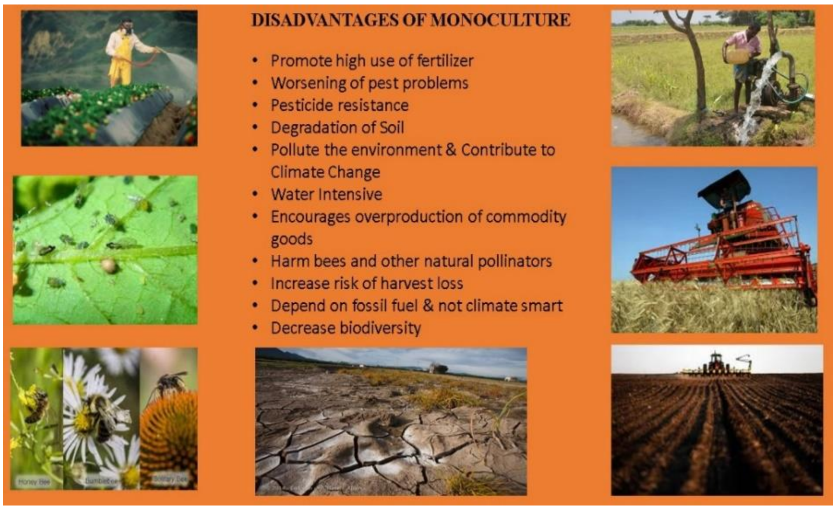


Figure 3.1: Disadvantages of Monoculture

specialized production thus optimizing operations; promotion of technological advances in agriculture; increased efficiency in tasks & processes; simpler to manage and increased profitability.

An example of the devastation monocultural farming can cause is the corn blight of 1970 which ruined more than 15 percent of corn crops in North America. This happened due to 70% of the crop being grown at the same high yield variety, making the corn more susceptible to harmful organisms. With the lack of diversity in a monoculture system it can cause a limit to the healthy functions nature can bring to crops and soil. Biodiversity on a farm creates an integrated Food Web as shown in Box 1, allowing biota to self-regulate with no pesticides needed. In a monoculture system, biodiversity struggles to exist. A variety of plants will provide beneficial nutrients and having a large range of insects is necessary for ensuring one doesn't damage too many crops. By directing away from natural elements provided by the ecosystem, monoculture must replicate these to protect the crops and the profit they make. This involves the use of synthetic fertilizers, herbicides, insecticides, bactericides.

An increasing number of studies demonstrate that agricultural practices, such as tree based intercropping, organic farming, reduced soil tillage, crop rotation and land use extensification have a positive impact on the abundance and richness of specific groups of soil organisms (e.g. arbuscular mycorrhizal fungi, earthworms) and on soil microbial diversity. Thus, by adapting farm management practices it is possible to favour recruitment of specific groups of soil organisms and enhance microbial diversity. There are a number of mechanisms by which microbial diversity can support agro-ecosystem functioning and particular ecosystem functions such as plant productivity, decomposition, nutrient cycles, etc. For instance, microbes can form "consortia" that enhance plant productivity (e.g. when different microbes provide different limiting resources to plants) or decomposition (e.g. when plant material is decomposed by specialized microbes with unique physiological properties that succeed each other). (Heijden *et al.*, 2012). Important disadvantages of monoculture is summarised in figure 3.1 (Source URL 3)

Box 2: Food Web

The different animals that can be found in an ecosystem depend upon other species in the ecosystem for food: this relationship can be summarized in a **food web**. Food webs are made up of a number of different levels, each including several different species: usually these include one or more levels of predators, a number of herbivores and a variety of green plants. For example, on a farm maize is grown. Maize is a green plant that uses energy from the sun to convert carbon dioxide from the atmosphere, water from rain and minerals from the soil to form its stems, leaves, roots and maize cobs. Stems and leaves are often fed to cattle and other farm animals, which use the energy and nutrients contained in them to maintain themselves and to produce milk.

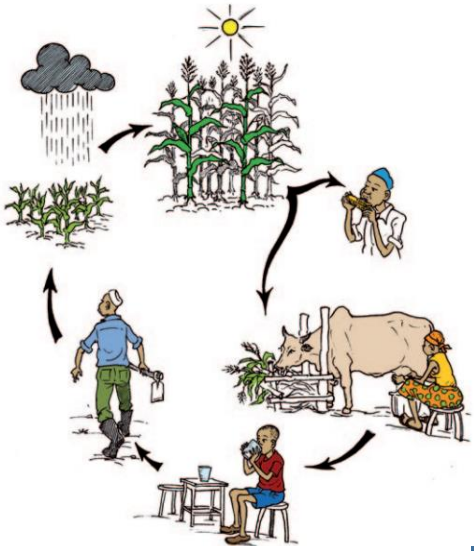


Figure 3.1 Adapted from FAO, 2018

People consume both maize grains and milk from cows. So, in this case energy and nutrients flow along the food web, from plants to people.

Typically, in an ecosystem, energy and nutrients flow along the food web, across populations of individual organisms of different sizes, which depend one on the other, in a circular relationship. For example, a small number of lions will hunt a population of several hundred gazelles, which in turn graze on thousands of plants. If the number of gazelles decreases – due to disease, or if drought reduces the amount of grazing land available – the number of lions will also decrease, reflecting the circular relationships between elements of the food web, where each component is dependent on the other. If the gazelles disappear altogether, then the lions which depend on them will also disappear.

4. Social, Cultural and Economic factors: Crop genetic diversity

Landscapes rich in agrobiodiversity are often the product of complex farming systems that have developed in response to the unique physical conditions of a given location, such as altitude, slopes, soils, climates and latitude, as well as cultural and social influences. Some systems long managed by indigenous and other traditional people, such as home and spice gardens, may not look like conventional farmland at all, resembling ‘wilderness’ to outsiders. The traditional cultural systems that have often developed over millennia can be closely linked to social stability and food security.

BOX 3: AGROECOLOGY AS SCIENCE, PRACTICE, AND SOCIAL MOVEMENT (source: IPES-Food, 2018)

Agroecology is the application of the science of ecology (the science of how nature works) to the study, design, and management of sustainable food systems, the integration of the diverse knowledge systems generated by food system practitioners, and the involvement of the social movements that are promoting the transition to fair, just, and sovereign food systems. Diversified agroecological systems, as defined by IPES, encompass wide-ranging approaches with a clear direction of travel: diversifying farms and farming landscapes; replacing chemical inputs with ecologically-based materials, practices, and processes; optimizing biodiversity; and stimulating interactions between different species as part of holistic strategies to build long-term fertility, healthy agroecosystems, and just livelihoods.

Social institutions and cultural traditions provide the context that shapes farmer seed and crop management choices. Social and cultural factors influencing the decisions a farmer makes include his or her traditional practices, local ways of life, or the identity of the group to which he or she belongs. Because of their use in particular foods and traditions, traditional crop varieties can play an important part in how a community, or a group within a community, perceives itself. This leads to a widely observed parallel between cultural diversity and crop genetic diversity. Social organization and institutions in a community influence farmers' access to and management of household and community level resources, affecting their actions regarding crop genetic diversity.

Over time, mountain farmers have created and maintained crop genetic diversity through the domestication and selection of a wide range of landraces and varieties of crops depending upon the type of soil. The existence of such large gene pools, inducing semi-domesticated and wild varieties of crops, enables farmers to adapt to changing climatic conditions and socio-economic pressures from unplanned development. Several factors are putting growing pressure on mountain farmers in the Sikkim Himalaya, including rapid increases in the non-farm population, rising demand, marginalization, and poverty; land degradation from conversion and erosion; the promotion of High Yield Varieties (HYVs) and the resulting disappearance of indigenous varieties; economic disparity; and environmental change. These pressures affect natural habitats that are home to wild relatives of crops, as well as domesticated animals, high-value cash crops (e.g., large cardamom, Sikkim mandarin, ginger, medicinal plants, etc.), and farmers, who maintain a significant amount of crop genetic diversity and animal genetic diversity.

Because the state of Sikkim doesn’t have a land use policy, agricultural land is being rapidly transformed into non-agricultural land, primarily for development activities like the establishment of pharmaceutical industries and hydropower projects.

Box 4: Loss of local traditional crop varieties and narrowing gene base of crops in Sikkim

(Sharma *et al.*, 2016)

Soon after Sikkim became the twenty-second state of India in 1975, traditional crop production systems started to give way to cash crop-based agriculture. New crop varieties from the plains, improved and hybrid varieties, and high yielding varieties (HYVs) were introduced to the traditional farming systems of Sikkim to increase crop productivity. The indigenous germplasms of Sikkim are disappearing rapidly for several reasons: the conversion of agricultural land to non-agricultural uses, the rising use of plastic in homesteads, floriculture in prime agricultural land, and the introduction of HYVs. The seeds of major traditional crops such as rice, wheat, maize, soybean, and mustard have been replaced by HYVs, leading to the disappearance of traditional landraces. At Daramdin, a major rice growing area in west Sikkim, about 30 traditional landraces of rice have been replaced by HYVs; 'marshi' is now the only traditional variety cultivated. There have been considerable changes in traditional farming systems, with modern approaches involving mono-cropping of HYVs. The displacement of traditional crops will eventually result in the disappearance of unique germplasms from the region.

4.1 Food diversity for Healthy and Diverse diet

One of the world's greatest challenges is to secure universal access to sufficient, healthy and affordable food that is produced sustainably. The contribution of food biodiversity to healthy and diverse diets can be measured at different levels. The highest level is food group diversity (e.g. cereals, dark green leafy vegetables and fruit), the next level is diversity within a food group (e.g. mango, banana and apple) and the lowest level considers diversity within a species (e.g. types of cultivated apple, such as Golden Delicious and Fuji, and also unnamed local and wild varieties). A diverse diet increases the likelihood of consuming adequate amounts of the full range of nutrients essential to human health. Figure 4.1 demonstrates this concept, showing how nutrient adequacy of the diet is improved as individual nutrient-dense foods are added to a meal. It shows the importance of consuming diverse range of nutritionally distinct food for nutrition needs.

