TRAINING MANUAL

- ENVIRONMENTAL MANAGEMENT -

SUSTAINABLE MANAGEMENT OF BIODIVERSITY

COLEACP

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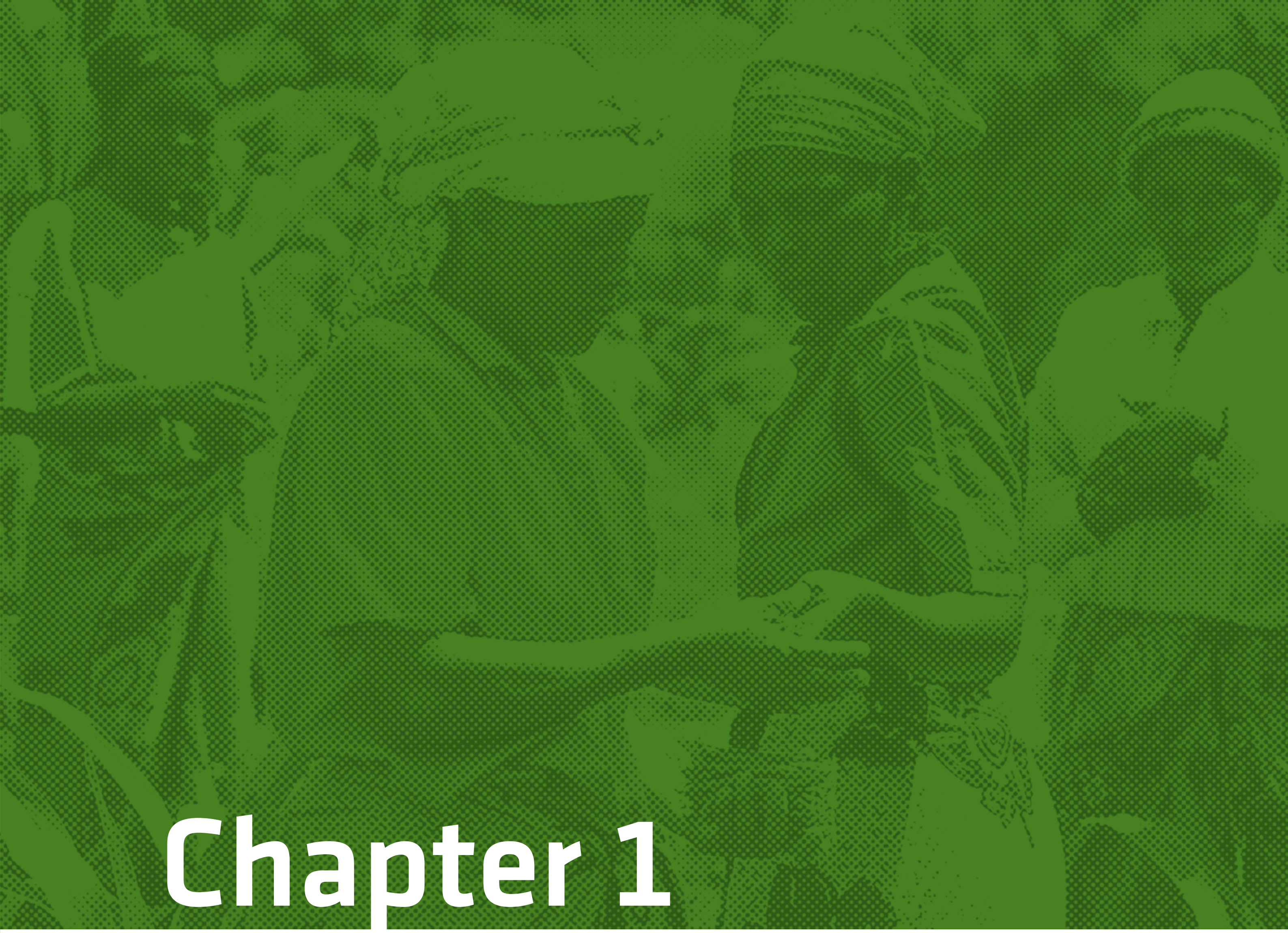
SUSTAINABLE MANAGEMENT OF BIODIVERSITY



Chapter 1

Biodiversity: Definition and importance

1.1. BIODIVERSITY: DEFINITION AND IMPORTANCE

1.1.1. What is biodiversity?

Etymologically-speaking, the word "biodiversity" consists of the prefix "Bio", which means "life" and the suffix "diversity", which means "variety". Biodiversity, or biological diversity, is therefore the incredible diversity of living beings in nature and the way they interact with each other (Ainsworth *et al.*, 2013). In other terms, biodiversity is the variability among living organisms and the ecological structures they are a part of, including diversity within species (genetic diversity), between species (species diversity) and in ecosystems (ecosystem diversity).

Box 1: Definition and origin of the word biodiversity

Thomas E. Lovejoy, an Amazon specialist, appears to have been the first person to use the term "biological diversity" in 1980. This became "biodiversity", a shorthand term (biological diversity = biodiversity) coined by Walter G. Rosen in 1985.

More recently (2000), Edward O. Wilson proposed the following definition: "Biodiversity is the diversity of all forms of life. For a scientist, it is the variety of life studied at three different levels: ecosystems, the species living in the ecosystems and the genes specific to each species". Biodiversity is defined at three levels: that of species, ecosystems and genes.

Source: (IBIS 2009)

The Rio de Janeiro conference of June 1992 was entirely dedicated to the new concept of: Biodiversity. The resulting "Convention on Biological Diversity" was signed by more than 150 countries. Article 2 of the convention defines biodiversity as: "The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and ofecosystems (Convention on Biological Diversity, 1992 page 3).

This definition is recognised in international law. It encompasses different areas, depending on the author, including:

- the diversity of genes (or genetic)
- the diversity of species (or species)
- the diversity of ecosystems (or ecosystem).

In other words, biodiversity refers not only to diversity among animals, plants, and fungi (diversity of species). It also encompasses the diversity among races and varieties within a same species (diversity of genes), and the diversity among natural habitats (diversity of ecosystems). Living beings don't exist alone. Together, they form ecosystems in which they mutually impact each and are interdependent on each other. Man is also part of this biodiversity and depends on the diversity of life (Pro Natura 2010).

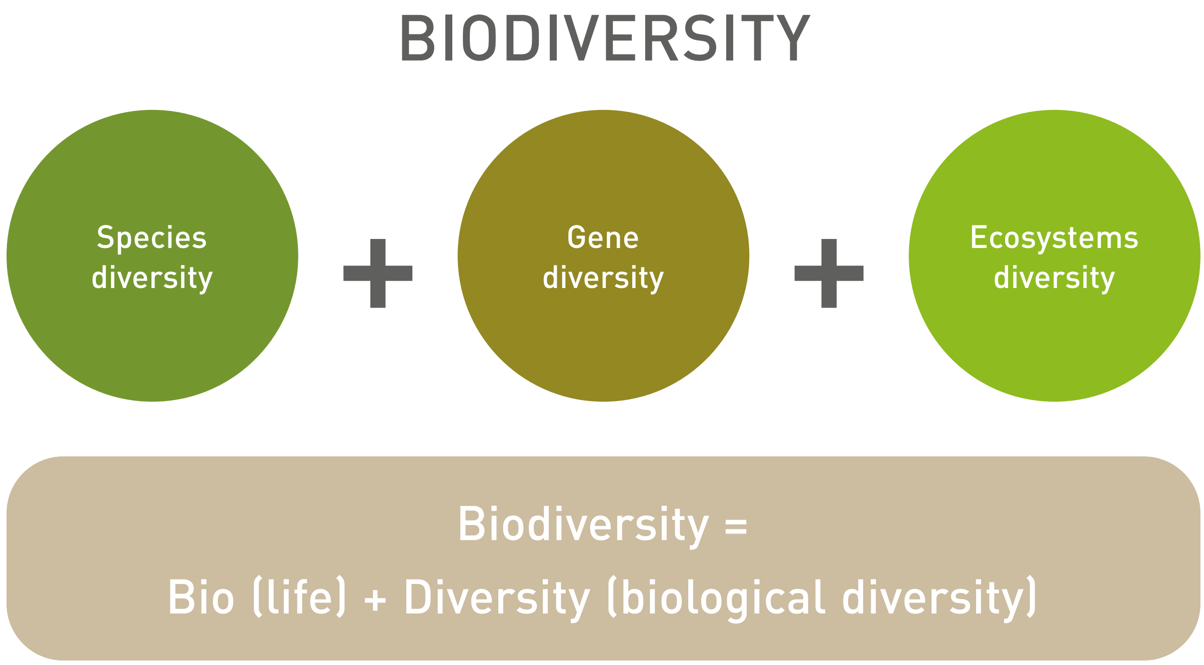


Figure 1: The components of biodiversity
Source: Author summary and (Tech&Bio, 2015)

1.1.2. Some arguments in favour of biodiversity

The progress of industrialisation in the 19th century, significant demographic growth and the resulting mass consumption had and continue to have, a dizzying impact on biodiversity around the world. The loss of biodiversity suffered by the populations of wild species is increasingly is a growing concern since it has risen 58% on average since 1970 and is expected to reach 67% by the end of the decade (Living Planet Report, 2016). Around the world, 25% of known mammals, 11% of birds and 17% of plants are threatened with extinction (IBIS, 2009:6). In October 2012, Neville Ash, the director of the UNEP biodiversity branch stated that: "Biodiversity has never been in such a poor state and it continues to get worse".

Governments and national and international non-governmental organisations have become aware of the situation and have initiated several projects and programmes to promote biodiversity. Several arguments have been developed since the 1992 Rio conference in favour of biological diversity. Many reasons justify the soundness of conserving biodiversity. The reasons are essentially based on the importance of biodiversity for the sustainability of life on Earth in general and human life in particular.

Biodiversity is the basis of all life. It provides protection, food and support to all living beings, including human beings. Pro Natura 2010 has developed **nine arguments** demonstrating the usefulness of species diversity for human beings.

I. Biodiversity contributes to the well-being of human beings
II. Biodiversity protects human health
III. Biodiversity promotes technical innovation
IV. Biodiversity provides food for human beings
V. Biodiversity uses natural resources more efficiently
VI. Biodiversity protects against erosion
VII. Biodiversity ensures the future of forests
VIII. Biodiversity is a form of insurance
IX. Biodiversity has enormous financial value

Given that the human race has the ability to impact nature, it has a special responsibility to biodiversity. Humanity's duty to preserve and restore biodiversity is based on ethical, physiological and economic considerations.

From an **ethical** standpoint, preserving and restoring biodiversity is a moral duty. Every living being has a fundamental right to life. Knowing that current biodiversity took billions of years to come about, Humans must avoid destroying it through their anthropic activities. In doing so, they show that they are respectful of the vital foundation of all living beings while working for their own development. The Brundtland report promotes this type of development: sustainable development which meets the needs of the present without compromising the ability of future generations to meet theirs.

From a **physiological**[1] standpoint, biodiversity is an essential resource. It is, moreover, the most important one because it is the basis of our existence. It reflects the interdependence of the living beings of the animal and plant worlds within the planet's life cycle. It has an impact on soil fertility and the plants we need for our survival (flower pollination, natural weed and parasite control), on the climate, on hydrology and water quality, which is vital to us. In addition, animal and plant substances are the base of many medicines.

From an **economic** standpoint, biodiversity it is immensely valuable. The economy, and in particular tourism and agriculture, depend on nature's diversity. For example, it is estimated that the Okavango Delta in southern Africa generates $32 million a year in profits for the local population of Botswana thanks to the use of the delta's natural resources and to the commerce and the income generated by the tourist industry. The total economic production of activities linked to the delta is estimated at over $145 million, i.e. approximately 2.6% of Botswana's gross national product. Genetic diversity makes it possible to raise livestock and cultivate crops that are adapted to their growing environment and provide good yields.

1 Which involves the internal and external functioning of a living organism

The last of Pro Natura 2010's nine points raises an issue which is extensively covered in the literature: ecosystem services. Ecosystem services are the benefits people obtain from the ecosystem (MEA, 2005). The authors have created a classification with four large groups:

I. Provisioning services: these are the products from the ecosystems;
II. Regulating services: these are the benefits resulting from the regulation of ecosystem processes;
III. Cultural services: these are the non-material benefits that people receive from ecosystems;
IV. Supporting services: these are the services required to produce all of the other ecosystem services.

The last category differs from the other three because its effects on people are either indirect or appear over longer periods of time. Some services, such as erosion control can be classified either as "supporting" or "regulating" services depending on the time scale of the effects of changes on human beings.

Figure 2: Ecosystem services
Source: CGIAR

The figure below summarises the close relationship between ecosystem services and human well-being. Biodiversity supports the provision of services provided by the ecosystems which maintain the conditions required for life on Earth. A loss of diversity leads to changes in the efficient and effective supply of support services. The changes have repercussions on other service categories (provisioning, regulating and cultural). When the latter are negatively impacted, they have a harmful socioeconomic impact on the well-being of people.

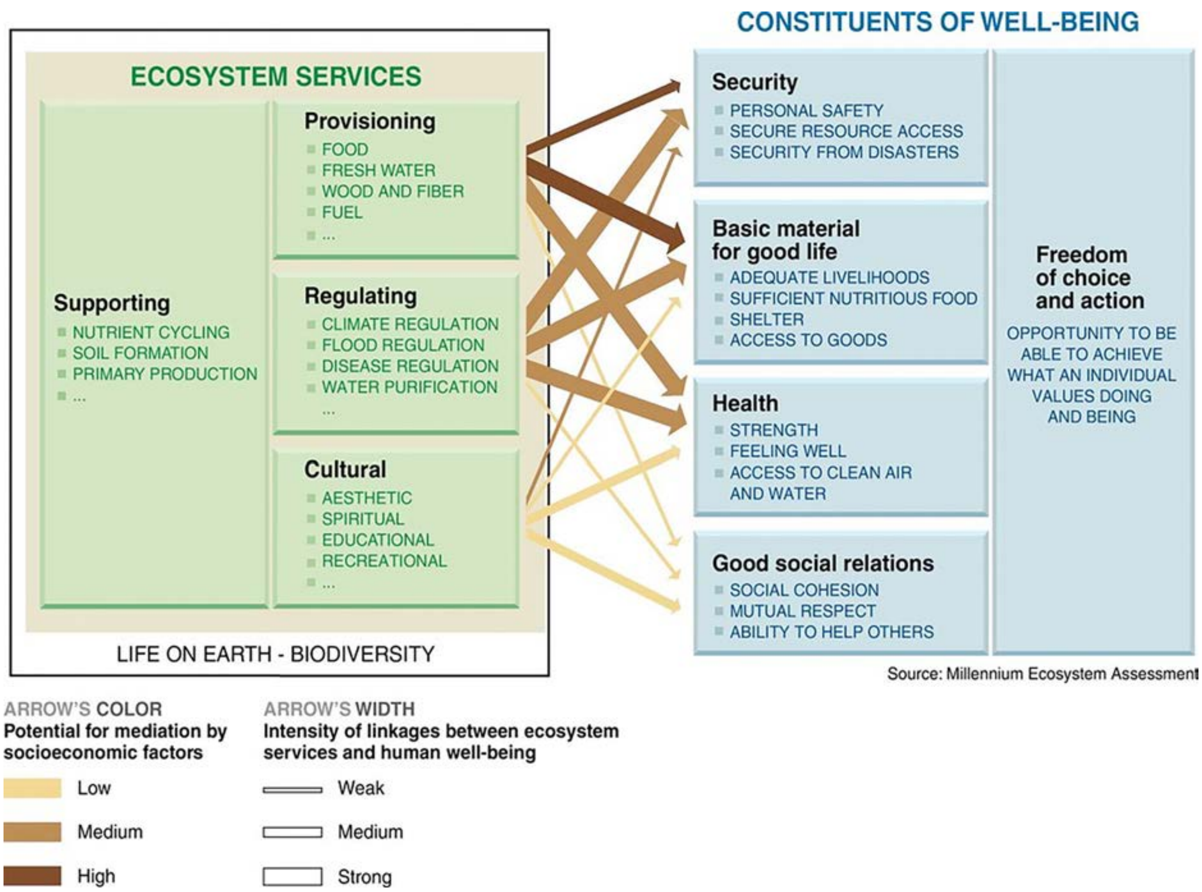


Figure 3: Relationship between ecosystem services and human well-being.
Source: GRID-ARENDAL

1.2. LEGISLATION AND PRIVATE STANDARDS

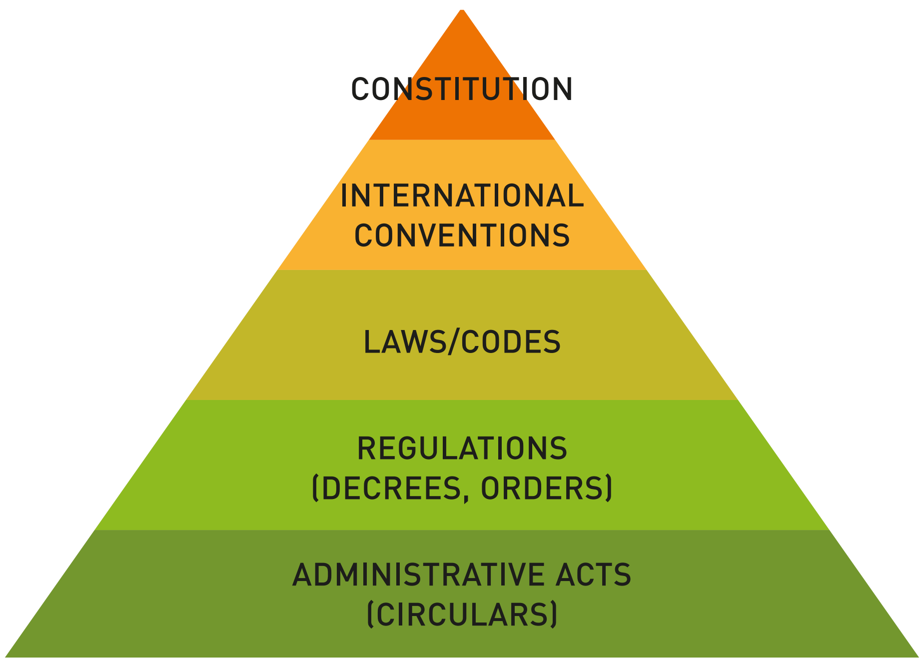


Diagram illustrating the hierarchy of laws and regulations governing the protection of wild animals and natural habitats

1.2.1. Overview

ACP countries have a legal and regulatory framework governing the protection of wildlife and natural habitats. Most of these countries have signed and ratified international conventions on the protection of the environment and, in particular, the **Convention on Biological Diversity**. However, implementation of the laws and regulations to ensure that the protection of wildlife and natural habitats is effective and sustainable runs into a range of obstacles. The legal and regulatory framework is primarily defined by the constitution, international conventions, laws and codes and regulatory and administrative acts.

The membership of ACP countries in the various conventions on the protection of wildlife and natural habitats have resulted in the countries passing laws and regulations which create a legal and regulatory framework which can facilitate the implementation of the conventions. The conventions are:

- The Convention on Biological Diversity (Rio Convention).
- The Convention concerning the Protection of the World Cultural and Natural Heritage (UNESCO).
- The Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention).
- The Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention).
- The Convention on International Trade in Endangered Species of Wild Fauna and Flora (Washington Convention).
- The African Convention on the Conservation of Nature and Natural Resources (Algiers Convention).
- Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern African Region.

Laws, orders, decrees and by-laws are in place to ensure the practical implementation of each of the above-mentioned conventions. The following table provides a few examples in Madagascar. In addition to the laws and regulations, several ACP countries have also implemented strategies for the protection and restoration of biodiversity. This is the case for Burkina Faso, which implemented the "***Strategies de conservation de la biodiversité au Burkina Faso***"[2] (Strategies for the conservation of biodiversity in Burkina Faso) which provide guidelines for all biodiversity protection and restoration projects and activities.

2 https://www.uni-frankfurt.de/47621090/BF_09.pdf

Examples of biodiversity laws and regulations in Madagascar

Conventions	Laws	Regulations[3]
Convention of Biological Diversity (CBD)	law 1995-013	decree 1995-695
Ramsar Convention	law 1998-003	decree 1998-261
Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).	order 1975-014	decree 2005-848
Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern African Region.	law 1998-004	decree 1998-260
Algiers Convention	law 1970-004	

Note that the protection of wildlife and natural habitats existed before the introduction of modern legislation. There were very effective methods and rites in place to protect the environment in traditional societies.

In northwest Benin (Copargo Municipality, Anandana Arrondissement), some trees were never cut because the local population believed that they brought rain. In ancient Rwanda, belonging to one of 18 clans had significant implications for the protection of the environment. Each clan had an animal species to protect. This is still the case in several African communities today and some Africans continue to behave this way[4].

In Zinvié (Abomey-Calavi Municipality) in Benin, a local NGO successfully protected biodiversity by integrating traditional beliefs and rituals, such as ceremonies involving fetishes installed around plant formations, into its work approach in order to protect both animal and plant species. This type of approach is often more successful than a purely legislative approach.

1.2.2. Conventions on animal resources and fauna

The conventions listed above apply both to animal species and their habitats. A list of protected animal species was created within the framework of the Convention on Biological Diversity and is constantly being updated. Each country, and in this case each ACP country, which has signed and ratified the Convention on Biological Diversity is required to implement laws and regulations to protect animals and their habitats. Most of the laws appear to involve animal species which are found in natural reserves or natural parks and they rarely apply to farmed or inhabited areas. The animals in the natural reserves and national parks, which cross the boundaries of these

3 In addition to the decrees for the implementation of international conventions, there are also others which contribute significantly to protecting and restoring biodiversity. These are decrees on the creation and management of protected areas (e.g.: decree 2005-848).

4 When a workshop attendee wanted to kill a spider they found in the classroom, the person sitting beside them, who was from Cameroon, prevented them from killing it because it was their totem. The Cameroonian calmly took the spider to the hotel garden.

areas, often stray into farmed or inhabited areas and are rarely protected despite the legislation. Despite significant demographic pressure on land, ACP countries have implemented laws to stop the expansion of cultivated areas, hunting and poaching, brush fires and pastures to the detriment of the natural habitats of wildlife. This is the case in Rwanda and the DRC which have laws and regulations which limit the Virunga Natural Park. Benin passed law no. 87-014 of 21 September 1987 and order no. 4 of 16 January as well as law no. 2002-016 of 18 October 2004 on wildlife in the Republic of Benin to protect 43 animal species, of which 19 mammals, 9 reptiles and 15 birds (MEPN and UNDP, 2009). There are other laws and regulations in existence (Appendix I). Like Benin, other ACP countries also have similar laws and regulations.

1.2.3. Conventions on plant resources and flora

A series of international conventions on the protection of wildlife was signed and ratified by ACP countries. The conventions apply both to animal species and their habitats. The Convention on Biological Diversity of the 1992 Rio Convention insists on the protection of ecosystems and habitats.

Execution of the Convention on Biological Diversity, particularly with respect to the protection of plant resources, requires that laws and regulations be implemented in each country. For example, Benin passed a framework law on the environment and other laws, notably the land and water codes. With respect to plant species in particular, decree no. 96-271 of 2 July 1996 implementing the forestry scheme, contains a list of about 50 forest species which are protected by Benin legislation. The species are found both in natural areas and in cultivated or fallow areas (African locust bean, shea, etc.). Implementation of other conventions related to the protection of plant resources, ecosystems and habitats in Benin (W Park, Pendjari Park, and the cross-border Mono biosphere reserve in Benin and Togo) and in Rwanda (Akagera Park, Nyungwe Park, and Virunga Park) has restricted the expansion of agricultural land to the detriment of these resources. In Madagascar, several laws and regulations are in place to protect and manage species. Madagascar's wildlife has been subdivided into protected species, harmful species and game (decree 2006-400). In addition, decree 1993-022 forbids the capture and killing of marine mammals including whales and dolphins throughout Madagascar's territory (Rakotoarivelo, R.D., 2011).

1.2.4. Conventions on water resources

The efficient management of water resources makes a substantial contribution to the preservation and restoration of biodiversity. The integrated management of water resources in most ACP countries is supported by a legal framework which enables the implementation of action plans for the integrated management of water resources. In addition to the Convention on Biological Diversity, several other conventions contribute to the efficient management of water resources and contribute to the preservation of biodiversity. This is the case of the United Nations Convention to Combat Desertification. The integrated approach to water resource management based on managing catchment areas involves a number of regional, national and local players. Laws and regulations are indispensable for ensuring the sustainable success of the measures implemented. For example, Benin instituted a water code in 2010 and Rwanda passed law no. 2013-43 of 16 June 2013 on land management. Other laws and regulations exist. Here are a few examples for Benin (Appendix I). Following Benin's example, other ACP countries also have similar laws and regulations.

1.2.5. Conventions on land resources

As is the case for water resources, the efficient management of land resources is a key aspect of the preservation and restoration of biodiversity. Land and water are essential elements for biodiversity. Demographic pressure on land continues to increase and is leading to the deterioration of land. This has a negative impact on biodiversity. There are many international, national and local efforts under way which are specifically intended to preserve and restore soil fertility. It is within this framework that the United Nations Convention to Combat Desertification was adopted by ACP countries. The implementation of the convention requires a suitable legal framework. Land laws are an indispensable condition for securing land and facilitating sustainable land management. The adoption of other international conventions also contributes to the efficient management of land resources. They include the Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention) and the African Convention on the Conservation of Nature and Natural Resources (Algiers Convention). Some examples of the laws and decrees in place in Benin are provided in Appendix I. Similar laws and regulations exist in other ACP countries or can be adopted by them.

1.2.6. Conventions on natural habitats

Natural habitats are generally confused with reserves or natural parks which are strictly protected by law and recognised by governments and international institutions. This is the case of the Virunga Park which is recognised under DRC, Rwanda and Uganda law and for which the European Union, in its resolution 2015/2728(RSP) of 17 September 2015, insists on the importance of it being protected. Most of these habitats have been protected by law since the colonial era (Virunga Park, Nyungwe Forest National Park in Rwanda, etc.). The laws have been amended several times to adapt them to the current socio-economic context. On the other hand, other natural habitats are not governed by any specific laws, for example, setting their boundaries. A master regional land use plan would contribute to limiting the deterioration of natural habitats.

Despite the significant demographic pressure on land, the natural habitats protected by law have been able to resist the expansion of agricultural land, forest operations, hunting and other anthropic activities. They are often caught up in conflicts between customary law and modern law which still co-exist in some countries. For example, areas along the Oueme River in Benin are claimed as collective property by local residents while the land code lists them as belonging to the State. All planning, management and preservation initiatives for these areas must first involve dialogue between the State and residents. The natural wetlands which are not classified as

Ramsar sites are rarely protected by law. As a result, mangrove deforestation is increasing continuously and rapidly. There are a few private areas where initiatives by local authorities, NGOs and private citizens ensure the protection of biodiversity. The law of ACP member countries should be able to apply in these habitats which are, however, very well protected.

1.2.7. The Biodiversity COP

The world Biodiversity Conference known as the Conference of the Parties to the Convention on Biological Diversity (COP) is the managing body of the convention. It ensures that the decisions of previous COPs are implemented. The 196 Parties are the States which have joined the Convention on Biological Diversity. While the Convention on Biological Diversity took effect on 20 December 1993, the first COP took place from 28 November to 9 December 1994 in the Bahamas. The COP has been held every two years since 2000. The topics discussed are varied and change from one COP to the next.

1.2.8. Governance of biodiversity

The governance of biodiversity implies the integration of biodiversity in policies, strategies, action plans, programmes and development projects, both at the national and international levels. It involves players from a range of institutions and organisations. The definition of the remit of the institutions and organisations which are responsible for implementing the biodiversity preservation and restoration measures is often not precise enough with respect to the limits of the competences of each institution or organisation. For example, there are often conflicts of interest between the ministry responsible for agriculture and the ministry responsible for the environment with respect to the sustainable management of land, as each claims priority and competence in this field.

The preservation and restoration of biodiversity are implemented at the local level where concrete actions are actually implemented. The involvement of local players requires a suitable legal framework to prevent conflicts of interest and duplication of effort. In most ACP countries, the laws on decentralisation clearly define the competence of the local authority, among others, in terms of local development and the protection of the environment. For example, in Benin, the environment is a constitutional right which local authorities must protect when implementing at the local level.

Once a legal and regulatory framework is in place and the organisations and institutions for the preservation or restoration of biodiversity are in place, a planning and implementation tool is essential. Often called the "*Schéma Directeur d'Aménagement du Territoire*" (Comprehensive Land Plan) in many countries, this tool is of capital importance for the preservation of biodiversity if it is put to effective use during the planning and execution of programmes, projects and activities. When it does not exist or is not taken into account, the results are harmful and include the deterioration of land and, as a result, the erosion of biodiversity (e.g., the expansion of agricultural land or urbanisation to the detriment of niche ecological areas).

The implementation of laws and regulations and of policies, strategies, action plans, programmes and projects for the preservation of biodiversity is confronted with a number of issues, including:

- influence peddling,
- the exaggerated politicisation of the government,
- inadequate laws,
- illiteracy,
- ignorance of the laws,
- financial considerations to the exclusion of environmental ones,
- insufficient human and financial resources, etc.

In many ACP countries, these constraints result in governance characterised by the absence of competitiveness in **efficiency** (results reflecting the resources involved) and **effectiveness** (results meeting objectives).

1.2.9. Requirements of private standards

The development of agricultural channels which respect the environment and society is growing thanks, in particular, to organic and fair trade certification. However, the certification methods do not fully include the preservation and restoration of biodiversity.

Efforts under way are specifically intended to achieve eco-labelling for the products of agricultural value chains. This consists in encouraging consumers to pay a premium for positive environmental externalities for biodiversity based on private standards (voluntary standards). Private standards enable farmers to include the stakes of biodiversity every day to improve the performance of their operation. Djama (2011) points out that the definition of good practices is increasingly based on partnerships between private players. Although there has been notable progress with respect to the implementation of the different conventions for the preservation of the environment and, specifically, for biodiversity in ACP countries, the implementation of tools such as certification for eco-labelling still requires an appropriate, or even binding, legal framework. The framework should ensure that the externalities of the agricultural production systems on biodiversity are sanctioned (negative externalities) or rewarded (positive externalities).

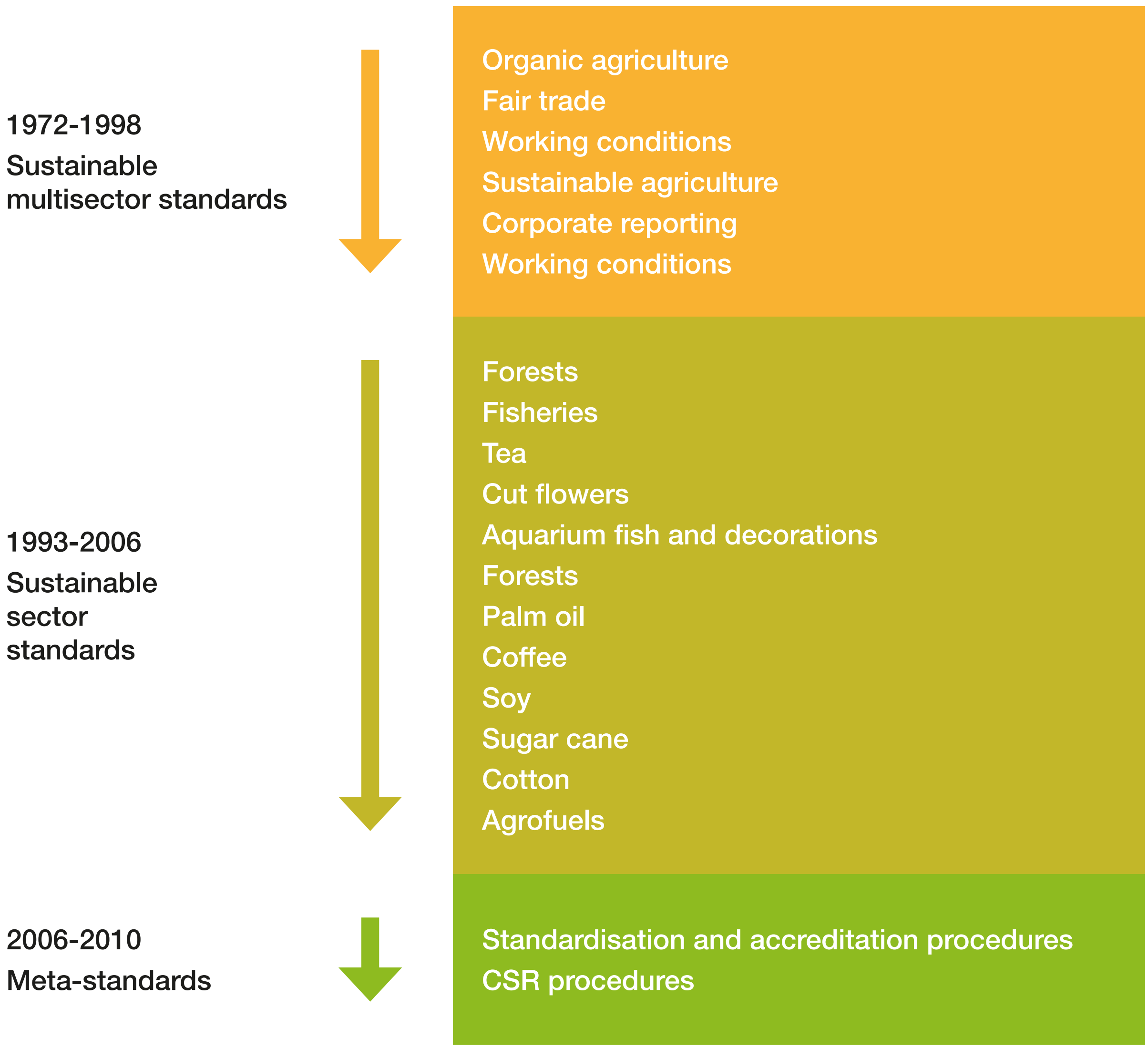


Figure 4: Evolution of voluntary multi-stakeholder private standards
Source: Djama, M. 2011[5]

There are initiatives which work to ensure that biodiversity is taken into account in the brands, labels and certifications of agricultural production and of the agri-foods industry. This is the case of the European Life Biostandards[6] project - Biodiversity in Standards and Labels for the Food Industry (Chapter 2). Fétiveau, J. *et al.* (2014) note that "*Although the inclusion of biodiversity by ecolabels is quite variable and real impact often difficult to establish given that there is no follow up and assessment, certification is an instrument which can be used as effective leverage to implement environmental standards and mechanisms based on eco-conditionality, including in countries which have low standards in terms of governance, as demonstrated by the significant progress made by FSC certification in Central Africa. Certification is a "private" instrument by definition. It can (i) contribute to changing public standards, (ii) complete them, (iii) be promoted by public policy (preferential public procurement*

5 Djama, M. (2011). Articuler normes volontaires privées et réglementations publiques; CIRAD, La recherche agronomique pour le développement in Madagascar conservation & development, volume 6, issue 1-June 2011; 4 p

6 https://solagro.org/life-biostandards--la-biodiversite-dans-les-marques-et-labels-du-secteur-agroalimentaire-reference-84

policies, including in the producer countries themselves, with a reduction in taxes for certified companies)".

Several standards for the preservation and restoration of biodiversity have been defined. The CCBA: (Climate, Community and Biodiversity Alliance) has developed standards related to the climate, communities and biodiversity. With respect to biodiversity standards, **for every agricultural activity, it should be possible to describe the initial biodiversity conditions of the plot or the area and the changes expected based on the scenario for the land's use if the activity isn't implemented.**

The **following indicators** have been selected to quantify the positive impacts of the activity or the project:

1. *Use appropriate methodologies to estimate changes in biodiversity, including an assessment of predicted and actual, positive and negative, direct and indirect impacts, resulting from project activities under the with-project scenario, in the project area and over the project lifetime. This estimate must be based on clearly defined and defendable assumptions.*
2. *Demonstrate that the project's net impacts on biodiversity in the project area are positive, compared with the biodiversity conditions under the without-project land use scenario.*
3. *Describe the measures needed and taken to mitigate negative impacts on biodiversity and any measures needed and taken to maintain or enhance high conservation value attributes, in keeping with the precautionary principle.*
4. *Demonstrate that no high conservation values are negatively affected by the project.*
5. *Identify all species used by the project and show that no known invasive species are introduced into any area affected by the project and that the population of any invasive species does not increase as a result of the project.*
6. *Describe possible adverse effects of non-native species used by the project on the region's environment, including impacts on native species and disease introduction or facilitation. Justify any use of non-native species over native species.*
7. *Guarantee that no GMOs are used to generate GHG emissions reductions or removals.*
8. *Describe the possible adverse effects of, and justify the use of, fertilizers, chemical pesticides, biological control agents and other inputs used for the project.*
9. *Describe the process for identifying, classifying and managing all waste products resulting from project activities.*

Other indicators have also been defined to assess the impacts of the activity or the project on biodiversity outside of the plot or zone. They are:

1. *Identify the negative impacts potentially caused by the project activities on biodiversity outside the project area.*
2. *Describe the measures needed and taken to mitigate these negative impacts on biodiversity outside the project area.*

3. *Evaluate unmitigated negative impacts on biodiversity outside the project zone and compare them with the project's biodiversity benefits within the project zone. Justify and demonstrate that the net effect of the project on biodiversity is positive.*

It is important to consider actions which include agricultural development, the climate (mitigation and adaptation) and biodiversity (preservation and restoration) rather than acting solely on one of these aspects without taking the other two into consideration. The following figure illustrates (sustainable) agricultural development compatible with climate and biodiversity. ACP countries can take their cue from the above-mentioned standards to define a legal framework which will enable them to implement follow-up assessment of the inclusion of biodiversity in certified agricultural production as well as for products consumed locally.

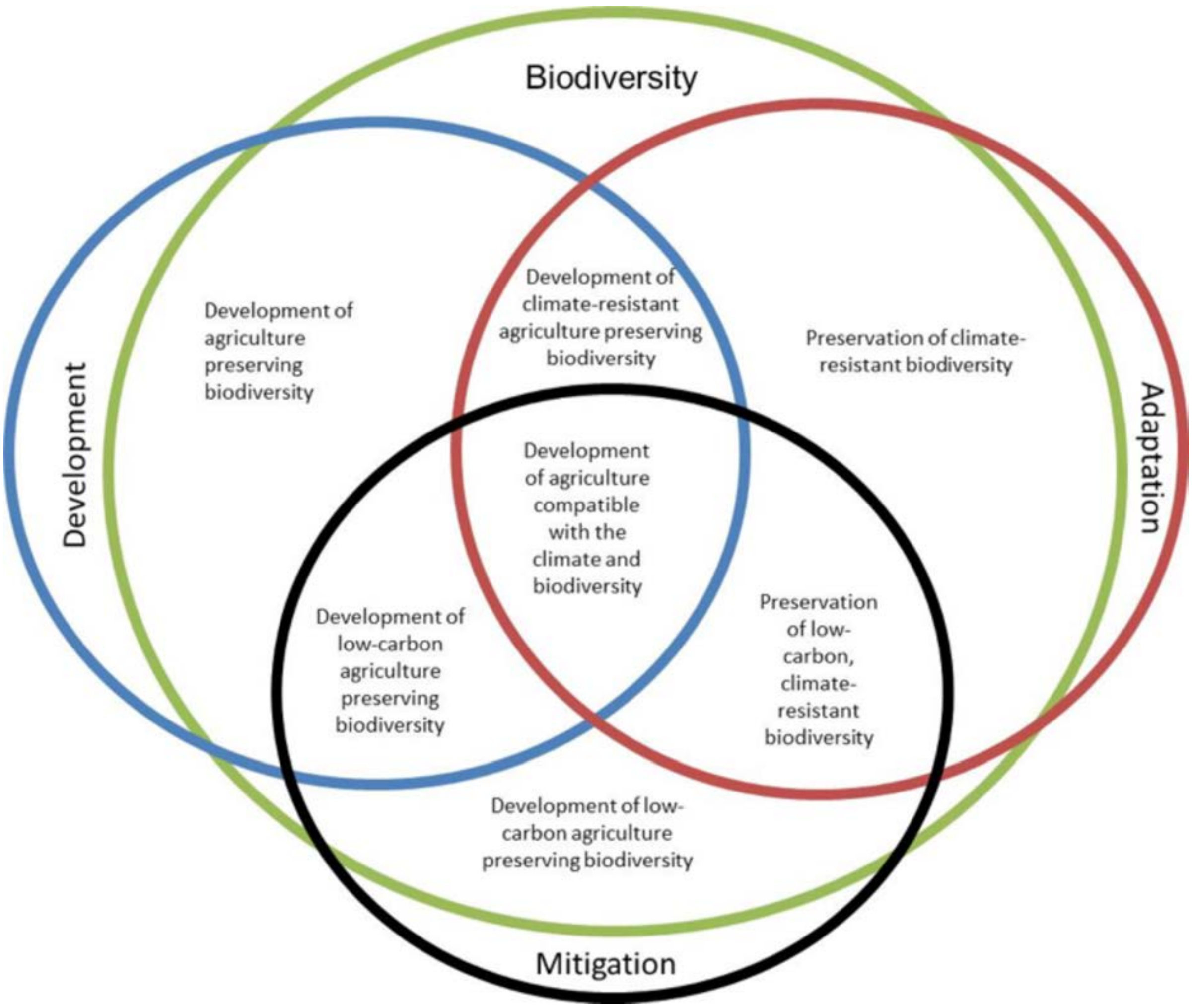


Figure 5: Agricultural development compatible with the climate and biodiversity; Source: adapted by Mulindabigwi, V. (2012)7 from S. Maxwell and Mitchell T. (Nov 2010) https://cdkn.org/wp-content/uploads/2012/10/CDKN-CCD-Planning_english.pdf

7 Presentation of the approach to agricultural development compatible with the climate and biodiversity as part of the Groupe d'Echanges sur les Changements Climatiques et la biodiversité (GECC) of the GIZ in Benin

1.3. BIODIVERSITY AND AGRICULTURE

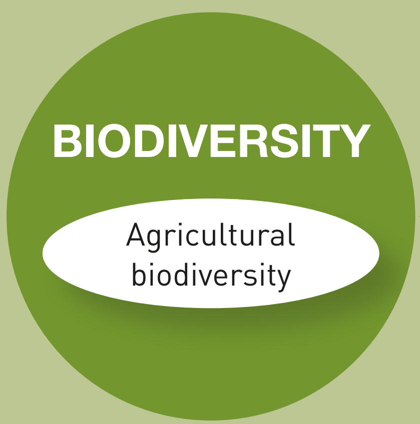
1.3.1. What is the relationship between biodiversity and agriculture?

In farming the term used is **agricultural biodiversity**. Agricultural biodiversity is a broad term that includes all components of biological diversity of relevance to food and agriculture, and all components of biological diversity that constitute agricultural ecosystems, also named **agroecosystems**. It designates, in other terms, 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 agroecosystem, its structure and processes (Secretariat of the Convention on Biological Diversity, 2008)[8].

Agricultural biodiversity is the result of natural selection processes and the careful selection and inventive developments of farmers, herders and fishers over millennia. Agricultural biodiversity is a vital sub-set of biodiversity. It comprises the diversity of genetic resources (varieties, breeds) and species used for food, fodder, fibre, fuel and pharmaceuticals. It also includes the diversity of non-harvested species that support production (soil micro-organisms, predators, pollinators), and those in the wider environment that support ecosystems (agricultural, pastoral, forest and aquatic) and contribute to their diversity (FAO, 1999).

Box 2: Key points of agricultural biodiversity

- biodiversity encompasses the variety in all living things: micro-organisms, plants, animals and human beings
- agricultural biodiversity is an essential component of biodiversity
- agricultural biodiversity is the result of interactions between genetic resources, the environment and the management systems and practices used by farmers.



- Mixed agricultural ecosystems
- Cultivated species/varieties
- Farm animals and different fish species
- Plants/animal genetic material
- Organism living in the soil of cultivated zones
- Biological agents
- Spontaneous species and species bred
- Cultural and local know-how about diversity

Source: (FAO, 2005)

8 Secretariat of the Convention on Biological Diversity (2008). Biodiversity and agriculture: Protecting biodiversity and ensuring food security. Montreal, 56 pages.

SCDB, 2008[9] listed six ecosystem services specifically provided by agriculture:

- Pest and disease control;
- Nutrient cycling, such as the decomposition of organic matter;
- Nutrient sequestration and conversion, as in nitrogen-fixing bacteria;
- Regulating soil organic matter and soil water retention;
- Maintenance of soil fertility and biota; and
- Pollination by bees and other wildlife.

According to Bioversity International, 2017 six reasons explain the importance of agricultural biodiversity:

- Agricultural biodiversity is the foundation of agriculture.
- Agricultural biodiversity can provide a cost-effective way for farmers to manage pests and diseases.
- Agricultural biodiversity gives farmers options to manage climate risks.
- Agricultural biodiversity can contribute to health and nutrition.
- Agricultural biodiversity can play a role in sustaining soil health, food and habitats for important pollinators and natural pest predators that are vital to agricultural production.
- Traditional knowledge of agricultural and cultural practices is often based on local species diversity and its use.

According to the FAO, 2007[10], biodiversity benefits agriculture in three ways: (i) productivity, (ii) adaptation, and(iii) maintenance of ecosystem functions. In return, agriculture also benefits biodiversity in three ways: (i) delivery of ecosystem services, (ii) incentives, and (iii) ecological knowledge.

Thrupp, 2003 summarises all of these ideas about the importance of biodiversity for agriculture (see box below).

9 Secretariat of the Convention on Biological Diversity (2008). Biodiversity and agriculture: Protecting biodiversity and ensuring food security. Montreal, 56 pages.

10 https://www.cbd.int/doc/external/cop-09/fao-factsheet-fr.pdf

Box 3: The role of agricultural biodiversity

Experience and research have demonstrated that biodiversity can:

- Increase productivity, food safety and profitability
- Reduce the pressure of agriculture in fragile zones and forests and on endangered species
- Make agricultural production systems more stable, more robust and more sustainable
- Contribute to the integrated management of pests and diseases
- Preserve soils and increase their natural fertility and their health
- Contribute to sustainable intensification
- Diversify products and income streams
- Reduce or share risks between individuals and nations
- Help to maximise the effective use of resources and the environment
- Reduce dependency on outside contributions
- Improve human nutrition and provide medical supplies
- Protect the structure of the ecosystem and the stability of species diversity.

Source: (Thrupp, 2003) [12]

1.3.2. Organic agriculture and biodiversity[11]

Agriculture is one of humankind's most basic activities because all people need to nourish themselves daily. Agriculture, in the broadest sense, includes the way people tend soils, water, plants and animals in order to produce, prepare and distribute food and other goods. It's also the way people interact with living landscapes, relate to one another and shape the legacy of future generations (IFOAM[12])'.

According to IFOAM, organic agriculture is a production system that sustains the health of soils, ecosystems and people. It is based on ecological processes, biodiversity and cycles adapted to local conditions, rather than on the use of chemical inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved.

Specifically, the principles of organic agriculture are (IFOAM, op. cit.):

- The principle of health: protect health at all costs: the health of soils, plants, animals, humans and the planet are one and indivisible.
- The principle of ecology: work with and sustain living ecological systems and cycles.

11 Thrupp, LA 2003. The central role of agricultural biodiversity: trends and challenges. In conversation and sustainable use of agricultural biodiversity. Published by CIP-UPWARD in partnership with GTZ, IDRC, IPGRI and SEARICE

12 IFOAM. The principles of organic agriculture.

- The principle of fairness: build on relationships that ensure fairness with regard to the shared environment and life opportunities.
- The principle of care: refrain in the event of doubt: responsibility, wisdom and precaution must guide the choice of technologies, methods and management for organic agriculture to prevent any risks for current and future generations.

The differences between organic and non-organic agriculture are a subject of interest to many scientists around the world. Systematic reviews of the literature undertaken on the topic identify hundreds of comparative studies. It is reported that many studies believe that biodiversity in organic agriculture is superior compared to non-organic agriculture. On the other hand, a minority of these studies state that biodiversity in organic agriculture is inferior or equal to non-organic agriculture (Hole, 2005).

Figure 6 illustrates the results of the systematic review of 95 studies carried out by the Research Institute of Organic Agriculture (FiBL). It shows the number of studies, categorised by animal and plant groups, documenting the positive (green bars) and negative (red bars) effects of organic farming on biodiversity compared to non-organic farming methods. The numbers in the white circles indicate the number of studies which did not show any significant differences between the two farming methods.

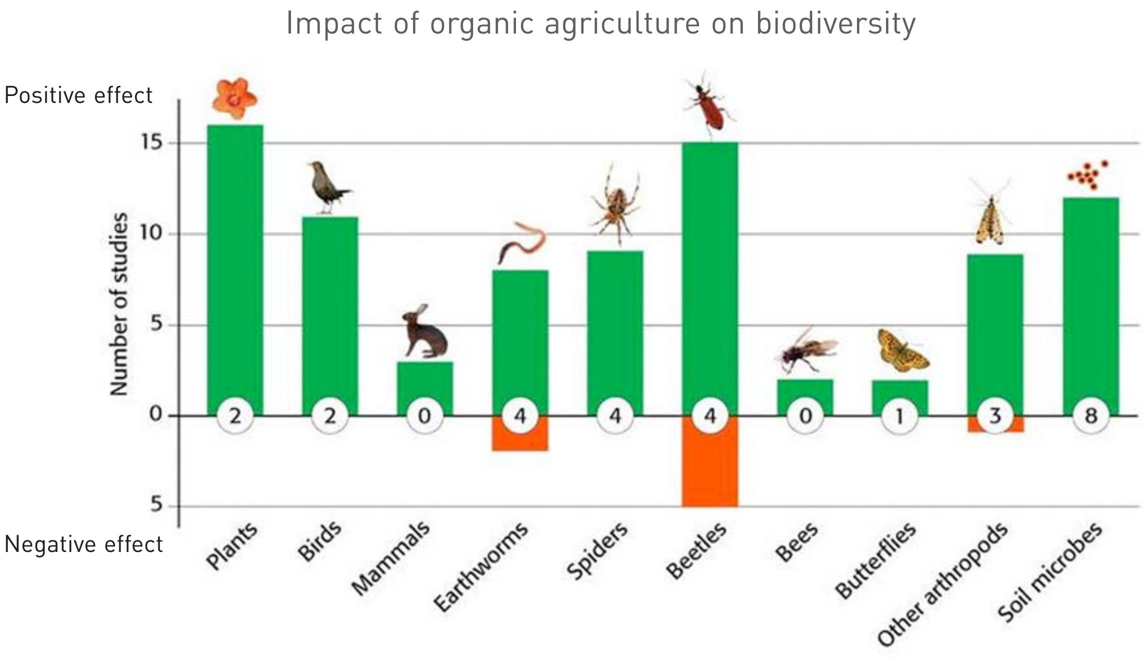


Figure 6: Studies documenting the effects of organic agriculture on biodiversity
Source: (Pfiffner and Balmer, 2011)

The FiBL summarises the theory proposed by most of the studies very well: "Compared to conventional agriculture, organic agriculture provides significantly more services which favour biodiversity". Organic agriculture is more valuable with about:

- 46% to 72% of area closer to its natural state than with conventional farming,
- 30% more species than with conventional farming,
- 50% more people than with conventional farming.

As a result, thanks to the low-intensity farming and the higher proportion of areas close to their natural state, there are still many typical regional plant and animal species present on organic farms.

There are several reasons for this greater biodiversity in organic farming. The reasons are primarily related to the production methods and the understanding of the landscape:

- no synthetic chemicals are used (chemical pesticides, mineral fertilisers),
- long and diversified crop rotations,
- similar crops,
- a smaller number of animals per plot,
- the use of beneficial insects and organisms which entails the need to preserve or plant hedges and other biodiversity reservoirs,
- the use of species adapted to the environment (cultivated biodiversity).

According to the AFD, the positive results of organic farming include: a healthier environment, living and fertile soil, water free of pesticide residue, reduced nitrate pollution, agricultural diversity, protected landscapes and a source of innovation and sustainable know-how.

1.4. THREATS TO BIODIVERSITY

1.4.1. Threats to biodiversity

The world is currently experiencing explosive human population growth which is impacting the natural environment and biodiversity. Biodiversity is being lost at a rate never before experienced in our planet's history. The current extinction rate of species is thought to be 100 to 500 times faster than it has been over the last 65 million years. Of the 15,000 known species of mammals and birds (for which we have better-quality data), approximately 210 species (1.5%) have become extinct since the sixteenth century. This is equivalent to 100 to 1000 times the natural rate of extinction. Many scientists believe that we are currently living the sixth great extinction era and that it is the result of the actions of human beings on the environment, primarily through agriculture, deforestation and urbanisation. Over 6,300 species are threatened in the short term and entire ecological systems could disappear. There are multiple causes for this rate of biodiversity loss. They are primarily the result of anthropic mechanisms.

Scientists summarise the anthropic mechanisms responsible for the loss of biodiversity in five major categories (Jourdan *et al.*, 2012) as follows (Tech&Bio, 2015)[13]:

i. Destruction, reduction and fragmentation of natural habitats.
ii. Biological invasions (introduction of natural invasive exotic species).
iii. Overexploitation of certain species, certain environments (e.g., deep soil cultivation).
iv. Pollution & bio-contamination of water, soil and air.
v. Global climate change.

13 Tech&Bio, 2015: Biodiversity (Poster) http://www.tech-n-bio.com/le-salon-bio-et-conventionnel/programme/supports-techniques-2015.html?file=tl_files/2015-

1.4.2. A summary of the mechanisms responsible for the loss of biodiversity

1.4.2.1. Destruction and fragmentation of natural habitats.

Fragmentation and loss of habitat are considered to be the main causes threatening the survival of 83% of the mammals and 85% of the birds threatened (UNEP, 2002)[14]. Fragmentation appears when a large ecosystem is divided by human action into many small, spatially isolated fragments. The fragmentation of habitats is highly correlated with their disappearance. These phenomena are linked to many human activities: urbanisation, agriculture, fishing, aquaculture, forestry, tourist and industrial facilities, materials extraction (such as quarries, etc.). The species most vulnerable to fragmentation are: species which are naturally rare; species with a low reproduction rate or a short life cycle; species which need extensive habitat; species which cannot disperse easily; species which live on unpredictably available resources; species which can only live at the heart of a habitat and not on the edges and species which are vulnerable to human exploitation.

1.4.2.2. Bio-invasions

Bio-invasion is the intentional or unintentional introduction by man of animal and plant species into places where they do not occur naturally. It has increased with the evolution of transportation and international trade. Its destructive impact on biodiversity is visible when a species is able to adapt to its new environment (10% of the time) and even more so when it becomes invasive. The extent of this phenomenon is now enormous as it is estimated that about 10% of plant species are introduced. The impact of introduced species on native species is primarily due to:

1. predation[15],
2. competition for resources and space[16],
3. habitat modification[17] and/or
4. genetic action[18].

Note, however, that all exotic species are not necessarily invasive. All invasive species have one characteristic in common: their strong ecological plasticity which enables them to easily adapt to all types of conditions. This is not the case for native species which are only adapted to the biogeographical zone in which they live. This is the reason why they are more sensitive to changes in their environment.

For example, the lantana (*Lantana camara*) has covered vast areas of India, Australia and a large part of Africa, reaching into openings in the African tropical forest

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14 UNEP, (2002): Global environment outlook, 3: *Past, present and future perspectives*; Mnatsakanian, RA.

15 Antagonistic interaction which is unilaterally harmful between a species called a predator and several species called prey on which the "harmful" species depends in an opportunistic or compulsory way from a trophic standpoint. For example, a wolf which eats a hare or a lion which eats a gazelle.

16 Rivalry between species which depend on the same limited resources (food, shelter, nesting areas). It can be interspecific (between different species) or intraspecific (between individuals of the same species).

17 This is one of the main causes for the disappearance of species. Humans fragment the landscape and natural habitats with the construction of roads and housing.

18 Genetic improvement or modification via the creation of new varieties and genetically modified organisms

(Uganda, etc.) and the dry plateaux of Kenya.[19] The species, originally from Central America and the Greater Antilles, was introduced as an ornamental plant by botanical gardens on several continents. It has adapted to tropical zones and become invasive.

1.4.2.3. Overexploitation

Biodiversity is used for a range of purposes: food, ornaments, raw materials, recreation and pets. Overexploitation refers to the excessive use of resources by human beings. The issue of the overexploitation of biodiversity is the result of the poor management of natural resources by humans who extract more than can be replaced by natural renewal. Overexploitation has an ecological impact (a direct cause of extinction, genetic drift, consanguinity, etc.) and indirect economic consequences. Overexploitation is currently a threat for over a third of mammals (primates, carnivores, lagomorphs, etc.). It is also a threat to fish populations. It causes a decrease in the size of the population, changes in the structure of the population (age/gender/size), changes in distribution and the destruction of target and non-target species.

1.4.2.4. Pollution

Physical and chemical pollution is the fourth cause of species extinction. The pollution of soil, water and the air accentuates the deterioration of natural habitats and directly impacts certain species. The deterioration of habitat caused by pollution is also a significant aspect of the erosion of biodiversity. It impacts the functioning of ecosystems and, consequently, leads to a decline in fauna and flora. The decline is due to several reasons: death by intoxication, changes in the functioning of food chains, changes in reproduction, etc.

1.4.2.5. Global climate change

Nowadays, climate change is putting on additional pressure on biological diversity (UNEP, 2010)[20]. The figure below describes the mechanism via which climate changes are disrupting biological diversity. Temperature is a fundamental abiotic parameter which regulates many living processes. The climate, which includes temperature and many other abiotic variables, also has a very significant impact on the life of organisms and the relationships these organisms have within ecosystems (Parmesan, 2003)[21]. According to scientists, climate change will have serious consequences on the composition, structure and functions of ecosystems. New ecosystems will develop in new regions, transforming existing land and aquatic ecosystems. It is estimated that the risk of extinction of about 10% of the known animals in the world will increase significantly with each 1°C increase in temperature. Many species will adjust or will adapt to the changes in their living conditions, but others will not be able to.

19 Invasive plants in Madagascar and in Africa - Benjamin Lisan - 2014

20 PNUE-PAM-CAR/ASP, 2010. Impact of climate changes on the biodiversity of the Mediterranean Sea. S. Ben Haj and A. Limam, CAR/ASP Edit., Tunis: 1-28.

21 C. Parmesan, G. Yohe. 2003. *A globally coherent fingerprint of climate change impacts across natural systems.* Nature 421

1.4.2.6. Hybrid varieties and Genetically Modified Organisms (GMOs)

The factors affecting the risk of loss of domestic biodiversity include hybrid varieties and Genetically Modified Organisms (GMOs). The use of hybrids[22] often leads to the uniformity of cultivated varieties and, as a result, a decrease in biodiversity in the fields. However, opinions are split on the impact of hybrids on biodiversity because some people are of the opinion that, in order to create hybrids, collections of parent plants must be maintained, thus safeguarding biodiversity.

The risks associated with GMOs are primarily due to the potential crossing of wild species with GMOs resulting in the uncontrolled dissemination of the cultivated species. The use of GMOs risks aggravating the loss of biodiversity in the fields as a result of the selection of one or two species. This is even more of a threat if the dissemination is irreversible and contaminates wild species.

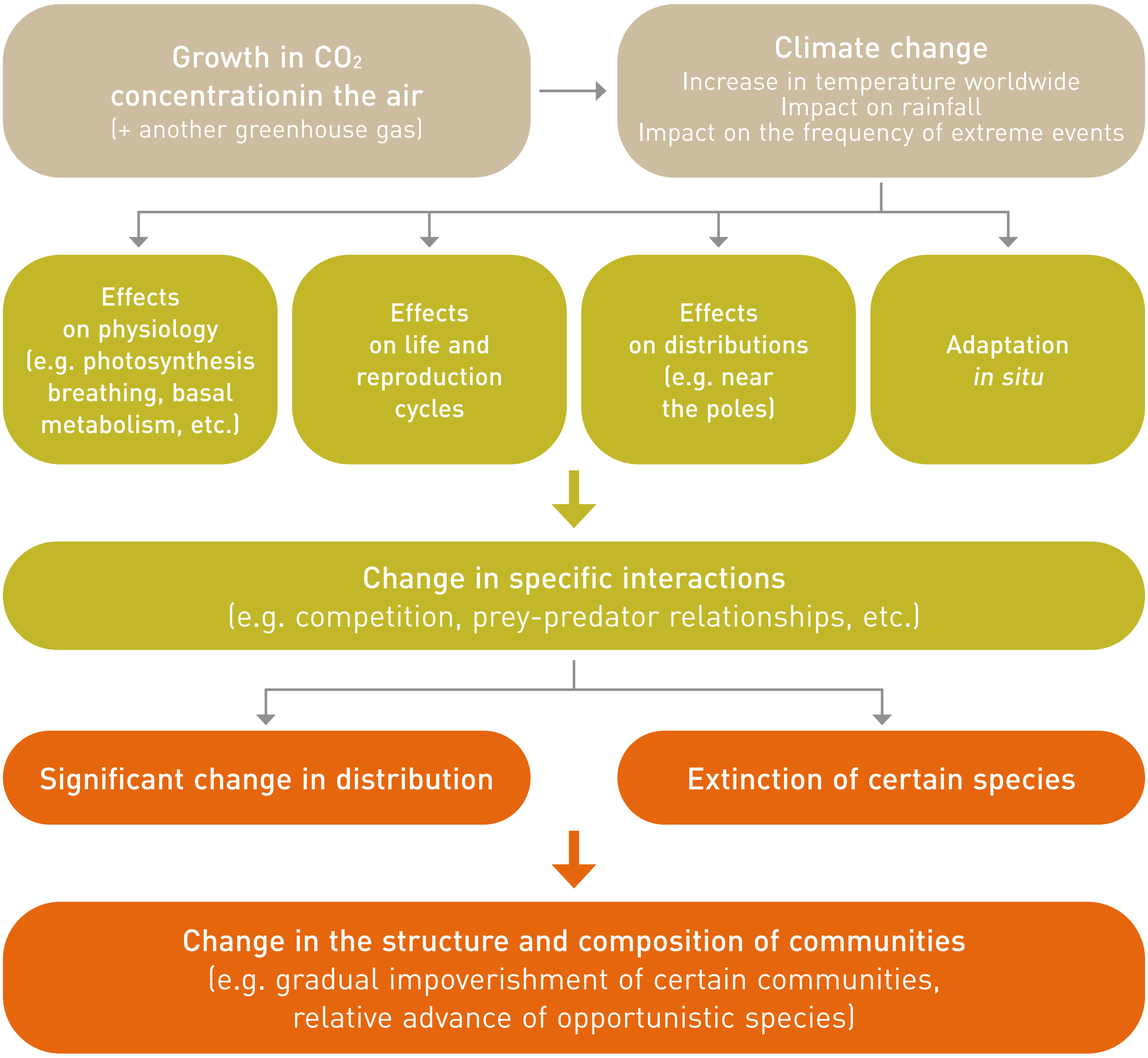

Figure 7: Impact of climate changes on the biodiversity (Source: UNEP, 2010)

22 *Hybrid varieties* are plants resulting from the crossing of two genetically different and pure varieties, generally to increase the value of one or more specific characteristics including colour, size, resistance to disease or climate conditions, etc. (Adapted from DGCI, 2001: Agriculture en Afrique Tropicale)

1.5. IMPACT OF PRODUCTION SYSTEMS AND AGRICULTURAL PRACTICES ON BIODIVERSITY

1.5.1. Introduction

Biodiversity is the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems. Agriculture is a process by which people lay out their ecosystems and control the biological cycle of domesticated animals in order to produce food and other resources useful to their societies. Therefore, agriculture can have a positive or negative impact on biodiversity.

Its impact on biodiversity is determined by several factors, of which the most important are agricultural production systems and the marginality index of agricultural land. While agricultural production systems are the result of demographic pressure on land or of technology advances, the marginality of agricultural land is obtained by taking several natural environmental factors into account. These factors are the potential productivity in biomass, climate conditions (aridity, seasonal fluctuations in precipitation), soil properties (soil fertility) and the soil slope steepness (erosion risk) (Röhrig, J., 2008). In Burundi, *"agroecosystems and natural ecosystems have a close relationship through the ecological services each system provides the other. In fact, as a result of their services in soil and water protection, the agroecosystems take part in mitigating erosion and sedimentation harmful to aquatic biodiversity. Agroecosystems have also enabled the preservation of biodiversity which has become rare in natural environments and also facilitate the conservation and maintenance of soil micro-organisms which would not exist without agricultural activities" (see Appendix 11).*

Taking into account the number of years a plot is cultivated (C), the number of years it is fallow (F) and the number of years it is used for another purpose excluding cultivation (L), Ruthenberg (1980) determined the coefficient of culture R expressed as a percentage.

$$R\ (\%) = \frac{C}{C + F + L} * 100$$

The coefficient enables the classification of agricultural production systems in three major categories:

Itinerant cultivation systems: $R < 30$

Semi-permanent cultivation systems: $30 \leq R \leq 70$

Permanent cultivation systems: $R > 70$.

Independently of the above-mentioned cultivation systems, the way in which crops are laid out on a plot, farm, or in a specific region will, in turn, determine another cultivation classification system, i.e., **monoculture** or **polyculture**. While monoculture is defined as a cultivation system for a single plant species on a farm (season by season), polyculture is a system in which several species of plants are grown on the same plot, farm or region. However, it should be pointed out that there are agricultural production systems in which farmers are engaged in both polyculture and monoculture at the same time. This is the case for farms in northern Benin where intensive cotton farming is a monoculture which has completely damaged the region's soil. Given this, the definition of a monoculture should refer to a plot or a field rather than to an entire farm. Polyculture includes several cultivation systems in different combinations.

MONOCULTURE

A single crop grown on the same plot year after year

POLYCULTURE

Rotation/ Sequence

One crop per year

- **Continuous agriculture** *Only annual species*
- **Mixed agriculture** *Alternating species, annual/perennial species*

Multiple crops

More than one type of crop per year

Sequential

- **Catch crops** *A second type of crop is sown just after the harvest of the first one for harvesting*
- **CIPAN** *Nitrate-fixing intermediate crop* *Goal: capture nitrogen not used by the previous crop*

Simultaneous

Several species at the same the on the same plot

- **Mixes** *Several types of crops sown at the same time*
- **Row intercropping**
- **Band intercropping**
- **Staggered** *Sowing is staggered for the various species*

Figure 1: Classification of different crop sequences

Source: Adapted from https://commons.wikimedia.org/w/index.php?curid=7667095

Several other farming systems exist concurrently with the above systems including agroforestry, agropastoralism, perennial crops (arboricultural and shrubs), irrigated crops, organic crops, etc. The impact of agriculture on biodiversity is measured based on the following farming systems:

- Itinerant cultivation system - polyculture
- Semi-permanent cultivation system - polyculture
- Permanent cultivation system - polyculture
- Permanent cultivation system - monoculture
- Perennial cultivation system
- Agroforestry system
- Irrigated cultivation system
- Organic cultivation system
- Agroecological cultivation system

Figure 2: Soil prepared with animal-drawn implements for intercropping
Source: Mulindabigwi, 2008

The land layout and farming practices are different from one cultivation system to the next. Therefore, their impact on biodiversity is also different. The impact on biodiversity at the plot or landscape level of each cultivation system is described in relationship to the soil, water resources and the fauna and flora.

1.5.2. The impact of biodiversity at the plot and landscape level

This subsection describes the impact of agriculture on biodiversity at the plot and landscape level. The impact is primarily the result of management methods and the use of land which varies from one cultivation system to another.

1.5.2.1. The itinerant-polyculture cultivation system

The primary agricultural input of the itinerant-polyculture cultivation system is seeds (generally produced by the farmers themselves). The ploughing implements consist of rudimentary tools such as the hoe and machete which do not have a negative impact on the structure of the soil. It does not use (or rarely uses) mineral fertilisers or pesticides or other chemical products which could have a negative impact on water and land resources. It does, however, entail deforestation. As a result of the lack of techniques to fight against erosion and the destruction of biomass with fire, the itinerant cultivation system leads to soil erosion. Erosion, combined with the absence of measures to improve soil fertility, accelerates the deterioration of soil fertility which, in turn, results in a rapid decline in agricultural productivity. The damaged land is often left fallow for long periods of time.

Deforestation, slash-and-burn farming, the decrease in organic material in the soil and the low retention capacity of the soil lead to a decline in the flora, fauna and micro-organisms in the soil.

The impact on biodiversity at the plot level

The destruction of biomass by fire at the plot level decreases the organic material content in the soil and, as a result, decreases the soil's ability to retain water. Rainwater infiltration gives way to run-off. Although tree cutting is selective when the plot is prepared (some species of trees are left on the plot), the itinerant cultivation system basically entails the elimination of a large portion of the plant species on the plot and, therefore, a decrease in the plant diversity of each plot. The plant species cultivated are generally from seeds long selected by farmers themselves. The seeds have low to average yields. They are, however, resilient and adapted to the conditions of farming without capital. The itinerant cultivation system destroys the habitats of certain animal species but, at the same time, they host a high density of other animal species thanks to the crops in place. For example, in the case of maize, there will be a high number of monkeys; with tubers, there will be many rodents, etc. Although opinions differ on the benefits and disadvantages of the itinerant cultivation system for biodiversity, there is unanimity about the fact that the system is sustainable as long as population density remains low enough to be able to leave the plot fallow for a long period of time to allow the soil to recover its fertility. When the fertility of land left fallow is regenerated, it becomes apparent in the vegetation cover with many species and the return of fauna and micro-organisms on and in the soil.

The impact on biodiversity at the landscape level

At the landscape level, the itinerant-polyculture cultivation system results in significant deforestation which transforms natural areas into long-term fallow land. Soil erosion carries away a significant amount of soil downstream of the plots where it silts up river beds and banks. It also disrupts ecological niches and, in particular, ecological corridors between aquatic and land ecosystems. Several authors have noted that the itinerant cultivation system increases hunting pressure on (large) game mammals around villages (Wilkie & Finn, 1990) (okapi, yellow-backed duiker, panther), Thomas (1991) in the Congo [Ituri] (chimpanzee and Hamlyn's monkey) and Lahm (1993) in Gabon (chimpanzee, gorilla, elephant, forest buffalo). In the Dja/Cameroon loop, the extinction of the gorilla, panther, elephant and giant pangolin around villages has been confirmed, but the sitatunga and yellow-backed duiker (Dethier, 1995) have survived.

i *The itinerant-polyculture cultivation system transforms natural or secondary formations in long-term fallow land. It causes an increase in hunting pressure on mammals and perturbs ecological niches and corridors.*

Key points of the itinerant-polyculture cultivation system

Brief description	Impact on the plot	Impact on the landscape
Long-term fallow period (R<30) Crop rotation Crop combinations Simple soil work Biomass destruction by fire Soil erosion Traditional seeds	**Negative** • Deterioration of soil fertility, • Decrease in organic material in the soil and in the ability to retain water • Decrease in water infiltration • Elimination of plant species • Decrease in plant diversity • Decrease in the number of animal species **Positive** • Recovery of soil fertility • Partial recovery of the vegetation cover • Repopulation of the fauna, organisms and micro-organisms in and on the soil	**Negative** • Deforestation • Silting of rivers and water sources • Destruction of ecological niches • Destruction of ecological corridors • Increase in hunting pressure on animals **Positive** • Preservation of crop diversity

1.5.2.2. Semi-permanent-polyculture cultivation system

Impact on biodiversity at the plot level

The semi-permanent-polyculture cultivation system differs from the itinerant-polyculture cultivation system in that fallow periods become shorter and shorter and no longer enable regeneration of soil fertility. Although clearing and planting of crops on the plot decreases the number of plants, the combination of different crops (polyculture) enables:

- improved biodiversity on the plot
- optimal use of the nutrients in the different soil layers
- the creation of micro-climates favourable to a range of insect and bird species.

On the other hand:

- soil erosion increases if no measures are implemented to fight it
- the rate of rain water infiltration decreases and is replaced by run-off
- crop productivity decreases quickly due to the lack of effective management of organic matter.

Contrary to itinerant cultivation in which mineral fertilisers, pesticides and other chemical products are virtually non-existent, the semi-permanent cultivation system is beginning to rely on agricultural inputs, although in low quantities. Given that there are no industrial crops, exports or commercial farming (which often abuses the use of the above-mentioned inputs), the use of mineral fertilisers and pesticides is relatively low. However, in certain cases, the use of mineral fertilisers without the addition of organic material can have a negative impact on the physico-chemical properties of the soil. It can result in the acidification of the soil which results in a decrease in organisms and micro-organisms in the soil and above-ground biomass. In addition, the non-selective use of insecticides can compromise biodiversity by eliminating many of the insects that are beneficial to the plot. Following the deterioration of soil fertility, some plants which indicate soil fertility such as the *Galinsoga parviflora Cav* give way to other types of grasses. The spatio-temporal relationships between plants change leading to changes in, or the disappearance of, insects on the plot.

The semi-permanent-polyculture cultivation system differs from the itinerant-polyculture cultivation system in that fallow periods become shorter and shorter and no longer enable regeneration of soil fertility. Chemical products begin to be used in this system.

The impact on biodiversity at the landscape level

The semi-permanent-polyculture cultivation system results in significant changes to the landscape in terms of biodiversity. Whereas the itinerant cultivation system enables the recovery of the vegetation cover with a number of different plants, including forest species, the fallow period for the semi-permanent cultivation system is relatively short which means that plant recovery is limited. Given that measures for the protection of wildlife are non-existent or are not strictly implemented, many animal species disappear from the zone very quickly.

There were buffaloes and other large mammals in the Bugesera District in Rwanda at the end of the 1960s. The demographic pressure on the land increased considerably due to migration and the animals completely disappeared from the zone.

Eight species of fish disappeared from Lake Aheme in southern Benin (Amoussou, E., 2004) as a result of silting, the drying of the floodplain and increased fishing. Amoussou, E. (2004) noted that the disappearance of mangrove along Lake Aheme has resulted in decreased biodiversity and the impoverishment of the lake's fish resources

In Serou, in northern Benin, fish-trap fishing, which was well organised and regulated annually no longer exists because the ponds have dried up due to agricultural activities.

Also, in northern Benin, the local population has reported that young baobab trees are becoming increasingly rare in nature. The reason most often given for this is the decrease in the number of monkeys due to the expansion of planted areas, to the detriment of natural habitat, and long fallow periods (monkey habitat). Hladik and Hladik (1967) realised that the primates could contribute to maintaining and the distribution of certain (plant) species by helping the germination of their seeds.

Although the semi-permanent-polyculture cultivation system only uses small quantities of chemical products, in some cases, the non-selective use of insecticides compromises biodiversity by eliminating certain insects directly and certain birds indirectly from the landscape.

With erosion becoming increasingly significant on the plots, the rate of infiltration and of groundwater regeneration decreases. The damage due to erosion is amplified by the semi-permanent cultivation system and by climate change, notably as a result of the intensity of heavy rains. In addition, the silting of waterways, lakes, ponds, valleys and banks is a direct result of the deterioration of the land eroded upstream. Some plant and/or animal species disappear, particularly when water resources decrease significantly. The ecological corridors between the ecosystems are destroyed. Until the 1970s, snakes were often seen coming down from the hills in certain areas of Rwanda (Sholi, Cyeza, Muhanga and Rwanda) during the dry season (July- September) on their way to water points. Just before the rainy season (March-June), ants could be seen travelling in the opposite direction, moving from the water to the sides of the hills. During this same period, many mushrooms would also grow in cultivated and natural areas. These movements of animal species depending on the time of year are now very rare or non-existent. Many multi-purpose plant species (used notably for building houses) including *Hibiscus vp. Ssp. (*umugusa in Kinyarwanda*)*, bamboos etc. no longer exist on sites once considered to be secondary or natural. The main reason is that water resources have decreased or dried up entirely.

Key points of the semi-permanent-polyculture cultivation system

Brief description	Impact on the plot	Impact on the landscape
Average fallow period (30≤R≤70) Crop rotation Crop combinations Low use of chemical products (mineral fertilisers, pesticides, etc.) Use of traditional and improved seeds	**Negative** • Decrease in the organic matter in soil • Increased erosion • Deterioration of soil fertility • Significant decrease in water infiltration • Change in, or disappearance of insects, organisms and micro-organisms on the plots	**Negative** • Significant negative changes to biodiversity • Limited regeneration of the vegetation • Disappearance of many plant and animal species (aquatic and land) • Increased erosion damage (silting of water sources, etc.) • Destruction of ecological corridors • Decrease in water resources
	Positive • Partial recovery of soil fertility • Very partial recovery of the vegetation cover • Limited repopulation of the fauna, organisms and micro-organisms in and on the soil	**Positive** • Partial regeneration of vegetation • Biological synergies between ecosystem components • Preservation of water quality (but not the quantity) • Healthy food for the population

1.5.2.3. Permanent-polyculture cultivation system

Impact on biodiversity at the plot level

With the permanent-polyculture cultivation system, the plot is being cultivated virtually all the time. It is used in densely populated zones where industrial or commercial production is intense. This cultivation system is very widespread, for example in Rwanda and in certain areas of southern Benin due to the very high population density. It is characterised by, among other things:

- soil work done primarily with simple ploughing implements, animal-drawn implements, light mechanised tools and virtually no heavy mechanisation;
- the plots are overexploited and, therefore, exposed to erosion;
- very significant deterioration of the vegetation (biomass and species) and of the land despite efforts by the farmers to ensure effective biomass management and the addition of organic materials;
- the soil becomes increasingly poor in organic material:
- erosion carries away much greater amounts of soil (e.g., 100t/ha per year on steep slopes in Rwanda (König., 1994);
- silting of water sources and of the plots as well as flooding;
- the rate of water infiltration in the ground is even less than with the semi-permanent cultivation system;
- groundwater regeneration is decreases substantially.