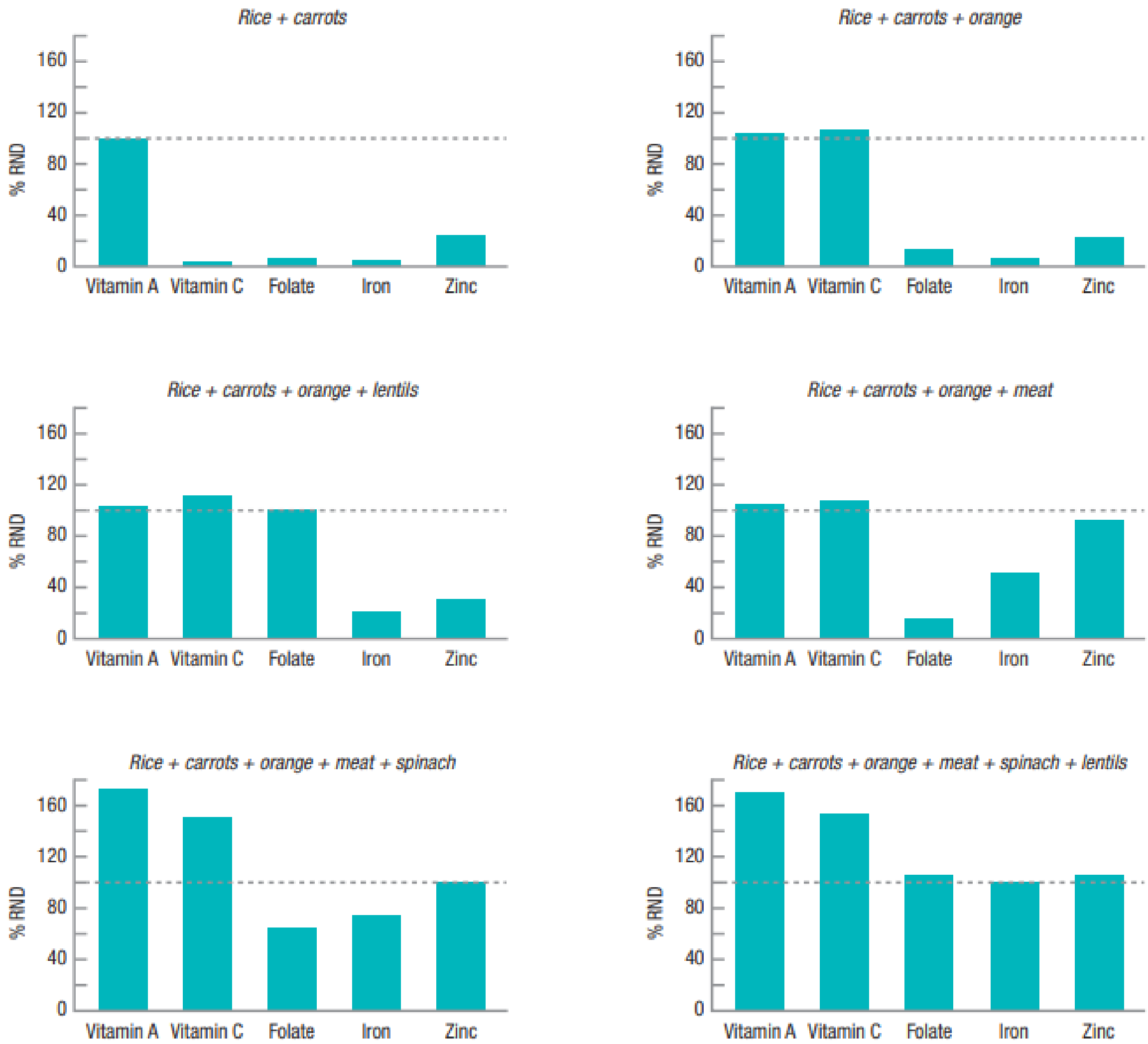


Figure 4.1 Recommended nutrient density of a white rice diet improves with each addition of another type of food (adapted from: Biodiversity International, 2017)

4.2 How biodiversity can increase farmer's income: Economic incentives

Poor and marginal farmers from East and South Asia depend on secondary crops such as finger millet, green gram, lentils, mungbean, sesame, local soybean, sweet potato, yam, etc.\ in particular as their main source of income as well as staple foods. Increased income to small-scale farmers and entrepreneurs is often quoted as one of the additional benefits of increased production of 'orphan' or 'underutilized' crops, specifically local fruits and vegetables. Multi-cropping gives some kind of insurance against failure of one crop, so that farmer have some crop left to harvest. At the same time by intelligent management and choice of crops, it increases overall production using the same or slightly increased inputs in the farm.

Box 5: Multilayer cropping for increasing profits in Kumaon region of Uttarakhand.

While we get dependent on external inputs like fertilizers, pesticides, insecticides, there are various cropping methods from traditional farming systems that help in increasing yield without using artificial fertilizers and pesticides. These methods provide a habitat for a variety of insects and soil organisms that would not be present in a single crop environment, thus increasing the biodiversity. **Multilayer Cropping** is a method adapted in certain farms for increasing the production. Farmers in Makrao village at Kumaon district of Uttrakhand have mastered this technique to maximize production from a unit area. They sowed seeds/seed-tubers of three different vegetable crops: colocasia, potatoes, and green leafy vegetables in the deep, middle and topsoil layers, respectively and simultaneously in a single crop field. To overcome the problem of nutrient competition in the multilayer crop fields, farmers apply a huge quantity of farmyard manure during the month of December, before sowing. Water is drawn from natural spring and stored in cement tanks; further used by the rotational system of land irrigation.

When it comes to profits the input-output money ratio of this system was computed to 1:8, which is significantly higher than the input-output ratio reported for potato (1:2), tomato (1:5), capsicum (1:2) and pea (1:2) cultivation (as sole plantation) in the other villages of the region. By using these methods, farmers can increase profits and encourage biodiversity at the same time. (Prakash Singh & G.C.S. Negi. 2013. Multilayer Vegetable farming: Small holder community innovates for improved Production. LEISA India 15 (4):23-24)

5. Agricultural systems promoting biodiversity

In the past decades, the global community has focused on two strategies for conserving genetic resources: *ex situ* conservation in gene banks and *in situ* conservation of ecosystems in protected area and reserves. The need for conserving agrobiodiversity on farms has gained attention more recently. Another, crucial, consideration is that the natural processes of adaptation and evolution cannot be maintained in gene banks. A large proportion of species' gene pools are still found outside of protected areas, in production landscapes. The *in situ* and *on-farm* conservation of crop wild relatives is an important but often neglected strategy for biodiversity conservation.

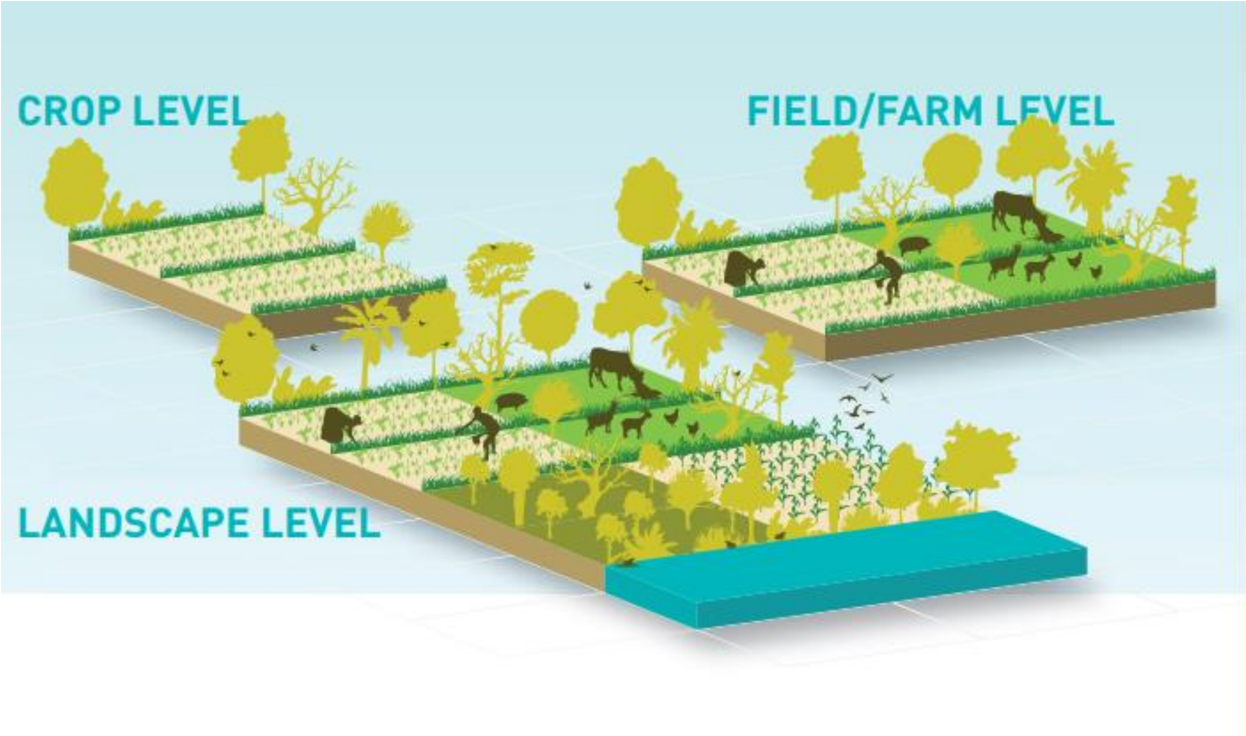


Figure 5.1 Agricultural biodiversity at different levels contributes to healthy farming landscapes (source: Biodiversity International, 2017)

One important agro-ecosystem management strategy is the use of *inter* and *intraspecific* crop diversity to mediate potential environmental stresses. If a crop population has a diverse genetic make-up, the risk of its being entirely lost to any particular stress, such as temperature extremes, droughts, floods, pests and other environmental variables is reduced. Different crops and varieties may differ in their vulnerability to specific threats e.g. traits for resistance to a specific disease. Crops with different planting times and times to maturity give the farmer the option to plant and harvest crops at multiple points in the season to guard against total crop loss to environmental threats.