The system forces farmers to adopt certain higher-performance technologies to improve agricultural productivity such as limited irrigation, the use of chemical products like mineral fertilisers and phytosanitary products. The seeds used are increasingly improved (in terms of yield but are less resistant), particularly for commercial crops such as maize, rice, tomatoes, etc. The improved seeds are generally hybrids which make the farmers dependent on their suppliers. Crops in different combinations contribute to preserving the biodiversity of several species of cultivated plants and a number of insects. The use of insecticides is increasing and eliminates insects from the plots, including bees, which play a very beneficial role in maintaining biodiversity.

If farmers don't provide organic material to the plot, the soil loses its organisms and micro-organisms. This is the case for the land in northern Benin, in the cotton-growing zone where, according to farmers, the earth no longer has any worms.

The permanent-polyculture cultivation system intensifies overexploitation of the land and leads to the deterioration of soils, reduced water resources and biodiversity erosion via the destruction of habitats and ecological corridors.

The impact on biodiversity at the landscape level

Figure 3: A permanent cultivation system landscape with banana plantations (perennial crop), agroforestry trees, a multitude of small subsistence level plots, coffee plants and woods.
Source: Mulindabigwi, V. 2007

With respect to the landscape, the permanent-polyculture system accelerates the deterioration of vegetation cover, water and land resources. The impact of agriculture and, in particular, of the permanent-polyculture system on biodiversity is summarised in the following story (observations from Rwanda):

"At the end of the 1960s and in the early 1970s, before the permanent cultivation system came to my home region (Sholi, Cyeza, Muhange), when the rains came, I could see clear water running down the sides of the mountains. You could see the water running from far away because of the vegetation cover which protected the soil against erosion. The loss of earth caused by erosion was still limited and the rate of rainwater infiltration was high. There were many water sources which had enough water for nearly the entire period of the year. During this period before the permanent-polyculture cultivation system, land-use included crops, fallow land, pastures, perennial crops (especially coffee and bananas) and marginal land where there were woods. During this period the waterways, lakes and ponds were filled with fish and the children and young people swam in them and had fun. Near the water, there were many different animal species, including insects, frogs, toads, snakes, different bird species, etc. With respect to birds, in particular, the common moorhen (Gallinula chloropus), the black-crowned crane (Balearica pavonina), the African hamerkop or Senegalese hamerkop (Scopus umbretta), the cattle egret (Bubulcus ibis), the mallard (Anas platyrhynchos), the black-headed heron (Ardea melanocephala), and others have completely disappeared or are becoming extinct in the zone since the permanent-polyculture cultivation system took over. During the dry season, farmers used the small waterways to irrigate their crops, the plot to be cultivated or to provide livestock with drinking water. The abundance of water sources and the richness of the organic matter in the earth were associated with several different animal species including insects (several beetle species) and earthworms. The water sources have disappeared or their flow has decreased significantly! Hunting for gazelles and hares was still possible and organised once a week, especially very early on Sunday mornings. It was during this period that the last pangolin in the area was killed. Several wild animals were still around, including jackals, foxes, squirrels, porcupines and others. Farmers often put traps in the fields to protect their crops from partridges, moles, etc. Farmers often killed snakes on the cultivated plots. They would put the snakes out on a rock, an embankment, a stone, or hang them on a piece of wood in the open so that the birds, and especially the birds of prey, could take them. There were very well-known traditional healers in the area. They were still able to find the different plant species they needed to make their medicines. There were many bees in the forest, and especially in the gallery forests, and honey production was still natural.

There were always beehives during the summer. There were still several bird species, notably those that eat bees, those that announced that the rainy season would soon be starting, owls, birds of prey, etc.".

Following the overexploitation of the land and the planting of crops everywhere, including in marginal areas, forests and pastures, these sights have become very rare.

The deterioration of the vegetation cover (consisting of several plant species) was followed by the deterioration of the soil and a decrease in the availability of water resources and the disappearance of certain animal species. However, the permanent-polyculture cultivation system is still preferable to the permanent-monoculture cultivation system with respect to biodiversity. There are still several domestic plant species throughout the landscape and it uses virtually no insecticides or other chemical products which can pollute water and land resources.

Figure 4: Silting of banks and irrigation and drainage channels in central Rwanda
Source: Mulindabigwi,V. 2007

Key points of the permanent-polyculture cultivation system

Brief description	Impact on the plot	Impact on the landscape
Crop rotation Very short or non-existent fallow periods (R>70) Overexploitation of plots Crop combinations and rotation Simple ploughing tools, animal-drawn ploughing or limited mechanisation Some organic matter management Limited use of chemical products (mineral fertilisers, insecticides, pesticides, etc.) Use of traditional and/or improved seeds Introduction of limited irrigation	**Negative** • Significant deterioration of the vegetation • Low rate of rainwater infiltration in the ground • Significant erosion • Significant soil deterioration • Decrease in insects, organisms and micro-organisms on and in the soil **Positive** • Preservation of crop diversity • Varietal diversity • Diversity of pollinating insects • Diversification of human food	**Negative** • Deterioration of the vegetation cover, water and land resources • Flooding • Silting of waterways, lakes and ponds • Drying out of waterways, lakes and ponds • No more fallow periods, disappearance of natural vegetation and pastures • Disappearance of multi-use plant species • Disappearance of aquatic and land animal species • Disappearance of animal species, notably birds, insects, etc. • Decrease or disappearance of edible mushrooms • Destruction of ecological niches and corridors **Positive** • Preservation of crop diversity • Varietal diversity • Diversity of pollinating insects • Diversification of human food

1.5.2.4. Permanent-monoculture cultivation system

The permanent-monoculture cultivation system is a system in which the land is overexploited and in which biodiversity is endangered because of industrial or (e.g. cotton, etc.) commercial crops (maize, rice, potatoes, etc.). There are also commercial market garden crops such as vegetables. This system is generally modern and devastating. It uses:

- external agricultural inputs such as chemical products (mineral fertilisers, pesticides, herbicides, etc.);
- improved or genetically modified seeds;
- in some cases, mechanisation with heavy machinery;
- the cultivated plots are generally very large on average contrary to the previous farming systems which, use small or average size plots;
- when large machinery is used, there is a risk that the soil structure will be destroyed and a risk of compacting the soil.

Impact on biodiversity at the plot level

Given the intensification of the system which implies the investment of capital which must create a return, farmers work to fight against erosion and improve soil fertility via the implementation of anti-erosion structures, the significant use of mineral fertilisers and, potentially, the use of additional organic matter. They also use phytosanitary treatments and control weeds using pesticides and herbicides. At the plot level, the intensive use of these inputs substantially reduces the number of plant and animal species. Therefore, for example, the termite and earthworm populations are significantly reduced on plots farmed in the cotton growing zone of northern Benin. The fact that there is no rotation or combination of crops on the plot promotes the proliferation of plant diseases and attacks by insects, which is why there is an increased use of phytosanitary products.

The impact on biodiversity at the landscape level

At the landscape level, a study carried out in northern Benin (Lawani *et al.*, 2017) showed that more intense cotton farming resulted in excessive use of mineral fertilisers, insecticides and herbicides which caused significant pollution of water resources. Some of these chemical products were found in the fish in waterways. Following the pollution of water resources and the decreased number of pastures, livestock farmers have definitively left the region for the centre of the country. In addition, given the excessive use of mineral fertilisers without the addition of organic matter, the risk of acidification of the land in the area is very high. To offset the decrease in cotton productivity (despite the use of mineral fertilisers), farmers are betting on larger fields to the detriment of pastures and natural reserves (which are, fortunately, protected). Deforestation is also very high in this area. Tree species which are legally protected (e.g., shea, African lotus bean, etc.) are also cut, whereas these trees were kept on plots with the other production systems. High concentrations of nitrates (300mg/l when the maximum threshold set by WHO is 50ml/l) have been found in underground water samples at a site in Benin (Doguè village, in the municipality of Bassila) when the drilling was done to install water pipes for the village. The non-selective use of insecticides is reducing the insect population although it plays an important role in maintaining biodiversity. In addition, monoculture weakens the immunities of pollinating insects due to the lack of balanced nutrition. In the West, the bee population has decreased significantly. In the United States, some beekeepers rent out their bees to farmers to pollinate their crops. In a landscape in which the permanent-monoculture cultivation system dominates, there is no or very little wildlife (unless there are biodiversity protection measures in place such as strips of shrubs around the windbreaks which have never been cultivated). In order to preserve or restore biodiversity in landscapes dominated by monocultures, some measures, including flower fallow (generally consisting of bands with several different types of flowering plants) are being planted more often. The use of polyethylene films (which are unfortunately not biodegradable) in pineapple fields in Benin helps to reduce weeding, manage water and significantly increase productivity. However, plant diversity is also reduced on the plot.

The permanent-monoculture cultivation system, which is characterised by the overexploitation of the land and the increased use of chemical inputs around industrial or commercial crops leads to significant deterioration of water and land resources and biodiversity.

Key points of the permanent-monoculture cultivation system

Brief description	Impact on the plot	Impact on the landscape
Almost non-existent fallow periods (R>70) Overexploitation of plots A single crop No crop rotation Heavy use of chemical products (fertilisers, pesticides, insecticides, herbicides, etc.) Improved and/or genetically modified seeds Average to large plots Little to significant mechanisation	Negative • Change in the soil structure • Substantial reduction in plant species • Definitive disappearance of certain wild animals, birds, insects, organisms and micro-organisms on and in the soil • Proliferation of plant diseases Positive • Partial restoration of soil fertility via the use of mineral and organic fertilisers • Relatively high crop yields	Negative • Increased deforestation • Soil deterioration (acidification, etc.) • Pollution of land and water resources • Destruction or contamination of fisheries • Disappearance of several plant species • Disappearance of pastures and natural habitats • Destruction of ecological niches and corridors • Decrease or disappearance of pollinating insects Positive • Crop rotation

1.5.2.5. Perennial cultivation system

The perennial cultivation system generally consists of crops such as coffee, tea, cocoa, rubber trees, oil palm, coconuts, cashews, mangoes, citrus, bananas, avocados, papayas, etc. It includes most fruit crops.

The perennial cultivation system, which includes the production of fruits, protects water and land resources. It creates micro-climates which provide habitats for certain animal species. However, the over-use of chemical products could compromise its positive role on biodiversity (e.g. banana plantations)

Impact on biodiversity at the plot level

This farming system preserves the soil very well against erosion and the rate of rainwater infiltration is very high. The abundant plant debris and very light or non-existent soil work mean that the soil is always very rich in organic matter.

Figure 5: A cocoa plantation with significant plant debris on the ground in Kpalime in Togo provides shade for discussions
Source: Mulindabigwi, V. 2017

As a result of the rich organic matter on the ground, the growing plots generally have abundant fauna and micro-organisms on and in the soil. The abundance of plant debris on the ground brings snails, notably in the cashew plantations in Benin and the cocoa plantations in Togo. However, cocoa producers in Togo have noted that, with the use of pesticides, there are no longer snails under the cocoa trees as in the past. While weeding was done manually until now, there has been a growing tendency to use herbicides in cashew plantations in Benin. This could have a negative impact on the quality of water resources. Perennial crops can be easily combined with other crops or activities which improve biodiversity. For example:

- beans under banana trees in Rwanda;
- wild yams under cocoa trees in Togo (in the past);
- bee hives under cashew trees;
- raising ruminants under coconut trees in Benin;
- agroforestry in coffee and cocoa plantations in Togo;
- the taungya system is very popular on perennial crop plots where annual crops (manioc, sweet potato, beans, cowpeas, soy, peanuts, sorghum, maize, etc.) are combined with perennial crops for the plantations first years (up to 4-6 years).

The impact on biodiversity at the landscape level

With respect to the landscape, the perennial cultivation system:

- preserves water and land resources on condition that the use of chemical products (mineral fertilisers, pesticides, insecticides, herbicides, etc.) is well controlled;
- contributes to the fight against erosion and, therefore, protects downstream land from silting;

- contributes to the protection of ecosystems and biodiversity around water sources downstream of perennial crops;
- creates micro-climates which provide habitats for certain animal species.

On the other hand, if large expanses of the landscape are dominated by a single crop, the perennial cultivation system could constitute a threat to certain animal species given the absence of balanced food, notably for some insects and birds.

Key points of the perennial cultivation system

Brief description	Impact on the plot	Impact on the landscape
Plantations (coffee, rubber tree, palm tree, cashews, mangoes, citrus fruits, bananas, etc.) No ploughing, but weeding Significant plant debris Taungya system Can be combined with other crops, trees, livestock, beekeeping, or snails) Use of insecticides	**Negative** • Animals species decrease if the use of insecticides is not regulated **Positive** • Soil conservation • Soil rich in organic matter • Increased water infiltration and better ability to retain water • Presence of organisms and micro-organisms on and in the soil • Presence of insects and molluscs	**Negative** • Food imbalance for certain animal species (insects and birds) **Positive** • Preservation of water and land resources • Waterways, lakes and ponds are protected against silting • Partial recovery of ecological niches and corridors

1.5.2.6. The agroforestry system

The agroforestry system combines forest species with annual or perennial crops. It can be integrated with the cultivation systems described above. The agroforestry system can lead to:

- clearing which only leaves a few tree stands for food, medicine and other uses. This is the case for agroforestry systems based on the baobab (*Adansonia digitata*), African locust bean (*Parkia biglobosa*), shea (*Vitellaria paradoxa*), etc. In West Africa;
- several stands of trees on the plot with avocado trees, ficus trees, castor bean trees (*Ricinus communis*), pigeon pea trees (*Cajanus cajan*), etc. In Rwanda or citrus trees and mango trees in Togo and Benin
- "Assisted Natural Regeneration" (ANR)[23]

23 ANR (Assisted Natural Regeneration): is an agroforestry approach intended to cause or stimulate the natural regeneration of tree species for multiple purposes and/or their development and integration in the agricultural space (field) in order to increase the overall yield of the area (UICN, 2009)

Figure 6: African locust bean tree loaded with pods in a field of subsistence crops in northern Benin
Source: Mulindabigwi, V. 2009

Impact on biodiversity at the plot level

- Agroforestry has several advantages for the plots:
- Protection of the soil against erosion;
- shade for crops, insects and birds;
- production of plant debris which provides organic matter and minerals to the soil;
- recycling of minerals in above-ground areas which are returned to the soil when they decompose;
- improvement in the rate of rainwater infiltration;
- efficient use of water resources and nutrients in the soil via different root systems;
- creation of micro-climates on the plot where insects and birds have their respective habitats;
- diversification of plant species on the plot;
- diversification of food for humans, insects and birds.

In addition, *"scientific work shows that 90% of beneficial insects must leave the crops they help to protect at least once in their lifetime in order to complete their cycle and remain in the agrosystem. The semi-natural habitats created by the woods on the edge or within plots therefore play an essential role in providing shelter, a reproduction zone and a wintering area for all of the species".* The agroforestry system ensures the diversity of plant species, strata, ages and layouts in the area.

Figure 7: Baobab with fruit in a northern Benin landscape which illustrates the benefits of agriculture which is respectful of biodiversity
Source: Mulindabigwi,V. 2009 0

The agroforestry system can be adapted to different cultivation systems. It contributes to the preservation of water and land resources, restores ecological habitats and makes a substantial contribution to the adaptation to climate change

The agroforestry system is one of the rare cultivation systems which improves the overall productivity of plots while creating a temperate micro-climate, sequestering carbon, stimulating and diversifying fauna and flora, regulating the water cycle and preserving and restoring soil fertility. "By providing increased diversity of ecological niches, agroforestry promotes the development of healthy, balanced and productive agrosystems". Agroforestry is currently recommended as a measure to help adaptation to, and mitigation of, climate change. It also strengthens the adaptation to climate change of the biological diversity in cultivated areas.

The impact on biodiversity at the landscape level

The agroforestry system has several benefits for the landscape which have a positive impact on biodiversity. The system creates a micro-climate which can contribute both to enriching the insect and micro-organism population and to diversifying plant species. It is an ecological niche for birds, insects and more and provides areas for reproduction and wintering. In addition, it ensures regulation of the water cycle and preservation of land resources. The agroforestry system can, however, also be a niche for pests which damage crops. When combined with animal husbandry, the agroforestry system reduces the carrying capacity of pastures and requires more space. Regardless, the balance sheet for agroforestry system is positive in terms of the preservation and restoration of biodiversity.

Key points of the agroforestry system

Brief description	Impact on the plot	Impact on the landscape
Combination of crops and trees Trees remaining after clearing or planted or obtained by artificial natural regeneration	**Negative** • Competition for light • Reduced crop yields • Habitat for crop pests **Positive** • Shade to protect crops against high temperatures • Decrease in soil erosion • Increase in soil water retention capacity • Decrease in water evaporation from the soil • Recycling of soil nutrients • Creation of micro-climates and niches for insects and birds • Diversity of plant species, strata, ages and layouts in the area • Preservation of soil fertility • Balanced food supply for insects and birds • Wood production (diversification of income sources	**Negative** • Habitat for crop pests • Reduced pasture carry capacity (to reduce damage to trees) **Positive** • Temperate micro-climate • Shelter and reproduction and wintering area • Increased diversity of ecological niches • Diversification of fauna and flora • Regulation of the water cycle • Preservation and restoration of soil fertility • Healthy, balanced and productive agrosystems

1.5.2.7. The irrigated cultivation system

The irrigated cultivation system is a system which is generally used for a single commercial crop, for example, rice. Faced with the harmful effects of climate change, irrigated cultivation is one of the adaptation measures that can be taken and it is becoming increasingly important. The land used for irrigated cultivation is usually in lower regions and valleys. The irrigated cultivation system uses different water sources, the most important of which are: rivers, lakes, wetlands, reservoirs, dams, rainwater stored temporarily in the ground, groundwater and recycled water. Small-scale irrigation, which doesn't require significant preparation work, is often used by farmers. It enables a significant increase in agricultural productivity at the plot level. Irrigated crops tend to focus on a single crop. This applies both to small and large farms (decrease in biodiversity). The current tendency is to move from subsistence farming to commercial agriculture, unfortunately typified by the erosion of biodiversity.

The irrigated cultivation system increases agricultural yields and enables adaptation to climate change but can be a handicap for biodiversity if the cultivation areas and systems do not take biodiversity into account.

The impact on biodiversity at the landscape level

Depending on the choice of irrigation water source, the irrigated cultivation system will have different impacts on biodiversity. Aquatic environments and their surroundings are ecosystems and ecological niches which are rich in biodiversity and play an important role in maintaining ecological networks and interconnections. The irrigated cultivation system entails negative changes to these environments which in turn negatively impact biodiversity:

- the construction of water retention structures and dams often floods large areas and destroys many non-aquatic plant and animal species;
- re-routing rivers and taking water from rivers for irrigation has a negative impact on biodiversity downstream;
- the use of lake water for irrigation threatens to dry out the lakes and disrupt their ecosystemic equilibrium:
- The use of groundwater for irrigation can affect the water table level and have a negative impact on the availability of water resources and the vegetation cover and consequently reduce the number of plant and animal species.

Figure 8: A plot of irrigated rice in a low-lying area in Benin
Source: Mulindabigwi, V. 2010

In addition, the type of irrigation used also determines the impact of the irrigated cultivation system on biodiversity. According to the FAO (1990) there are several irrigation methods: basin irrigation, furrow irrigation, border irrigation, sprinkler irrigation and drip irrigation. These methods can be further divided into three main categories: gravity irrigation; sprinkler irrigation and localised micro-irrigation using a drip system. The salinisation of soils is one of the consequences of irrigated cultivation system. The main consequences are plant toxicity and deterioration of the land leading to the deterioration of biodiversity.

Impact on biodiversity at the plot level

The irrigated cultivation system can have a number of different effects at the plot level depending on the irrigation techniques used. Submersion irrigation reduces biological diversity in the soil while drip irrigation or sprinkler irrigation can contribute to improving biological diversity.

Key points of the irrigated cultivation system

Brief description	Impact on the plot	Impact on the landscape
Generally, a single crop (commercial) No fallow period or very short (R>70) Low percentage of irrigated land Intensive farming using chemical products (mineral fertilisers, pesticides, etc.) Irrigated land is generally in valleys and low-lying areas Sources of irrigation water: rivers, lakes, wetlands, water retention areas or dams, stored rainwater, groundwater and recycled water; Types of irrigation: basin, furrow, border, sprinkler and drip.	**Negative** • Salinisation resulting in the sterilisation of soils resulting in the disappearance of plant and animal species (both aquatic and land-based) • Pollution of groundwater and waterways if the use of chemicals isn't regulated • Enormous water losses if the irrigation techniques are inadequate (40 to 60% of irrigation water is lost in Africa) • Drying out of the plot if the implementation is not done properly. **Positive** • Potential crop diversification (water is no longer a limitation) • Increase in plot productivity • Agricultural production losses due to drought are limited • Adaptation to climate change	**Negative** • Destruction or disruption of ecosystems • Destruction of ecological niches of plant and animal species • Drying out of water sources (lakes, wetlands, rivers, groundwater, etc.) if water pumping is excessive or the implementation is poorly done • Pollution of the water by the use of chemical products (e.g., mineral fertilisers, pesticides, etc.) • Major water consumption can contribute to accelerated desertification and to conflicts between the users of water resources **Positive** • Food security for the population • Socioeconomic development of the zone • Adoption of integrated management measures for the water resources to preserve irrigation water • Integrated catchment area management restores biological diversity

1.5.2.8. The organic cultivation system

The organic cultivation system does not use most synthetic chemical products or genetically modified organisms. Soil fertilisation is done using organic matter, green fertilisers and/or composting. The coupling of agriculture/livestock is important for the production large quantities of high-quality manure. In addition, the organic cultivation system relies on crop rotation, cover crops and reduced soil work. This reduces carbon emissions by the quick decomposition of organic matter contained in the soil. With respect to protecting plants against weeds, diseases and pests, the organic cultivation system uses organic practices. The most important ones are:

- organic pesticides and herbicides;
- biodegradable ecological films;
- insects and micro-organisms to eliminate predators;
- sowing repelling plants, etc.

The organic cultivation system does not use most synthetic chemical products or genetically modified organisms. It contributes to the preservation of water and land resources. However, when commercial, it favours monoculture over biodiversity.

Impact on biodiversity at the plot level

At the plot level, the organic cultivation system preserves soil fertility, fauna and flora. Water and land resources are not exposed to pollution through the use of pesticides, insecticides or mineral fertilisers. However, the organic cultivation system has become economically viable and farmers are tending to eliminate crop rotations to maximise income at the expense of biodiversity.

In terms of the landscape, the organic cultivation system "*enables the preservation and strengthening of biodiversity, promotes the balance between parasites and beneficial animals and reduces pollution of the environment. In terms of soil fertility, the requirement for organic soil conditioners and crop rotation enable the sustainable fertility of soils and sustained production of commercial crops and rotation cereal crops* enabling the strengthening of the means of existence and adaptation to the effects of desertification and climate change" (EU, OSC and SPONG, 2012). However, given the relatively lower yields, organic agriculture could lead to the enlargement of growing areas at the expense of natural habitats, long-term fallow and pastures.

Key points of the organic cultivation system

Brief description	Impact on the plot	Impact on the landscape
Synthetic chemical products or genetically modified organisms are not used Soil fertilisation with organic matter (green fertilisers, compost) Very high agriculture/ livestock pairing Crop rotation	**Negative** • Lower crop yields than with conventional agriculture • More labour required **Positive** • Less water and energy consumption • Preservation of soil fertility • Preservation of water resources (qualitative and quantitative) • Preservation of ground fauna • Preservation of insect diversity • Healthy agricultural production (vegetables contain more minerals and nutrients than those grown by conventional methods)	**Negative** • Limited use of the space available to enable crop rotation and fallow periods **Positive** • Crop rotation and fallow periods • Preservation of water and land resources • Preservation of animal species diversity • Production of healthy agricultural products • Job creation in the zone (requires labour)

1.5.2.9. The agroecological cultivation system

The agroecological cultivation system is ideal for ensuring the sustainability of agricultural production, the management of water and land resources and the preservation and restoration of biodiversity. Contrary to organic farming, which also respects the environment but is primarily limited to avoiding the use of synthetic chemical products and genetically modified organisms, the agroecological cultivation system is based, in addition, on rotations and crop combinations, agroforestry and fallow periods for the plots. The system tries to understand how nature works, to rebuild the complementarity of trees, crops, animals, insects, micro-organisms, etc. on the plots and in the landscape.

Soil, Water, Plants, Animals and the Landscape are in constant interaction (Figure 9):

- The soil is the result of altering the bedrock and is fashioned by Man.
- The soil contains nutritional elements required for plant development which assimilates them using water (role of the root system).
- Plants in the leguminous family fix nitrogen in the soil.
- The water in the subsoil provides for irrigating the plants and resources to deep-rooted plants.
- Plants feed animals.
- Animals provide organic matter (manure): it nourishes the soil which in turn nourishes plants = recycling.
- The landscape protects the plant (windbreak) and nourishes the soil (providing biomass) which nourishes plants = recycling.

- Plants protect the soil from solar radiation, wind, and strong rain.
- Plants, through photosynthesis, absorb carbon dioxide, sequester carbon, and release oxygen into the atmosphere. Soil that is protected and enriched with organic matter has better water-retention capacity and better capacity for fixing nutritive elements...

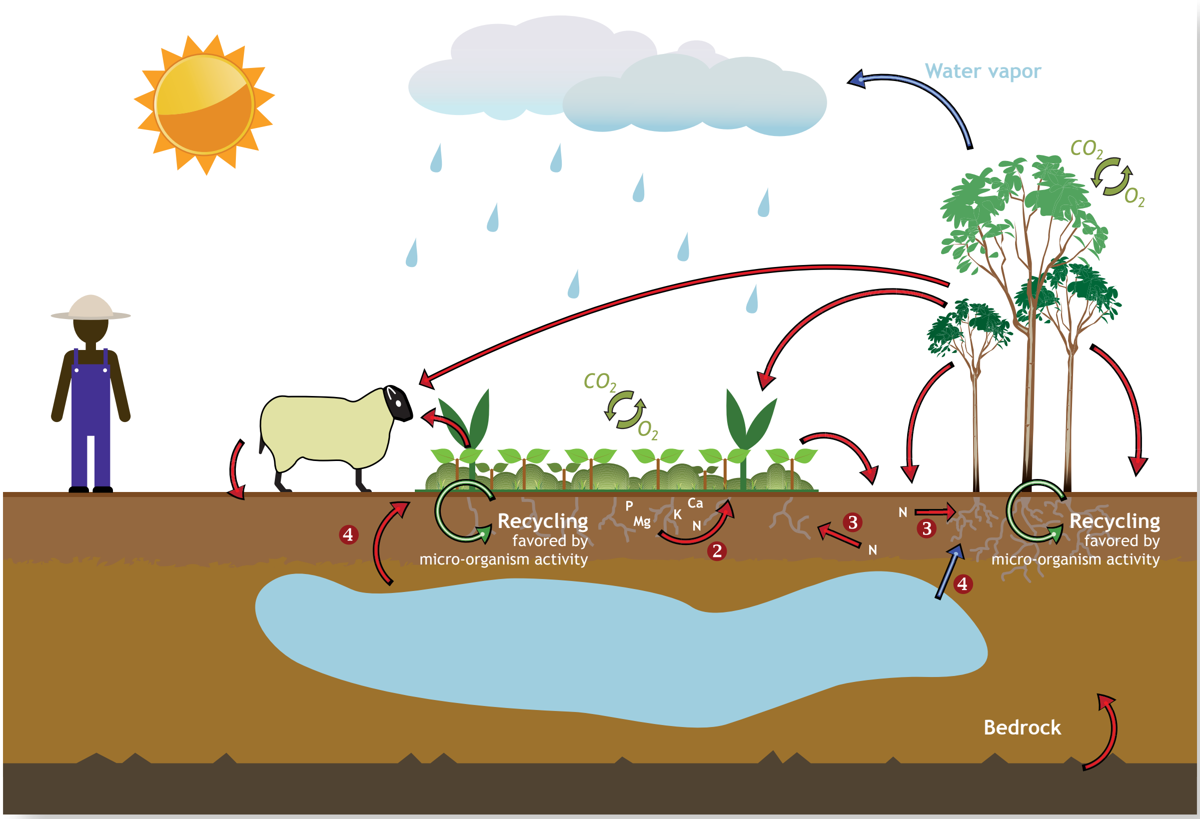

Figure 9: Elements of an agrosystem and their interaction
(Source: adapted from AGRISUD INTERNATIONAL, 2010;
http://www.agrisud.org/wp-content/uploads/2013/05/Guide_Francais.pdf)

The agroecological cultivation system is the system that works with nature and seeks the complementarity of trees, crops, animals, insects, micro-organisms, etc. on the plots and in the landscape. It is ideal for biodiversity

However, this system has not received technical or financial support or, therefore, support to promote its development. The efforts of government and technical and financial partners have favoured export crops and, generally, monocultures (e.g. bananas in Cameroon, cocoa in Ghana and in Côte d'Ivoire, coffee in Uganda, cashews in Mozambique and Guinea, cotton, etc.) or subsistence crops without taking the agroecological approach into account. With the growing demographic pressure on land and the increasing importance of the intensification of supply chain agriculture, semi-permanent polyculture cultivation system resembling the agroecological cultivation system is giving way to other farming systems which damage biodiversity.

However, with the agroecological cultivation system, we could also achieve high agricultural yields while preserving biodiversity (preservation of heritage seeds, rebuilding of ecological niches, etc.). Thanks to its diversity at the plot and landscape levels, the agroecological system can limit (minimise the risks) of economic and climate disruptions. In addition, by reducing the use of external inputs (chemical products, including mineral fertilisers, pesticides, etc.) connected to fossil fuels, the agroecological cultivation system provides high profitability. Lastly, thanks to the diversity of its production, the agroecological cultivation system provides communities with food independence and quality (balanced) food.

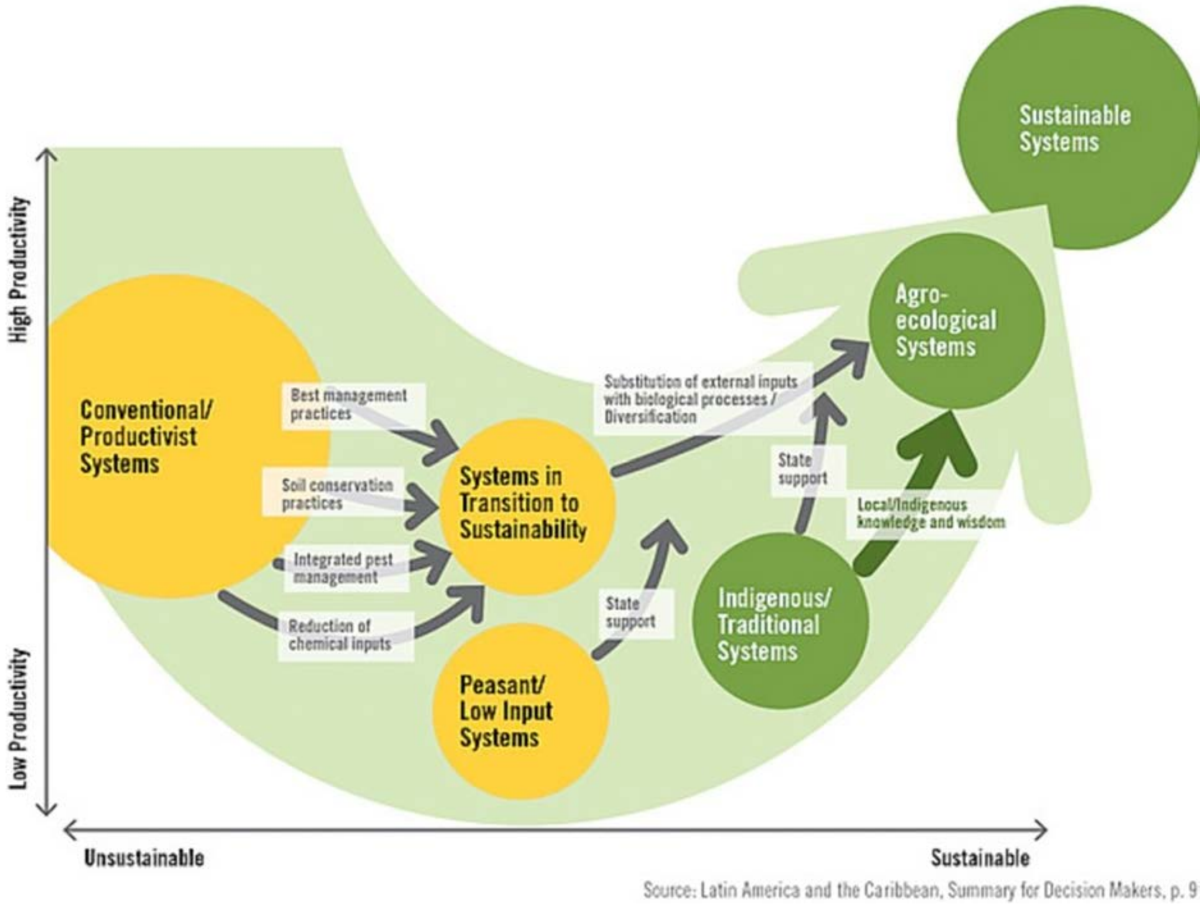

Figure 10: Principles of agroecology
(Source: Globalagriculture.org)

Key points of the agroecological cultivation system

Brief description	Impact on the plot	Impact on the landscape
Combination of different crops Combination of trees Agriculture/ livestock coupling Crop rotation Organic fertilisation Light or no labour Genetically modified seeds are not used Complementarity of crops, trees, animals, insects, organisms and micro-organisms	**Negative** • Natural phytosanitary treatments are often less effective than synthetic chemical products (but beneficial in the medium to long term) • Lower individual crop yields (but high total crop yields when considered together) • Requires significant labour **Positive** • Fights soil erosion • Biomass recycling • Improved soil fertility • Reduced use of artificial inputs harmful to the environment • Improved biological soil activity • Optimised use of water and soil nutrients • Fights soil deterioration • Optimised use of soil nutrients and water resources • Improved species diversity on the plot • Biological synergies between ecosystem components • Crop production staggered over time • Adaptation to the harmful effects of climate change	**Negative** • Large areas are required (rotation, fallow, etc.) **Positive** • Reduced use of artificial inputs harmful to the environment • Fight against desertification • Preservation of biodiversity • Preservation of water and land resources • Reuse of natural and local resources • Healthy food for the population • Increase in resistance and resilience thanks to rotation and the association of crops and the combination of agriculture and livestock • Food security for the population • Stabilisation of populations in their ecosystems • Improvement in genetic diversity and species • Biological synergies between ecosystem components • Job creation.

1.5.3. Impact of vegetable and fruit production on biodiversity

Analysis of the impact of vegetable and fruit production in many ACP countries can be understood from two main angles: production for own consumption and commercial production.

The production of fruits and vegetables for own consumption is generally integrated in the different traditional production systems listed above which hardly use any chemical inputs and are normally polycultures. Although the main objective is not to sell, farmers will take their surplus vegetable and/or fruit production to the local markets, which enables them to increase their farm income. The production of vegetables and fruits is generally healthy and compatible with biodiversity but subject to many limitations and constraints for commercial production, and especially export.

The commercial production of fruits and vegetables is generally intensive (use of chemical inputs, monocultures, etc.). In some cases, it is carried out in organic cultivation systems and, in rare instances, in agroecological cultivation systems. Vegetable farming uses a great deal of water (e.g., tomatoes, lettuce, cabbage, cauliflower, amaranth, etc.) and chemical inputs. It, therefore, has a high potential to be a significant factor in the deterioration of biodiversity if measures to promote production systems which are respectful of biodiversity are not taken and implemented. In the case of most fruits, production is carried out in perennial production systems which are generally positive for biodiversity, on condition that the use of agricultural inputs is regulated.

1.6. BIODIVERSITY RISKS

Biodiversity provides many services to a range of field including agriculture. It contributes to improving agricultural yields, to reducing farming costs and to the environment. However, it also creates risks in some instances.

The agents responsible for these risks include pests, birds, monkeys, hippopotamuses and the seeds of weeds. They can transmit diseases, devastate crops, lead to the loss of entire harvests, etc.

1.6.1. Disease spread by contact with animals

Wildlife and domestic animals can transmit many diseases through contact, licking (saliva), scratching and biting:

- Certain species (snakes, scorpions, frogs, toads, fish, jellyfish, etc.) are also highly venomous.
- Avian influenza (birds, poultry, etc.) is a recent example of an emerging disease transmitted to humans from an animal reservoir[24].
- Rabies is a viral disease which attacks the nervous system. It can be fatal if a vaccine isn't administered quickly.
- Rodents can also transmit diseases to humans and other animals: Leptospirosis (also known as "Weil's disease"), salmonella poisoning, Haverhill fever (rat-bite fever), tularaemia, meningitis, tapeworms, infectious jaundice, bubonic plague and hantavirus[25]. Voles and field mice are rodents which also eat birds. They are vectors for hantavirus, a virus which is found in their urine, stool and saliva.
- Although bats are the best mammals with respect to safeguarding biodiversity, they are also a reservoir of many fatal diseases including Ebola, Marburg disease and human and animal rabies, some of which are the source of devastating epidemics.

24 http://www.voyagezen.fr/risques-sanitaires-iles-canaries/
25 http://www.rentokil.fr/blog/9-maladies-transmissibles-vehiculees-par-les-rongeurs/

Bats (a)

Field mice (b)

Bank voles (c)

Figure 8: Several mammals which are disease vectors
Source: (a) Konaté and Kampmann (2010) (b) https://anipassion.com/rongeurs/conseils / http://www.nhe-services.fr/rongeurs,(c) http://www.ulb.ac.be/sciences/use/documents/Presse/maladies_animaux_ulb.pdf

In order to prevent contamination people must wash their hands, avoid contact with these animals at all times, clean and disinfect any surfaces which are contaminated or could be contaminated by rodents,

1.6.2. Crop destruction by pests[26]

1.6.2.1. Definition of a pest

Crop pests are animals which attack crops or stored harvests and cause financial harm to farmers. Pests can cause direct damage to cultivated plants by eating (plant-eating, wood-eating, etc.) or by their parasitic life style or via indirect damage, for example, when they are vectors for diseases such as viral diseases.

There are five categories of pests: mammals (primarily rodents), birds, nematodes, arthropods (primarily insects and acarids) and molluscs.

26 http://www.lespetitsdebrouillards.org/Media/prods/prod_1/Media/livret.pdf
https://www.un-jardin-bio.com/rongeurs-au-jardin-potager-bio/

A "pest" is animal which humans consider to be dangerous for crops, for trees and for vegetation in general, contrary to beneficial animals which assist agricultural production. The concept is very subjective. A "pest" is only harmful depending on their environment:

1. where they can attack plants that are useful to humans (crops, ornamental plants, etc.)
2. when it promotes their proliferation (no predators, when host plant or prey has low immunities or no defence against the new "aggressor").

When a plant is grown on a large scale, the species will take advantage of the concentration of host plants to multiply and, therefore, harm the benefit humans expect from their crops.

Some animals/insects have been described as "pests" for several centuries whereas others, recently introduced outside of their original range are, in fact, exotic insects which have been imported (accidentally or intentionally). Given that they have no natural predators or parasites, some species can adapt to their new environment with new behaviour which is much more aggressive toward crops. When they spread over a wide range, they are classified as invasive species.

Example of the subjectivity of the "pest" concept: Phylloxera

One of the most representative instances of the subjectivity of the pest concept is phylloxera (*Daktulosphaira vitifoliae*). This grapevine aphid attacks the roots of the plant and sucks on its sap. While its existence went unnoticed in North America because the native vines are resistant, its introduction in Europe in the 19th century decimated vineyards for over 30 years.

It was introduced by nurseries or careless experimenters and gradually infested grapevines around the world despite the protection measures implemented by the United States. Wine growers were forced to completely change their vine stock reproduction methods. Instead of using European rootstocks, they had to use American ones which were resistant to the pest. Phylloxera is still present in most vineyards but the rootstocks are now resistant and it is no longer considered to be a "pest" that has to be controlled.

1.6.2.2. Mammals

Among mammals, rodents are the main pests (field rats, voles, mole-rats, field mice, moles, rabbits, etc.) which can cause many problems in the fields (carrots completely eaten, smaller potato crops, etc.) and to stored harvests. The damage is regular, but can also be sudden and very serious.

Rabbit Gerbil Field rat Dormousew

Figure 9: A few rodents harmful to crops
Source : https://anipassion.com/rongeurs/conseils / http://www.nhe-services.fr/rongeurs

One of the methods or combination of methods to protect crops and harvests against rodents below can be used depending on the specific conditions and the level of harm done:

- **Traps**: the rodents are trapped and released where do won't do damage.
- **Ultrasounds to repel the rodents:** The use of special ultrasounds is another solution to rodent problems.

Certain natural predators like cats can be used. Although less popular, grass snakes can also be used. Lastly, some plants can also be used to repel rodents. They include the *Fritillaria imperialis*, a toxic ornamental plant whose bulbs have a disagreeable smell.

1.6.2.3. Birds

Bird beaks are shaped and sized differently depending on their diet (insectivore, granivore, frugivore, carnivore, herbivore, nectarivore or omnivore). In their search for food, some birds eat crop seeds, grains and fruit and sometimes contribute to the destruction of crops. Others ensure pollination or contribute to organic pest control. As a result, there are conflicts between farmers and wildlife.

Insectivores Granivores Omnivores: grains, insects, worms, fruit

Frugivores and granivores

Nectarivores

Herbivores; solid particles

Figure 10: A few birds according to their diet
Source: http://www.lespetitsdebrouillards.org/Media/prods/prod_1/Media/livret.pdf

To limit the downsides:

- They can be captured;
- Rodents can be used to eat the birds;
- The birds can be frightened away using sound systems or scarecrows (human figures) in the fields;
- Crops can be combined.

1.6.2.4. Nematodes[27]

There are many species of nematodes (over 27,000) which are nearly microscopic worms (0.5 to 3 mm) which live in the ground: some are formidable pests which attack vegetable gardens and others are precious allies for the decomposition of plant matter on the ground.

They go after most plants, but primarily the roots of tomato and potato plants. This causes the stems and leaves to dry out. They are harmful for gardens and not easy to eliminate naturally. However, there are ways to fight them using nematocide plants whose roots secret a chemical substance called thiophene which inhibits the growth of these microscopic bugs. This is particularly true for all Tagetes, a genus to which the French marigold belongs.

However, there are useful nematodes. In nature, certain nematodes are underground allies that help decomposition, transforming plant matter and dead animals into compost called humus. They release mineral elements, particularly nitrogen, which plants need to grow. Nematodes live a few centimetres underground, together with other small creatures including woodlice, centipedes, ants, bacteria, etc. They make up a mesofauna which is also found in compost, where they also contribute to decomposition.

27 https://jardinage.lemonde.fr/dossier-1023-nematodes-ravageurs-redoutables-auxiliaires-precieux.html

1.6.2.5. Arthropods[28]

Of an estimated 500,000 species of phytophageous insects, only 10,000 are considered to be a risk to agriculture (Riba and Silvy, 1989).

Among the pests present "naturally", the desert locust is dreaded and widespread around the world. During swarming periods, they can reach southern Europe, Africa north of the equator and the Arabian Peninsula, India and Pakistan. They are harmless to crops when alone but swarms can be very dangerous because they are voracious, highly mobile, cover vast areas and move in very large numbers. For example, the last major invasion of locusts lasted from 2003 to 2005 and devastated millions of hectares in 20 North African countries. Thirteen million litres of pesticides were needed to put an end to it. It cost over half a billion dollars and caused over $2.5 billion in lost crops.

Figure 11: Locust colony eating a manioc field
Source: http://cd.one.un.org/content/unct/rdc/fr/home/actualites/la-securite-alimentaire-de-plus-de-15-000-menages-menaces-en-itu.html

In addition to insects, harmful arthropods also include acarids. These pests do significant damage to many crops. They reproduce quickly, causing a great deal of damage over a short period of time. The red spider mite (*Tetranychus urticae)* is the most common pest found in greenhouses. Other types of acarids also cause damage to field crops.

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28 https://www.usherbrooke.ca/environnement/fileadmin/sites/environnement/documents/Essais2010/Lambert_N__12-07-2010_.pdf

1.6.2.6. Molluscs[29]

Snails and slugs are two land gastropod molluscs which have a soft body and two pairs of tentacles on their head, one of which is used to detect smells and the other for sight. The muscular contractions that move down the ventral of the foot move the molluscs, which secret mucus, a lubricant which facilitates their movement and also protects them against bacterial and viral infections, etc. They use their radula (a rasping tongue) to eat. They primarily eat plants, with a preference for cabbage, lettuce, nettles, etc. They are hermaphrodites, with both male and female organs, but reproduce by coupling.

They are particularly harmful when weather conditions are damp. Snails and slugs eat young plants, fruits, tubers, fleshy roots and leaves. They cause enormous damage to crops and gardens. They are voracious and prolific. They make holes and cut the leaves of edible plants. These pests destroy lettuce crops, make holes in cultivated plant leaves and will also eat radishes. They eat the stems and flowers of ornamental plants and of garden vegetables. The harmful behaviour of snails and slugs causes visible damage to cultivated and wild plants.

There are a number of alternatives to chemical products to fight effectively and organically against snails and slugs, notably repelling plants. They chase away molluscs which do not like their smell. Crops can be surrounded with onions, chives and begonias. The smell of garlic and mustard also repels these pests or slows their progress.

1.6.3. Weeds

Weeds are plants which grow in places they are not wanted or when they are not wanted during the growing season. Weeds are usually not wanted in planted fields because they compete with crops for water, nutrients and sunlight and prevent them from growing under ideal conditions. Weeds can also reduce benefits by interfering with harvest, negatively impacting the quality of the harvest and producing seeds or rhizomes which infest the fields and, in turn, the next crops.

1.6.3.1. Preventive measures and elimination of weeds

Several preventive measures can be applied at the same time. The importance and effectiveness of the different methods will depend to a great extent on the types of weeds and environmental conditions. However, some methods are very effective for a wide range of weeds and, therefore, used frequently:

1. Mulching: the weeds are not able to get enough sunlight to grow and may not be able to get past the layer of mulch. Hard, dry plant matter decomposes slowly and has a longer protective effect than fresh mulch.
2. Cover vegetation: successfully competes with weeds for sunlight, nutrients and water and therefore helps to prevent them from growing by denying them the resources they need.

29 Source: Snails and slugs, gastropods // Agroneo

3. Crop rotation: the most effective technique for controlling weed roots and seed. The changes in crop conditions interrupt the growth cycle of weeds and prevent their growth and spreading.
4. Sowing time and density: a) the pressure from weeds during the critical period (juvenile stage of the crop) can be reduced by sowing at the right time; b) sowing density can be increased when significant pressure from weeds is expected.
5. Balanced fertilising: can increase the crop's strength and promote its growth to the detriment of the weeds.
6. The methods used to work the soil can have an impact on the pressure from weeds and on their diversity: a) for example, minimal ploughing systems can increase the pressure from weeds, especially, that of stoloniferous species; b) given that the seeds of weeds can germinate during the period between ploughing and sowing, weeding before sowing can be an effective way to reduce the pressure from weeds; c) the use of superficial stubble (the part of the grain plants which remains after the harvest) is effective against persistent weeds. However, this must be done under dry conditions to ensure that the roots of the weeds that are brought to surface dry out.
7. Prevent the spread of weeds by eliminating them before their seeds are dispersed.
8. Reduce the risk of infestation of grain crops by weeds by avoiding the introduction of weed seeds into the fields via tools or animals.
9. The application of manure or compost which has not been thoroughly fermented can also be a source of contamination by weeds.

Insert 4: Example of a dangerous weed in Africa: *Striga spp.*, witchweed

A total area of 48 million hectares of cereal-growing regions in Africa is potentially threatened by weeds like Striga (witchweed). Striga is a parasite of cereal crops like maize, sorghum, millet and rice. After it germinates, Striga penetrates the root of the host plant to draw nutrients. It causes significant damage which can be seen in the gradual discolouration of the plant's leaves. These negative effects reduce yields by 30% to 70%.

Striga was a real headache for farmers in the Sahel for many years. The soil is often poor and easily invaded by this weed. The Striga seed matures two to three months after the main crop is harvested (sown during the rainy season). Inexperienced farmers would leave the Striga seedlings in their field during fallow periods. However, the plants would become a source of infestation as their seeds were dispersed by the wind. The farmers were often forced to abandon their fields because the infestations were so severe that it became impossible to grow anything.[30]

30 Additional information is available in the COLEACP manual: "Integrated management of bioaggressors".

1.7. APPENDIX: SAMPLE LAWS AND REGULATIONS (BENIN)

1.7.1. A1. Animal resources (wildlife/animals, etc.)

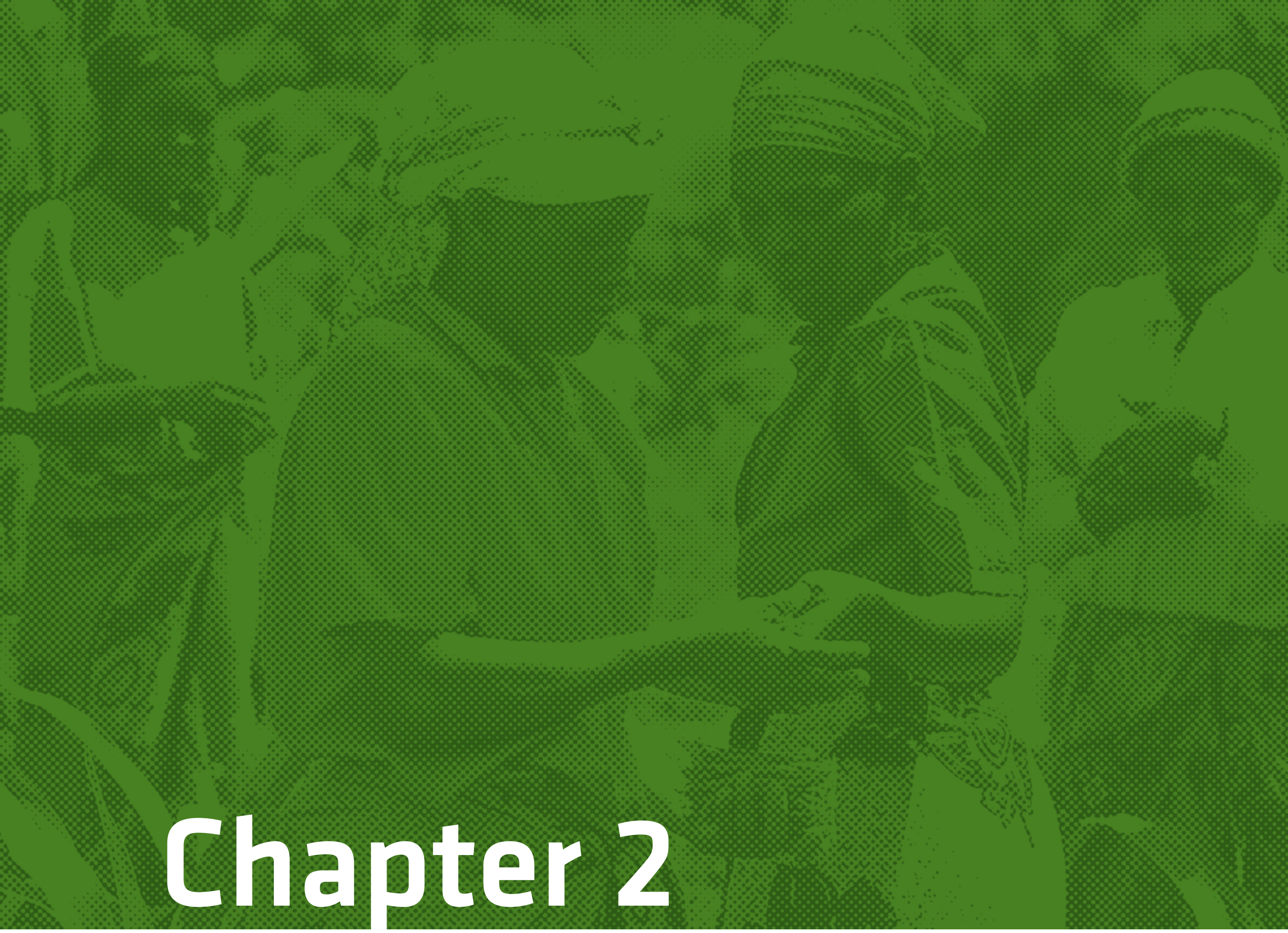
- Law No. 87-013 of 21 September 1987, regulating common grazing, the custody of domestic animals and transhumance.
- Law N° 87-014 of 21 September 1987 regulating the protection of nature and hunting in the People's Republic of Benin (repealed by Law 2002-16 of 18 October 2004.
- Law N° 87-030 of 12 February 1999 on the framework law for the environment in the Republic of Benin.
- Law N° 93-011 of 3 August 1993 on the conditions for hunting and visual tourism in the Republic of Benin.
- Law N° 2002-16 of 18 October 2004 on fauna management in the Republic of Benin.
- Law N° 2014-09 of 7 August 2014 on fisheries and aquaculture in the Republic of Benin.
- Decree N° 83-204 of 31 May 1983 on the membership of the People's Republic of Benin in the Bonn Convention on the Conservation of Migratory Species of Wild Animals signed on 23 June 1979.

1.7.2. A2. Water resources

- Law N° 2010-44 on water management in the Republic of Benin.
- Law N° 2013-01 of 14 January 2013 on land and state-owned property in the Republic of Benin.
- Law N° 98-030 of 12 February 1999 on the framework law for the environment in the Republic of Benin.
- Law N° 2013-01 of 14 August 2013 on land and state-owned property in the Republic of Benin.
- Decree N° 83-435 of 30 December 1982 prohibiting brush fires and plantation fires in the Republic of Benin.
- Decree N° 2001-094 of 20 February 2001 setting the quality standards for drinking water in the Republic of Benin.
- Decree N° 2001-109 of 4 April 2001 setting the quality standards for waste water in the Republic of Benin.
- Decree N° 2011-671 of 5 October 2011 defining the procedures for setting protection perimeters.

1.7.3. A3. Land resources

- Law N° 87-030 of 12 February 1999 on the framework law for the environment in the Republic of Benin.
- Law N° 2013-01 of 14 January 2013 on the land and state-owned property in the Republic of Benin.
- Law N° 2013-01 of 14 August 2013 on land and state-owned property in the Republic of Benin.
- Decree N° 83-435 of 30 December 1982 prohibiting brush fires and plantation fires in the Republic of Benin.
- Decree N° 83-291 of 23 July 1982 instituting National Tree Day.
- Decree N° 96-271 of 2 July 1996. Forest management implementation decree.



Chapter 2

Biodiversity Assessment

2.1. BIODIVERSITY AT THE FARM LEVEL

2.1.1. Domesticated and wild biodiversity

Both the species diversity and landscape diversity of a farm can be examined. In terms of species, there are two types of biodiversity: domesticated diversity and wild biodiversity.

i. ***Domesticated biodiversity***

Domesticated biodiversity includes the collection and richness of species and subspecies (races, varieties) domesticated by humans and subjected to artificial selection. The term "domesticated biodiversity" is also used to express the global decline in the diversity of cultivated and raised species in recent years.

ii. ***Wild biodiversity***

Wild biodiversity exists spontaneously, is often not directly managed by humans but is greatly influenced by human activity. Wild biodiversity can be exceptional or ordinary. It is *exceptional* when it is made up of living organisms and habitats which are rare or at risk of disappearing. In this case, it can be regulated. In the opposite case, it said to be ordinary. Wild biodiversity plays many roles in maintaining the balance of ecosystems (oxygen production, carbon sequestration, temperature regulation, etc.). It provides many ecological services for agriculture (e.g. soil fertility, water purification, pest control, pollination, living environment). Seen from the angle of its ecological services, it is known as functional biodiversity.

Several scientific publications demonstrate the importance of a mosaic landscape for the conservation of biodiversity in agricultural zones. This heterogeneity is based on the diversity of the crops present, but also and especially on the presence of natural and semi-natural environments such as hedges, untreated and non-fertilised plot edges, copses and untreated and non-fertilised grassy areas. These areas are known as Agro-Ecological Infrastructures (AEIs), biodiversity promotion areas (BPAs), and biotopes. They contribute to the diversity of wild species whether they are functional or not. All farms should include a sufficient amount (% of the farm's land) and quality of AEIs.

The biodiversity promotion areas (BPAs) are useful because numerous species of plants and animals cannot survive on intensively-farmed agricultural land. The BPAs properly maintain and support existing environments which are close to their natural state. If there are no suitable areas on the farm, new ones must be created. BPAs are developed and maintained extensively in order to conserve the plants which are typical of meadows, pastures, copses and fields, in order for wild animals to have access to ideal protection and feeding conditions[31].

31 Biodiversity on the farm - Practical guide - FIBL 2016

Figure 1 illustrates these different types of biodiversity.

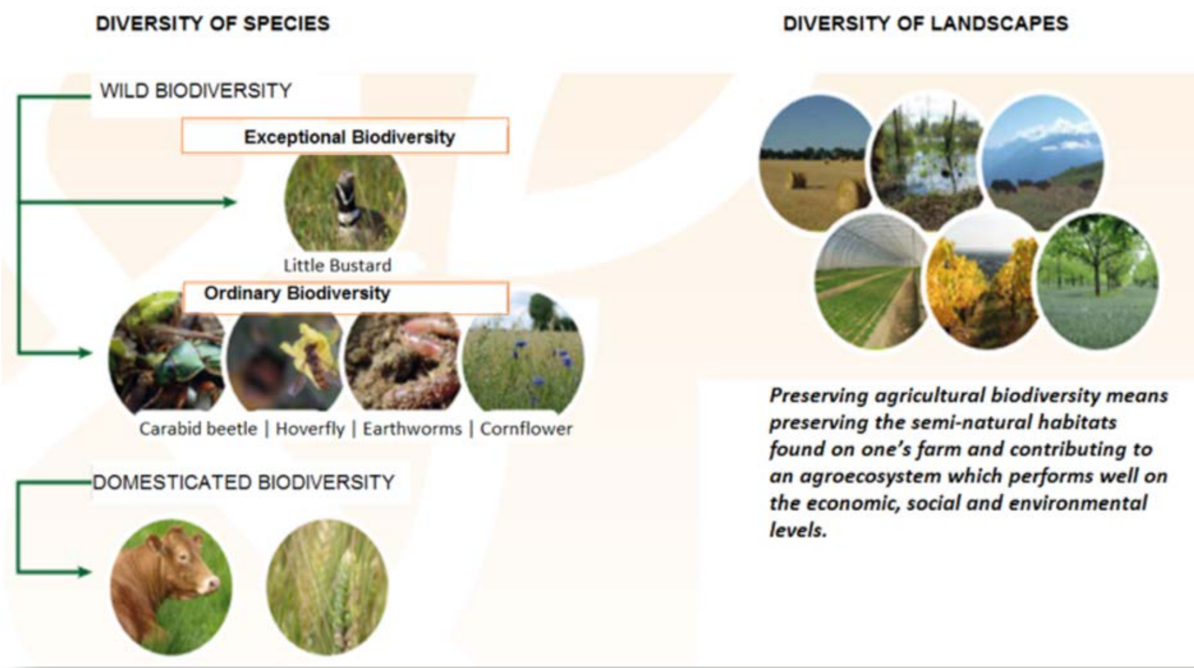


Figure 1: Different types of biodiversity (Source: Tech&bio, 2015)[32]

Agriculture can contribute to creating and/or conserving biodiversity. At the farm level, for example, if the conditions are known and respected, it is possible, via layouts and suitable practices, to have, to a certain extent, the three levels of biodiversity described at the beginning of this chapter (genetic diversity, species diversity and ecosystem diversity (or environment diversity). This will be covered in more depth in the other chapters of this manual.

For example: the ARFA Agroecological Farm (Association pour la Recherche et la Formation en Agro-écologie) located in the village of Natiaboani, 45 km from Fada N'Gourma, in Burkina Faso. This farm was initially set up in an arid area in 1996. Thanks to agroecological practices, this once arid and almost desert area has been transformed into a true reservoir of biodiversity.

In fact, in terms of the number of animal and plant species, we can draw a distinction between wild species and domesticated species. On the farm, domesticated species refers to:

- cultivated plants: cereals (millet, maize, rice), legumes (cowpea, peanut), oleaginous plants (sesame), vegetables (tomato, bell pepper, green bean, chilli pepper);
- trees and fruit trees: mango, papaya, jujube, lemon, moringa, gum arabic (*Acacia nilotiqua*), white acacia (*Acacia albida*);
- animals: poultry (chickens, guinea fowl, ducks, geese), mammals (cattle, sheep, goats, donkeys, pigs).

32 Tech&bio, 2015: Biodiversity (Poster) http://www.tech-n-bio.com/le-salon-bio-et conventionnel/programme/supports-techniques-2015.html?file=tl_files/2015-

As for wild species, there are:

- non-cultivated plants: several kinds of grasses and nearly 80 identified species of woody plants;
- wild animals: hares, squirrels, monkeys, monitor lizards, partridges, etc.

In terms of the diversity of environments, different environments overlap and allow the movement of species. This proliferation of life is the result of agroecological practices which integrate the management of natural resources via:

- the implementation of a planted anti-erosion system which forms crop corridors;
- the use of land based on its agricultural capacities;
- the integration of agricultural, forestry and pastoral production systems to improve yields and for better natural resources management;
- laying out pasture areas for small ruminant animals;
- enhancing the value of local resources (composting by-products)
- establishing an agroforestry park;
- establishing a forest reserve;
- collecting rainwater and using it efficiently in agropastoral production activities.

At the genetic level, different layouts and practices have produced new species over the years and within the species, plant varieties and domestic and wild animal races which are in contrast to the immediate surroundings of the farms.

2.1.2. Why assess the "level" of biodiversity on a farm

When agricultural land takes up a significant portion of a region's land, agriculture must be considered the primary anthropic factor affecting biodiversity. [33]

In South Africa, 80% of the land is agricultural (69% as pastures). The maintenance of ecosystem health therefore lies in the hands of South Africa's farmers.

In South Africa, 80% of the land is agricultural (69% as pastures). The maintenance of ecosystem health therefore lies in the hands of South Africa's farmers.[34]

In these regions, agricultural areas are home to a significant level of wild biodiversity, whether "ordinary" or "exceptional".

33 http://biodiversityadvisor.sanbi.org/wp-content/uploads/2012/11/GreenChoice_Living_Farms_Reference.pdf

At the European level, 46% of the natural habitats of community interest and 173 priority bird species are found in agricultural areas.

In France, 90% of protected plant species are linked to agricultural activities.

A link between a decline in the biodiversity of agricultural lands and the modernisation of agriculture in recent decades can often be observed. The latter has led to a specialisation of production at the farm and regional levels and to a significant change in production methods. There has been an intensification of productive land: massive use of synthetic fertilisers, phytosanitary products and re-parcelling to facilitate mechanisation. These transformations have had a negative impact on biodiversity and have, in particular, resulted in a loss and consequent deterioration of the semi-natural environments of agricultural and pastoral areas.

The arguments in favour of maintaining and/or improving biodiversity were already covered in Chapter 1. Below, we provide the **four principle reasons** why it is useful to assess the level of biodiversity on an agricultural operation:

1. The agronomic benefits
2. The regulatory obligations
3. The requirements of the agri-foods sector
4. The producer's image in public opinion

2.1.2.1. The agronomic benefits

The **ecosystem regulation and support services** provided by elements of biodiversity are of major importance to ensure the **sustainability of agricultural operations.** Functional agrobiodiversity is considered useful to agriculture. It consists of plants, animals, bacteria and fungi living in or above the soil. In this sense, food production and biodiversity are inextricably linked.

For example, the life and biodiversity in the soil are often neglected, even though they are very important to agricultural production, because they make minerals and nutrients available which are crucial to plant growth, facilitate air circulation and water infiltration and can eliminate pests.

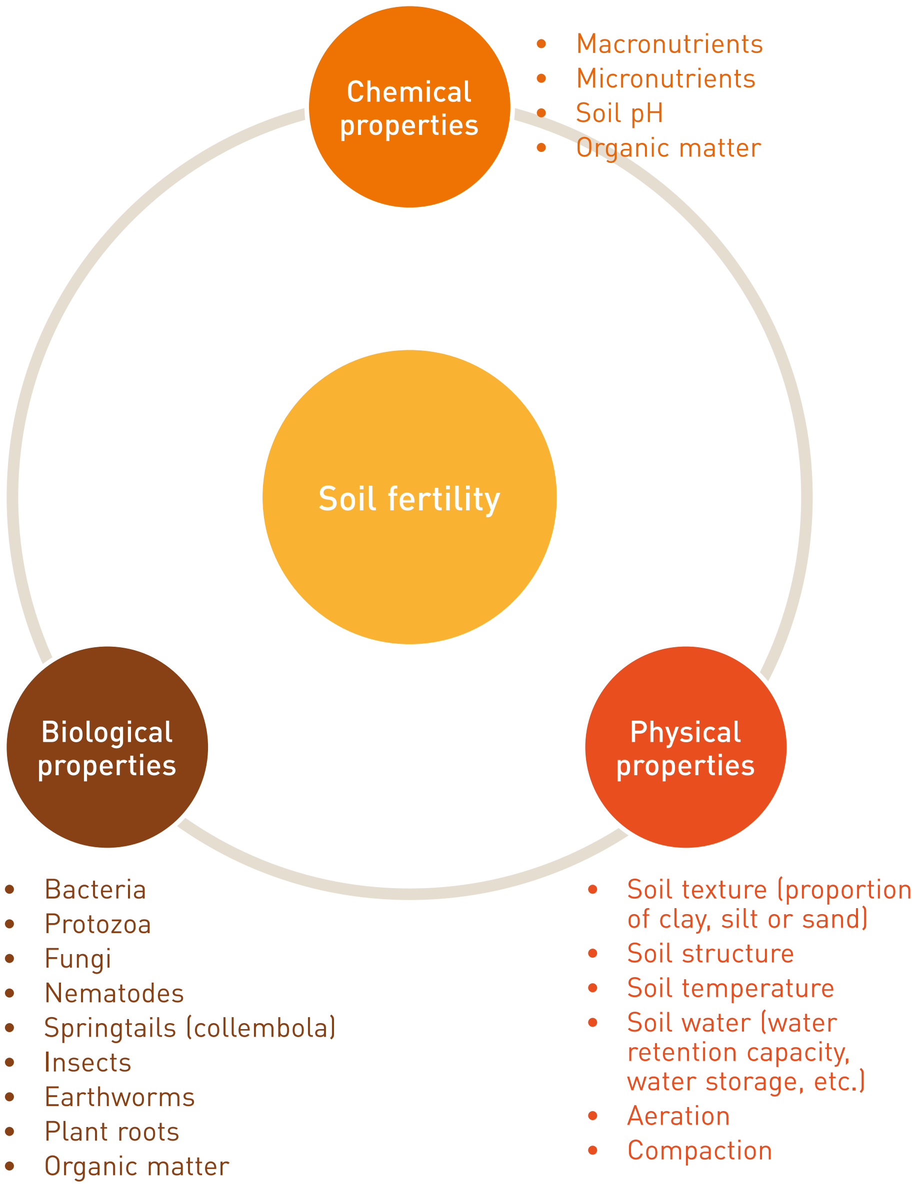


Figure 1: The three factors of soil fertility
Source: Adapted from Functional agrobiodiversity - Nature serving Europe's farmers - 2012 European Learning Network on Functional AgroBiodiversity (ELN-FAB)

Knowing and assessing agrobiodiversity on a farm and knowing how to use it without depleting it can provide several agronomic benefits for the producer, such as:

- Using diversity enables producers to reduce the effects of pests on crops without turning to Plant Protection Products.
- Providing more crop choices and thereby helping to reduce the negative consequences of extreme weather conditions such as droughts and floods.
- Providing the soil with enough time to regenerate and stay healthy over time.

2.1.2.2. The regulatory obligations

The regulations protecting wild species and natural environments were covered in Chapter 1 of this manual.

The maintenance and promotion of biodiversity at the farm level can also be a **regulatory obligation.** It is therefore necessary to show that the farm takes the applicable legislation into account, in particular to obtain aid and subsidies.

Some examples of regulations which favour biodiversity in France[34]:

- *Regulations on Equivalent Topographic Surfaces (ETS)*

  New Good Agricultural and Environmental Conditions (GAEC) standards have been in effect since 2010. Among these standards, Measure No. 7 directly involves the "maintenance of topographical features" (another way of referring to semi-natural elements). This measure requires farmers to have a minimum presence of (measured in % of the Utilised Agricultural Area (UAA)) ecological infrastructures: Currently 5%.

- *The nitrate directive and its 4th action programme*

  The regulations relating to "adaptive land management" require 100% winter coverage of the land which can, under certain conditions, offer many benefits for biodiversity.

- *Decree of 28 November 2003 (OJ of 30 March 2004) on the conditions for the use of agricultural insecticides and acaricides for the purpose of protecting bees and other pollinator insects.*

  This law specifies the obligations of applicators regarding the use of insecticides and acaricides during the times crops are visited by pollinators (use of products with disclosures, no bees present during treatment).

2.1.2.3. The requirements of the agri-foods sector

In addition to regulatory requirements, agriculture is facing strong **societal demands** regarding environmental questions. Many initiatives have been launched to try and respond to growing consumer demands. For example, some operators selling agricultural products require farmers to follow **sustainable development standards** which include a **"biodiversity" component.** The implementation of this biodiversity component requires the farm operator to complete a diagnostic (an assessment) and create an action plan to preserve and/or improve biodiversity[35].

Le lien ne fonctionne pas

34 http://www.jacheres-apicoles.fr/14-biodiverite-dans-les-paysages-agricoles-une-question-de-reglementation

35 Natural Spaces Conservatory Languedoc Roussillon | SupAgro Florac, Diagnostic of the biodiversity on farms in Languedoc-Roussillon - Manual adapted within the framework of the Ecodiag Leonardo Da Vinci project innovation transfer work package no. 3.

The **agri-foods sector** is a major driver for changing practices in favour of biodiversity. In fact, in a context in which the loss of biodiversity is one of the main challenges of our era, the agri-foods industry, through its supply chains, represents a massive opportunity to curtail this loss and maintain the ecosystem services which depend on it (pollination, natural pest control, soil fertility, etc.) at the farm and agricultural region levels.

The many initiatives include the European Project **Life Biostandards**[36] **- Biodiversity in the brands and labels of the agri-foods sector**

This project aims to preserve the biodiversity linked to agricultural production by improving awareness of biodiversity in the brands, labels and certifications of the agri-foods industry, such as GLOBALG.A.P., LEAF (Labeling Ecologically Approved Fabrics), EU Organic Farming, FSC, PEFC, Fair Trade, UTZ certified, Rainforest Alliance, SAI platform, Naturland, RSPO, etc.

A study conducted in 2017 within the framework of this project indicates that only one out of two standards clearly defines biodiversity and its related terms and that there is significant room for improvement to better the effectiveness and verifiability of the criteria and/or requirements. Moreover, fewer than a quarter of the standards decided to refer to international conventions (CDB and CITES) and to the "avoid/reduce/compensate" hierarchy[37]. Ideally, private standards should follow this regulation and in some cases, go beyond it (good environmental practices).

36 https://solagro.org/travaux-et-productions/references/life-biostandards--la-biodiversite-dans-les-marques-et-labels-du-secteur-agroalimentaire

37 The purpose of the "avoid, reduce, compensate" hierarchy is to prevent damage to the environment, reduce the damage which could not be sufficiently avoided and, if possible, compensate for the notable effects which could not be avoided or sufficiently reduced. https://www.ecologique-solidaire.gouv.fr/eviter-reduire-et-compenser-impacts-sur-lenvironnement

LIFE supports other initiatives such as "Biodiversity in Standards and Labels of the Food Sector", implemented by a consortium of organisations and companies from different European nations.

This initiative provides recommendations and information such as the "Easy Guide"[38] document, which is specifically targeted at the quality and purchasing managers of companies which purchase foodstuffs. It is, however, beneficial for producers to be familiar with it in order to know what buyers' requirements are or will be.

2.1.2.4. The producer's image in public opinion

In addition to the requirements of regulatory and private standards, it's important that the **greater public** sees that farmers are taking biodiversity into account when choosing their practices. In fact, agriculture is often, correctly or not, viewed by the greater public as a major factor in the decline of the population's health or the destruction of the landscape and biodiversity. Biodiversity must therefore also be viewed as a **marketing asset**[39]. Many consumers are concerned about the protection of the environment. They appreciate it when farmers are respectful of nature and deliberately favour biodiversity. There are therefore willing to pay a higher price for farm products. The natural development of the land around the farm also serves as good publicity for those who organise agrotourism activities.

Several input suppliers have understood the importance of their public image. They have developed biodiversity support programmes and are working closely with farmers to promote them on farms. Note, however, that these businesses often argue that the best way to protect wild biodiversity is to reduce the loss of wild areas by increasing productivity per hectare, in particular via the integrated use of their inputs. Higher yields mean less cultivated land and therefore more room for natural

38 http://www.business-biodiversity.eu/37564/Top-Metanavigation/Publications/Easy-Guide/ebbc_index01.aspx?addhilite=easy&addhilite=guide

39 Biodiversity on the farm - Practical guide – FIBL, Swiss Ornithological Institute – 2016 - http://www.fibl.org/THfileadmin/documents/fr/actualites/2016/guide-biodiv-prevue.pdf

ecosystems[40]. It could be argued in return that biodiversity management cannot be limited to avoiding the destruction of wild forest habitats or other areas to make room for crops; in fact, the biodiversity to maintain and restore also includes the areas found within agricultural operations. Furthermore, inputs are not the only means of improving productivity per hectare. The deterioration of soil and parasitic pressure can also be avoided with other methods described in this and other COLEACP manuals.

Note that the vendors of post-harvest technologies often provide similar arguments: infrastructures such as cold chambers can reduce post-harvest losses, thus more can be sold for an identical amount of cultivated land; this in turn reduces deforestation and the cultivation of other, unexploited lands.

These companies have undertaken several actions with the support of a network of participating farms, often in partnership with other suppliers of inputs and farming equipment. For example, in Europe:

- The development on farms of flower strips which are favourable to pollinators (bees, etc.) and crop auxiliaries (beneficial insects).
- Support for defining indicators for the relevant assessment of the richness of the biodiversity in various agroecosystems.
- The creation of a non-exhaustive list of layouts or cultivation practices which enable the improvement of biodiversity on a farm.

Figure 2: Land use on a farm in the Interra Farm network in Belgium
Source: Gilles Delhove

40 https://croplife.org/news/plant-science-protects-biodiversity-with-best-land-use/

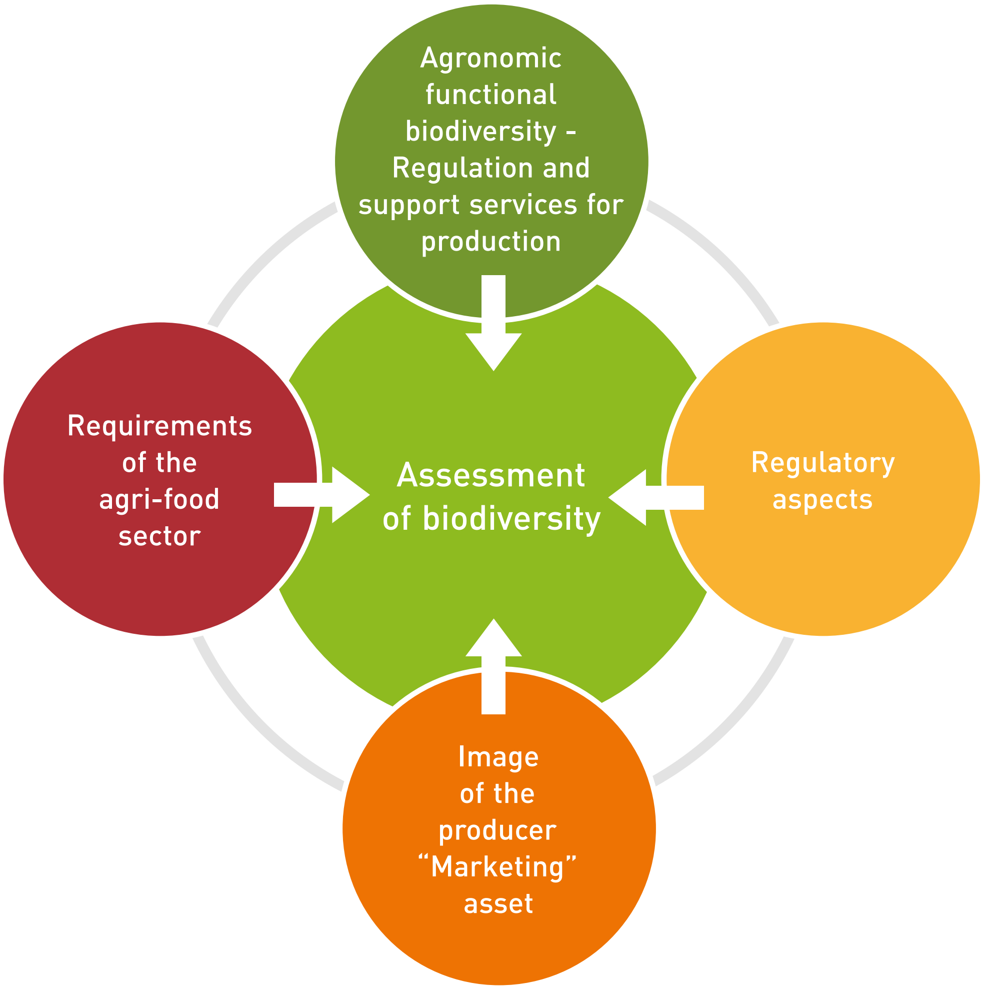


Figure 3: KEY POINT - The primary reasons for the biodiversity assessment

It is therefore vital that the practice of **assessing biodiversity** on farms be developed in one way or another. This diagnostic is a tool to aid with decisions about what actions to take to favour biodiversity (see section 2.4). On the other hand, agricultural practices and their impacts must be documented with **ongoing monitoring of the biodiversity on the farms.**

It is, however, important that the biodiversity assessment not be too complex, so that the producer can take charge of it, with the potential assistance of technical advisers. It is essential to first specify what scope the assessment must cover and what its level of precision must be.