As species vary in the ways they acquire and maintain resources (such as water, nutrients, or carbon), biodiversity enhances farming ecosystems. More biodiversity leads to greater biomass and healthier soils, which are critical for ensuring and increasing food production. Conversely, when 40 percent or more of the species in an ecosystem disappear — whether plant, animal, insect, fungi, or microbe — the effects can be as devastating as those caused by major drought.

5.1 Crop based systems

Figure 5.2 Agro-ecosystem example (adapted from: FAO, 2018)

Agriculture systems include cropping systems, livestock, fisheries and related management practices in the landscape. Figure 5.2. shows a complete picture of such systems. The various systems involved and methods used agriculture diversity development has been briefly described in following section.

A few of the many agricultural practices that farmers use to promote biodiversity are as follows:

- **Rotation**

It is the main means to control soil-borne pathogens. Soil and residue-borne pathogens are usually destroyed by natural decomposition processes and many dies if no host is present for some time (in many cases between 2 and 8 years). Rotations have therefore been the mainstay of plant protection in the past. For example, until the late 1990s there was no fungicide registered to fight Sclerotinia white mould in oilseed rape because it was known that if rotated properly (four-year break) this pathogen will not pose serious problems. However, the cropping frequency became higher and higher, and nowadays it is common practice to spray against this disease.

It is important to adapt the rotations to the soil management practice. When ploughing or deep tillage are performed, infected straw often comes back to the surface in the second year; thus, growing a crop with the same susceptibility will require more than a two-year rotation.

Figure 5.3 Sclerotinia white mould in oilseed rape (source: agriculture.basf.com)

- **Multiple Cropping**

In principle, sequential cropping, where a second crop is grown after the harvest of a first crop, is a simple form of multi -cropping. However, most multi-crops involve the cultivation of two or more species on the same piece of land where the growth cycles of different species overlap for at least part of their duration. Multi-crops containing species with different times to full canopy resist the establishment of weeds and may protect the soil against erosion and wind damage. Similarly the late planting of a second crop into one that is reaching maturity (relay cropping) is common in climates with a distinct wet and dry season where the rainy season cannot support the growth of two full-season crops (Azam Ali, 2003).

- **Conservation Tillage**

Tilling the soil is the practice of using a tool, like a plough to turn up the soil. This practice helps to turn over the residue from the previous crop, provide loose soil to make it easier for seeds to take root, and disturb weed growth. However, this practice can increase the potential for soil erosion. Conservation tillage minimizes the soil disturbance by using tools that turn over the soil lightly or hardly at all in some cases. The practice can leave some crop residue on the surface to lessen the opportunity for the soil to erode. The main benefit of this method is that it aids in building organic matter for the soil, which helps to promote biodiversity.

- **Agroforestry**

In agroforestry systems, crops and trees are grown in combinations that are highly complementary or even synergistic, to generate production, economic and/or ecological benefits. Tree species may produce economic products that serve as food, feed, medicines, timber or building materials, spices and other products, and if managed effectively they also benefit soils, watershed functions, and provide windbreaks for other economic crops. Following are some of the benefits of agroforestry over monoculture:

- It can result in higher overall yields and reduced operational costs.
- It can control runoff and soil erosion and can maintain soil organic matter and biological activity at good levels
- This increases biodiversity of the area and facilitate in availability of pollinators.
- This reduces insect pests and increases resilience from associated diseases.
- Highly recommended for reclamation of eroded and degraded land.

This system facilitates in developing more diverse farm economy and stimulate the whole rural economy leading to reduction in economics risks.

- **Planting Cover Crops**

Cover crops are those planted by farmers in between the harvest of one cash crop and the planting of another. These crops, such as rye or radishes, can assist with soil conservation, keeping soil from eroding and returning nutrients and benefits to the soil for future crops. Cover crops also provide habitat for birds and insects, an important component of biodiversity. Adding cover crops such as brassicas, legumes, or other flowering plants in the off-season usually increases organic matter in the soil, providing additional food for earthworms and microorganisms. Additional benefits are soil protection, weed suppression, and the provision of urgently needed pollen and nectar for pollinators.

- **Planting Buffer Strips**

Buffer strips are wide strips of land, usually grass, between fields of crops that help ease soil erosion and water runoff. These strips of land also play an important role in promoting biodiversity by providing a habitat for birds and animals. They are particularly beneficial in areas with hilly terrain.

- **Well-functioning Seed Systems**

Some of the *on-farm* losses of crop genetic diversity have been partially offset by the maintenance of genetic diversity in seed banks. Seed systems, which also include the propagules of vegetative reproduced plants, are crucial for the generation and distribution of agrobiodiversity through wide-ranging governance mechanisms. Both market and non-market practice, as well as combined traditional and new cultural practices, are evidenced in agrobiodiversity seed fairs, seed banks, seed networks (including the roles of social networks), and seed saving and potential social responsibility agreements. Seed exchange is vital to agrobiodiversity conservation and smallholder resilience, as it has been practised in various traditional Himalayan regions (Zimmerer *et al.*, 2019). Informal networks of seed exchange can play an important role in maintaining agrobiodiversity, underlining the link between seed exchange and the in-situ agrobiodiversity conservation of home gardens. Another point to note is that seeds and knowledge are transmitted together, which directly contributes to the conservation of genetic material along with the associated knowledge.

5.2 Diversity in Aquatic systems

The definition of agro-diversity encompasses “wild and farmed fish and other aquatic organisms” and thus is an important aspect for this module. As per studies reported about 48 species of fish from Sikkim. A strong decline in the diversity of fish fauna in the river Teesta is also observed. (source: Saroj Toppo, H. Rahman and N. Haque, Fish Biodiversity as an Indicator of Riverine Status of Sikkim). Biodiversity within freshwater ecosystems in the Eastern Himalaya region is both highly diverse and of great regional importance to livelihoods and economies. Major threats to freshwater biodiversity can be grouped under five interacting categories: over-exploitation; water pollution; flow modification; destruction or degradation of habitat; and invasion by exotic species, with global scale environmental changes being superimposed upon all of them (Allen *et al.*, 2010).

Figure 5.4 The development of transport links and other construction activities can have major impacts on freshwater systems (Allen et al., 2010)

5.3 Diversity in Livestock Systems

Domesticated animals are also a part of agricultural biodiversity of a regions and it has important economic value for local population to meet domestic and farming needs (draught animals, manure, milk products, meat, wool, and skin). Such local breeds are well adapted to extreme mountainous environmental conditions with development of specialized genetic traits. Local cow breeds like ‘*pahadey gai’* and ‘*siri gai’* and local goat breeds like ‘*sigari bakhra’* are on the verge of disappearance from the agrobiodiversity landscapes of Sikkim. Animal husbandry is the backbone of farming community providing livelihood and food security apart from other indirect advantages (Sharma *et al.*, 2016). In the recent decades livestock grazing in the protected areas and reserve forest areas was banned by the Government of Sikkim during 2000–2005, and through the farmers have initiated stall feeding of farm animals. Farmers grow diverse tree and grass fodder species to feed farm animals. Many farmers in Sikkim have converted cultivated farms into farm-based agroforestry for growing fodder species (tree/understorey grasses) due to labour shortage.

6. Agroecosystems in hilly terrains: An overview

Agroecosystems are comprised of the non-living (abiotic) and living (biotic) components in a human-managed, agricultural system. Agroecosystems provide the arena in which crop evolution occurs, presenting stresses, but also opportunities, to which crops must adapt in order to thrive. Abiotic components of agroecosystems include temperature, soil, water, relative humidity, light and wind. Biotic factors include parasitic and herbivorous pests, competition from other plants, and favourable (symbiotic) relationships with other organisms. The farmers who manage these factors in terms of irrigation, nutrient input, pest control, land preparation, mixed/relay cropping and other practices are also a biotic component of agroecosystems.

Habitats located at higher altitudes are commonly associated with particular abiotic factors, including low carbon dioxide availability and high variation in precipitation, light, soils and temperature. Nutrient deficiencies or toxicity may be particularly important in determining the survival and productivity of crop varieties in the agro-ecosystem. Soils may be deficient in nitrogen, phosphorus or potassium, as well as secondary micronutrients such as magnesium, sulphur, zinc and boron. In contrast, iron, manganese and aluminium may occur in such high quantities as to cause toxicity. Nutrient availability may be related to soil pH and precipitation regimes. Information on soils can help identify soil-related constraints and explain current management practices.

7. Good practices around the world

Case study 1: Advantages of diversity in pollinators for ecosystem services in cardamom plantations of Sikkim (source: Sinu and Shivanna, 2007)

Background: Three out of four crops across the globe producing fruits or seeds for human use as food depend, at least in part, on pollinators. Sikkim, a hotspot for natural biodiversity harbouring more than 4500 flowering plants also depend highly on pollinators. The sustainable production of various native fruits, medicinal plants, cash crop like cardamom in Sikkim depend on insect pollination which directly contributes to state economy, health & well-being of citizens and finally biodiversity of the region. Most important of these pollinating agents is the mighty bee. Sikkim has about 30 species of bees- majorly carpenter bees, bumble-bee and few honey bee species. Flowers that are visited more often by bees will produce larger and more uniform fruit than those visited less often. Improving pollinator density and diversity boosts crop yields –pollinators are important for 19 percent land in Sikkim cultivated for various crops, fruit, vegetable and spices.