The objective here is to provide an approach for a diagnostic at the scale of a primarily fruit and/or vegetable producing farm in a tropical environment.

2.2. EXTENT AND PRECISION LEVEL OF THE ASSESSMENT

2.2.1. Introduction

Most of the tools developed for assessing biodiversity on farms are focused more on wild biodiversity, whether functional or not, than domesticated biodiversity. It is, however, also important to consider the latter. In fact, agroecology assigns a great deal of importance to domesticated biodiversity because it contributes greatly to a farm's sustainability, which must have an autonomous and resource-efficient system. Scientific studies have demonstrated the importance of domesticated diversity. For example, cultivating multiple varieties together reduces the risk of disease and increases a plot's yield (Pellet D. *et al.*, 2005, de Vallavielle-Pope C. *et al.*, 2006).

It's therefore also important that the assessment of the biodiversity of an agricultural operation be conducted **both for domesticated biodiversity as well as wild biodiversity.**

The biodiversity assessment should ideally be done for all of the living organisms present, but this is impossible in practice. As a result, it must **be limited to certain organisms selected** based on their importance or relative ease of assessment (see Part 2.3 of the manual).

Agricultural practices should be examined closely enough to assess their impact on wild and domesticated biodiversity.

Several works (for example, those of the ESCo group of scientific experts (Collective Scientific Expertise) on behalf on INRA (Le Roux X., 2008) in France) reveal that biodiversity in agricultural areas is above all, linked to the complexity of the landscape and the intensity of practices. Farming heavily influences the complexity of the landscape, primarily depending on the crops, and also on the types of semi-natural or natural areas which are more or less maintained in terms of area.

The biodiversity assessment must therefore be carried out **in every area of the operation, including the areas surrounding it**, to ensure a reduction of the negative effects of agricultural practices on these areas.

The spatial scale of the biodiversity assessment is elaborated on further down.

It should also be noted that the assessment of biodiversity must be **both quantitative and qualitative**. For example, it is not enough to simply quantify the percentage of the surface of the farm which is dedicated to semi-natural and natural areas. The quality of these areas (in particular, their richness in species diversity and in different functions) must also be assessed.

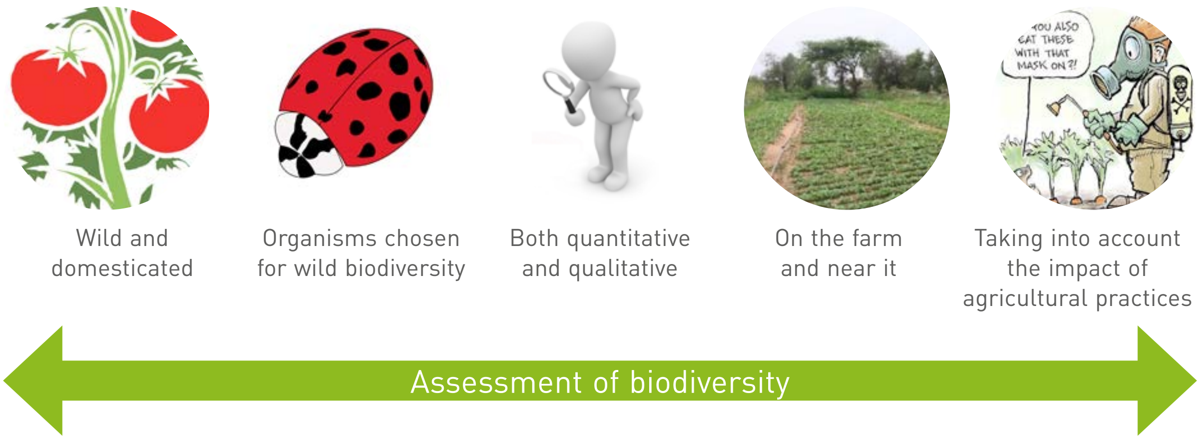


Figure 4: Key points to retain for the assessment of biodiversity at the scale of a horticultural farm (fruits and vegetables)

2.2.2. Biodiversity at the spatial scale

2.2.2.1. The farm

As previously stated, biodiversity must be examined at different "places" on the farm. These are known as "**compartments**" of the farm which must, of course, be viewed as interconnected.

The **two first major compartments** are divided up **vertically**: these are the "soil compartment" and the "air compartment".

- Air compartment: the biodiversity of organisms on and above the ground must be taken into account.
- Soil compartment: the biodiversity of organisms found in the ground, including plant roots, must be taken into account. The soil compartment of the farm is sometimes "replaced" by a "water compartment": a lake, backwater, pond or stream which is permanent or temporary. The biodiversity in the water is of interest in this case.

Horizontally, the "air and soil" compartments can be subdivided into **compartments based on the use of the land on the farm**, with the exception of built areas and transportation components (roads, paths). The compartments illustrated in Figure 5 and described below are to be taken into account for a farm. The different compartments discussed make up the elements of the farm's landscape.

1. The compartment of areas used for an **individual cultivated plant** (inset of a tomato plant in Figure 6)

   Of interest here is the biodiversity of the organisms around or on the plant, with low mobility, often deeply linked to the plant's life.

   Underground, this consists especially of organisms living near the roots. This consists of organisms which are beneficial or harmful to plants. This also consists of organisms which are between the soil particles and which play an important role in soil fertility.

   Aboveground, most of the organisms found on a plant are mobile. This aboveground biodiversity must be considered in terms of the field as a whole.

2. The compartment of areas occupied by **cultivated lands**.

   These are heterogeneous and change over time as a result of the diversity of crop types, crop successions (rotations), the size and spatial arrangement of the plots and the farmer's land use planning. These are, for example:

   - Annual crops.
   - Perennial crops (e.g. orchards, hedges, forests, windbreaks).
   - Prairies.

   At the cultivated plot level, biodiversity must be assessed primarily in terms of domesticated biodiversity: number of cultivated species and varieties of each species, diversity of the "type" of cultivated plants. The structure (growth habit type (creeping, climbing, upright, etc.) and height of the vegetative portion, extent and depth of roots) of the plants of species or varieties cultivated at the same time on the same plot is also important to take into consideration, because, depending on the structure of the plant, the aboveground or underground space used varies and the associated organisms vary as well.

   Wild biodiversity must also be assessed for the cultivated plot as a whole using sampling at different places on the plot. Emphasis should be placed on the diversity of beneficial organisms such as auxiliary insects. Wild plant biodiversity is also important to take into consideration, especially in cultivated plots with perennial plants, such as orchards.

3. The compartment of areas occupied by **semi-natural ecosystems** and the areas occupied by **natural ecosystems**.

   The biodiversity of fauna and flora on the farm must also be assessed for the uncultivated areas, whether they are semi-natural (e.g. hedge, flower strip, copse, pond, permanent prairie, fallow land, grass edge of field) or natural (e.g. backwater, meadow, forest, river). The difference between natural and semi-natural lies in the level of anthropisation: a natural area has normally not been subjected to any human intervention. In practice these areas are very rare, and most of the time, semi-natural uncultivated areas are found in an agricultural environment.

   The biodiversity of these areas is important because it often provides ecosystem services which can be beneficial to the production of various crops on the farm.

4. The compartment of **outside areas** surrounding the farm (cultivated, semi-natural or natural)

   At the spatial level, the biodiversity of the areas in the immediate proximity of the farm is also of interest. In fact, the farm's practices can also influence this biodiversity and it can, in return, have an impact on the growth of the plants grown on the farm.

   The occupation type of these areas does not depend on the choices made by the owner of the farm, but can sometime depend on collective approaches at the regional level. If they consist of protected areas, the agricultural operator has an "ethical" and "regulatory" duty to not endanger these areas with their practices.

For all of the horizontal compartments mentioned, both the soil biodiversity and the air biodiversity must be taken into account (and the water biodiversity as well for aquatic areas).

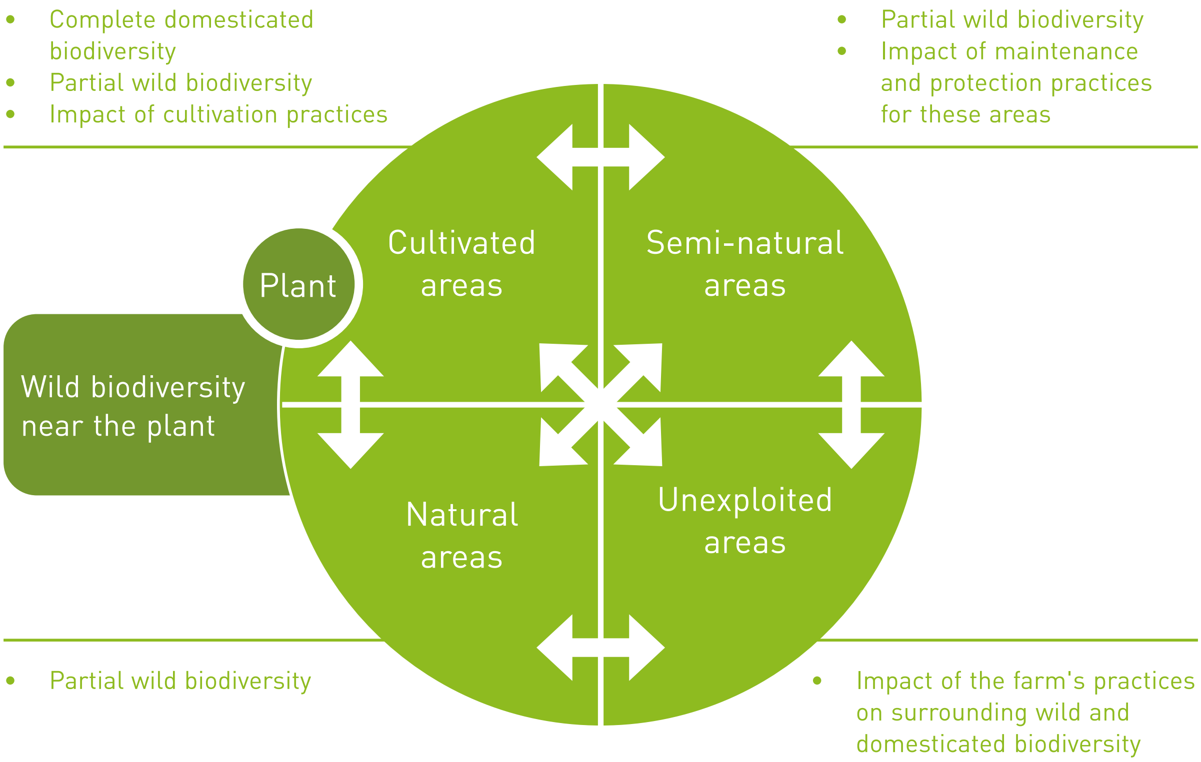


Figure 5: Extent and precision of the assessment at the horticultural farm (fruits and vegetables) scale - the arrows show the interactions between compartments

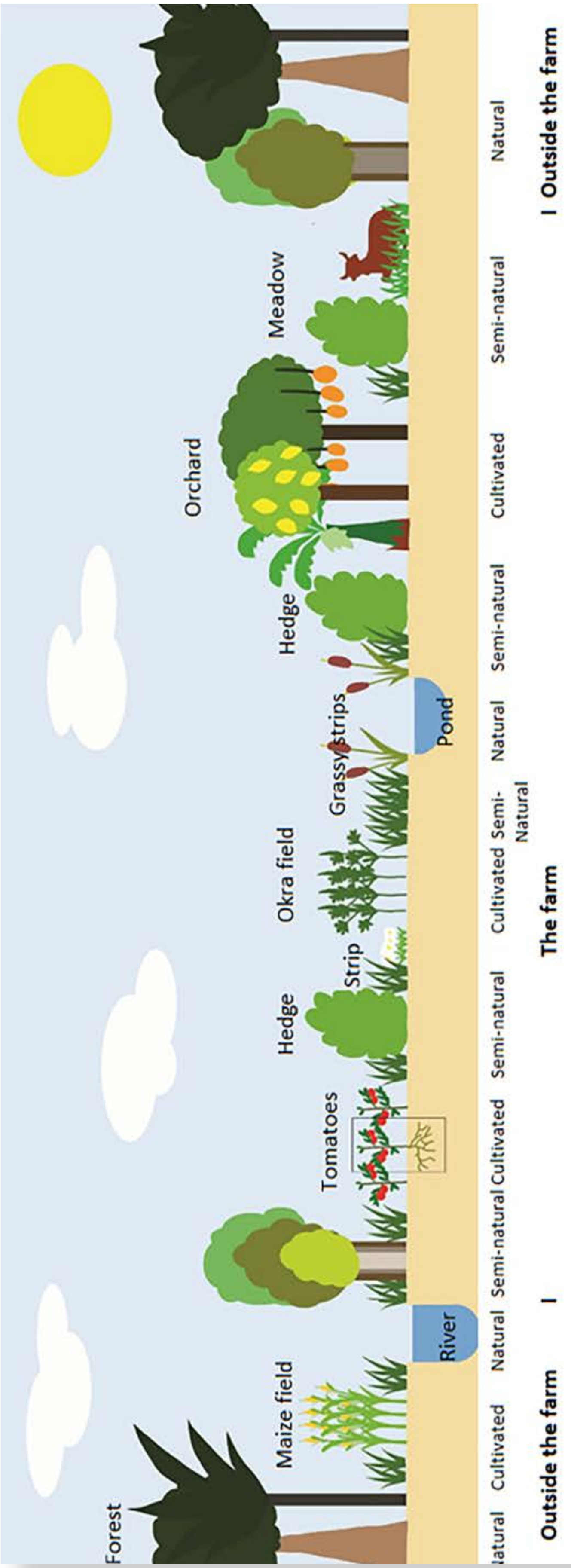


Figure 6: Example of compartments on a farm

2.2.2.2. The landscape

At the spatial level, some authors differentiate between three types of biodiversity outside of the farm area itself: alpha (α), beta (ß) and gamma (γ).

- **Alpha biodiversity**

  The number of species which coexist in a uniform habitat of a fixed size. For example, the richness of species within the agroecosystem of an operation (plot).

- **Beta biodiversity**

  The difference in diversity between elements of the agricultural landscape.

  Or, depending on the references and the context:

  - The change in alpha diversity between habitats/ecosystems.
  - The extent of the difference in species between habitats. Beta diversity reflects the change in alpha diversity when moving from one ecosystem to another on a site. For example, when moving from a cultivated field to a meadow on a farm.
  - Beta diversity measures the difference in the populations of two neighbouring biotopes in an area (habitat similarity index).

- **Gamma biodiversity**

  The richness in species at the regional and geographic level. This is the total biodiversity of the landscape.

In addition to these three types, other authors include "point biodiversity", which is the number of species present at a given point in the area called a "site"; for example, an individual plant or group of plants. Also sometimes mentioned is delta biodiversity, a similarity index of regions or sectors (between two geographically separate landscapes). Delta biodiversity involves a larger scale than covered by this manual. These types of biodiversity are illustrated in the two figures which follow.

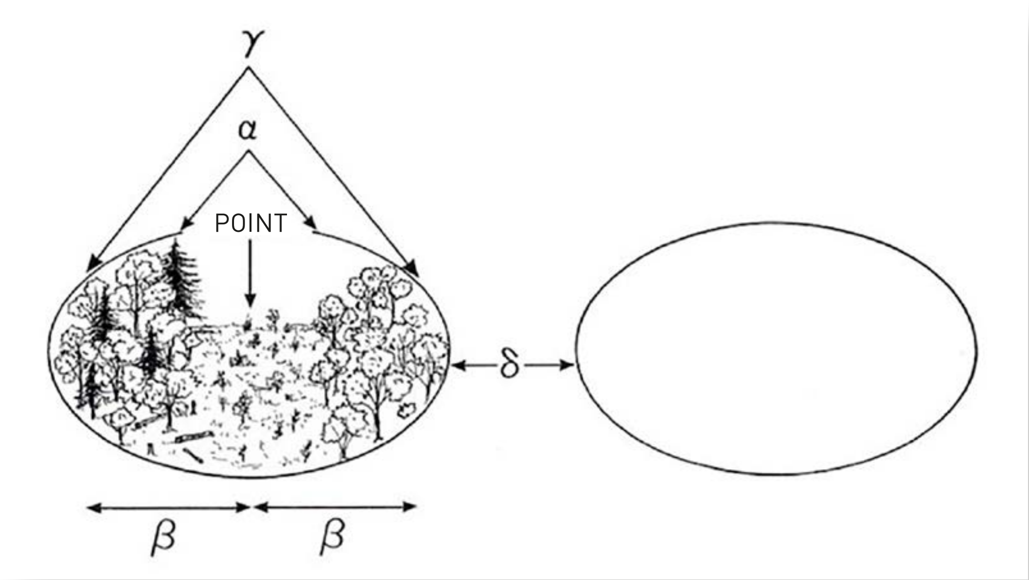


Figure 7: The five types of biodiversity: point, alpha, beta, gamma and delta
Source: How can Biodiversity be measured? Pr Francour Patrice - Université Nice-Sophia-Antipolis - ECOMERS

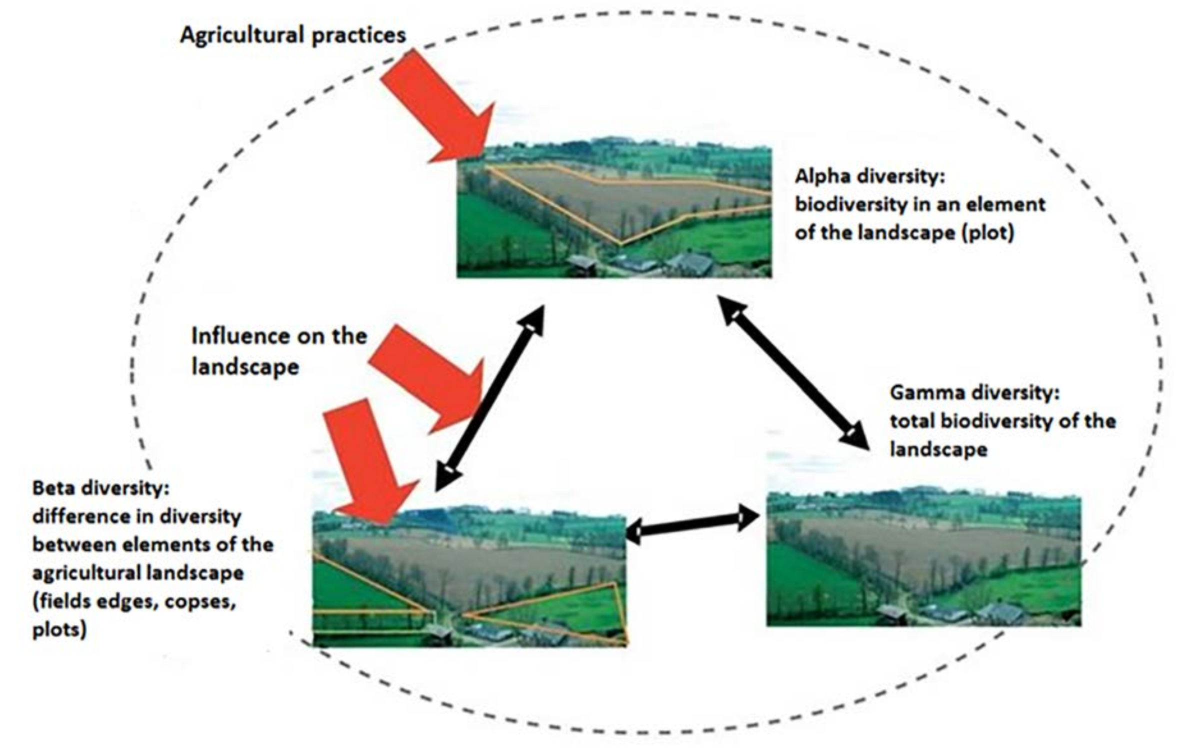


Figure 8: Biodiversity example: alpha, beta and gamma in an agricultural area: Incidence of agricultural production modes
Source: X. Le Roux, R. Barbault, J. Baudry, F. Burel, I. Doussan, E. Garnier, F. Herzog, S. Lavorel, R. Lifran, J. Roger-Estrade, J.P. Sarthou, M. Trommetter (editors), 2008. *Agriculture and biodiversity. Adding value to synergies.* Collective Scientific Expertise, Report summary, INRA (France)

2.2.2.3. Heterogeneity

Two components of landscape heterogeneity have been explicitly defined based on Duelli's original concept (1997): a more heterogeneous landscape or farm has:

- a greater variety of land cover types (**compositional heterogeneity**);
- and/or a more complex spatial layout of its land cover (**configurational heterogeneity**).

The figure below illustrates these two types of heterogeneity. The four large squares represent a landscape or an operation, and the different colours represent the different types of land cover. The compositional heterogeneity increases from left to right with an increase in the number of cover types, while maintaining a balance between them. The configurational heterogeneity increases from bottom to top with an increase in the complexity of the spatial organisation of these covers.

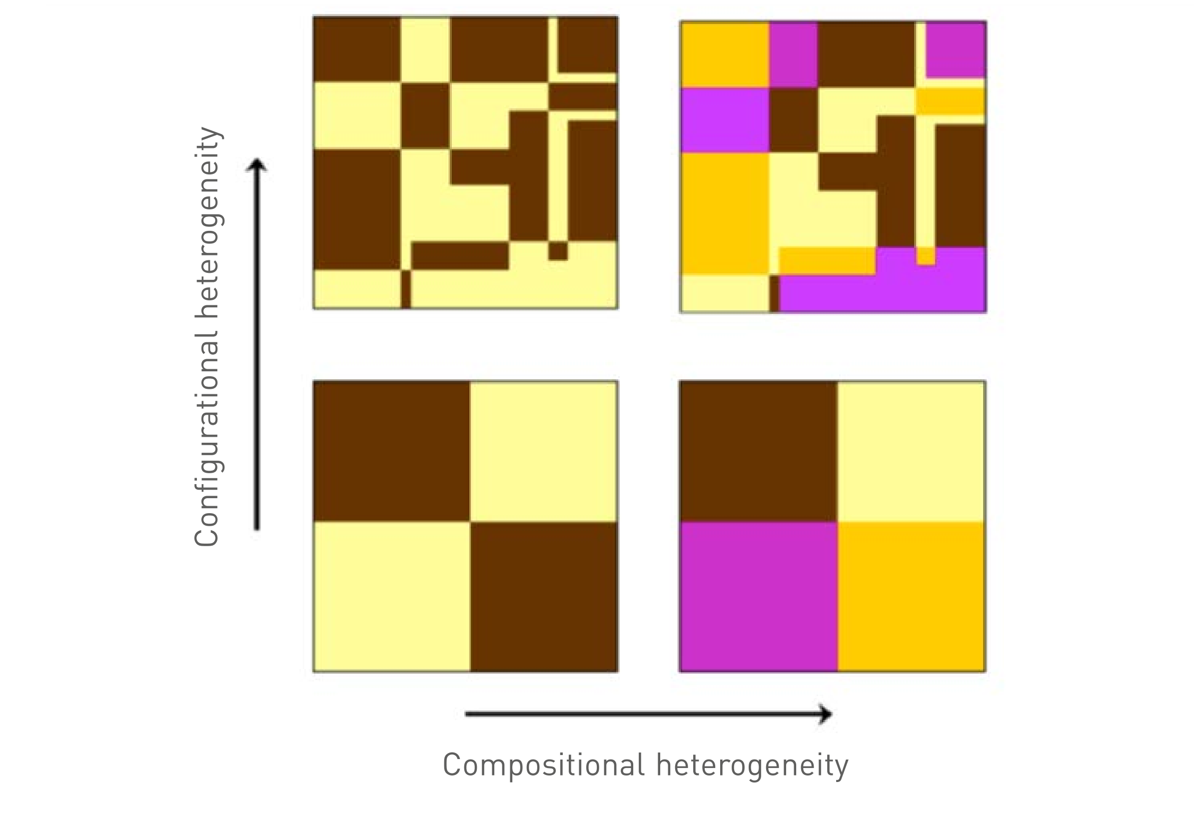


Figure 9: Illustration of the two components of spatial heterogeneity: composition and configuration. Source: from Fahrig *et al.* 2011[41]

2.2.2.4. Key points to retain

The figure below summarises the key points to retain about spatial biodiversity. Remember that biodiversity must be assessed both in the soil and air compartments.

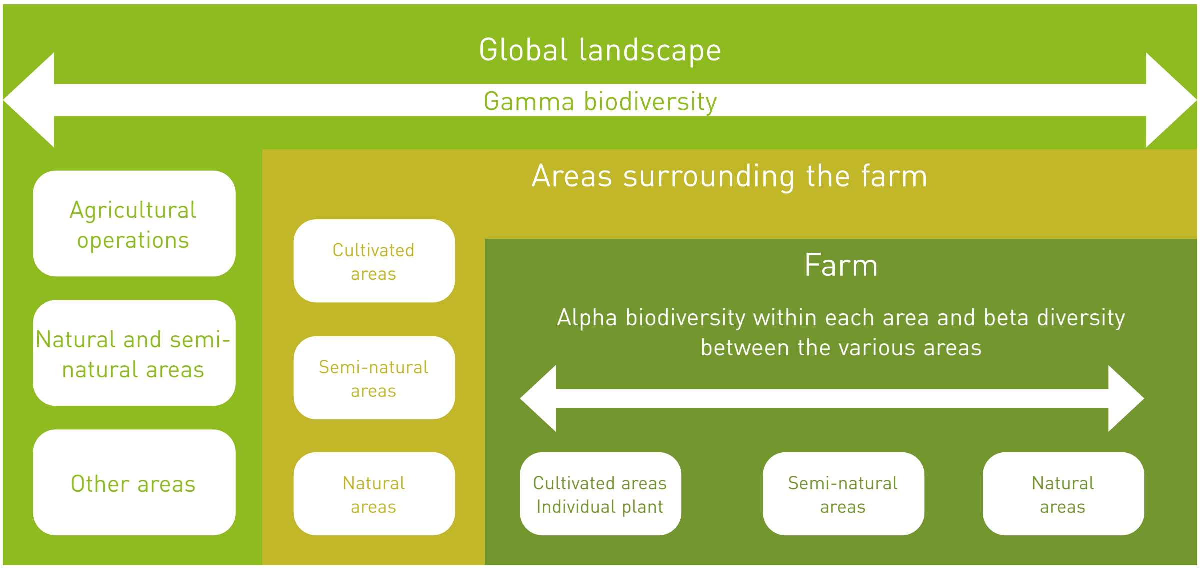


Figure 10: Biodiversity on the spatial scale

41 Remi Duot. Functional heterogeneity and biodiversity: what is the role of connections or borders in agricultural landscapes? Agricultural sciences. Université Rennes 1, 2013.

2.2.3. Biodiversity on the temporal scale

The assessment of biodiversity must also be considered on the temporal scale. The composition of an ecosystem in terms of species **varies over time according to the seasons** (for example, certain animals, such as birds, may migrate) and the stages of plant development (the fauna found in an orchard will not be the same at every crop growth stage, etc.). For domesticated biodiversity, the land occupied by cultivated annual plants also varies according to the seasons, and different rotations can be implemented for each plot.

The assessment of biodiversity and of the impact of practices must therefore be done, ideally, **at different times in the year** in each compartment of the farm mentioned previously.

To assess the results of an action plan to improve biodiversity at the farm level, the change in biodiversity must be estimated by carrying out a diagnostic **every year, at the same times of the year** and, preferably, at the same places.

The temporal scales are not the same for field data collection and observations. Work must be carried out based on the seasons and the crops. Another important factor which must not be omitted is the life cycle of the taxon studied. For example, the presence of crop auxiliaries can only be assessed if the pests which they control are present on the crops, and grassy strips or areas occupied by perennial plants must be assessed when the grasses are in full vegetative growth. The taxons targeted for study **must not be in a state of rest at the time of the assessment**.

In addition, regarding temporal scales, most current studies focus on time periods of at best a few years, although the history of agricultural practices at the plot level and the dynamic of the landscape affect the response of biodiversity to new practices or new arrangements. Ongoing agricultural practices over a century have a notable influence on biodiversity in comparison to short time periods characterised by regularly alternating agricultural practices.[42]

42 X. Le Roux, R. Barbault, J. Baudry, F. Burel, I. Doussan, E. Garnier, F. Herzog, S. Lavorel, R. Lifran, J. Roger-Estrade, J.P. Sarthou, M. Trommetter (editors), 2008. *Agriculture and biodiversity. Adding value to synergies.* Collective Scientific Expertise, Report summary, INRA (France)

2.3. INDICATORS

Biodiversity is a difficult concept to grasp and generalise because it is expressed at various levels of life: genes, species, habitats and ecosystems. The fact that it is impossible to inventory it exhaustively makes biodiversity indicators a requirement.

2.3.1. What is an indicator?

In the biodiversity field, indicators are most often indexes which enable the quantification of biodiversity, its spatial distribution and its variations over time. However, the terms indicator and index are not well defined and their use can vary depending on the country or discipline (Duelli and Obrist, 2003).

Indicators must make it possible to assess biodiversity and its state of "health" in relation to the farmer's practices, with the ultimate objective of enabling the farmer to develop an action plan (maintenance, change in practices, land use, destruction, restoration, etc.).

An indicator is a **summary of complex information which enables various players to communicate in a common language**. It must be scientifically robust, understandable and usable by every player.

2.3.2. The main families of indicators

In the agricultural field, biodiversity is generally assessed via two (2) major categories of indicators[43]:

- The indicators of **domesticated biodiversity** which enable assessment of the diversity of the species and varieties of plants cultivated and species and races raised;
- The indicators of **wild biodiversity** which enable assessment of, in particular, **"para-agricultural" biodiversity**, which relates to the diversity of living organisms that play an important role in agroecosystems. This primarily consists of crop auxiliaries and organisms which play an important role in soil fertility, but also of pests and weeds which have negative effects on crops.

  They can also assess the **"extra-agricultural" biodiversity**, which concerns organisms living on the farm that don't play an important role in agroecosystems. This is called "patrimonial" biodiversity.

We can also distinguish between **state indicators** and **pressure indicators**.

2.3.2.1. State indicators

These show the state of biodiversity based on observations which make it possible to determine the number of species present and their relative abundance.

The most used index of species diversity for this type of indicator is the Shannon (H') Index. This index gives an idea of an environment's species diversity. That is, the number

43 Biodiversity indicators in the agricultural environment – MAAP/MNHN study - Working document – November 2009

of species in the environment (species richness) and the distribution of individuals within these species (species evenness). This index makes it possible to quantify the heterogeneity of a studied environment's biodiversity and to observe changes over time. A higher H' index value indicates higher diversity. It is calculated using the formula below.

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

H': Shannon biodiversity index
i: one species from the environment studied
S: species richness (number of species)

Pi: Proportion of species *i* compared to the total number species (S) in the studied environment (or species richness of the environment), which is calculated as follows: *pi* = *ni*/N where *ni* is the number of individuals for species *i* and N is the total population (the number of individuals of all the species).

The figure below depicts two examples of biodiversity situations in a forest environment. The number of species is greater in the image on the right but the biodiversity is considered better in the image to the left because the evenness of species is greater. The measure of evenness corresponding to the Shannon index is calculated as follows:

E = H'/lognS. E = 1.39/logn4 = 1 for the figure to the left and

E = 1.33/logn8 = 0.64 for the figure to the right.

The value 1 is the maximum value that indicates that all of the species have the same level of abundance (maximum evenness).

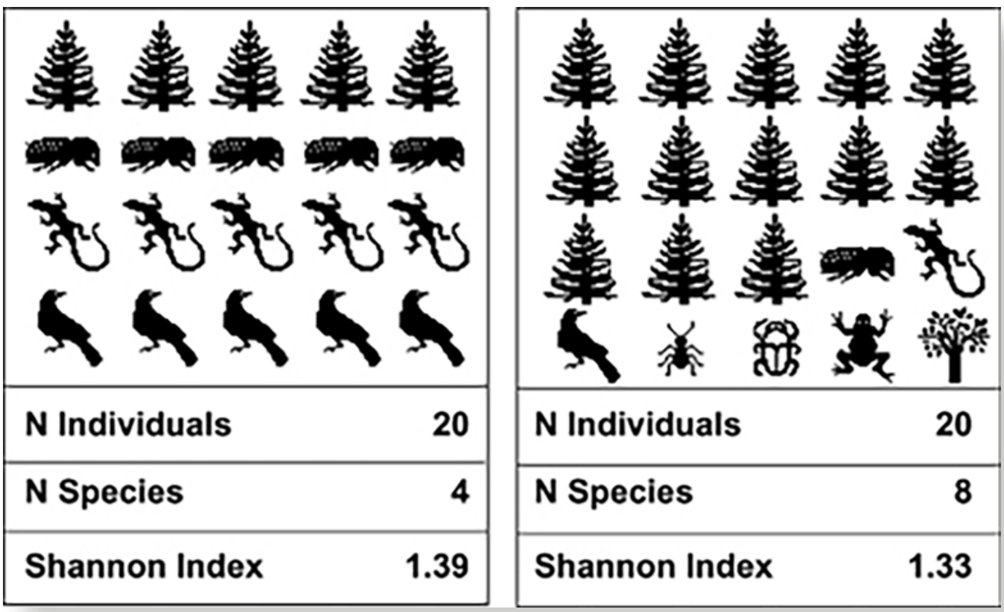


Figure 11: Shannon Index examples
Source: Biodiversity indicators: the choice of values and measures - Peter Duelli*, Martin K. Obrist - Swiss Federal Research Institute WSL, Zürcherstrasse 111, CH-8903 Birmensdorf-Zurich, Switzerland

The Shannon Index can be easily calculated with an Excel spreadsheet as follows. In the table below, the formulas to enter are shown in red and the values to enter are shown in blue.

	A	B	C	D
1	Species	Number of individuals per species	Name of the Shannon Index variable	Shannon Index calculation
2	A	x	=n1	=(B2/B$6)*LN(B2/B$6)
3	B	x	=n2	=(B3/B$6)*LN(B3/B$6)
4	C	x	=n3	=(B4/B$6)*LN(B4/B$6)
5	D	x	=n4	=(B5/B$6)*LN(B5/B$6)
6	**Total**	=SUM(B2:B5)	**=N**	=-1*SUM(D2:D5)

The following two tables show how the indexes in Figure 11 were calculated:

- Image to the left of Figure 11

Species	Number of individuals per species	Shannon Index variable name	Shannon Index calculation
A	5	=n1	-0.347
B	5	=n2	-0.347
C	5	=n3	-0.347
D	5	=n4	-0.347
Total	**20**	**=N**	**1.39**

- Image to the right of Figure 11

Species	Number of individuals per species	Shannon Index variable name	Shannon Index calculation
A	13	=n1	-0.280
B	1	=n2	-0.150
C	1	=n3	-0.150
W	1	=n4	-0.150
F	1	=n5	-0.150
G	1	=n6	-0.150
H	1	=n7	-0.150
I	1	=n8	-0.150
Total	**20**	**=N**	**1.33**

2.3.2.2. Pressure indicators

These are agricultural practices which potentially have an impact on biodiversity. For example:

- Plant Protection Products are the inputs which have the greatest potential negative impact on biodiversity given that their purpose is to eliminate living organisms.
- Fertilisers, whether mineral or organic, can have an indirect effect on biodiversity, especially on soil organisms (see Chapter 3).
- The use of water in agriculture can also have indirect effects, especially on diversity outside of the farm (water sources drying up, etc.).
- The percentage of the farm's surface area dedicated to production will also affect biodiversity.

The causal relationship between practices and potential effects on biodiversity is not always easily established. This often implies that in the field we are often happy with, incorrectly and out of convenience, only assessing the state of biodiversity for the farm, without taking into account the impact of practices.

The table below shows that the potential impact of agricultural practices on an environment depends on the level of sensitivity of the environment to the practices.

Five (5) categories of risks can be established based on the pressure and sensitivity values, from very low (green light) to very high (red light). The category limits are determined from specialists' opinions.

Table 1: Combination of the pressure exerted by agricultural practices and the sensitivity of the environment.

		Pressure from agricultural practices				
		Very low	Low	Average	High	Very high
Sensitivity of the environment	Very low	Very low	Very low	Low	Low	Average
	Low	Very low	Low	Low	Average	High
	Average	Low	Low	Average	High	High
	High	Low	Average	High	High	Very high
	Very high	Average	High	High	Very high	Very high

Source: Assessment of the environmental impacts of agricultural practices on the plot and farm scale for the purpose of developing an action plan: a method of spatial diagnostic based on indicators, the DAE-G1. Audrey Ossarda, Marie-Béatrice Galanb, Hubert Boizardc, Christine Leclercqd and Célie Lemoinee

2.3.2.3. Direct and indirect indicators

Some authors also identify **"direct" indicators** and **"indirect" indicators** to measure biodiversity.

- **"Direct" indicators**

  These indicators count the number of species present and their abundance. They are state indicators. This is often a long process because, in the case of wild biodiversity, it requires repeated sampling in the area and over time. Furthermore, it often requires advanced skills (specialists) to recognise genera/species/varieties and requires passing through during specific periods and even at specific times.

- **"Indirect" indicators**

  In this case, we are especially interested in natural or semi-natural habitats found on the farm. The indicators are considered "indirect" because they consist of the plants which support the animal biodiversity which is beneficial to crops and wild animals (food, shelter, etc.). These are generally fixed elements of the agricultural landscape which are not cultivated and which have not had any fertilisers (or a very low dose and frequency) or pesticides applied in at least five years. The vegetation must be primarily spontaneous. In other words, allochthonous species must not make up the majority of the cover.