Case study: The following case study takes place in large cardamom plantation in Sikkim at Eastern Himalayan landscape. The farm has scattered shade trees along with some patches of native bamboo thickets. Only two flower visitor species, a bumble-bee and a honey bee species are the pollinators for large cardamom plantation crop. The bumble-bee is the effective and only pollinator here due to certain adaptation. Major flower adaptations for pollination by the bumble-bee are the length of the nectar tube, which is not accessible to short-tongued bees and a narrow passage in the fresh flower between the anther–stigma column and the labellum. The honeybee, with its short proboscis, buzzes in and out of same flower several times, trying in vain to reach the nectar. In the process, it depletes the flower of its pollen but is usually unable to penetrate it deep enough to effect pollination. Meanwhile, the bigger bumblebee, with its longer proboscis, penetrates the flower, sucks out the nectar and flits on to the next bloom, transferring pollen effectively. The narrow passage forces the bumble-bee to push the anther–stigma column to enter the flower, which brings the body of the bumble-bee in contact with the anther and the stigma, and effects pollination. It shows the importance of native species which is adaptations for its function in local ecosystem.

Discussion: Pollination efficiency of the cardamom plantations is decreasing in Sikkim, as about 70% of the flowers remained un-pollinated as claimed in a scientific study. This can be related to lower population density of the wild pollinator species, Bumble Bee. This study shows the importance of locally adapted bee species as one of the many pollinating agent in Sikkim. Such pollinating agents have the potential to directly contribute to the agricultural sustainability of Sikkim, which has a rich heritage of traditional agricultural systems supporting agro-biodiversity. Safeguarding bees safeguards biodiversity: the vast majority of pollinators are wild, including over 20 000 species of bees in the world but recent trends of mono-cropping and introduction of high yielding varieties pose a threat to the survival of agro-biodiversity and related agents in Sikkim.

Solution: Farmers can help by planting fallow fields and agricultural field edges with flowering plants to support wild pollinators throughout the growing season, and by reducing pesticide use, especially during crop bloom when more bees are in their fields. The average person can help, too. By filling their gardens with diverse, native plant species and limiting pesticides, anyone can create more pollinator-friendly spaces and help keep their local pollinator community diverse, healthy and beautiful.

Case study 2: **Managing Agro-Biodiversity for Sustainable Livelihoods in Timor-Leste** (source: URL 2)

Context: German development cooperation is supporting Timor Leste to enhance the adaptability and resilience of the population to external shocks and crises such as highly volatile food prices and the consequences of climate change. For the same rich agricultural diversity of the country is focused. The objective of the project is to protect the rich agro-biodiversity by promoting its sustainable management.

Approach: Important steps include the participatory mapping of existing agro-biodiversity and the establishment of an ABD database and a monitoring system in order to be able to document changes over time. Farmers and their advisors jointly identify and apply improved farming methods and protect and breed native species and varieties. Measures aimed at protecting and promoting agro-biodiversity are integrated into village development plans, and value-added chains for native species with potential for generating greater income are developed and implemented. The project also supports the National Directorate for Industrial Crops in developing and implementing locally adapted strategies that promote agrobiodiversity protection and the rehabilitation and cultivation of cocoa. Selling cocoa will give smallholder families the opportunity to earn additional income.

Results: The Ministry of Agriculture has established the theme of agro-biodiversity in the National Directorate for Community Development and Agricultural Extension. It is gaining importance at all levels. The national rice campaign of the Ministry has promoted the use of local rice varieties and biodiversity-friendly farming practices. The Ministry has adopted an approach under which farmers are to learn from one another in groups. A database with species and varieties under cultivation has been handed over to the agricultural faculty of the National University of Timor-Leste, where it is being maintained. The University is to regularly provide the State Secretariat for Environment with current data that are to be included in the national biodiversity report 2014. The participating groups of farmers have a plant register of their own and have started applying biodiversity-friendly farming practices which include composting, for example.

Case study 3: Conserving Traditional Seeds and Agriculture- Beej Bachao Andolan in Uttarakhand (Chettri *et al.*, 2012)

Conserving traditional seeds and agriculture is a priority agenda of the Beej Bachao Andolan (Save Seeds Movement), an ongoing people's movement that started in the mid1980s in Uttarakhand.

Problem: Since the 1960s, the 'green revolution' has promoted a new agriculture system through a deeply entrenched nexus between seed-chemical companies and governments, which has systematically downgraded and marginalized small farmers and their holistic farming practices. It has also contributed to the loss of once rich traditional agrobiodiversity and natural resources, and caused land and soil degradation, water depletion, and soil and water pollution, as well as other socio-cultural losses.

Approach: Through the Beej Bachao Andolan, farmers decided to take their own farming decisions and refuse chemicals and high-yielding varieties (HYV) of seeds. Long marches and tours were undertaken to collect and exchange local seeds. Meetings were organised to advocate for community resilience, safe food, health, and livelihoods by returning to local agricultural practices such as mixed cropping, crop rotation, cattle rearing, and community inter-dependence in agriculture.

Outcome: Beej Bachao Andolan's work has addressed forest conservation, while promoting the localisation of food production and consumption, now considered vital to address climate change concerns. Most importantly, Beej Bachao Andolan revived the communal nature of farming, which had been eroded by the green revolution. Beej Bachao Andolan's approach enabled farmers to have control over their own agriculture, which was being seized by market forces. Diversity in crop production systems strengthened household food security and nutrition, while generating a surplus for exchange or sale. Use of local seeds promoted water conservation, and the rejection of chemical fertilisers and pesticides revived the health and quality of the soil and water. Today, Beej Bachao Andolan has an in-situ collection of over 350 rice varieties, over 200 bean varieties, 30 wheat varieties, and 27 millet varieties, as well as various other local crops, vegetables, and spices. The movement has helped revive *baranaja*, a traditional mixed cropping system wherein 12 or more different crops are grown simultaneously in a single season.

Case study 4: Integrated agriculture in Kosi Hills Tamilnadu and Wayanad, Kerala (Oliver *et al.* 2014)

In the hilly regions of southern India known as the Eastern and Western Ghats, the native agrobiodiversity (which includes farmed species) is being replaced by the cultivation of cash crops in order to generate farming income. In Kolli Hills (Tamil Nadu), over the last three decades, cassava has increasingly replaced the native millets. A parallel shift has happened in Wayanad, Kerala where banana is replacing paddy rice. While enabling farmers to generate some income, the loss of diversity, increasing monoculture of market-driven cash crops (like cassavea and banana) is accelerating rates of soil erosion, promoting crop disease while making farmers more vulnerable to climate risks. It also lead to reduction in local food productivity and increasing dependence on outside region for food.

In Kolli Hills, cassava is a significant cash crop that constitutes 70% of crop production in the region for fulfilling industrial demand. However, monocropping of a single cassava variety over such a large area has resulted in increased disease prevalence and soil erosion, causing productivity loss. It has also displaced mixed farming systems and associated local crop diversity, negatively impacting on food security and climate resilience. MS Swaminathan Research Foundation (MSSRF) has initiated participatory varietal selection (PVS) for cassava varieties, undertook intercropping trials with pulses and millets and organized high quality millet seed production through community seed banks.

Outcomes:

Greater Diversity in Cassava Through Participatory Varietal Selection with higher starch content and edibility, thus increasing diversity in the region.

Inter-cropping for Increased Incomes: Farmers in Kolli Hills have intercropped cassava with finger millet, black bean and onion, increasing the diversity of their crop production. A farmer-driven intercropping approach using onions led to the production of 300 kg/acre of onions, resulting in a 60% increase in family income.

Resilience Through Community Seed Banks: Seed banks are managed by farmers' clubs or women's self- help groups; those borrowing seed are required to pay back double the quantity after the harvest, helping to make the seed banks sustainable. Community members also mastered skills for identifying superior varieties and producing quality seeds. It increases overall resilience of food system by better diversity, quality and capability.

In Wayanad, Kerala for cultivation of foot yam during fallow period in rice fields, through participatory research, farmers have identified best varieties and adopted low cost farming practices, such as a reduced seed rate, mulching of crops to induce early sprouting and application of farmyard manure.

Figure 7.1 Seed banks in Kolli Hills, TamilNadu (Source: Greenfoundation.in)

8. Farm Biodiversity Management and Related Services

The so-called modern approach for increasing food production has more frequently been to raise yields per unit area of existing agricultural land through a range of management activities and processes collectively known as agricultural intensification, which often involves increased use of inorganic fertilizers and synthetic pesticides, increased mechanization, irrigation and increased use of monocultures. The simplification of the world's farming and food systems leaves farmers with fewer resources to draw upon to manage the risks of crop failure due to pests and diseases, or the impacts associated with increasing climatic variability. Together agricultural intensification and the simplified food value chains that accompany it, affect both environmental and human health. Agricultural intensification contributes directly to environmental degradation through loss of biodiversity, pesticide impacts, soil degradation and negative effects on native vegetation remnants.

The agricultural biodiversity provides resources which include cultivated biodiversity and also wild biodiversity, which plays an important role in agriculture, by cross-pollinating with cultivated crops to generate new sources of novel and adaptive traits, or by providing nutrient cycling, pollination, pest control and/or climate mitigation services to crops. Agricultural biodiversity's contribution to sustainable food systems occurs at four interacting scales: (i) within species (e.g. different varieties of bean or wheat), (ii) between species (e.g. wheat, beans, ginger, pears), (iii) field and farm e.g. farming decisions such as the location and timing of different crops and (iv) land use and landscape e.g. cultivated fields, fallow, waterways, groves, hedges). It is scientifically challenging to understand what the actual ecological processes are that link agricultural biodiversity and ecosystem services i.e. how they work.

In situ conservation *on-farm*, sometimes referred to as "*on-farm* conservation," has been defined as "the continuous cultivation and management of a diverse set of populations by farmers in the agro-ecosystems where a crop has evolved". These benefits relate not only to genetic diversity but also to ecosystem health and human well-being. Some of the major benefits are as follows:

Conserving the processes of evolution and adaptation: This benefit is central to *in situ* conservation, as it is based on conserving not only existing germplasm but also the conditions that allow for the development of new germplasm.