  These elements are called AEI or AEU, but authors often use the term AEI for both.[44] In this document we will use the term AEI/AEU to refer to both types.

  - Agro-Ecological Infrastructures (AEI)

    Point and linear elements such as, for example, hedges, trees in rows, isolated trees, grassy strips, ditches, canals, banks, low walls and ponds.

  - Agro-Ecological Units (AEU)

    Surface elements such as, for example: natural meadows, orchard meadows, copses, borders, lawns, wetlands and fallow land.

Note: Depending on the context and the country, AEI and AEU are sometimes referred to as: Ecological Compensation Areas (ECA), Non-Productive Areas (NPA), interstitial environments or habitats, fixed landscape elements, semi-natural habitats, ecological reservoir zones (ERZ) and biodiversity promotion areas (BPA45).

The type of spatial organisation of the cultivated areas and their temporal management can also be considered indirect indicators of animal biodiversity. It is generally accepted that it is favoured by the diversity of rotation crops, reduced plot size, the mix of plants per plot and the temporal continuity of crops.

44 Diagnostic of the biodiversity on farms in Languedoc-Roussillon - User manual - Natural Spaces Conservatory Languedoc Roussillon - March 2009

45 Promotion of biodiversity on the farm Base requirements and quality levels Conditions, obligations, contributions - https://agridea.abacuscity.ch/abauserimage/Agridea_2_Free/1443_5_F.pdf

2.3.3. Indicator selection

There are several kinds of questions to ask before establishing/choosing the indicators to assess the biodiversity of a farm (adapted from Galan *et al.* 2005, Girardin *et al.* 2000):

- *What is the **objective** of my assessment (develop ecosystem services which are beneficial to my production, meet a regulatory requirement, meet a certification requirement, promote my operation in the public eye, etc.)?*
- ***Who** is my assessment intended for (farmer, advisers, technicians, decision-makers)?*
- *At what **spatial scale** do I want to conduct my diagnostic? What areas (compartments) do I want to analyse on the farm site: cultivated plots, semi-natural areas, natural spaces, sites, farm surroundings?*
- *What **data are necessary and available** for my assessment?*
- *What **resources (human and financial)** am I implementing or making available for this assessment?*

Depending on the answers to the questions asked above, it is necessary to have an indicator for each aspect of biodiversity for which an assessment is desired.

The indicators chosen must be understandable, easy to implement, sensitive to variations in agricultural practices, reliable and relevant.[46]

For biodiversity assessments of vegetable and fruit farms, the fact that they often consist of relatively small areas (at least in relation to the large cereal and industrial crops) must be taken into account. These operations therefore generally have very little influence on the biodiversity of the landscape (except in urban areas or areas with a high density of farms of this type). However, the often intensive use of inputs on this type of farm can have fairly significant indirect repercussions on the environment, and therefore on biodiversity. The objective for this type of farm should therefore be to especially favour regulation and support system services, namely **para-agricultural biodiversity**, over **extra-agricultural biodiversity**, which is the biodiversity on a farm which does not play a very important role in agroecosystems.

It is not possible to conduct an assessment of every living thing present on a farm. It is therefore necessary to try and reduce the work to be undertaken with a suitable selection of what needs to observed.

A few principles for choosing the different types of indicators are given below.

2.3.3.1. Indicators of domesticated biodiversity

The state indicators are the name and number of cultivated species and varieties and the occupation rate of each of them. Also of interest are:

- the origins of the varieties and providing an indicator of the use of "local" varieties;
- the presence of animal species and races raised on the farm.

46 What agri-environmental indicators are useful for the environmental management of a farm? – David Peschard and Marie-Béatrice Galan – ALTERNATECH – Section Agro-Transfert

Point A of Part 2.4.2.2 of this manual provides a detailed methodology.

Pressure indicators can also explain the influences of the characteristics of the farm or of external factors on the level of domesticated biodiversity. For example, the local variability of the availability of seeds, market demands, the impact of pests and climate conditions.

2.3.3.2. Indicators of para-agricultural biodiversity

- **Indicators of plant kingdom biodiversity**

  The inventory of **wild plants** present is quite easy to carry out. Biodiversity can generally be assessed for a large number of plant species, but it is sometimes necessary to limit the assessment to the most common well-known species. For example, for hedges, the woody species present can typically be inventoried whereas in a meadow or forest it is not possible to inventory all of the plants present without the outside help of specialists.

  On a farm, wild plants are primarily found in the AEI/AEU. Plant diversity is assessed with two indicators; one measuring quantity and the other quality. Assessing AEI/AEU implementation for several years in European agricultural operations has brought to light that the **quantity** of semi-natural elements is not enough to counteract the loss of biodiversity and that the **quality** of these elements must also be promoted. For example, if only the quantitative aspect is taken into account, a low single-species hedge trimmed twice a year can appear to be as equally beneficial as a highly diverse hedge trimmed only once every two or three years. Whereas, in fact, the second is qualitatively better because it is diverse and trimmed less often, and is therefore more beneficial to biodiversity than the first one.

  - **Quantitative indicator**: provides a measure of the portion of the farm dedicated to IAE/UAE. It shows the level of heterogeneity of the farm's landscape and its biodiversity.

    What are we measuring?

    The surface area of the semi-natural and natural areas is often measured with the aid of maps and potentially with a drone[47]. The measure is provided as a **% of AEI/AEU** = Total area occupied by the AEI/AEU (ha) x 100/UAA (Utilised Agricultural Area) (ha). Within the context of this manual, the UAA is the total surface area of the operation, minus the areas occupied by buildings and yards. The wooded areas and wetlands of more than 5,000 m^2 included in the boundaries of the farm are not included in the UAA and are not considered a part of the AEI/AEU.

    Given its importance and ease-of-measuring thanks to cartography tools, this factor is used as an indicator of biodiversity in several farm diagnostics. It is also used in agri-environmental policies as a result objective, for example in the French certification project for operations of High Environmental Value (HVE project), in the ecological compensation system implemented in Switzerland and in an agri-environmental measure in Spain.

47 http://ictupdate.cta.int/wp-content/uploads/sites/5/2016/04/ICT_Update_Issue_82_FRENCH.pdf

Objectives as a % of AEI/AEU are often specified. They vary from one country to another and from one type of crop to another. For example, in Europe, the percentage goes from a minimum of 5% up to 20%, which experts consider to be genuinely meaningful for biodiversity. A 10% ratio is generally regarded as the minimum ratio to reach. The calculation method for this percentage is described in Point A of Part 2.4.2.3 of this manual.

- **Qualitative indicator:** This provides information on the conservation state of AEI/AEU regarding the issue of conservation (species, natural habitats, species diversity, etc.).

  What are we measuring?

  The percentage of infrastructure in a good, average or unfavourable conservation state (conservation state = ecological quality).

  The state of each infrastructure is assessed using assessment charts composed of multiple sub-indicators (or criteria). More information is available in Point B of Part 2.4.2.3 of this manual.

  The quality of AEI/AEU can be assessed:

  - **At the level of each AEI/AEU**

    The indicators which determine this state are systematically defined and connected with the practices which most likely produced this state.

    The management recommendations must therefore enable the adaptation of these practices to reduce their unfavourable effects as much as possible. This can also consist of layouts to be implemented.

  - **At the farm level by aggregating the preceding data.**

    At the farm level, quality is assessed by aggregating all of the conservation states obtained for all of the AEI/AEU on the farm. It provides a diagram showing the share of AEI/AEU in a good, average or unfavourable conservation state (Figure 13).

    This indicator makes it possible to quickly see if the AEI/AEU are beneficial to biodiversity or not and to visualise the improvement required to reach a proper level of biodiversity on the farm.

CONSERVATION STATE OF THE AEI/AEU

Definition of the state of conservation:
State of an AEI or AEU in comparison to an optimal reference state for biodiversity. Three criteria are assessed: structure, composition and disruptions.

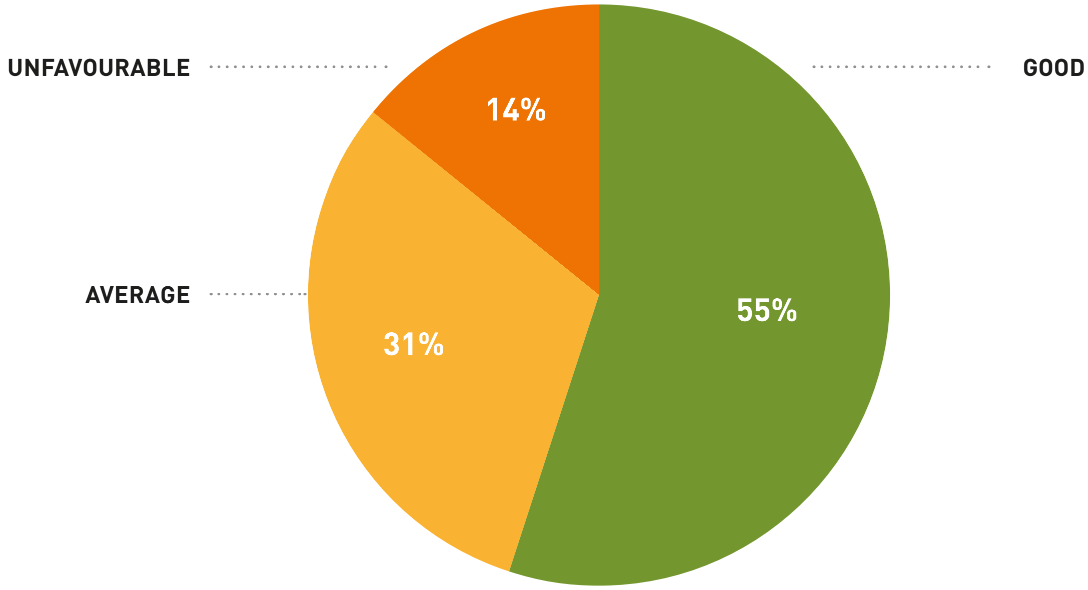


Figure 13: Example of a diagram showing the share of AEI/AEU in a good, average, and unfavourable conservation state.
Source: Natural Spaces Conservatory Languedoc Roussillon | SupAgro Florac, Diagnostic of the biodiversity on farms in Languedoc-Roussillon - Manual adapted within the framework of the Ecodiag Leonardo Da Vinci project innovation transfer work package no. 3.
https://ecodiag.eu/ftp/DAE_fran%C3%A7ais_080413_imp.pdf

- Indicators of animal kingdom biodiversity

Species or groups of species considered to be indicators of the state of **para-agricultural biodiversity** (e.g. carabid beetles, syrphid flies, birds, etc.) are generally used for the biodiversity of **wild animals**. For a species or group of species to be considered and selected as an indicator, several major criteria, mentioned below, must be fulfilled. Criteria taken from Büchs, 2003[48] and Preud'Homme, 2009.[49]

48 Development of an indicator for the assessment of citrus cultivation orchards in Guadeloupe - End of study report on the Master 2 programme *Biodiversity management - Defended in September 2009 in Toulouse by Maxime Pfohl - Supervised by Fabrice Le Bellec, Agronomist at CIRAD Station, Vieux-Habitants*

49 Rose-Line Preud'Homme (2009). Élaboration d'un jeu d'indicateurs permettant de mieux suivre la biodiversité en lien avec l'évolution de l'agriculture

Presence in an agricultural environment and distribution	The indicator must be **common** and **widespread.** It can be found under various environmental conditions.
Ecological services provided	Indicators which play an important **support** or **regulator** role must be given preference.
Persistence	Species which remain in an area or **closed** spatial unit must be used.
Identification and observation	It must be **easy**. There must be **observation protocols** for non-specialists or the ability to create them.
Sensitivity	It must react to **changes in the environment.**

In cultivated areas, estimates of biodiversity using **arthropods** are the most widespread today (Burel and Baudry, 1999; Cotes *et al.*, 2010)[50]. The emphasis placed on invertebrates in addition to plants reflects the importance of their contributions to overall species diversity, since arthropods alone represent almost two thirds of all multi-cellular organisms (Hammond, 1994). In addition, due to the low flexibility of their ecological requirements (reflecting precise environmental conditions), their low relative mobility, their limited lifespan and the iconic nature of some species, invertebrates perform well as indicators of the impact of human activities in ecosystems and, in particular, in agroecosystems (Paoletti and Bressan, 1996; Duelli and Obrist, 1998).

It is preferable to initially assess a limited number of animal species (for example, five) selected based on criteria such as the cultivated plants present and their primary identified pests. For example, if plants which are often attacked by aphids are grown on a farm, insects which prey on aphids, such as hoverflies, ladybirds, etc. would be selected as indicators. If plants which are highly dependent on pollinators are grown (e.g. melon), bees and bumblebees, for example, are of greater interest.

The assessment can later progress by steps and become more complete. It would then look for support from public institutions or organisations working in the field of nature conservation, research and education (for example, support from student work).

The following table is an example of an aid for selecting wild animal organisms as indicators based on the services provided, the vertical compartments occupied, the AEI/AEU and the changes in beneficial practices which can be implemented within an operation.

50 Indicators of biodiversity on organic and conventional farms in the valleys and on the hillsides of Gascogne, French case study from the BIOBIO European project. Agronomic Innovations 32 (2013),333-349

Table 2: Aid for selecting wild animal organisms as indicators

Animal organism	Occupied vertical compart-ment		Service provided			Favourable AEI/ AEU			Favourable change in practice		
	soil	air	crop protection	soil fertility	pollination	hedge	grassy strip	flowering fallow land	pesticide reduction	tilling reduction	permanent cover
pollinating insects		X			X	X	X	X	X		(X)
syrphid flies (hoverflies)		X	X		X	X	X	X	X		
ladybirds		X	X						X		
chrysopa (lacewings)		X	X						X		
termites	X			X					X	X	
ants	X	X	X						X	X	
ground beetles	X	X	X			X	X		X	X	X
spiders		X	X			X	X	X	X		
earthworms	X			X					X	X	X

Source: Modified from "Development of a set of indicators to better monitor biodiversity in connection to changes in agriculture - MAAP/MNHN study - Working document - November 2009"

The purpose of the assessment is not to perform an exhaustive diagnostic of the biodiversity at the farm level but to assess the biodiversity according to changes in agricultural practices. For this reason, point observations, selected by the observer depending on the particular practice, are preferable to proposals to carry out representative sampling of the farm.

2.3.3.3. Indicators of wild patrimonial biodiversity (extra-agricultural)

Concerning patrimonial biodiversity (plants and animals), the species found in the UICN's red list of threatened species may be of interest if some of these species are found on the farm or in the areas surrounding it. The government services handling the protection of nature should be contacted to find out whether these species are present or not at the local level. Information can be found on the UICN websites - http://www.iucnredlist.org/; https://www.iucn.org/regions; https://www.iucn.org/resources/conservation-tools/iucn-red-list-ecosystems. In the context of this manual, the indicator is the presence or non-presence of these endangered species on the farm or in its nearby surroundings. If some are present, their destruction must be avoided and they must be protected through suitable practices on the farm. For plants, species becoming scarce should be planted at the AEI/AEU level.

2.3.3.4. Examples of steps for choosing indicators

A research project called BioBio (Biodiversity indicators in organic and low-input agricultural systems, EU FP7 KBBE-227161, 2009-2012) had the goal of identifying a set of biodiversity indicators which are (i) scientifically grounded, (ii) generic at the European scale, and (iii) pertinent and useful to the stakeholders. BioBio applied a two-phase approach to filter the indicators, as illustrated in the following figure.

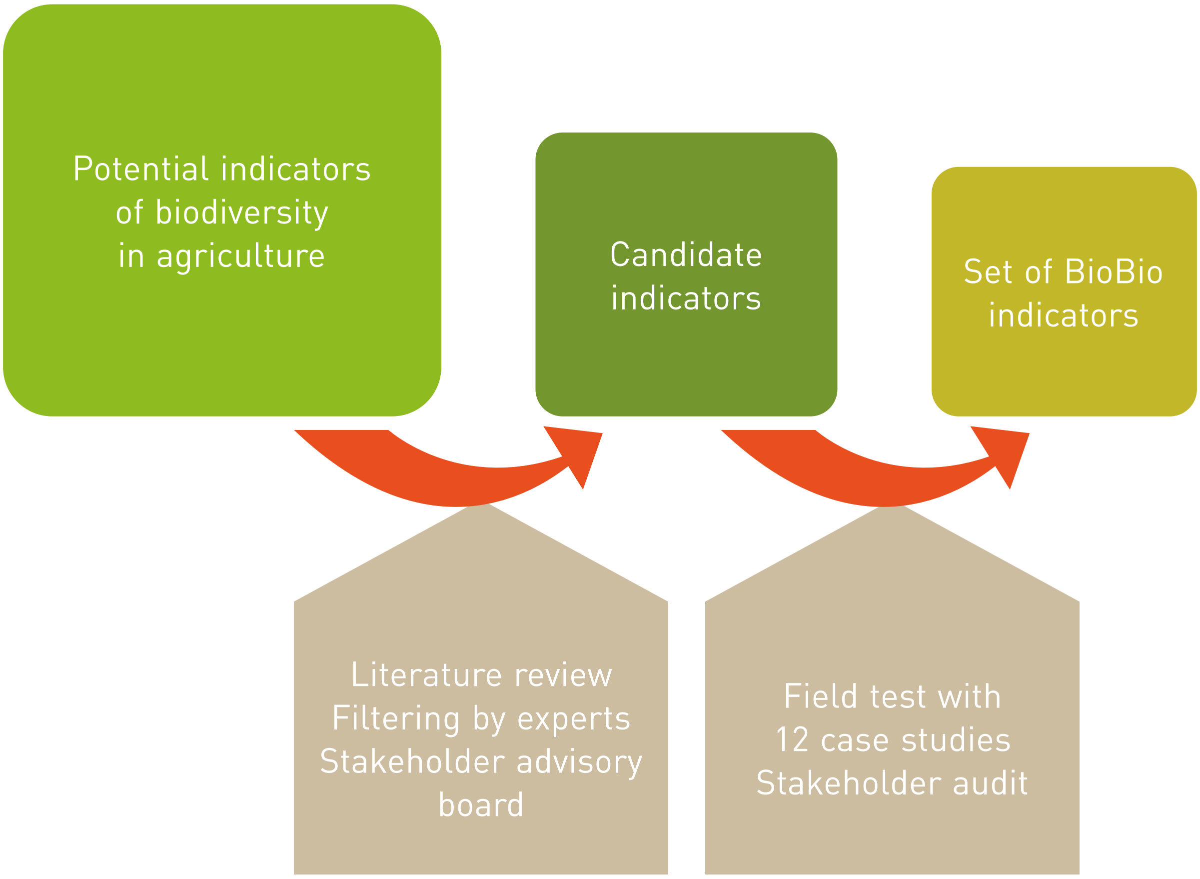


Figure 14: Steps for filtering and choosing indicators in the BioBio Project
Source: Biodiversity indicators in European agricultural systems - Guide summary - Editors: Felix Herzog, Katalin Balázs, Peter Dennis, Ilse Geijzendorffer, Jürgen K. Friedel, Philippe Jeanneret, Max Kainz, Philippe Pointereau - Research Station Agroscope Reckenholz-Tänikon ART – 2012

This example shows that choosing indicators requires multiple steps which can be quite long and which require the participation of several types of players, as well as a validation period.

BioBio kept the following indicators for field crops and horticulture:

Indicators of plant and animal genetic diversity

- Number and quantity of different varieties
- Crop origin

Indicators of species diversity

- Vascular plants
- Wild bees and bumblebees
- Spiders
- Earthworms

Indicators of habitat diversity

- Habitat richness
- Habitat diversity
- Average size of habitat plots
- Length of the linear elements per hectare
- Crop richness
- Percentage of agricultural land with shrubs or small trees
- Tree coverage
- Percentage of semi-natural habitats

Agricultural management indicator

- Total direct and indirect energy input
- Intensification/Extensification
- Production input expenses
- Surface area with mineral nitrogen fertilisers applied
- Total nitrogen input (chemical, organic and symbiotic)
- Number of application campaigns on fields
- Pesticide use

For the purpose of dissemination, the possibilities for a wider application of the BioBio indicators were tested in other agroecological areas and in a different public policy context. They were, notably, tested on subsistence, organic and non-organic agriculture in Uganda.

The BioBio approach was generally applicable in this country while requiring adaptations and developments to be usable taking national specificities into account:

- Habitat indicators: the key used for habitats does not cover the diversity of the intercropping practised by small farmers in Uganda and requires additional developments to be applied in the tropics.
- Species indicators: taxonomic expertise is lacking in Uganda.

- Plant and animal genetic diversity: the indicators were used the same way as in those in the European case studies. Uganda was the only case study with a substantial share of local varieties.
- Management indicators: the socio-economic context, the farmers' level of education and the technological level are different in Uganda compared to the European case studies and the questionnaire had to be adapted in turn.

The test in Uganda demonstrated that, for a practical application, it is necessary to adapt the set of indicators to a different level of resources (financing, knowledge, infrastructure and institutions).

2.3.3.5. Summary of key points

The following table summarises the key points by giving some examples of indicators for a vegetable and/or fruit farm.

Domesticated biodiversity	State indicators	Direct indicators: • Number of cultivated plant species • Average number of varieties per species • Presence of local species/varieties • Presence of livestock
	Pressure indicators	• Availability of different seed types • Variability of market demand • Pest impact
Para-agricultural plant biodiversity	State indicators	Direct indicators: • Quantitative indicator: ratio of AEI/AEU on farm • Qualitative indicator: state (ecological quality) of AEI/AEU
	Pressure indicators	• Herbicide impact • Agricultural machinery impact • Maintenance trimming practices
Para-agricultural animal biodiversity	State indicators	Indirect indicators: • Ratio and state of AEI/AEU • Spatial layout and temporal management of crops Direct indicators: • Number of species and abundance
	Pressure indicators	• Type of soil work • Ground cover • Phytosanitary products used • Fertiliser use • Water use

Non-agricultural biodiversity (patrimonial)	State indicators	Direct indicators: • Number of exceptional (patrimonial) plant and animal species on the farm, number of individuals for each species
	Pressure indicators	• Type of land clearing • Herbicide impact • Agricultural machinery impact • Phytosanitary products used

2.4. BIODIVERSITY ASSESSMENT METHODS

Before undertaking actions in favour of biodiversity at the level of an agricultural operation, a **diagnostic** must be performed.

The diagnostic must be based on the observation of **state indicators** in the field, which consists in carrying out an inventory of the species and ecosystems which the farm hosts and thus reflects the actual state of the situation. Knowing the actual state of the situation at a given moment enables better planning of the actions to take based on correctly defined objectives and to thereafter measure the growth of biodiversity.

The state indicators translate the results of **"positive" or "negative" pressures** exerted by practices on the farm. It's therefore useful to also identify the **agricultural practices** by analysing them to determine if they have positive or negative effects on biodiversity. The practices can then be replaced or modified to improve the state of the biodiversity.

It should be noted that, until very recently the diagnostic to assess biodiversity was usually not carried out at the farm level. The time and, therefore, the cost generated by the field observations required are an obstacle to performing the diagnostics.

In order to heighten the awareness of farmers and provide a tool to make it possible to carry out the diagnostic, several initiatives have attempted to develop dependable, realistic and more feasible working methods.

2.4.1. Some current methods

Existing references have been catalogued to identify the existing assessment methods currently offered. It should be noted that the assessment of biodiversity is often only a small part of the environmental or sustainability diagnostics.

Three main types of diagnostic or assessment methods have been identified in France[51]:

- agroenvironmental diagnostics, generally made up of indicators, with scales or ratings and a more or less developed biodiversity section;
- "natural" methods, of the inventory/species tracking type, generally requiring proficiency in terms of species/environment identifications as well as substantial time for completion;

51 IBIS Project https://www6.inra.fr/ciag/content/download/3822/36230/file/Vol25-10-Cervek.pdf

- methods with more open-ended questions, aiming to understand the farming system.

  The methods developed or in development are most often methods intended for consultants or mentors to aid them in advising producers on biodiversity. These methods are the culmination of a collaboration between the different players involved. However, methods or tools which are directly usable by producers are rare, and the possibility of their adoption by farmers depends on their determination and especially on their level of knowledge.

  The following methods and tools are examples of those that deal directly with biodiversity.

- DBPA: Biodiversity and Agricultural Practices Diagnostic

  This diagnostic arose from environmental concerns in agricultural areas. The tool aims to improve farmer awareness, by involving different players mobilised around this issue and combining biodiversity and agricultural practices. The purpose of the diagnostic is to encourage farmers to develop actions in favour of biodiversity.

The diagnostic is made up of 27 indicators grouped into five topics:

- Crop rotation and plots.
- Soil cover.
- Distribution of Agro-Ecological Infrastructures (AEIs) and connections.
- Crop management.
- AEI quality and management.

- IBIS Project (Integrating Biodiversity in Farm Management Systems)

The IBIS Project is based on the collaborative work of various players in the development of agriculture, the environment, the management of wildlife, research and training. It produced a toolbox for players who wish to advise farmers on the topic of Biodiversity.

The IBIS diagnostic method can be used on field crop or livestock-polyculture operations, located in environments ranging from open plains to bocages.

- **ECODIAG - Ecological Diversity and Agriculture**

  ECODIAG consists of three complementary tools which allow the state of biodiversity to be assessed, both at the level of the cultivated plot and of the farming system.

  They can also be used as awareness-raising tools, assessment tools or tools for managing a farm with the aim of preserving biodiversity and understanding its usefulness.

- IBEA

  The IBEA tool (Impact of Practices on the Biodiversity of Farms) is software for assessing the impact of agricultural practices on biodiversity at the farm level.

  The tool does not assess the state of biodiversity directly, but through agricultural practices and their impact on biodiversity.

  The diagnostic performed by the IBEA tool applies at the farm level as a unit influenced by the farmer's decisions (entire site, including non-agricultural spaces managed by the farmer). The practices as a whole are thus taken into account (production choices, technical itineraries, rotations and succession, plot organisation, etc.).

  The biodiversity in question is also understood in the broader sense: domesticated (species, races and varieties) and wild biodiversity, ordinary and exceptional biodiversity.

  The tool can be used on any type of farm: any production system and any agricultural context.

- **Cool Farm Tool Biodiversity**

  This tool, available online, enables farmers to quantify their practices in favour of biodiversity with points. They can then demonstrate that they are taking actions to foster biodiversity and track their progress in including biodiversity.

- **Gaia Biodiversity Yardstick**

  An online tool for quantifying the biodiversity on a farm. It gives farmers and food businesses an idea of the level of biodiversity protection and promotion on the farm. The tool indicates the effects expected from practices and activities on biodiversity on and around the farm.

It includes 40 questions broken down in 6 themes:

- Crops and varieties grown.
- Overall management applied and benefits for biodiversity (crop protection, fertilisation and soil management).
- Production areas managed to protect the environment (extensive cultivation, late mowing, etc.).
- Non-productive areas on the farm and their management (streams, hedges, etc.)
- Management of natural reserves.
- Farmyard green areas and their management.

This non-exhaustive list of methods and tools shows that there are many initiatives in existence, at least in Europe. However, it must be noted that the existing methods were mainly developed for field crops. The methods for fruit and vegetable crops are underdeveloped and virtually not at all for tropical environments.

FOR MORE INFORMATION

DBPA
http://www.hommes-et-territoires.asso.fr/nos-outils/dbpa

IBIS
http://www.centre.chambagri.fr/cd_ibis/ibis_le_site.html;
http://ecophytopic.fr/tr/innovation-en-marche/programmes-casdar/ibis-int%C3%A9grer-la-biodiversit%C3%A9-dans-les-syst%C3%A8mes-d

ECODIAG
http://ecodiag.eu/wakka.php?wiki=Accueil

IBEA
http://ibea.portea.fr/indicator/index.php?r=site/genPage&id=67

Cool Farm Tool Biodiversity
https://coolfarmtool.org/coolfarmtool/biodiversity/

Gaia Biodiversity Yardstick
www.gaia-biodiversity-yardstick.eu

2.4.2. Proposed methodology

Assessing biodiversity to then plan and implement measures in favour of biodiversity on one's own farm is a captivating, instructional and enriching process. The process is an opportunity for farmers to better integrate the services provided by biodiversity into the operation of agroecosystems.

Such a project can, however, turn out be a real challenge, because it requires a decent level of specific knowledge about plants, wild animals and ecosystems as well as other information for planning. [52]

In general, the measures for improving biodiversity must be pertinent not only at the ecological level but also from an economic standpoint. It's for this reason that they must always be adapted not only to the characteristics of the natural environment but also to the specific conditions of the farm.

The assessment method used must have the following characteristics:

- Be quick and as accessible as possible (ease-of-use).

  Be implementable, at least partially, directly within the operation by adequately trained farmers, business managers and executives in charge of the "environmental" aspect or of sustainable production.

  It must also be of use to agricultural advisers/popularisers and must therefore favour understanding and exchanges between these players and farmers. In fact, before offering advice, the operation of the farm must be understood in order to take the farmer's constraints, projects and objectives into account.
- Robust (have a large field of application in terms of environments and systems)
- Sensitive (discriminating).
- Pertinent (contribute effectively to raising awareness and to progressing towards greater biodiversity and sustainable agriculture).

It must also make it possible, through its form and content, to inform the farmer about their natural heritage and enable them to take ownership of it.

Furthermore, the farmer must be able to, on the basis of the diagnostic, work in collaboration with potential external supports on the construction and implementation of recommendations for the management of biodiversity within the management system.

The methodological procedure proposed here makes it possible **to assess the state of biodiversity and the level of pressure of the practices** on a farm primarily producing fruits and/or vegetables. This is in order to be able to create an **action plan** to preserve or foster biodiversity and to easily assess the results and progress.

The methodology is "open". In other words, it is not only based on indicators. It can be characterised as "a global approach to the farm, environments and agricultural practices, applied to biodiversity".[53]

52 Adapted from: Biodiversity on the farm - Practical guide - FIBL, Swiss Ornithological Institute - 2016

53 Biodiversity in farming systems: the IBIS Project - Céline CERVEK – Agronomy-environment - OCL VOL. 18 N8 3 May-June 2011

The process must be carried out insofar as possible by the farmer and their team. Requests for outside assistance must only happen as a matter of necessity.

Note: *The methodology provided here has not been tested and validated within the context of fruit and vegetable production in ACP countries. It is simply a proposal which must be tested and validated in practice to make improvements/adaptations and to develop it further. It is also important to jointly build the method via exchanges between the main beneficiaries, i.e., the farmers and the requesters such as the certifiers, marketeers and public institutions.*

This proposal refers primarily to an objective to develop ecosystem services which are beneficial to production. In particular, those which enable a reduction in the use of Plant Protection Products. This is in line with the proposal of the IUCN (World Conservation Congress, Hawaii 2016) which considers that promoting **sustainable** practices to protect wild biodiversity involves **reducing the use of phytosanitary products54**. For example, neonicotinoid products and fipronil are highlighted in particular because they are considered to be highly damaging to animal biodiversity, and require replacing with alternatives[55].

The proposed methodology is broken down based on the compartments discussed previously and restated in the diagram which follows. Indicators are established at the level of each of these compartments.

54 Biodiversity in agribusiness standards – Solagro - MAAF - 16 May 2017

55 http://www.tfsp.info/resources/ https://www.linktv.org/shows/earth-focus/episodes/neonicotinoids-the-new-ddt

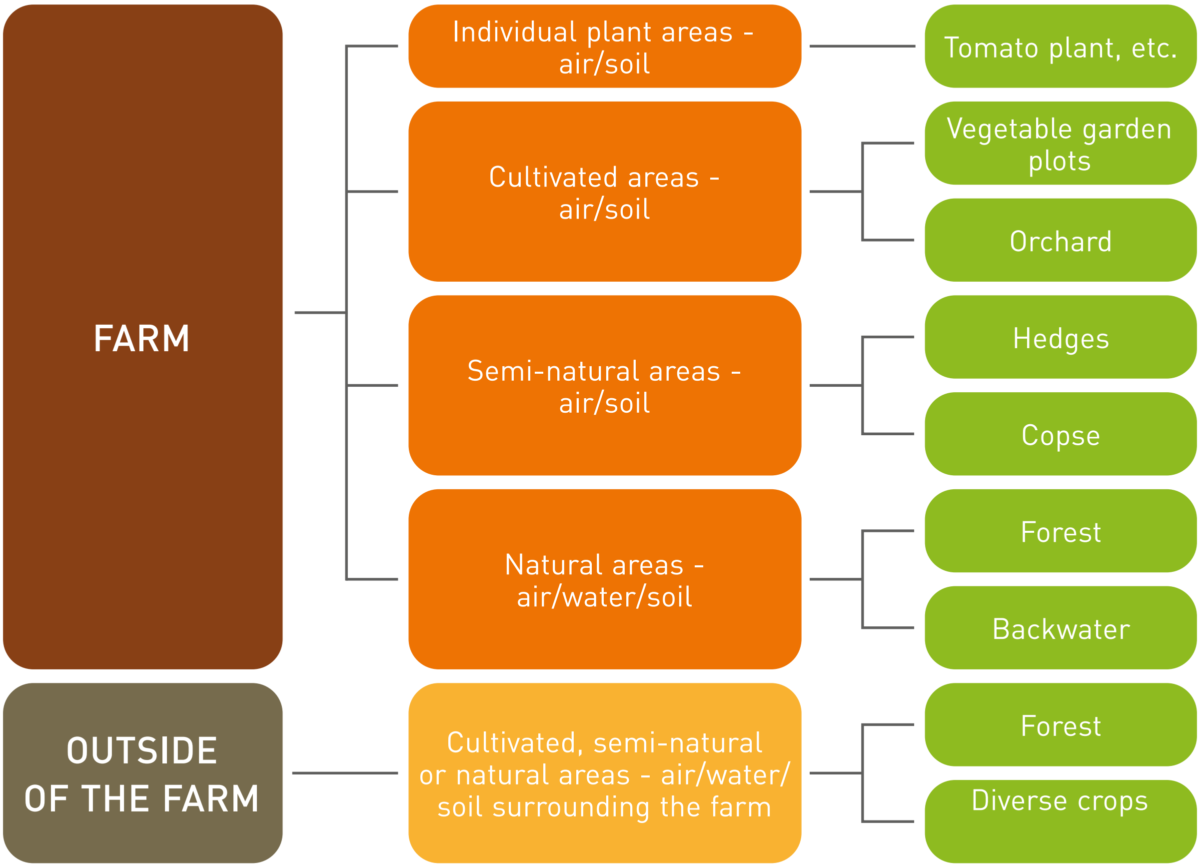


Figure 15: Examples of compartment occupancies on and outside of the farm

2.4.3. Description of the steps to follow

The following **steps** are **proposed** for carrying out the assessment. We do not take the individual plant compartment into account here because the assessment of its biodiversity is fairly demanding and usually out of the farmers' reach.

1. Describe the farm overall **by mapping the plot distribution, and with a description of the state of biodiversity change** via a questionnaire for the farmer
2. Conduct the **assessment of biodiversity and analysis of practices** for the **"cultivated areas" compartment on the farm**
3. Conduct the **biodiversity assessment and analysis of practices** for the **"semi-natural area" and "natural area" compartments on the farm**
4. Conduct the **assessment of the impact of practices** for the areas located in the **"farm surroundings" compartment** and vice-versa
5. Write the **report**

The time required to complete this assessment will depend on the objectives set, the resources available and the extent and level of precision which is desired or can be provided. It is generally necessary that the assessment take place over an entire year to cover the location's different seasons; furthermore, hundreds of observations must be carried out at specific times of the year or in a crop cycle.

2.4.3.1. Step 1: Describe the farm

- **Plot distribution mapping**

  This mapping will enable the identification, localisation and measurement of the areas on the farm occupied by:

  - annual or perennial crops (orchards, etc.);
  - semi-natural or natural elements (or AEI/AEU) including, potentially, established patrimonial species and species with a high conservation value such as exceptional trees;
  - cultivated permanent meadows;
  - permanent infrastructure, rivers and streams, paths, buildings, etc.;
  - the slope, main local characteristics (sensitivity to erosion, presence of a river which is prone to major flooding, sinkhole, etc.);
  - etc.

It will also enable identifying and locating the types of areas found around the farm, given that they can be impacted by farming practices.

In practical terms, it consists of identifying and locating the areas mentioned previously, if possible on aerial photos (for example, from Google Earth or with the aid of a drone). Once the boundaries of the farm are known and mapped, the spaces are delineated and drawn on aerial photographs during the field visit.

For example, in the following figure, the AEI/AEU on the farm are highlighted with colours: semi-natural areas (Dehesa, Matorral), isolated trees, rows of trees, grassy strips and natural meadows.

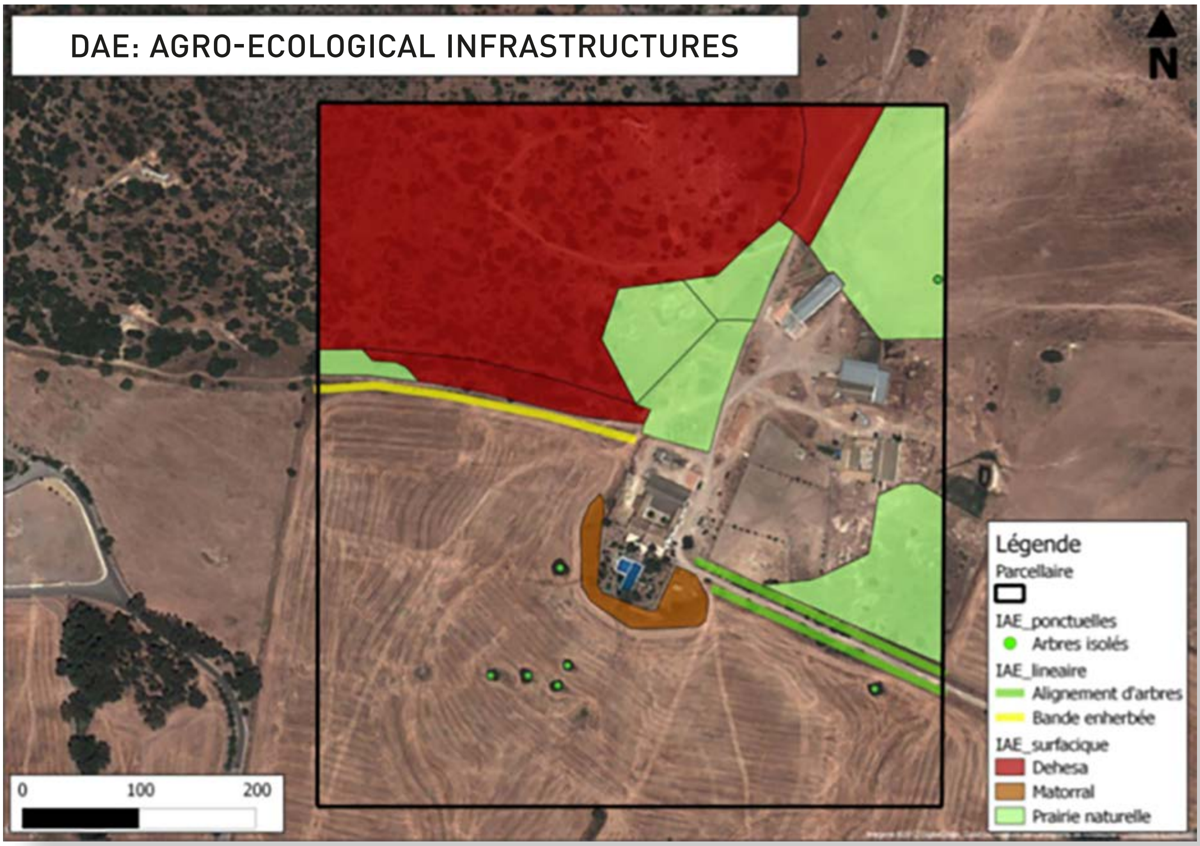


Figure 16: Example of AEI/AEU identification on an aerial photograph.
Source: https://www.ecodiag.eu/ftp/typesIAE.pdf

During the field visit, photographs can also be taken to better illustrate the use of certain areas and their changes (see example in Appendix 2).