Conserving diversity at all levels: In its maintenance of farming systems, on-farm conservation applies the principle of conservation to all three levels of biodiversity: ecosystem, species and genetic (intraspecific) diversity. When species – plants, animals and microbes – within the agro-ecosystem, and genetic diversity within the species are maintained, the diverse interactions of crop populations are preserved. Moreover, the conservation of these three levels of agro-biodiversity, and the various interactions that they support, contribute to the overall principle of ecosystem health in local farming systems.

Conserving ecosystem services and functioning: On-farm conservation may be an important way to maintain local crop management systems for agro-ecosystem sustainability by ensuring soil formation processes, reducing chemical pollution and other waste emissions from farms, and restricting the spread of plant diseases.

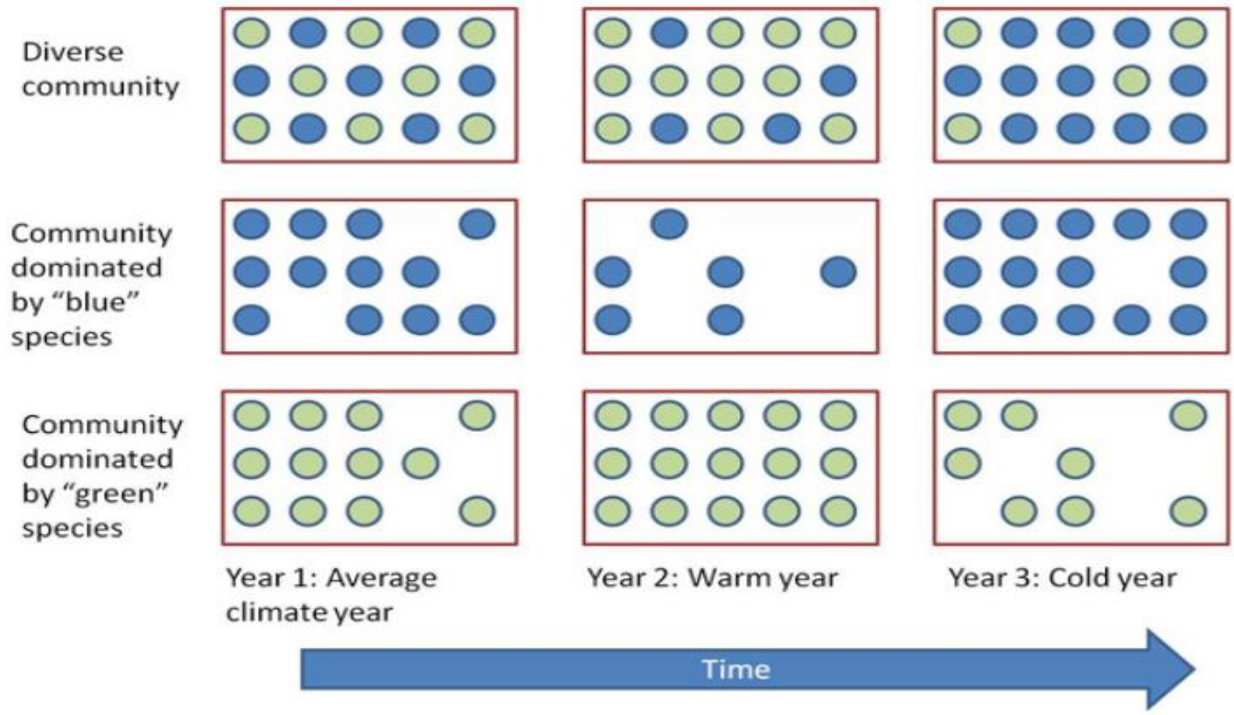


Figure 8.1 Conceptual diagram showing how increasing diversity can stabilize ecosystem functioning

Each rectangle represents a plant community containing individuals of either blue or green species and the total number of individuals corresponds to the productivity of the ecosystem. Green species increase in abundance in warm years, whereas blue species increase in abundance in cold years such that a community containing only blue or green species will fluctuate in biomass when there is inter-annual climate variability. In contrast, in the community containing both green and blue individuals, the decrease in one species is compensated for by an increase in the other species, thus creating stability in ecosystem productivity between years. Note also that, on average, the diverse community exhibits higher productivity than either single-species community. This pattern could occur if blue or green species are active at slightly different times, such that competition between the two species is reduced. This difference in when species are active leads to complimentary resource utilization and can increase total productivity of the ecosystem.

Improving the livelihoods of resource-poor farmers: Farmers will benefit from the continued agricultural diversity and ecosystem health that on-farm conservation supports. Local crop resources can be the basis for initiatives to increase crop production or secure new marketing opportunities.

Public and private benefits (socioeconomic, ecological and genetic): The importance of conservation of agro-biodiversity for the future of global food security lies in its potential to supply crop breeders' and other users' future needs for germplasm. On-farm conservation will allow the processes of evolution and adaptation to continue in crop plants, ensuring that new germplasm is generated over time, rather than limiting conservation to a finite set of genetic resources conserved in gene banks. Society can benefit from the agro-ecosystem stability and decreased use of chemicals in agriculture promoted by the use of diverse local varieties.

9. On-field biodiversity and its importance for ecosystem services

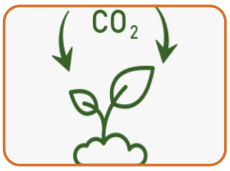
The agro-diversity of the Sikkim Himalaya provides many goods and services that are of vital importance for human wellbeing and the functioning of ecosystems. Ecosystem goods and services in the region's mountain environment largely support mountain communities. These services are divided into four categories:

Supporting Services

The agro-diversity of the landscape supports primary and secondary production, biogeochemical cycling of nutrients, provision of habitats, and agrobiodiversity, which is necessary for sustaining the goods and services that mountain societies obtain from these ecosystems.

Provisioning Services

The agro-diversity of the landscape provides agricultural products such as food (crops, roots, tubers, seeds, nuts, fruits, fodder, spices, etc.), construction materials (timber), energy (fuelwood), fibre (wood, textiles), and medicinal and aromatic plants.



Regulating Services

The agro-diversity of the landscape and forest ecosystems are critically important for carbon sequestration; water and climate regulation; pollination; protection from natural hazards such as floods, landslides, and avalanches; water and air regulation; and disease and pest regulation.

Cultural Services

Agro-diversity in the Sikkim Himalayan Demazong/Indrakil sacred landscape is of great spiritual, cultural, and aesthetic importance. Traditional mountain societies play a key role in conserving and protecting these ecosystems for present and future generations. (Sharma *et al.*, 2016)

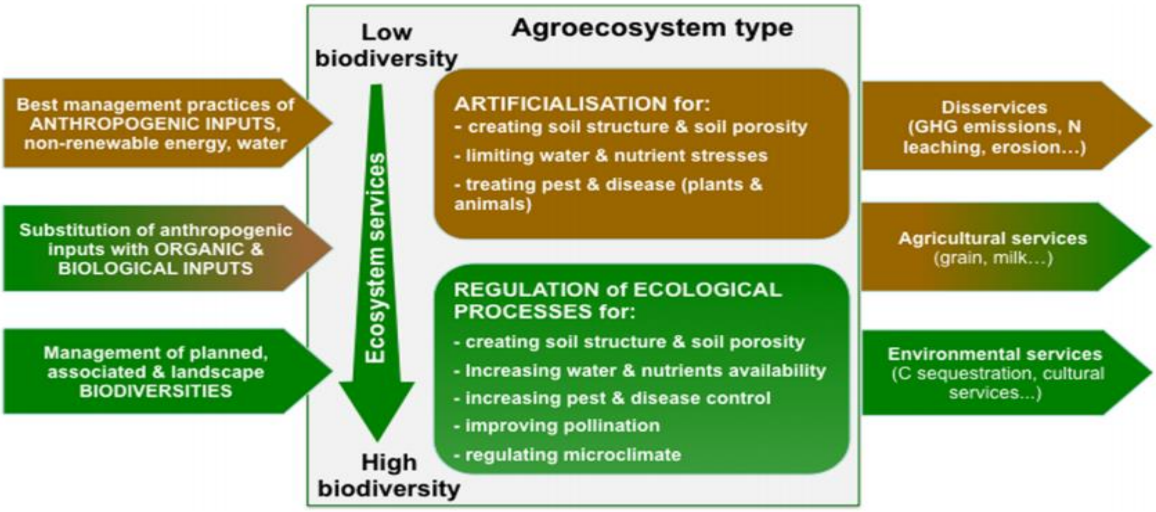


Figure 9.1 Synoptic representation of the main characteristics of the efficiency/substitution-based agriculture (brown) and the biodiversity-based agriculture (green) (source: Duru et al., 2015)

The above figure gives a synoptic representation of the efficiency/substitution-based agriculture (brown) based on efficient (optimized) use of anthropogenic inputs and the biodiversity based agriculture (green) makes use of harnessing biodiversity to promote input (ecosystem) services. These two opposing strategies develop two different types of agroecosystem. The color code (brown to green) indicates the relative intensities of inputs (anthropogenic vs. input services) and of the main types of outputs in both strategies. Input services are those provided to farming systems. They correspond to “supporting services” (e.g., soil fertility, microclimate regulation) and “regulating services” (e.g., pollination, natural pest control). Agricultural services (provisioning services) and environmental services (non-marketed services) are those provided by agriculture to the whole society.

The role of agricultural biodiversity in few important ecosystem services:

1. Soil erosion control: Soil erosion is a natural process currently accelerated to extremely high rates in some agricultural landscapes. Agricultural biodiversity management strategies to reduce soil erosion include hedgerows which help reduce runoff speed, facilitate infiltration and reduce wind erosion, cover crops which protect soil from impacts of raindrops or wind erosion, agroforestry which increases infiltration, produces mulching material, and the canopy reduces the speed of raindrops or wind, riparian buffer protection which increases in-filtration, retains sediment and reduces runoff speed, intercropping which reduces exposed bare soil and optimizes nutrient cycling, non-cropped vegetation, and rotational livestock grazing regimes. The capacity of biodiversity to control soil erosion depends on combinations of functional traits of the species included in the farming system e.g. high root density, deep roots and dense vegetative structure, their location within the landscape, and the growth stage of the main crop

2. Pest and disease control: Agricultural biodiversity can play an important role in plant protection through ‘natural pest control’, enhancing natural enemies, using pest-resistant crops and crop combinations, adapting cultural management, and judicious use of pesticides. Farmers and plant breeders select and use varieties with genes that are resistant to pathogens and pests of their crops, and have developed farming systems that reduce the damage these cause. At the field scale, mixing varieties or species reduces the risk of pest epidemics. Many farmers worldwide maintain a diversity of traditional crop varieties as part of disease management strategies. Loss of local crops, which narrows down genetic options, reduces farmers' capacity to cope with changes in pest and disease infestations and leads to yield instability. For instance, a meta-analysis of multiple studies examining populations of many insect and other invertebrate groups in monocrop compared to diverse, multi-species systems found reduced numbers of plant-eating pests (23%) and increased natural enemy abundance (44%) in mixed plant associations, and found increased pest predation (54%) in diverse compared to monocropped systems. As a general tendency, increasing diversity at each scale, from within species diversity to landscape diversity, reduces risk of large crop losses.

The main reason why genetic uniformity or low variety or mono-cropping increases disease problems and thus the use of pesticides are:

i. Lack of or too short rotations: Soil-borne pathogens depend on the presence of their host plants for survival. The tendency in modern agriculture to use fewer and fewer crop plants has led to very short breaks between crops and to an increase in field size. Not only the crops but also the weeds need to be considered. Many legumes share pathogens and often need to be separated by more than four years in order to produce a healthy crop.

ii. Inability of crops to adapt to changing pathogen populations: Because modern crop plants are genetically very uniform, they have only little potential to adapt to their pathogens through natural selection. Thus, besides increasing the need for pesticides, genetic uniformity also creates the necessity for costly breeding programmes and overall makes farmers dependent on inputs of seeds and chemicals. (ELN-FAB, 2012).

Figure 9.2 Informed selection of flowering plants for pest control in Europe (source: ELN-FAB, 2012)

The creation of wildflower strips and management of other non-crop vegetation has emerged as a key tool to support beneficial insect groups and the services they deliver. There is a need for targeted approach in the choice of flowering plants for field margins or other types of non-crop vegetation. This targeted approach is based on the simple concept that different insect groups exploit different flowering plants. By selecting those plants that are especially suitable for the insects delivering pest control, while excluding plants that are preferred by nectar/ pollen-feeding pests, the positive impact of flowering landscape elements can be maximized. As an alternative to the 'hit-and-miss' approach, this 'targeted approach' is based on three key steps:

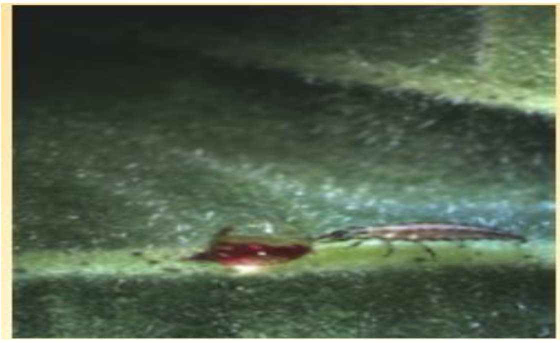


Figure 9.3 Lacewing larva feeding on cotton extrafloral nector (source: ELN-FAB, 2012)

(1) quantify the nectar or pollen bottleneck (level of food limitation of insect predators and parasitoids) under field conditions; (2) informed selection of flowering plants that can be successfully exploited by the target beneficiaries; (3) provide the flowering plants at times and in locations that optimize their exploitation by the predators delivering natural pest control services.

Depending on the ecological behaviour and movement of the predator, the distance also matters, one typically sees a declining impact of flowering margins over a distance of 30-50 metres. To get closer still, one can grow 'flowering companion plants' alongside individual crop plants. This is especially effective in crops such as cabbages that are planted in plugs, rather than sown. In these instances, the companion plant can be grown together with the crop plant in the nursery. If companion plants are selected not to compete with the crop for water, light and nutrients, as well as for providing suitable nectar, this can be highly effective. The **best option**, of course, is to provide the necessary food directly on the crop plant itself. Evolution has actually come up with this best solution. Extrafloral nectaries are also found on the leaves and stems of a number of crop plants, including broad beans, zucchini, cherries, plums and cotton (ELN-FAB, 2012).

Note: In agriculture, pest species find themselves in a land of plenty where there is an overabundance of food plants and enemies are few. In natural ecosystems, on the other hand, plant-feeding insects (known as pest species in agricultural crops) usually do little damage. This is to a large extent due to the fact that natural habitats tend to be teeming with insect predators and parasitoids that attack plant feeders, keep their numbers in check and thereby protect plants from serious damage.

3. Pollination: Pollination is a critical ecosystem service supporting 75% of the 115 major crop species grown globally. Pollinators also play a critical role in maintaining plant genetic diversity, which is essential for the long-term survival and adaptation of crops. Genetic diversity can increase pollinators by ensuring the availability of nectar resources over a prolonged time period. Of practical importance to farmers and farming communities are the pollination services provided by native and imported pollinators to the 75% of crops (majorly fruits and vegetables) requiring pollination to produce yield.

Diverse landscapes provide bees with better hibernating, nesting and foraging opportunities than intensively managed homogeneous fields. The results of several studies have shown that greater abundance and species diversity of bumblebees are found in smaller fields with higher crop diversity and heterogeneous landscape.

Ensuring food for pollinators: The size of the field has an important influence on the number of bumble bees present, since many bumblebees have a limited foraging range, which for some species is restricted to only 450 m. This might be one explanation for why many bumblebee species with shorter flight distances have disappeared from intensively farmed open areas.

Native and managed bees cannot survive if food is not available throughout the foraging season. Therefore, flower-rich field margins of different native wild flowering plants should be created. . For example, long-tongued bumblebee species have suffered the strongest declines. This is at least partly connected to the shift in agricultural plants grown on farms. Traditionally hayfields consisted of different wild plants, including a lot of flowering plants, but nowadays in cultural hayfields with intensive management carefully chosen graminaceous species are grown. Also, the traditional hay contained very many leguminous plants, which constitute the major part of pollen collected by long-tongued bumblebees.

Ensure nesting and niche areas: The small areas suitable for different kinds of wild pollinators work as real conservation areas only if they are in close proximity to each other or to lower quality but still suitable areas. Small populations can be maintained only if there is sufficient migration between neighbouring areas.

Importance of organic farming: Wild pollinators benefit from organic farming as well as maintenance of grassy field margins and various larger patches of natural (forests, wetlands) or semi-natural (fallows, grasslands, parks, trees, hedgerows) habitats. The positive effect of organic farming is explained by the smaller field size and more fragmented configuration of agricultural landscape compared with conventional farms, and the restricted use of pesticides, greater number of weeds that provide food for both pollinators and rodents, whose nests may be used by ground-nesting bumblebee species (ELN-FAB, 2012).

Box 6: Bee Gardens

Pollinators need food supplies throughout the vegetative season. This is usually much longer than the flowering of food crops. Human settlements, for instance, are often surrounded by flower beds, where the plant species are selected according to their varying flowering times. The flowers in pleasure grounds start flowering early in the season, and the various species continue flowering until late autumn. Therefore, rural and suburban gardens can provide unique food sources for bees. Large, colourful flowers and an attractive smell usually signal nectar sources, and pollinators use these signals to find flowers from a distance and learn to look for similar sources. Bee gardens should contain plants with flowers that are good nectar and pollen producers. Another point to remember is that bees prefer more abundant flowers. Bees learn profitable flower types and then use that knowledge to save time and energy when foraging. Therefore, they often avoid single-standing flowers, because too much energy is wasted learning how to obtain the nectar. Perennial plant species also enhance pollinator fauna near human settlements. The undisturbed soil beneath perennial plants contains cavities which ground-nesting bees use as nesting sites. The distances between nesting and foraging sites, as well as between individual foraging sites, are important to bees. The foraging range of the honeybee can be 1 to 5 km, depending on food resources present. Bumblebees forage up to 1.5 km from the nest and solitary bees often forage within a range of few hundred metres. Therefore, the landscape may play an important role for bees in using bee gardens as an extra foraging and nesting source.

4. Soil Quality and Structure: Soil quality recognizes that soil is a living surface rather than an inanimate surface. A healthy soil is formed by the balance between its physical properties, its biology and its chemical state. Soil provides functions such as litter decomposition and carbon cycling, nutrient cycling, soil structure formation and maintenance, and biological population regulation (pest suppression by predatory species). Soil biodiversity regulates biological processes that underpin long-term agriculture sustainability and crop health. Soil biodiversity includes complex relationships among diverse taxa from millipedes (nutrient cycling) and centipedes (pest predation), earthworms (soil structure, water infiltration), and springtails (organic matter decomposition), to spiders (predation) and millions of microbes in the soil. What makes the relations even more complex is that many organisms contribute to more than one soil process or function at a time. Soil organisms such as earthworms and potworms, for instance, feed on organic matter and mix it with mineral soil. By doing so, they not only affect carbon and nutrient mineralization but also create and modify soil structures (thus contributing to water infiltration and soil aeration).