The mapping of the AEI/AEU and cultivated plots in a Geographical Information System (GIS) subsequently makes it possible to determine the surface areas they occupy and the length of linear elements, such as hedges, and also the number of ponds or isolated trees. If a GIS is unavailable, measurements will have to be made in the field.

The mapping also makes it possible to assess the level of compositional and configurational heterogeneity and the level of connection between natural and semi-natural areas.

At the same time, during the field visit or by consulting databases or experts, the farm technician in charge of the diagnostic will identify and locate, possibly with outside support, the species and ecosystems of patrimonial interest (protected species, endangered species, etc.). This work then allows the owner to be informed of the existence of species and ecosystems of high conservation value and to raise their awareness in terms of their responsibility for their preservation.

- **Description of the state of biodiversity change**

Before any biodiversity assessment or analysis of practices, the farmer must describe the changes in the cultivated area's biodiversity. The definition of biodiversity will have to be translated into the local language, using language that is understandable by the farmers.

Guide questions	Answers (from the farmers)	Since when?
What wild plants (grasses, shrubs, trees, etc.) are no longer found on the farm?		
What cultivated plants are no longer found on the farm?		
What new wild plants are growing on the farm?		
What new plants are cultivated on the farm?		
What flying and non-flying insects are no longer found on and in the farm's soil?		
What new flying and non-flying insects are found on and in the farm's soil?		
What animals (e.g. rodents) are no longer found on the farm?		
What new wild animals are found on the farm?		
What combinations of crops no longer exist?		
What crop rotation systems (succession of crops and fallow land on the operation) no longer exist?		
What are the other changes in relation to plants, insects, animals and crop systems?		
What are the reasons behind these observed changes?		
What are the consequences of these changes?		
What are the responses provided by the farmer(s)?		
What is the impact of these responses on biodiversity?		

2.4.3.2. Step 2: Biodiversity assessment and analysis of practices for the "cultivated areas" compartment

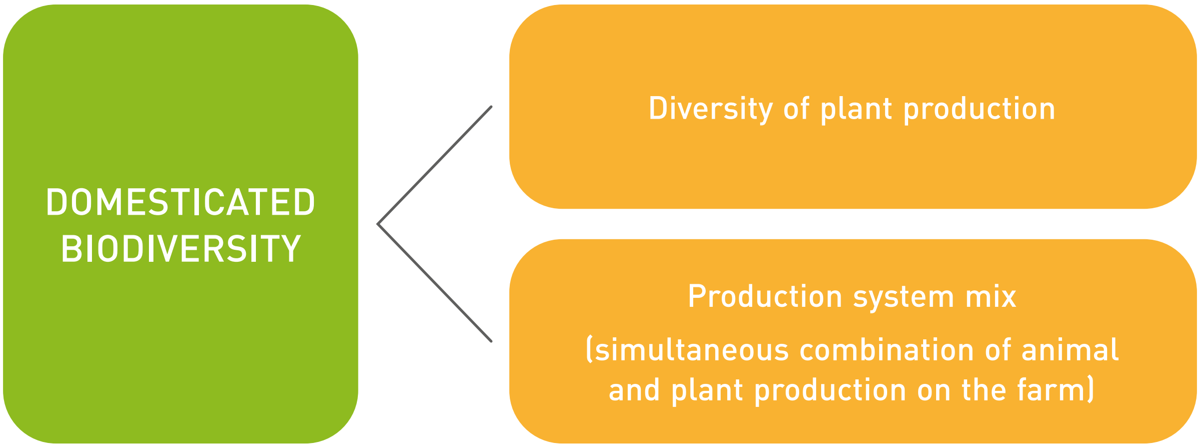
For this compartment, the assessment covers the **domesticated biodiversity** first then the **wild biodiversity. An analysis of practices** will then be carried out.

For areas where annual plants are grown, it is necessary to carry out the assessment at multiple times in the year or at least once every main climatic season because the occupancy of these areas changes depending on the seasons.

The assessment method proposed here is based on the method developed in the document "IBEA - A diagnostic tool for the impact of practices on the biodiversity of farms - Scientific manual - 1st version, March 2013"

- **Domesticated biodiversity**

The total level of domesticated biodiversity can be assessed by aggregating two very unequally weighed indicators such as indicated below.



After aggregating the two indicators, the domesticated biodiversity on the farm is classified in the table below as very low, low, average, high, or very high. The diversity of production carries much more weight than the system mix.

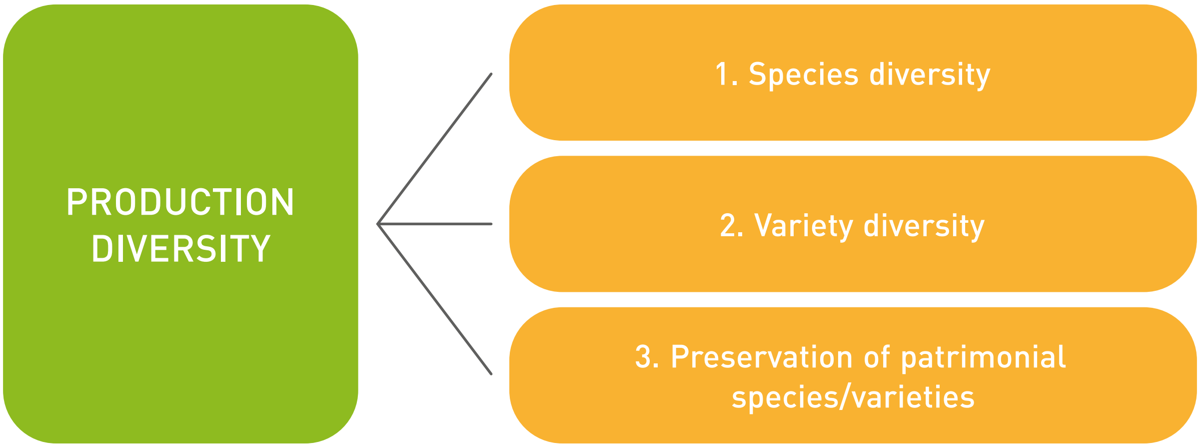
Production system mix	Production diversity	Domesticated biodiversity
no	very low	**very low**
no	low	**low**
no	average	**average**
no	high	**high**
no	very high	**high**
yes	very low	**low**
yes	low	**average**
yes	average	**high**
yes	high	**very high**
yes	very high	**very high**

The levels of production diversity and mix are defined below.

a. **Diversity of plant production**

The diversification of production is considered a very important tool for increasing biodiversity, both in terms of wild species diversity as well as domesticated species diversity (species, races and varieties).

The diversity level of a farm's production is assessed by aggregating three indicators as follows.



In the aggregation table in Appendix 3, a greater level of importance is attributed to species diversity, based in particular on crop rotation and a balanced system.

In order to determine the level of these indicators, the species and varieties grown on the farm must be inventoried. The total number of species and varieties grown on the farm is calculated. For annual crops, which vary in number and in composition during different times of the year on a tropical vegetable farm, an average of these numbers over the year must be calculated. Two examples of the procedure to follow, one for perennial crops and the other for annual crops, are found in the appendixes.

The diversity levels of the three indicators are defined below.

i. **Species diversity**

The level of species diversity can be defined with the following thresholds.

Level of species diversity	Thresholds of the average number of species cultivated on the farm at the same time
Very low	Lower or equal to 3
Low	From > 3 to = 5
Average	From > 5 to = 7
High	From > 7 to = 9
Very high	Greater than 9

ii. Variety diversity

The level of variety diversity can be determined with the aid of the thresholds presented below. It is assessed based on a criterion reflecting the average number of varieties for all of the plant species found on the farm.

Level of variety diversity	Thresholds of the average number of varieties/species for all of the species cultivated on the farm.
Very low	< 2
Low	From 2 to < 3
Average	From 3 to < 4
High	From 4 to 5
Very high	> 5

iii. Preservation of patrimonial species or varieties

Some farmers grow "heirloom" or local species or varieties which are often threatened by extinction. The value of this important function of patrimonial management is valued with this indicator, regardless of the area in question. The indicator shows whether they are present or not on the farm. In addition to the patrimonial value, the use of heirloom varieties can offer interesting results in extensive farming systems, in particular in organic agriculture, such as, for example, a greater tolerance to weed infestations (Cosser *et al.* 1997 in ESCo, 2008) and a greater resistance to pests (Kuc, 2001, in ESCo, 2008) which reduces the use of herbicides (Watson *et al.* 2005, in ESCo, 2008), fungicides and insecticides.[56]

b. Mixed production system

Mixing refers to the combined presence of livestock raising and plant production on the farm ("livestock polyculture")

These combinations generally strengthen the biodiversity of the environment because each trophic level (plant and herbivore/granivore) is accompanied by its dependent species (commensal, auxiliary, concurrent, parasitic, symbiotic, etc.).

The "mixing" indicator supplements domesticated diversity by underlining the benefit of systemic combinations of agriculture and livestock. Tapping into the synergies between crops and livestock can limit the impact of agricultural practices on the environment in general, and on biodiversity in particular. The indicator reflects the presence or lack of mixing within the operation.

If livestock is present on the operation, the species and races present can also be inventoried and recorded and their presence can be expressed as a number per hectare of the farm. For example, if there are 20 cows on a 20 ha operation. The occupancy rate by livestock is 1 per hectare. However, this measure is not taken into account here.

56 IBEA - A diagnostic tool for the impact of practices on the biodiversity of farms - Scientific manual - 1st version, March 2013

- **Wild para-agricultural biodiversity in cultivated areas**

This biodiversity is made up of the living organisms which play an important role in agroecosystems.

It is recommended that only the organisms which are best known to the farmer and easiest to assess be evaluated at first. This can be limited at first to four or five types of organisms then be increased progressively, if necessary and possible, to, for example, a maximum of 12 different types.

For the air compartment, beneficial arthropods (especially auxiliaries) are of the greatest interest. For example, the presence of the following can be assessed: syrphid flies, ladybirds, predator heteropterans, chrysops, phytoseiids (predator mites), bees, bumblebees and spiders. A choice between these arthropods is made depending on the system services desired and the most frequently occurring phytosanitary issues. See the example in Chapter 5 (case study).

At the level of the soil compartment, the presence of carabid beetles and earthworms is usually of greatest interest, but in tropical environments, termites can also be of interest (termites often make up the dominant group of pedofauna in tropical environments), as well as ants, which play an important role (see Chapter 3). In tropical environments, it appears there is competition between carabid beetles and ants for soil occupancy. It has been observed that ants dominate in lowlands, to the detriment of carabids, and that on the contrary, carabids dominate over ants as the altitude increases.[57]

Earthworms are generally found in greater numbers in the humid and sub-humid tropics, whereas ants and termites are more present in semi-arid and arid regions.

There are different methods to assess the diversity and size of the populations of wild para-agricultural organisms, but few are truly adapted to an assessment carried out by a farmer. They cannot all be described here; however, a few examples are provided below.

a. **Observation methods for flying auxiliaries**

There are several methods. The three methods most easily employed by farmers are provided in Appendix 5: hitting or beating branches; direct observation of plants and visual inspection; yellow traps.

In Appendix 6, a few examples of direct observation are provided for the natural predators of pests such as aphids, spider mites, white flies, thrips and mealybugs, as well as the thresholds for estimating the extent of the presence of these auxiliaries. Identification aid references can be found in this manual.

57 Population Biology of Tropical Insects Allen M. Young

b. Observation methods for soil macrofauna organisms

Soil macrofauna is made up of invertebrates ranging from 2 mm to 80 mm in length[58]; [59].

Relatively simple assessment techniques for carabids and earthworms are provided in Appendix 7. These methods also enable assessment of the presence of other soil macrofauna organisms, such as those illustrated below.

ANTS

Source: http://ephytia.inra.fr/fr/C/25142/jardibiodiv-Fourmis

TERMITES

Source: www.fao.org/tempref/docrep/fao/011/i0211e/i0211e04.pdf

SPIDERS

Source: http://ephytia.inra.fr/fr/C/25150/jardibiodiv-Araignees

MYRIAPODS (MILLIPEDES AND CENTIPEDES)

Source: http://ephytia.inra.fr/fr/C/25153/jardibiodiv-Myriapodes-diplopodes; http://ephytia.inra.fr/fr/C/25152/jardibiodiv-Myriapodes-chilopodes

ISOPODS (WOODLICE)

Source: http://ephytia.inra.fr/fr/C/25151/jardibiodiv-Cloportes

For identification help also see:
https://animasol.jimdo.com/%C3%A9tudier-la-faune/classer/

The data obtained from these observations should enable assessment of the abundance and diversity of the macrofauna. However, there are few references or studies available on macrofauna in the tropical agricultural environment. It is therefore difficult to say if an environment is more or less replete with beneficial macrofauna at the soil level. The observations will therefore serve more to compare the different parts of the operation, the farms in a same area or the changes over time to assess the impact of the changes in practices on macrofauna.

58 http://www.supagro.fr/ress-pepites/OrganismesduSol/co/macrofaune.html

59 http://www.cnrs.fr/cw/dossiers/dosbiodiv/index.php?pid=decouv_chapC_p5&zoom_id=zoom_c1_1

For example, orders of magnitude of the number of individuals per m² and proposals of abundance classifications (rated from 1 to 3) for myriapods, ants and termites are given below. References on the abundance of carabid beetles in a tropical environment are nearly non-existent and we cannot provide any information. The same is true for isopods and spiders:

- Myriapods: 20 to 700[60] - three classifications are proposed:
  low (< 100), average (100 to 300), good (> 300).
- Ants: 300 to 500 m² in Senegal in a dry area in a natural environment - three classifications are proposed:
  low (< 300), average (300 to 500), good (> 500).
- Termites: 20 to 130 in Senegal in a dry area in a natural environment - three classifications are proposed:
  low (< 50), average (50 to 100), good (> 150).

These classifications are provided for illustrative purposes and must normally be established locally on the basis of observations conducted over the long term and in various locations in the area concerned.

There are no thresholds for earthworms, so to speak, since the level of earthworms possible depends on many climatic and edaphic factors. However, the following values can be applied. For example, far fewer than 100 earthworms/m² will be found in soils poor in organic matter (about 10 in extreme cases), while soils rich in organic matter can contain up to 1,000 individuals/m². In organic agriculture the number is often about 150/m². For illustrative purposes, we propose three abundance levels below for an assessment using the TSBF method.

Number of earthworms per m² at a depth of 30 cm	Abundance and rating
Less than 50	Low
From 50 to 100	Average
More than 100	Good

When observing earthworms, it is useful to be able to distinguish between the three major ecological categories of earthworms, if possible. See the illustration below.

60 Biodiversity and soil functioning S. Barot IRD UMR 137 http://studylibfr.com/doc/3490268/esol--biodiversit%C3%A9-et-fonctionnement-des-sols

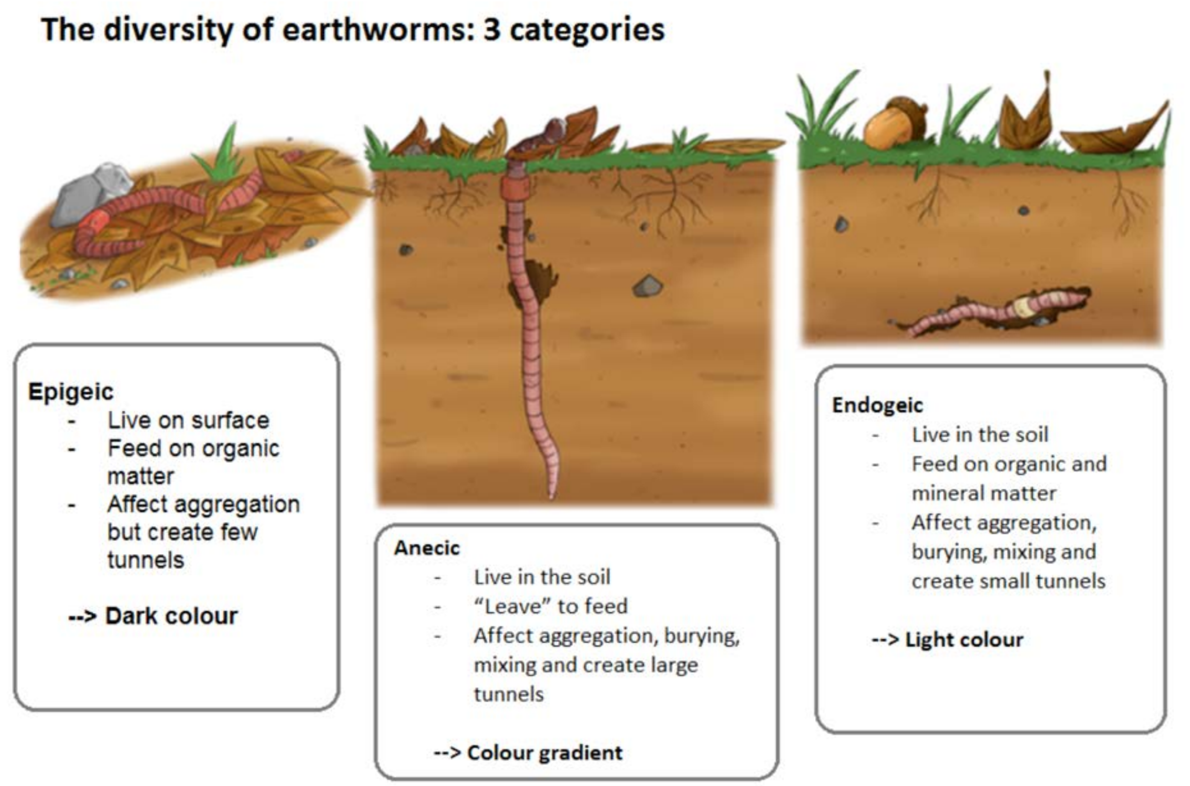


Figure 17: Earthworm diversity
(Source: https://animasol.jimdo.com/voir-et-comprendre/zoom-sur-les-vers/)

Earthworms are abundant and constitute significant biomass where recorded rainfall exceeds 1,000 to 1,100 millimetres. In the savannahs of West Africa, endogeic geophagous earthworms which eat organic matter in the soil are often the dominant group, contrary to temperate zones where epigeic and anecic earthworms, which primarily eat litter, predominate (Lavelle *et al.* 1990). [61]

To carry out an overall assessment of the macrofauna of the soil on the farm, the data collected can be compiled by giving a score in an evaluation table which uses three indexes: abundance, diversity and evenness. Greater weight is given to abundance than to the two other indexes by following the rating system below:

- Abundance: low = 2, average = 4, good = 6
- H' (Shannon Index): low (< 0.5) = 1, average (0.5 to 1) = 2, good (> 1) = 3
- E' (Evenness Index): low (0 to 0.5) = 1, average (> 0.5 to 0.75) = 2, good (> 0.75 to 1) = 3
- If there is no data for H' and E = by default, the same category value as abundance.

Based on the average of the total scores for the different types of organisms, it can be determined if the macrofauna biodiversity at the plot level is problematic, average or favourable, taking into account the thresholds defined below.

61 http://horizon.documentation.ird.fr/exl-doc/pleins_textes/divers09-03/010024634.pdf

Average of the total scores of the three indexes	Overall value of macrofauna diversity
4 to 7	problematic
> 7 to < 9	average
9 to 12	favourable

For example:

Organism	Abundance	Diversity (H')	Evenness €	Total overall assessment
Earthworms	2	/ (1)*	/ (1)*	4
Termites	2	2	3	7
Ants	6	2	3	11
Myriapoda	4	2	2	8
				30/4 = 7.5 Average soil macrofauna biodiversity

*default value when data is lacking

The abundance and structure of the soil macrofauna populations can vary significantly depending on climate, soil and vegetation conditions. The densities (500 to 2,000 individuals/m^2) and biomasses (10 to 40 g/m^2) of macroinvertebrates found in the fallow land in Senegal, in the centre of the peanut-growing basin and in Haute-Casamance, are relatively high given the climate conditions: dry season longer than six months; annual recorded rainfall of 750 millimetres in the centre of the peanut-growing basin and of 1,000 millimetres in Haute-Casamance. These densities and biomasses are on the same scale as the tropical agroecosystems of wetter areas (Lavelle & Pashanasi, 1989; Lavelle *et al.*, 1991; Gilot *et al.*, 1994). These biomasses are higher than those of the vertisols of northern Cameroon where precipitation is 750 millilitres. In Zimbabwe (850 mm of precipitation in five months of rainy season), the macroinvertebrate populations of the shrub savannah, dominated by termites, have biomasses of 10 grams per square metre related to the lower abundance of earthworms (Dangerfield, 1990).[62]

Assessment of the soil macrofauna at the farm plot level can be first done by simply weighing the macrofauna collected per m^2 using the TSBF method. This would provide at least an estimate of the incidence of the macrofauna by comparing it to the references above, or other references which may be found.

62 http://horizon.documentation.ird.fr/exl-doc/pleins_textes/divers15-11/010024585.pdf

c. Other information

Other, more detailed information, can be found at "How to observe and trap auxiliaries":

- How to observe and trap entomophagous auxiliaries
  http://arena-auximore.fr/observer-2/
- How to install and check traps to monitor populations. -
  https://www.arvalis-infos.fr/comment-installer-et-relever-des-pieges-pour-suivre-les-populations--@/view-21732-arvarticle.html
- A Pocket Guide - Common Natural Enemies of Crop and Garden Pests in the Pacific Northwest -
  http://www.ipmnet.org/Pocket_guide_of_Natural_Enemies.pdf

Assessment examples and methods are also available for bees, bumble bees, spiders and earthworms at http://www.biobio-indicator.org/indicators.php?l=3 (in English).

Other sources of information for termites and ants, among others, are available at: Field data collection methods to assess and monitor biodiversity
https://www.uni-frankfurt.de/47671015/BJ_10_REG_5.pdf.

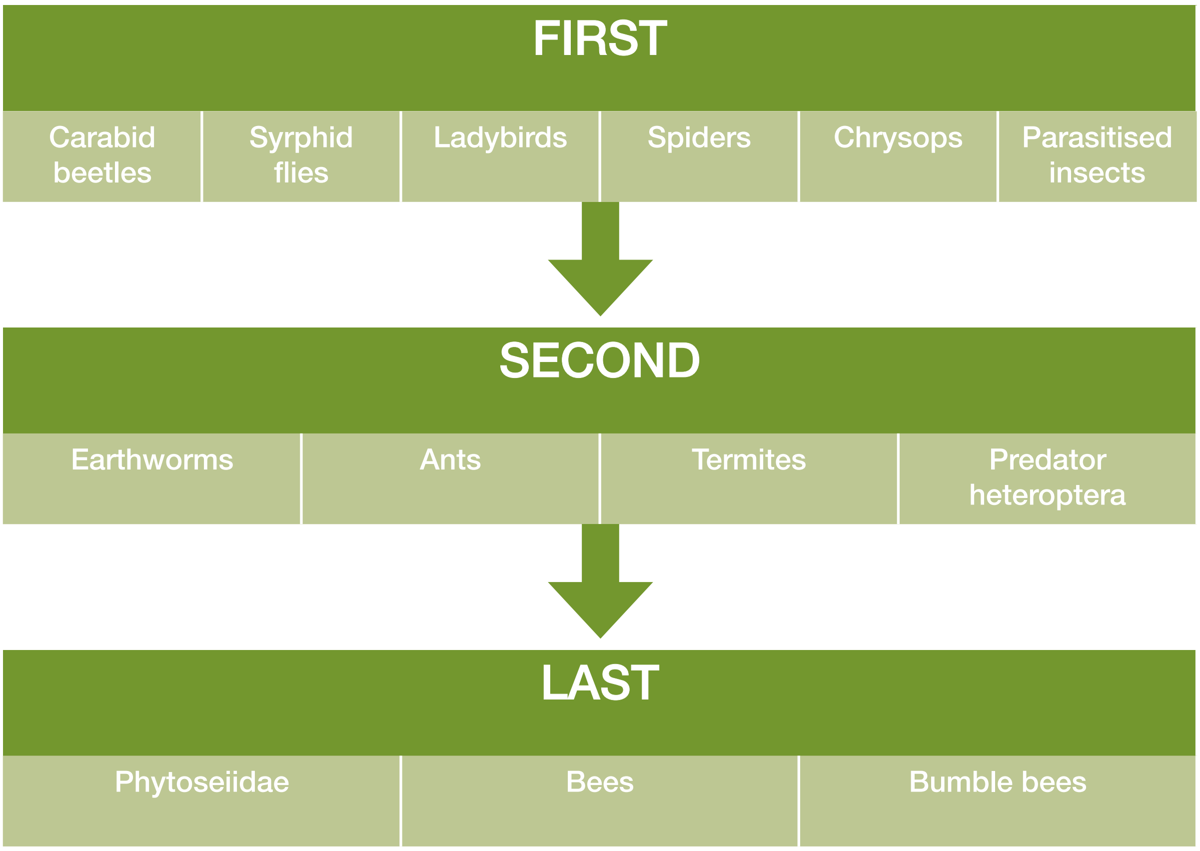


Figure 17: KEY POINTS: Type of wild para-agricultural organisms to be classified by order of observation ease/importance

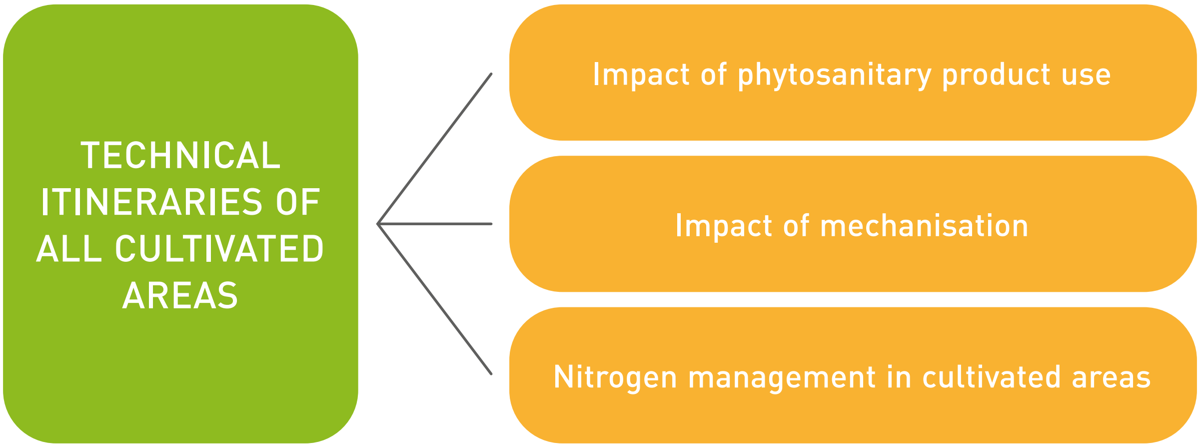
- **Analysis of practices in cultivated areas**

This analysis consists in measuring the quality of cultivated areas based on practices. Quality refers to the ability of the areas to sustain a relatively large number of wild species, particularly wild para-agricultural biodiversity which is most useful to farm production processes.

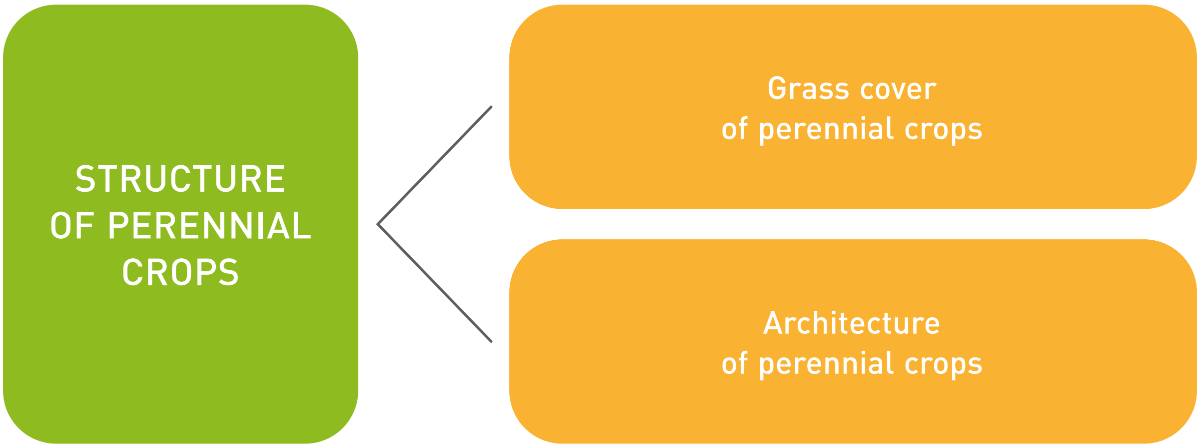
Cultivated areas include all worked soil (rotated), which excludes all permanent and temporary meadows over five years old (considered semi-natural environments), forest (even with pastures) and non-UAAs (Utilised Agricultural Area).

In this case, we are interested in the **technical itineraries** of all cultivated areas and in the **structure of perennial crops** to assess the quality of cultivated areas.

The impact analyses for the technical itineraries break down as follows:



The quality analysis of the structure of perennial crops (woody species and banana and papaya trees) breaks down as follows:



The procedure to carry out to assess the quality of the technical itineraries and of the structure of perennial crops is available in Appendix 8.

Aggregation of the analysis of the **technical itineraries** of all cultivated areas and of the **structure of perennial crops** can enable the classification of the “quality of cultivated areas” of a farm based on four categories: **problematic**, **poor**, **acceptable** and **favourable**. To establish the classification, the “technical itinerary of all cultivated areas” criterion has greater weight in the final result than the “specificities of perennial crops”, since it contains more basic criteria.

Aggregated assessment table

	Technical itinerary of all cultivated areas	Structure of perennial crops	Quality of cultivated areas
1	problematic	poor	**problematic**
2	problematic	acceptable	**problematic**
3	problematic	no perennial crops	**problematic**
4	problematic	favourable	**poor**
5	poor	poor	**poor**
6	poor	acceptable	**poor**
7	poor	no perennial crops	**poor**
8	poor	favourable	**acceptable**
9	acceptable	poor	**acceptable**
10	acceptable	acceptable	**acceptable**
11	acceptable	no perennial crops	**acceptable**
12	acceptable	favourable	**favourable**
13	favourable	poor	**acceptable**
14	favourable	acceptable	**favourable**
15	favourable	no perennial crops	**favourable**
16	favourable	favourable	**favourable**

- **Spatial organisation and temporal management of cultivated areas**

a. **Annual and pluriannual crop rotation diversity**

Crop rotation diversity refers to multiple crops and the absence of a dominant crop. It provides a wide range of habitats and resources for biodiversity. In very simple agricultural systems, the main crop can cover over 50% of the area (e.g., rotation of two crops) or even 100% (a single crop) and result in severe and abrupt shortages of resources and habitats for animal species immediately following harvests. In some regions, simple crop rotations at the regional level also result in very significant temporal and spatial resource interruptions which can compromise the survival of many taxons. Inversely, complex and diversified crop rotation buffers and limits these critical periods.

Crop rotation diversity is assessed based on the percentage of the total area occupied by the main crop or botanical group (e.g., the *Solanaceae* family) compared to the UAA. Main crop refers only to annual and pluriannual crops of less than five years.

Crop rotation diversity level	Percentage of area occupied by the main crop
Low	Greater than 50%
Average	Between 30% and 50%
High	Under 30%

Crop rotation is heterogeneous. For example, depending on the period, tomatoes (*Solanaceae*) or okra (*Malvaceae*) are the main crop. These two main crops account for 50% of the cultivated area at the time they are present in the fields. This is an example of an average crop rotation diversity level.

b. **Mosaic effect resulting from plot size**

The mosaic effect resulting from plot size is assessed by the average size of the cultivated plots on the farm. For field crops like cereals, it is generally considered that when the average plot size is over 10 hectares, the ecological networking of the environment is too loose and wild biodiversity is penalised. A reduction of plot size and the presence of hedges are a requirement for maintaining high biological diversity (Van Elsen, 2000, ESCo, 2008, Chapter 1). Field crops with plots under five hectares improve the stability of the landscape and, as a result, trophic resources (resilience of the environment).

The complexity of the mosaic is assessed based on the average size of the plots farmed. In this case, a plot is a unit defined by its physical or management limits. For example, two maize fields separated by a hedge count as two plots. Likewise, two mango tree units with no physical boundaries, but consisting of different varieties and/or managed based on different technical itineraries count as two plots. This means that the cadastral definition of the plot is not taken into account.

We propose the following category limits for vegetable and fruit crops.

Mosaic complexity	Average plot size thresholds
Low	Average plot size greater than 10% of the cultivated UAA of the farm
Average	Average plot size between 5% and 10% of the cultivated UAA of the farm
High	Average plot size less than 5% of the cultivated UAA of the farm

For example, the thresholds for a farm with five hectares of cultivated land would be:

Mosaic complexity	Average plot size
Low	Average plot size greater than 5,000 m^2.
Average	Average plot size between 2,500 m^2 and 5,000 m^2.
High	Average plot size less than 2,500 m^2.

c. Intra-plot mixing

Intra-plot mixing consists in combining several species and/or varieties on a plot. See Chapter 4 for examples of intra-plot mixing (combinations).

In the IBEA[63] document, these criteria are assessed by the mix of species and/or varieties on a cultivated plot: combination at the time of sowing/planting by the farmer. A plot is considered to have intra-plot mixing when at least 5% of the cultivated area contains a mix of species. Five percent is sufficient to assign a "Yes" to this indicator. However, it is clear that having more than 5% of the area planted with mixed crops and having a number of combinations is better for increasing interaction and improving diversity.

We preferred to recommend the use of the categories below for vegetable and fruit crops. Note that mixing species which grow to different heights is more beneficial than combinations of plants of similar height. For example, a mix of maize + sorghum or of beans + peanuts/ground-beans is less beneficial for biodiversity than a mix of beans + sorghum/maize or peanuts + sorghum/maize. For areas used for combinations of plant species which are significantly different in height, we recommend applying a x2 coefficient which will double the area included in the calculation.

Mix level	Percentage of the cultivated area with a mix of species
Low	Less than 5% of the cultivated UAA of the farm contains a mix of species
Average	5% to 25% of the cultivated UAA of the farm contains a mix of species
High	Over than 25% of the cultivated UAA of the farm contains a mix of species

d. Temporal management of cultivated vegetation cover

When, as a result of the homogeneity of crops and of technical itineraries, large areas are left bare during the same period, the result is an abrupt and significant temporal break in resources and habitat for many animal species. This temporary period of scarcity is worse when it occurs during certain critical periods.

Continuity is assessed via the management of the inter-crop period: farmers must estimate the percentage of land with vegetation cover during the critical period (dry season in tropical areas).

The land with a vegetation cover includes both living plants and litter on the ground (plant waste) which are both potentially shelter and/or a food source for fauna and, notably for entomofauna (insects).

63 "IBEA - A diagnostic tool for the impact of practices on the biodiversity of farms - Scientific manual - 1st version, March 2013" - http://ibea.portea.fr/images/file/Notice&GuideImpression-Avril2013/20130308-IBEA-NoticeScientifique-versionImpression.pdf

Continuity level	Average percentage of land with vegetation cover during the dry season
High	Over 50% of the cultivated area
Average	From 25% to 50% of the cultivated area
Low	Less than 25% of the cultivated area

For example, in a tropical climate with an eight-month dry season, in order to achieve an acceptable continuity level, at least 50% of the cultivatable land must maintain good vegetation cover during the dry season. For example, it must be fallow with no biomass destruction by fire (e.g. brush fires) during that period.

e. Crop rotation

The temporal management of vegetation cover can also include an assessment of crop rotation practices. The simplification of crop rotations is thought to be one of the factors responsible for the decline in biodiversity (Ewald & Aebischer, 2000; in ESCo, 2008, Chapter 1, p. 43[64]). However, as stated in Chapter 4, implementing a crop rotation system is fairly complex because several local factors specific to each farm must be taken into account.

A method to assess the quality of crop rotation at the plot level is provided below.

R[65]: Ruthenberg coefficient	More than two successive growing cycles* with the same crops	Two successive growing cycles with the same crops	No successive growing cycles with the same crops
R < 33.4	low	average	high
33 < R < 66.7	low	average	high
> 66	low	low	average

*In this case, a crop cycle (or growing cycle) is the period running from planting or sowing to the harvest of the crop.

To assess the quality of rotations at the overall farm level, the quality of the rotations of all of the plots must be aggregated. This can be done by assigning a score to each plot as follows, based on the previously defined level:

Rotation quality	Score
Low	1
Average	2
High	3

64 http://documents.cdrflorac.fr/INRA_AgricultureEtBiodiversite.pdf

65 $$R = 100 * \frac{N_c}{N_c + N_b}$$ where N = the number of years a plot is cultivated and F = the number of years a plot is left fallow

The score is then weighted based on the area of the plot by multiplying the score by the % of cultivated area compared to the total cultivated area planted with annual crops.

The sum of the weighted scores obtained is then compared to the table below to obtain an assessment of the quality of the rotations at the farm level.

Score for the farm	Rotation quality
1 to 1.6	Low
1.7 to 2.3	Average
2.4 to 3	High

For example, the 10-hectare vegetable farm in the table below. The score for the farm is 2.2, which is equivalent to average rotation quality.

Plot number	Area in ha	Rotation score	Weighted rotation
1	2	1	1 x 2/10 = 0.2
2	4	3	3 x 4/10 = 1.2
3	1	2	2 x 1/10 = 0.2
4	1	2	2 x 1/10 = 0.2
5	2	2	2 x 2/10 = 0.4
Total	10		2.2

f. Aggregation

The aggregation of crop rotation diversity, the mosaic effect, the crop mix and temporal continuity, together with a scoring system, will enable determination of the spatial and temporal organisation of the cultivated areas which are favourable to biodiversity.