The expansion, intensification and mechanization of agriculture have been identified as major causes of soil biodiversity decline and soil degradation. Other, related, threats to biodiversity and to agriculture include soil erosion, soil compaction, soil contamination, soil sealing, salinization and climate change. Tillage is generally negative for soil biodiversity, although it depends on soil texture and depth. Generally speaking, stimulating biodiversity-based soil functions requires management practices that improve the habitat quality for beneficial organisms. This is often done by applying the following five management principles:

- Manipulating the quality and amounts of organic matter inputs in the soil.
- Reducing mechanical soil disturbance, especially ploughing (soil inversion) and compaction by heavy machines.
- Keeping a continuous green soil cover through the use of cover crops.
- Crop diversification (crop rotation, intercropping).
- Reducing harmful synthetic inputs such as pesticides and avoiding biocides.

5. Run-off Reduction: Leaving strips of land around arable fields vegetated captures excess nutrients and pesticides and prevents them from running off into ditches and rivers Resilient agricultural landscapes

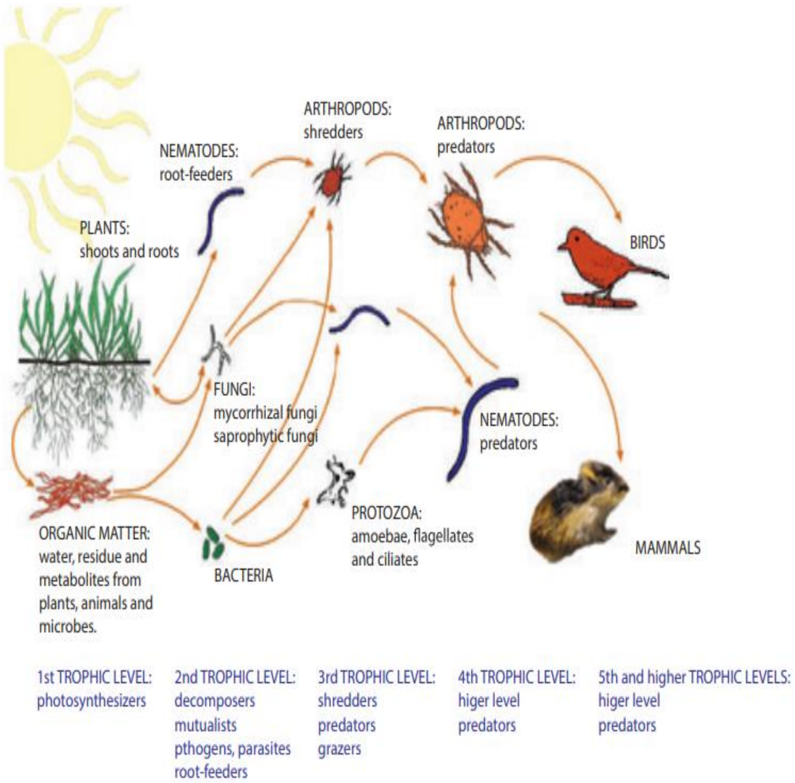


Figure 9.4 Soil food web (adapted from ELN-FAB, 2012)

Box 7: Ecosystem Engineers

Organisms impact the environment in which they live in several ways. Organisms that create, modify, destroy or maintain a habitat in which they live or frequent are known as ecosystem engineers. Ecosystem Engineers maintain the health and stability of the environment they live in. By conserving ecosystem engineers, protection is extended to the overall diversity of a landscape. The biodiversity of an area can also be affected by the ecosystem engineer's ability to increase the complexity of the ecosystem processes which allow for further species greatness.

Figure 9.5 Earthworm casts: digested material that earthworms excrete (photo credits: Ross Gray)

A study conducted by a group of scientists in Mexico to find the contribution of home gardens for biodiversity. Soil invertebrates were studied for their various functions, like allowing the soil to absorb processed organic matter such as leaves, wood, trunks and branches and with this nourishing crops; maintaining an ecological balance capable of preventing the invasion of pests and provide greater fertility without using chemicals. This happens when growing different types of plants, allowing the existence of a wide variety of soil invertebrates. It is important to note that the presence of such organisms does not mean that the garden is infested with pests. According to the researcher, "If you let them live there, they fulfill their tasks and at the same time control their population because the variety of invertebrates generates food chains."

The pest problem, she says, appears when the land is handled as a monoculture. In these cases only one type of organisms thrives and rapidly increases in number and, because nobody eats them, they become a threat to the plantations. (Desarrollo, 2014).

Table 2. Benefits from on-farm conservation (source: Jarvis *et al.*, 2000)

	Economic and sociocultural benefits	**Ecological benefits**	**Genetic benefits**
Farmer household	Manage risk and uncertainty Fit different budget constraints Avoid or minimize labour bottlenecks Fulfil rituals or forge social ties	Minimize use of chemical inputs Soil structure amelioration Manage pests and diseases	Insurance against environmental and socioeconomic change

	Fill nutritional needs		
Society	Global food security Empowerment of local communities Social sustainability	Reduction of chemical pollution Restriction of plant diseases Regulation of hydrological flows	Insurance against environmental change, pests and diseases Use for the agricultural industry

10. Biodiversity Based Solutions

Methods to diversify in space are to grow more species on a farm, to reduce field sizes and to add flowering field margins or hedgerows, to intercrop different species or to grow mixtures of varieties possessing different resistances.

Soil and Water Conservation Practices

Storing water in soil decreases the negative impacts of droughts. Several grey measures are available, and include measures based on the use of technology in agriculture, e.g. no-tillage, or cropping systems implemented to reduce water runoff. Conservation tillage, as explained above, reduces evaporation from the soil surface, preserving soil organic matter in the upper soil layers and, consequently, increasing water retention capacity of the soil. Terracing and contour ploughing terrace is another method of soil conservation to slow or prevent the rapid surface runoff. Contour ploughing is the farming practice of ploughing across a slope following its contours, which have the effect of slowing water run-off during rainstorms so that the soil is not washed away and allows the water to percolate into the soil. The rows made by the plough run perpendicular rather than parallel to slopes, generally resulting in furrows that curve around the land. Efficient use of irrigation systems also helps to store the water. In Sikkim, the springs and streams are conserved as the center of sacred sites where the protective deity dwells, with traditional and customary rituals performed on auspicious days by different indigenous communities. They are managed to ensure water retention and protection within farm-based agroforestry for potable water and water for irrigation in villages. Another traditional practice involve plantation of water retaining species in and around the springs developing the catchment (Sharma *et al.*, 2016)

Mulches and their advantages

Mulch is a layer of organic material, such as hay, cut grass or bagasse which is placed on the surface of the soil in order to conserve moisture in the soil, to hold down weeds, and eventually to improve the soil structure and fertility. Living mulches are cover crops planted either before or with a main crop and maintained as a living ground cover throughout the growing season. If the living mulch is a perennial, it may be possible to maintain it from year to year without the need for reseeding. This living mulches is especially important for mountainous regions. The presence of winter annual or living mulches will help control escape weeds and may prevent or slow down the invasion of new weeds that might otherwise become a problem in no-till corn (Hartwig and Ammon, 2002). Mulching can save the farmer time and labour. A mulched garden will have very few weeds, especially if the mulch is applied before the weeds get a start. The mulch also keeps the soil loose, and thus reduces the need for cultivation.

Crops such as tomatoes, melons and cucumbers are especially benefited by mulch. The mulch stops soil from coming in contact with the fruit and leaves, thus reducing fruit rot and fungus disease. Soil that is mulched will not allow mud to splash leaves of crop plants which are susceptible to leaf fungus diseases.

Reduced field sizes and interrupting with different species and hedgerows generally reduce disease pressure, as the amount of spores produced in smaller fields is reduced and spores are lost while travelling to the next susceptible field. Hedgerows may function as windbreaks, but increased shade in the mornings may mean that leaves stay wetter for longer, thus helping some pathogens to develop. Therefore, it makes sense to manage the hedges for height and to keep a certain distance to the fields.

Undersowings of low-growing legumes such as white or subterranean clover can be of direct benefit to a cereal by providing biologically fixed nitrogen and by suppressing weeds. Many foot and foliar diseases are dispersed by water splashing. The foliage of intercrops and undersowings reduces rain splash and has been shown to reduce dispersal from plant to plant and upwards within the canopy through barrier effects

Variety mixtures of cereals have been extremely successful in controlling rust and powdery mildew. Cereal variety mixtures and sometimes also species mixtures are officially recommended in Denmark, the UK, Switzerland, and several states of the USA and they are very popular in Poland.

Natural Habitat Patches and Networks: There is a growing trend in agriculture toward landscape simplification, where regions that once included diverse systems like forests, fencerows, woodlots, streams, pastures, and wetlands shift toward the more profitable (at least in the short term) monoculture crop production systems. It can include implementation of hedgerows, riparian buffer zones, and other types of corridors both on-farm and across the broader landscape. Preserving natural areas is a way to combat the threat of landscape homogenization. Studies have shown that preserving natural habitats can benefit a variety of taxa including birds, bats, mammals, insects, and plants. For example, preservation and restoration of natural habitats provides an opportunity for decomposition to occur naturally which enriches the organic matter present in soil. This in turn provides a more hospitable environment for soil microbes.

11. Mainstreaming

Knowledge of the value of using agricultural biodiversity is a useful first step towards food system sustainability, but to have impact, practices need to be ‘mainstreamed’ into other sectors.

As per Convention of Biological Diversity, mainstreaming biodiversity is defined as: “the integration of the conservation and sustainable use of biodiversity in cross-sectoral plans such as poverty reduction, sustainable development, climate change adaptation/mitigation, trade and international cooperation, as well as in sector-specific plans such as agriculture, fisheries, forestry, mining, energy, tourism, transport and others.”

In practice, mainstreaming means that specific components of biodiversity (e.g. genetic, varietal, species, and landscape) are integrated into other sectors for the generation of mutual benefits. Examples are: linking tourism to biodiversity for conservation and economic returns; or using diversity in agriculture to increase productivity and resilience while at the same time conserving biodiversity. Integration may be into the plans, policies and practices of natural resource sectors, such as agriculture or forestry, or other economic and social sectors, such as poverty alleviation or climate adaptation. Developing the policy approach and identifying plans and priorities for agricultural biodiversity may involve the following range of stakeholders:

- Ministry of Environment,
- Ministry of Agriculture,
- Public and Private Agricultural Research Bodies,
- Agricultural Extension Agencies,
- Agricultural Colleges or Training Establishments,
- The National Focal Point(s) for FAO-related matters, including for the International Treaty on Plant Genetic Resources for Food and Agriculture,
- Agro-Biotechnology Industry Associations,
- University or other research bodies,
- Associations of peasants or small farmers,
- Agribusiness Associations,
- Indigenous and local community associations,
- Agricultural Economists,
- Germplasm and Seed Bank Managers,
- Specialist non-governmental organizations,
- Associations of bee-keepers or other sectors relating to pollinators,
- Plant and Animal breeding bodies,
- CBD national focal point for ABS (access to genetic resources and benefit sharing) matters.

These are only the 'direct' agricultural stakeholders. However, given that the agricultural sector in most states plays an important role in food security, foreign trade and export earnings, and is often supported by policies for agricultural credit, land reform, education and vocational training, and science and technology, relevant stakeholders in this case should be taken to include, not just those directly involved in agricultural biodiversity issues, but the full range of organizations whose mandates relate to the issue.

These could include ministries and government agencies relating to health, trade and commerce, planning and finance, education and training, science and technology and others. It also includes those civil society sectors that work on these issues, for example, rural credit unions, organizations working on health and nutrition issues, economists and analysts with expertise in identifying new markets for traditional products of agricultural biodiversity, and others.

Challenges

First, using agricultural biodiversity is not a 'one size fits all' solution. On the contrary, it is complex. It is about the diversity of varieties, species and systems, and how to manage such a range of options for multiple objectives – income generation, nutrition, sustainable natural resources and risk mitigation. Mainstreaming agricultural biodiversity therefore requires a systems approach, which recognizes the connectivity among elements, multiple viewpoints and the multi-functionality of food systems.

Second, there is a clear tension between specialization for increasing productivity, cost-efficiency and reaching economies of scale, and diversification for risk mitigation and stability. Specialization, with intensified production geared towards local, national or international markets, can foster transitions out of poverty and boost local economic development. But important trade-offs may exist in terms of livelihood security, gender equity and landscape resilience.

Third, mainstreaming diversity across the food system requires new ways of cross-sectoral working. While an increasing number of government and private sector departments are embracing multidisciplinary approaches (e.g. Mexico, the successful coordination and implementation of such efforts remains a challenge.

Box 8: Example of Successful Mainstreaming

Mainstreaming agricultural biodiversity into nutrition programmes: Brazil has made progress in promoting agricultural biodiversity for improved nutrition by taking advantage of the horizontal and cross-sectoral governance mechanisms already in place under the Zero Hunger Strategy umbrella and strategically targeting relevant public policies and instruments that can facilitate agricultural biodiversity mainstreaming. Public policies – such as the National School Meals Programme and the Promotion of Socio-biodiversity Product Chains among several others – provide entry points for potentially improving nutrition or livelihoods with links to native agricultural biodiversity. Results include new dietary guidelines that take into account healthy diets derived from socially and environmentally sustainable food systems. The guidelines support multiple small retail channels, including those using organic and agro-ecological methods, and family farming.

Box 9: Bumble-bee and Cardamom Pollination

Sikkim, as a hotspot for natural biodiversity harbouring more than 4500 flowering plants depend highly on pollinators, Cardamom being an important cash crop depending highly on bee based pollination. Only two flower visitor species, a bumble-bee and a honey bee species are the pollinators for large cardamom plantation crop. The bumble-bee is the effective and only major pollinator here due to certain adaptation for length of the nectar tube narrow passage in the fresh flower. The honeybee, with its short proboscis, buzzes in and out of same flower several times, trying in vain to reach the nectar, depletes the flower of its pollen in the process. Meanwhile, the bigger bumblebee, with its longer proboscis, penetrates the flower, sucks out the nectar and flits on to the next bloom, transferring pollen effectively. It shows the importance of native species with functional adaptations in local ecosystem.

Pollination efficiency of the cardamom plantations is decreasing in Sikkim, as about 70% of the flowers remained un-pollinated as claimed in a scientific study. Therefore, such pollinating agents have the potential to directly contribute to the agricultural sustainability of Sikkim, thus supporting agro-biodiversity. Farmers can help by planting fallow fields and agricultural field edges with flowering plants to support wild pollinators throughout the growing season, and by reducing pesticide use, especially during crop bloom when more bees are in their fields.

With this as a backdrop, IIPA has developed a short video emphasizing upon importance of agrobiodiversity. It will be helpful to communicate this message to general masses and farming community.

(Adapted from Pollination biology of large cardamom (Amomum subulatum) Palatty Allesh Sinu and K. R. Shivanna, Current Science, VOL. 93, NO. 4, 25 August 2007.)

Presentation for Training

Training Module I: Agriculture and Biodiversity

What is agrobiodiversity?

CBD defines agrobiodiversity as a "broad term that includes all components of biological diversity of relevance to food and agriculture, and all components of biological diversity that constitute the agricultural ecosystems, also named agroecosystems: the variety and variability of animals, plants and micro-organisms, at the genetic, species and ecosystem levels, which are necessary to sustain key functions of the agroecosystems, its structure and processes"(CBD,2014).

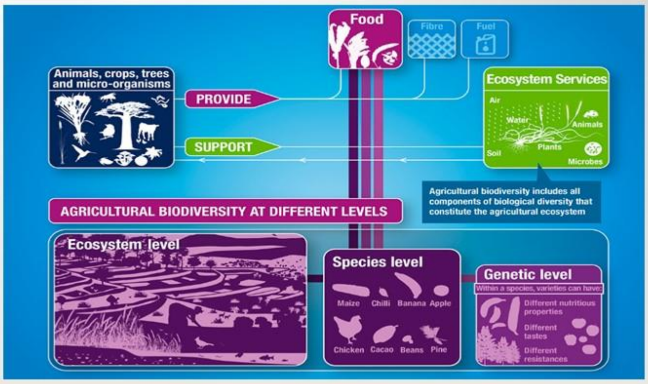
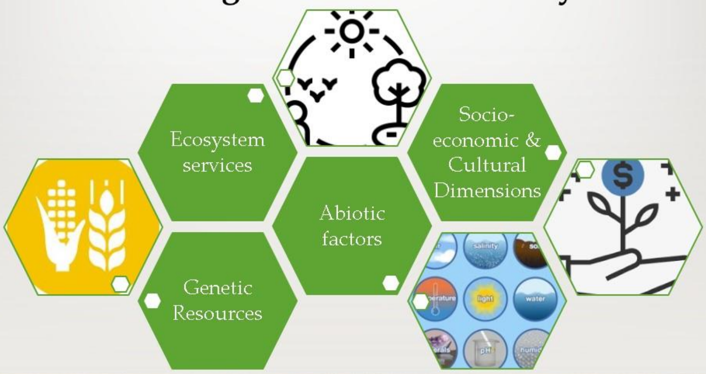


Figure: Agriculture Biodiversity (adapted from: Biodiversity International)

Dimensions of Agricultural Biodiversity



On-field biodiversity and ecosystem services

- Supporting Services
- Provisioning Services
- Regulating Services
- Cultural Services

MONOCULTURE

ADVANTAGES

- One species of genetically uniform plants present on the field at one time
- Specialized production thus optimizing operations
- Promotion of technological advances in agriculture
- Increased efficiency in tasks & processes
- Simpler to manage and increased profitability

DISADVANTAGES

- Biodiversity struggles to exist
- Promote high use of fertilizer and worsening of pest problems
- Degradation of soil
- Pollute the environment & contribute to Climate Change
- Water intensive
- Encourages overproduction of commodity goods
- Harm bees and other natural pollinators
- Increase risk of harvest loss
- Depend on fossil fuel & not Climate Smart

Agricultural Systems promoting biodiversity

- Crop-based systems: Rotation
- Multicropping
- Conservation Tillage
- Agroforestry
- Planting more cover crops
- Planting buffer strips
- Well functioning seed syste,

Each system need to explained with examples

Advantages of agrobiodiversity

Increasing biodiversity, greater biomass and healthier soils	Increase income to famers
Increase in over all production without using artificial fertilizer and pesticides	Reduced risk of crop loss to any particular stress
Control runoff and soil erosion	Facilitate in availability of pollinators

Case study 1: Advantages of diversity in pollinators for ecosystem services in cardamom plantations of Sikkim

(source: Sinu and Shivanna, 2007)

- This case study of a farm, having scattered shade trees along with some patches of native bamboo thickets.
- A bumble-bee and a honey bee species are the pollinators for large cardamom plantation crop
- The bumble-bee is the effective and only pollinator here due to certain adaptation
- But due to lower population density of bumble-bee, pollination efficiency of the cardamom plantation in Sikkim is decreasing
- Farmers can help by planting fallow field and agriculture field edges with flowering plants to support wild pollinators throughout the growing season, and by reducing pesticide use

More such case studies can be picked up from modules depending upon the level of participation

Stimulating biodiversity-based soil functions

- Manipulating the quality and amounts of organic matter inputs in the soil.
- Reducing mechanical soil disturbance, especially ploughing (soil inversion) and compaction by heavy machines.
- Keeping a continuous green soil cover through the use of cover crops.
- Crop diversification (crop rotation, intercropping).
- Reducing harmful synthetic inputs such as pesticides and avoiding biocides.

Mainstreaming agricultural biodiversity

- For system's sustainability agrobiodiversity practices needs to be mainstreamed in other sectors
- Integration may be into the plans, policies and practices of natural resource sectors, such as agriculture or forestry, or other economic and social sectors, such as poverty alleviation or climate adaptation.
- Developing the policy approach and identifying plans and priorities for agricultural biodiversity involving key stakeholders

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