Annual and pluriannual crop rotation diversity	Mosaic resulting from plot size	Intra-plot mixing	Temporal continuity of cultivated vegetation cover	Rotation	Score for each indicator
low	low	low	low	low	1
average	average	average	average	average	2
high	high	high	high	high	3

The overall level is subdivided into four categories: problematic, poor, acceptable and favourable, as follows:

Total of the five indicator scores	Spatial-temporal organisation of cultivated areas
5 to 6	problematic
7 to 9	poor
10 to 12	acceptable
13 to 15	favourable

2.4.3.3. Step 3: Assessment of biodiversity and analysis of practices in terms of "semi-natural area" and "natural area" compartments

With respect to these areas (AEI and AEU), observation will be limited to the vegetation which is the best integrator of the ecological conditions of the environment and relatively easy to carry out. The assessment of animal biodiversity in these areas is more complicated. It can potentially be done with specialists at a later time.

To ensure that the AEI/AEU are favourable to biodiversity, they must cover a sufficient portion of the operation, be of high quality, diversified and interconnected. Four indicators are used for the assessment:

- the AEI/UAE ratio,
- the quality of habitats,
- AEI/AEU diversity,
- AEI/AEU interconnectivity.

First indicator: the AEI/AEU ratio

This ratio indicates the extent of the land occupied by natural or semi-natural habitats which are part of the "landscape" of the farm. It is a quantity indicator.

The higher the ratio, the more favourable the farm is for habitats and the existence of many animal species. It is generally considered that the right ratio to achieve is 5% to 15%. However, it would be better to reach 15% to 25% with at least 5% dedicated to hedges.

EXAMPLE OF AN AEI/UAE RATIO CALCULATION VINEYARD

Total AEI/AEU area 4 ha

- Hedges: 3000 m x 3 m = 0.9 ha
- Grass strips: 1,500 m x 3 m = 0.45 ha
- Ditches: 500 m x 3 m = 0.15 ha
- Fallow: 0.5 ha + 1.5 ha = 2 ha
- Copses:

Vineyard: 21 ha

UAA = 25 ha => **AEI/AEU rate = 16%**

For the calculation of different AEI/AEU areas in Europe and as part of the conditions for CAP (Common Agricultural Policy) subsidies, all farmers must have a percentage of these "topographical features" on their farm. An "Equivalent Topographic Surface" (ETS) value is assigned to each of the features. A multiplier (coefficient) is assigned to each topographical feature to calculate the SET. The weighting may change in line with European legislation.

For the purposes of this manual, and given that no weighting is available for tropical areas, the actual surface areas occupied by the AEI/AEU will be used.

The calculation of the AEI/AEU surface areas occupied is generally straightforward. For random AEIs like large trees, the area occupied per tree can be considered to be from 50 to 100 m^2, depending on the size of the trees. For linear AEI/AEU (hedges, rows of trees, the edges of roads, ditches, waterways, etc.), the area occupied is calculated by multiplying the length by the average width occupied.

AEI/AEU ratio level	AEI/AEU ratio threshold
Poor	< 5%
Average	Between 5% and 15%
Good	> 15%

Second indicator: quality (also called the state of preservation) of the habitats.

This is a composite (or summary) indicator because it is built on indicators for the state of the vegetation constituting the natural and semi-natural habitats. The quality of the AEI/AEU must, therefore, first be assessed individually.

Qualifying the state of an AEI/AEU consists in first estimating its quality from the standpoint of biodiversity. This quality is estimated in reference to its ability to provide a favourable living environment to as many species as possible which can provide broad support for functional biodiversity. The term "state of conservation" designates this quality.

It is assessed based on several indicators defined for each type of AEI/AEU. The indicators belong to three categories of criteria, as follows.

STATE OF THE AEI/AEU

- Structure
- Composition
- Deterioration/disruptions

The indicators selected in each of the three categories measure the state of the vegetation resulting from the practices (pressures). The indicators reflect the results of "positive" and "negative" pressures. They are easy to assess, measurable, repeatable over time and enable monitoring of the state of the AEI/AEU over time.

a. Structure

This refers to all of the types of vegetation which are part of an AEI/AEU. Differences between types are usually based on size, age and density criteria, and also differentiated by ligneous and grassy type. For example, for hedges, which are the most frequent and important AEI, we refer to stratification. A hedge consists of several levels of vegetation called strata.

The strata are identified based on their height and composition[66]. They are:

a tree stratum:
consisting of high-branching trees taller than 3 m;

a high shrub stratum:
ligneous vegetation from 1.5 m to 3 m high;

a low shrub stratum:
ligneous vegetation under 1.5 m;

a herbaceous stratum:
non-ligneous vegetation alongside the hedge. This includes vegetation at the foot of the hedge not exceeding 1 m in height on either side of the hedge. A 1.50 m to 2 m space should be left on each side of the hedge.

Figure 18: Examples of hedge stratification levels - Source: Feedback - Hedge identification method contributing to the ecological continuities of forests Parc naturel régional Normandie-Maine. 2014

66 Hedge identification method contributing to the ecological continuities of forests and bocages - Published June 2014 Design-creation Parc naturel régional Normandie-Maine - Editors Gabriel Soulard / Mélanie Massias / Pauline Gautier

Optimal hedge stratification

Score: 9/9

Mostly high-branching trees (higher than 8 m) and high shrub stratum (higher than 1.5 m) and lower shrub stratum = optimal structure = score of 9

Medium hedge stratification or of interest in several years

Score: 3/9

Two ligneous strata present or hedge recently replenished or planted = average structure = Score of 3

Severely degraded hedge

Score: 1/9

Lack of ligneous strata on more than 50% of the linear surface = severely degraded hedge = Score of 1

b. Composition

This is the AEI/AEU's alpha diversity, i.e. The number of different species present within an AEI/AEU.

With respect to hedges, a study has shown that diversity consisting of six species of trees, shrubs or bushes (vines are also taken into account) along a 100 m hedge is richest in bird species (Hinsley and Bellamy, 200). On the other hand, the number of species in an orchard hedge should not be greater than 15 because, beyond that, the environmental gain is no longer significant. If this number of species is exceeded, the population of plant eaters will benefit (Debras *et al.*, 2003). According to the technical sheets of Agriculture et environnement of CREN Languedoc-Roussillon (Conservatoire Régional des Espaces Naturels), a plantation with six to 10 species quickly achieves the characteristics of a natural hedge.[67]

67 Development of an indicator for the assessment of citrus cultivation orchards in Guadeloupe - End of study report on the Master 2 programme *Biodiversity management - Defended in September 2009 in Toulouse by Maxime Pfohl - Supervised by Fabrice Le Bellec, Agronomist at CIRAD Station, Vieux-Habitants*

c. Deterioration/disruptions

In order for the recommendations made to be relevant with respect to the practices of farmers and the farming system, and to better identify the causes (pressures) which have resulted in the deterioration of an AEI/AEU, it is necessary to take an inventory of the practices used in each of the farm's AEI/AEU.

The goal of the inventory is not to gain exhaustive or in-depth knowledge of the practices, but to have enough information to be able to make a connection between the quality of the AEI/AEU and the practices. For example, in order to fully benefit from the advantages created by the agroecological infrastructure, it must never have been directly or indirectly treated with chemicals (drifting of spray). There can have been no chemical treatment in the AEI/AEU and a wide enough buffer zone must always be in place between the AEI/AEU and the cultivated areas treated.

The inventory will also enable definition of the farmer's objectives for the AEI/AEU, including maintenance, planning, destruction, restoration, etc.

In this case, the analysis will be limited to the practices the farmer can control. However other causes can change or have changed the quality of the AEI/AEU. These causes can be external to the operation (e.g., decline in the ground water available due to the practices of neighbours upstream or to climate change, notably in oases, to changes in roadway infrastructure or building construction, etc.). However, while a detailed analysis isn't required, this information should be noted as observations at the time of the assessment.

d. AEI/AEU quality assessment procedure

There are no references for assessing the state of AEI/AEU in tropical areas. Given this, the method developed for crops in Europe can be used. Appendix 9 contains tables that assist with the assessment of the state of conservation of certain AEI/AEU (hedges, tree lines, copses, ditches, ponds, grass strips, etc.)

Appendix 10 also provides a method for assessing forest quality for the special case of farms which have natural forest cover.

Third indicator: AEI/AEU diversity

The diversity of types is the AEI/AEU beta diversity.

Environments potentially rich in biodiversity on the farm are accounted for solely because they are present and not for the agricultural practices implemented on them. The presence of many different environments is, in fact, an important condition for the diversity of resources and habitats.

The diversity level is assessed by the number of different, non-cultivated environments on the farm. The environments which can be taken into consideration are:

- Permanent natural meadows.
- Temporary meadows.
- Pastures/dry grasslands.
- Still water (ponds, marshes, backwaters, etc.).
- Running water (streams, rivers, wadis, etc.).

- Marshes/peat-bogs/flood zones.
- Isolated trees in cultivated areas.
- Hedges:
- Copses.
- Forests.
- Non-productive grass environments (fallow land, grass strips, plot edges).
- Long-term fallow land.
- Other environments (cliffs, fallen rocks, caves, quarries, ruins, etc.).

The diversity level of AEI/AEU can be determined based on the presence of a sufficient number of types of AEI/AEU on the farm.

AEI/AEU diversity level	Number of AEI/AEU types on the farm
Poor	Between 0 and 3
Average	Between 4 and 6
Good	Greater than 6

Fourth indicator: AEI/AEU interconnectivity

The quality of the interconnection and networking of the environment is the main reason for its effectiveness. Due to the fact that the density of ecological interactions generated by the beneficial entomofauna (insectivores, pollinators, etc.) is more dependent on the size of the ecotons (borders between two environments) than on the total surface area of the natural environments, it is better to have three hectares of hedges spread around the farm than three-hectare islands/copses disconnected from the agroecosystem[68].

Linear elements such as hedges, the edges of roads, ditches, waterways, etc. are considered to be travel "corridors" which promote the movement of fauna and flora between different natural environments (hedges, woods, ponds, meadows, etc.). The corridors play an important role in the search for food and shelter as well as for the reproduction and survival of populations, notably for less mobile species like frogs, insects, etc. To ensure that they fulfil their role, the corridors must be interconnected and create a network which is consistent with the natural surroundings and the landscape.[69] The drawing below illustrates the concept of an ecological corridor very well.

68 *Lionel Vilain, The IDEA method, indicator A8*

69 Sheet - Where is biodiversity found on a farm? http://www.farre.org/fileadmin/medias/pdf/Fiche01.pdf

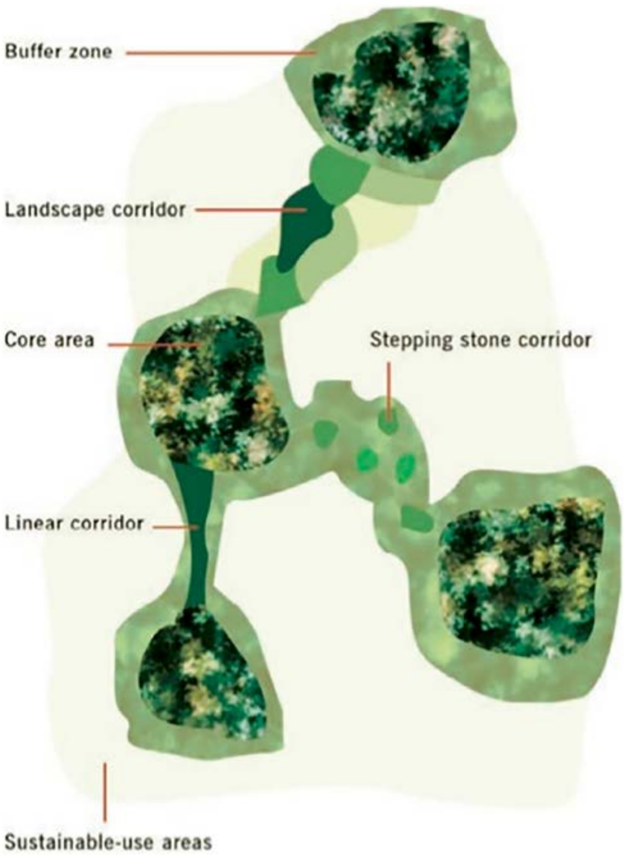


Figure 19: The ecological or wildlife corridor concept
Source: http://www.mddelcc.gouv.qc.ca/jeunesse/chronique/2008/0803-corridors-definition.htm and Connecting Science to Conservation

It isn't possible to quantify the level of connectivity; however, connectivity can be categorised as good, average or poor based on the distance between the wooded AEI/AEU (with the exception of wooded areas such as orchards) on a farm. Some authors believe that the distance must be maximum 150 m for field crops. We are of the opinion that this distance can be used for areas planted with perennial crops (orchards). On the other hand, for vegetable crops, we believe that the maximum distance should be 50 m.

We therefore propose the following categories for "perennial" fruit crops:

Connectivity	Good	Average	Poor
Distance between natural or semi-natural wooded areas (hedges, lines of trees, isolated trees, copses and forests)	Less than 100 m	100 to 200 m	Over 200 m

However, we suggest the following categories for vegetable farms.

Connectivity	Good	Average	Poor
Distance between natural or semi-natural wooded areas (hedges, lines of trees, isolated trees, copses and forests)	Less than 50 m	50 to 100 m	Over 100 m

In the case of the farm in Senegal in Appendix 2, the connectivity is average because a significant portion of the perimeter has no hedges and there are several wooded areas which are too far away from other wooded areas (over 50 m).

Figure 20: Example of recommendations for hedge planting (in blue) enabling the interconnection of existing elements (in red) (hedges, wooded areas) and improvement of the network of ecological corridors.
Source: http://www.farre.org/fileadmin/medias/pdf/Fiche02.pdf

Aggregation of the four AEI/AEU indicators

Aggregation of the four major AEI/AEU indicators (ratio, quality, diversity and connectivity) using the table below will provide a good idea of the overall value of the AEI/AEU of the farm.

A calculation method is proposed below which assigns a score of 1 to 3 for each indicator as follows.

Ratio	Quality	Diversity	Connectivity	Score for each indicator
poor	unfavourable	poor	poor	**1**
average	average	average	average	**2**
good	good	good	good	**3**

The sum of the scores of the four indicators provides the overall AEI/AEU value for the farm.

Total of the four indicator scores	Overall AEI/AEU value
4 to 5	problematic
7 to 8	poor
9 to 10	acceptable
11 to 12	favourable

2.4.3.4. Step 4: Assessment of the impact of practices on areas located in the compartment "around the farm" and vice-versa

The areas of the compartment are identified in the first step of the proposed methodology. Depending on the type and characteristics of the areas, the layout and farming practices should be checked to ensure that they reduce disruptions in the areas to a minimum. The two main principles to remember are that the spaces must be sufficiently isolated from the cultivated areas of the farm by adequate buffer areas and that the wooded areas surrounding the farm should not be too isolated from each other by the farm layout (principle of corridor connectivity). The buffer zones are usually sufficiently-wide grass strips (at least 5 m alongside wet areas) which are well structured (no bare ground, not too many bushes, etc.) or wind-break hedges which are sufficiently well structured (with three strata) and high (over 3 m). The instructions in Appendix 10 provide help.

For example, we can look at the case of a farm which created adequate buffer zones for the following neighbouring areas: two natural forests, a river, a pasture and rain-fed crops.

- The two natural forests are protected from the cultivated plots by a grass strip of 5 m and a wind-break hedge consisting of three strata and reaching 4 m in height. The farm does not break the connectivity between the two forests because they are connected by other natural elements outside of the farm.

- The river is isolated from the cultivated areas by a 10 m grass strip consisting solely of perennial species.
- The pasture is isolated by a wind-break hedge consisting of three strata and reaching 4 m in height. The hedge controls any potential harmful effects of the practices used in the cultivated areas (e.g., phytosanitary spraying).
- The crops surrounding the farm are also isolated from the farm crops by a similar wind-break hedge, notably to prevent the drifting of phytosanitary spraying in either direction.

2.4.3.5. Step 5: Report preparation

The assessment report will first be used internally. A decision will be taken later on measures to improve biodiversity on the farm (see the practical case).

It must be interpreted based on the regional context. That is, a comparison must be made with neighbouring farms or farms with similar agroecological conditions.

The report can also be used as a reference document to show the buyers of the farm's produce what has been done to preserve and promote biodiversity on the farm.

It can be structured around the key points below:

Description of the farm via the mapping of areas on and outside of the farm and description of the state of changes in biodiversity	• *Prior action essential for the actual assessment* • *Aerial photos* • *Plan and measurement of the areas* • *Photos of the areas* • *Identification of patrimonial species and ecosystems* • *Questionnaire for the farmer*
Domesticated biodiversity of the cultivated areas	• *Production diversity: Vegetation species diversity + genetic vegetation diversity + preservation of species and patrimonial varieties* • *Production system mixing*
Para-agricultural wild biodiversity in the cultivated areas	• *Crop pest enemies* • *Organisms beneficial to the soil*
Practices in the cultivated areas	• *Technical itineraries: use of phytosanitary products + mechanisation + nitrogen management* • *Structure of perennial crops: grass cover + architecture*
Spatial organisation and temporal management of cultivated areas	• *Crop rotation diversity* • *Mosaic effect* • *Intra-plot mixing* • *Temporal continuity of the vegetation cover* • *Rotation*
AEI/UAE ratio	• *Calculation of the areas occupied by the different AEI/AEU* • *Ratio defined with respect to the UAA*
Quality of the AEI/AEU habitats	• *Structure* • *Composition* • *Deterioration/disruptions* • *Assessment by AEI/AEU based on references*
AEI/AEU diversity	• *Number of types of non-cultivated environments present*
AEI/AEU interconnectivity	• *Distance between natural or semi-natural wooded areas*
Impact of farming practices on the areas close by	• *Assessment of the preventive measures taken to prevent potential disruptions*

2.5. CONCLUSIONS AND RECOMMENDATIONS

Before initiating a process to promote biodiversity, farmers should ask themselves several questions, including the following fundamental ones:

- *What would the benefits of farming which is respectful of biodiversity be for me?*
- *Do I have the know-how needed to plan measures to promote biodiversity myself? Am I able to obtain any missing information on my own?*
- *Do I have time and am I motivated enough to plan effective measures and assess their economic impact?*
- *Who can help me with the process and how much will advice cost me?*

In addition, the following specific questions can be asked from the outset when a new operation is set up:

- *What animal and plant species and varieties should I choose to ensure profitable and high-quality sustainable production which will also contribute to species variability?*
- *Which AEI/AEU already exist and what areas are available to create new ones? How can interconnections be created between the AEI/AEU?*
- *What opportunities are there to contribute to the management of natural areas and to harvest the products?*

The references used in this manual are primarily the result of experiences in Europe. As mentioned previously, the methodology proposed herein must be adapted to the local context and knowledge during process implementation based on testing the methodology in different situations. Universities and researchers can provide precious assistance for the development and testing of assessment methods and criteria together with farmers, popularisation services, NGOs and other stakeholders.

It is recommended that the farmers in a given production zone network to exchange (positive and negative) experiences and develop knowledge about the management of biodiversity and practices which promote it (example in France https://biodiversid.com/). In this respect, the strengthening of partnerships with the various players involved is very important for undertaking information, training, demonstration and implementation activities.

It is also necessary to raise the awareness of farmers about conservation and the promotion of biodiversity on farms using entertaining activities which enable group discussions (see an example of a game developed in France for this purpose - http://www.rmt-biodiversite-agriculture.fr/moodle/course/view.php?id=36).

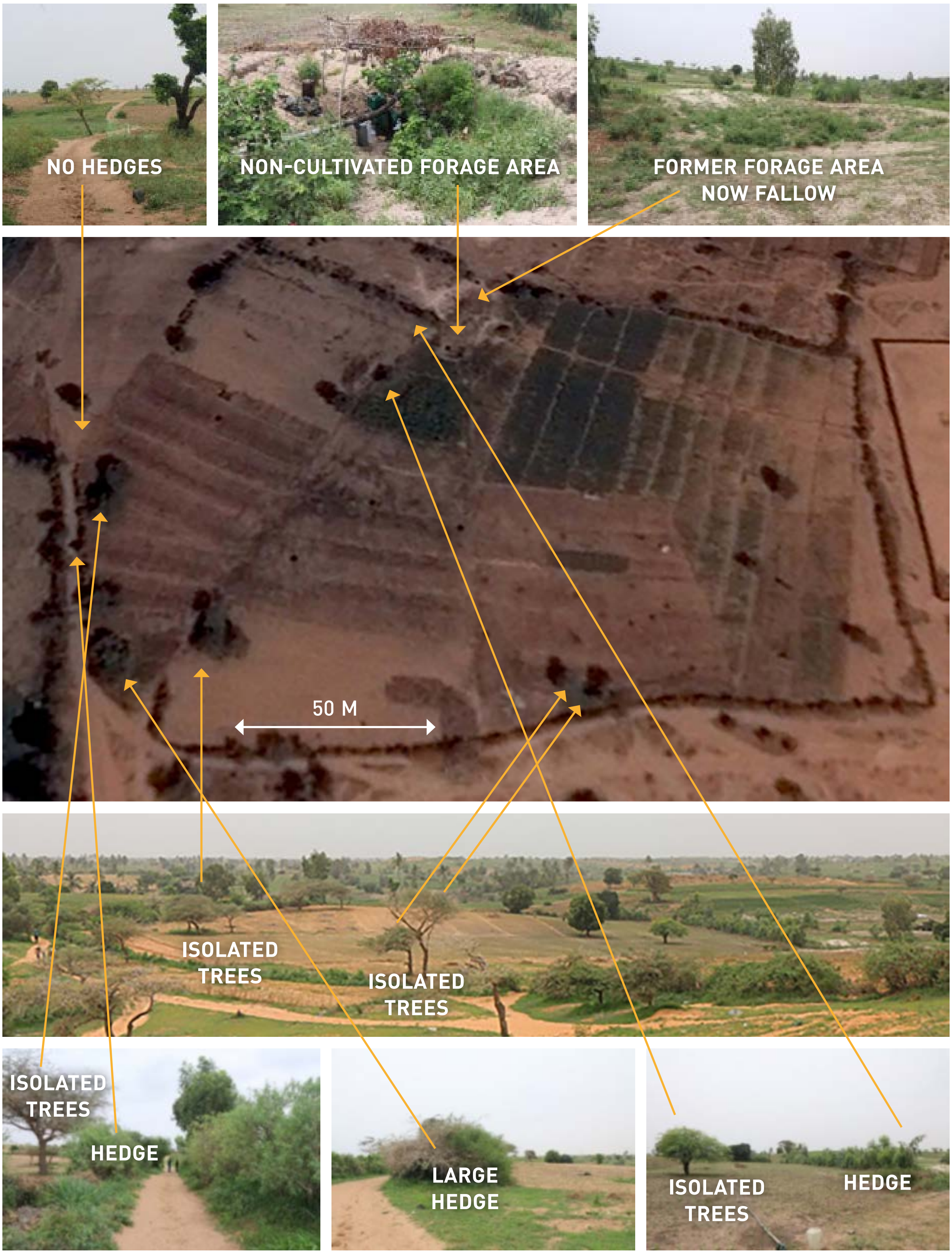
The work done by farmers to promote biodiversity should also be rewarded in some way (e.g. with fair prices) to stimulate initiatives.

Current technical manuals to ensure the success of the assessment of vegetable and fruit crops in tropical regions are currently insufficient. They are, however, required to develop an action plan and to successfully promote biodiversity on farms.

2.6. APPENDIXES

2.6.1. A1: Example of the photographic identification of AEI/AEU

Example of photographic identification (photos by Gilles Delhove) of AEI/AEU on Google Earth – Collective farm of about 4 ha in Diogo, Senegal.



2.6.2. A2: Aggregation table for the assessment of a farm's production diversity

	Preservation of patrimonial species and varieties	Vegetation species diversity	Vegetation genetic diversity	Production diversity
1	no	very low	very low	very low
2	no	very low	low	very low
3	no	very low	average	very low
4	no	very low	high	very low
5	no	very low	very high	very low
6	no	low	very low	very low
7	no	low	low	very low
8	no	low	average	low
9	no	low	high	low
10	no	low	very high	low
11	no	average	very low	low
12	no	average	low	low
13	no	average	average	average
14	no	average	high	average
15	no	average	very high	average
16	no	high	very low	average
17	no	high	low	average
18	no	high	average	high
19	no	high	high	high
20	no	high	very high	high
21	no	very high	very low	high
22	no	very high	low	high
23	no	very high	average	very high
24	no	very high	high	very high
25	no	very high	very high	very high
26	yes	very low	very low	very low
27	yes	very low	low	very low
28	yes	very low	average	very low
29	yes	very low	high	very low
30	yes	very low	very high	low
31	yes	low	very low	very low
32	yes	low	low	low
33	yes	low	average	low
34	yes	low	high	low
35	yes	low	very high	average
36	yes	average	very low	low
37	yes	average	low	average
38	yes	average	average	average
39	yes	average	high	average
40	yes	average	very high	high
41	yes	high	very low	average
42	yes	high	low	high
43	yes	high	average	high
44	yes	high	high	high
45	yes	high	very high	very high
46	yes	very high	very low	high
48	yes	very high	average	very high
49	yes	very high	high	very high
50	yes	very high	very high	very high

2.6.3. A3: Summary table of plots occupied by annual crops for a full year

Species	Variety	Hectares occupied per month												Total
		1	2	3	4	5	6	7	8	9	10	11	12	
Total														
Hectares	Area													
Number	Species													
Number	Varieties													

2.6.4. A4: Observation methods for flying auxiliaries

Beating or hitting branches

- Best suited for woody plants.
- Number of items to be observed: 25 to 100 branches per study unit (see the earlier comment on the study unit).
- Observation frequency: Generally weekly during the development period of the pest targeted by the auxiliaries.
- Particularly suited to the observation of spiders, chrysops and entomophagous insects (larvae and adults), ladybirds (adults and larvae), earwigs (adults), predator heteroptera (adults and larvae).
- Equipment: a bat and a platter (or an elevated sheet).

Direct observation on the plant

- Same method as that used for other crops to estimate the risks related to pests or disease.
- Number of items to be observed: 25 to 100 leaves, flowers, fruits, plants or branches by study unit (area in which observations are spread out homogeneously. This can be a small plot or a representative part of a larger homogeneous plot (if the area studied is heterogeneous, several study units must be defined).
- Observation frequency: variable depending on the dynamics of the pests targeted by the auxiliaries.
- This is particularly suited to the observation of phytoseiid mites. (mobile forms and eggs), chrysops and entomophagous insects (eggs, larvae and cocoons), ladybirds (eggs, nymphs, adults and larvae), predator heteroptera (eggs, adults and larvae), mummified pests with mycosis or parasites, syrphid flies (eggs, larvae and nymphs).
- A magnifying glass (8x or 10x) can be useful.

A yellow pan trap (Moericke trap)

- These are made using a yellow pan filled with water and a drop of detergent.
- The trap is used to detect the arrival of certain pests like weevils, but some beneficial organisms are also trapped, primarily syrphid flies. The trap is installed at crop height. As with any destructive trap, it is emptied and its contents are transferred to a jar for storage before identifying the sample. The pans must be checked on a regular basis (three days).

2.6.5. A5: Examples of methods for assessing the presence of auxiliaries for several crop pests

Le lien ne fonctionne pas

Based on the following source http://agriculture.gouv.fr/guide-dobservation-et-de-suivi-des-organismes-nuisibles-et-auxiliaires-de-lutte-biologique, the data below provide instructions to assess, via visual observation of the plants, the presence of auxiliaries for several of the most common pests on vegetable and fruit crops. Visual assessment of the auxiliaries on the plants is usually done when the pest populations are fairly high (e.g., aphid colonies). The first step is to determine when the observations can be carried out. This can only be determined by regular observation of the phytosanitary state of a crop which will enable identification of the first significant infestation foci.

As soon as the first significant foci are detected, and to identify other potential foci in the plot, inspect the entire plot looking for other foci or carry out a random inspection. When at least 10 significant foci have been detected on the plot, make a physical identification of the foci using numbered stakes or other markers.

The identified locations will enable monitoring of the foci and measurement of the effectiveness of the treatment, as well as of the density and impact of the beneficial fauna. The plants should be watched closely for the presence of any auxiliaries. The observations should be carried out before any treatment. The markers must be removed when the foci disappear.

1. Procedure for aphids
   - Observations
     - **Type of observation:** visual
     - **Special equipment required:** linen tester magnifier (10 times).

     - **Items to be observed:** leaves, young terminal shoots, young fruit, depending on the crop.
     - **Minimum number of items to be observed per location:** 5 items with colonies/ location (to be observed on several plants at the location, if possible).
     - **Observation frequency:** weekly, until the foci with high infestation levels disappear.
   - Assessment criteria
     - **Assessment criteria for the pest during the foci identification phase:**
       0 = isolated winged or wingless individuals
       1 = presence of wingless individuals, small colony(ies)
       2 = large colony(ies) without winged individuals, with no significant symptoms
       3 = large colony(ies) without winged individuals, with significant symptoms
       4 = winged colony(ies)
       Only situations 2, 3 and 4 are considered to be significant foci.
     - **Auxiliaries to be taken into account while the 10 locations identified are being monitored and proposed scoring system:**

Auxiliaries	Assessment criteria/ score by item observed	Presence level based on the total score for the 50 items observed (10 locations x 5 items per location)	Presence scores
Ladybirds	0 = no auxiliaries 1 = presence of a few larvae or adults 2 = many larvae or adults	0 to 20 = very low > 20 to 40 = very low > 40 to 60 = average > 60 to 80 = high > 80 to 100 = very high	= 1 = 2 = 3 = 4 = 5
Syrphid flies	0 = no auxiliaries 1 = adults only nearby 2 = eggs only 3 = larvae only 4 = eggs and larvae	0 to 40 = very low > 40 to 80 = low > 80 to 120 = average > 120 to 160 = high > 160 to 200 = very high	= 1 = 2 = 3 = 4 = 5
Chrysops	0 = no auxiliaries 1 = eggs without larvae 2 = larvae only 3 = larvae and eggs	0 to 30 = very low > 30 to 60 = low > 60 to 90 = average > 90 to 120 = high > 120 to 150 = very high	= 1 = 2 = 3 = 4 = 5
Hymenoptera parasitoids	0 = no auxiliaries 1 = a few mummies 2 = many mummified individuals 3 = most of the individuals are mummified	0 to 30 = very low > 30 to 60 = low > 60 to 90 = average > 90 to 120 = high > 120 to 150 = very high	= 1 = 2 = 3 = 4 = 5
		Overall total of the presence levels of different types of auxiliaries	0 to 4 = very low > 4 to 8 = low > 8 to 12 = average > 12 to 16 = high > 16 to 20 = very high

2. **Procedures for spider mites**
   - **Observations**
     - **Type of observation:** visual with a magnifying glass.
     - **Special equipment required:** linen tester magnifier (10 to 15 times).
     - **Item to be observed:** Underside of leaves.
     - **Minimum number of items to be observed per location:** 5 items sufficiently attacked/location (to be observed on several plants at the location, if necessary).
     - **Observation frequency:** weekly, until the foci with high infestation levels disappear.

- Assessment criteria
  - **Assessment criteria for the pest during the foci identification phase:**
    0 = no living life form
    1 = presence of living life forms and/or eggs without significant symptoms
    2 = presence of a few living life forms with significant symptoms
    3 = presence of many living life forms with significant symptoms and webbing
    Only situations 2 and 3 are considered to be significant foci.
  - **Main auxiliaries to be taken into account while the 10 locations identified are being monitored and proposed scoring system:**

Auxiliaries	Assessment criteria/ score by item observed	Presence level based on the total score for the 50 items observed (10 locations x 5 items per location)	Presence scores
Phytoseii-dae	0 = no auxiliaries 1 = 1 phytoseiid 2 = several phytoseiids 3 = phytoseiids and eggs	0 to 30 = very low > 30 to 60 = low > 60 to 90 = average > 90 to 120 = high > 120 to 150 = very high	= 1 = 2 = 3 = 4 = 5
Aphid-eating ladybirds *(Stethorus* sp)	0 = no auxiliaries 1 = presence of a few larvae or adults 2 = presence of many larvae or adults	0 to 20 = very low > 20 to 40 = very low > 40 to 60 = average > 60 to 80 = high > 80 to 100 = very high	= 1 = 2 = 3 = 4 = 5
Predato-ry thrips (*Scolo-thrips* sp.)	0 = no auxiliaries 1 = presence of a few larvae or adults 2 = presence of many larvae or adults	0 to 20 = very low > 20 to 40 = very low > 40 to 60 = average > 60 to 80 = high > 80 to 100 = very high	= 1 = 2 = 3 = 4 = 5
		Overall total of the presence levels of different types of auxiliaries	0 to 3 = very low > 3 to 6 = low > 6 to 9 = average > 9 to 12 = high > 12 to 15 = very high

3. Procedures for whiteflies
   - Observations
     - **Type of observation:** visual under leaves.
     - **Special equipment required:** linen tester magnifier (10 times).
     - **Item to be observed:** mature and juvenile leaves

- **Minimum number of items to be observed per location:** 5 items sufficiently attacked/location (to be observed on several plants at the location, if necessary).
- **Observation frequency:** weekly, until the foci with high infestation levels disappear.

- Assessment criteria
  - **Assessment criteria for the pest during the foci identification phase:**
    0 = no living life forms and/or symptoms
    1 = primarily adults
    2 = all stages without sooty mould and/or silvering on leaves
    3 = all stages with sooty mould and/or silvering on leaves
    Only situations 2 and 3 are considered to be significant foci.
  - **Main auxiliaries to be taken into account while the 10 locations identified are being monitored and proposed scoring system:**

Auxiliaries	Assessment criteria/ score by item observed	Presence level based on the total score for the 50 items observed (10 locations x 5 items per location)	Presence scores
Phytoseiidae	0 = no auxiliaries 1 = 1 phytoseiid 2 = several phytoseiids 3 = phytoseiids and eggs	0 to 30 = very low > 30 to 60 = low > 60 to 90 = average > 90 to 120 = high > 120 to 150 = very high	= 1 = 2 = 3 = 4 = 5
Hymenoptera parasitoids	0 = no auxiliaries 1 = a few mummies 2 = many mummified individuals 3 = most of the individuals are mummified	0 to 30 = very low > 30 to 60 = low > 60 to 90 = average > 90 to 120 = high > 120 to 150 = very high	= 1 = 2 = 3 = 4 = 5
		Overall total of the presence levels of different types of auxiliaries	0 to 2 = very low > 2 to 4 = low > 4 to 6 = average > 6 to 8 = high > 8 to 10 = very high

4. Procedures for thrips
   - Observations
     - **Type of observation:** visual.
     - **Special equipment required:** linen tester magnifier (10 times).
     - **Item to be observed:** leaves, flowers, young fruit depending on the crops, and whole plants for auxiliary bugs.

- **Minimum number of items to be observed per location:** 5 items sufficiently attacked/location (to be observed on several plants at the location, if necessary).
- **Observation frequency:** weekly, until the foci with high infestation levels disappear.

- Assessment criteria
  - **Assessment criteria for the pest during the foci identification phase:**
    0 = none
    1 = 1 individual on the item observed
    2 = 2 to 3 individuals on the item observed
    3 = 4 to 7 individuals on the item observed
    4 = 8 to 15 individuals on the item observed
    Only situations 3 and 4 are considered to be significant foci.
  - **Main auxiliaries to be taken into account while the 10 locations identified are being monitored and proposed scoring system:**

Auxiliaries	Assessment criteria/ score by item observed (or plant observed for true bugs)	Presence level based on the total score for the 50 items observed (10 locations x 5 items per location)	Presence scores
Phytoseiidae	0 = no auxiliaries 1 = 1 phytoseiid 2 = several phytoseiids 3 = phytoseiids and eggs	0 to 30 = very low > 30 to 60 = low > 60 to 90 = average > 90 to 120 = high > 120 to 150 = very high	= 1 = 2 = 3 = 4 = 5
True bugs	0 = no auxiliaries 1 = 1 true bug per plant 2 = 2 to 3 true bugs per plant 3 = more than 3 true bugs per plant	0 to 30 = very low >30 to 60 = low >60 to 90 = average >90 to 120 = high >120 to 150 = very high	= 1 = 2 = 3 = 4 = 5
		Overall total of the presence levels of different types of auxiliaries	0 to 2 = very low > 2 to 4 = low > 4 to 6 = average > 6 to 8 = high > 8 to 10 = very high

5. Procedures for mealybugs
   - Observations
     - **Type of observation:** visual.
     - **Special equipment required:** linen tester magnifier (10 times).
     - **Item to be observed:** entire plant: interstices, stalks, leaves.

  - **Minimum number of items to be observed per location:** 5 plants sufficiently attacked/location
  - **Observation frequency:** weekly, until the foci with high infestation levels disappear.
- Assessment criteria
  - **Assessment criteria for the pest during the foci identification phase:**
    0 = none
    1 = a few sparse individuals with or without eggs per plant
    2 = several colonies per plant
    3 = many colonies and/or significant damage per plant
    Only situations 2 and 3 are considered to be significant foci.
  - **Main beneficial organisms to be taken into account while the 10 locations identified are being monitored and proposed scoring system:**

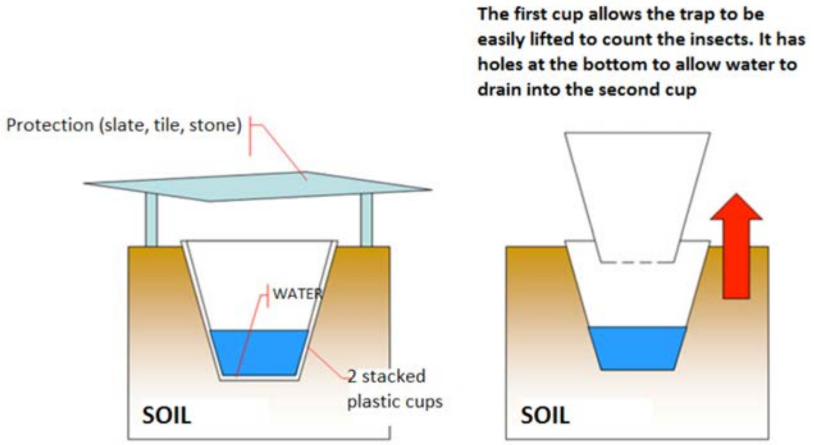
Auxiliaries	Assessment criteria/ score by body observed	Presence level based on the total score for the 50 items observed (10 locations x 5 items per location)	Presence scores
Hymenoptera parasitoids	0 = no auxiliaries 1 = a few mummies 2 = many mummified individuals 3 = most of the individuals are parasitised	0 to 30 = very low > 30 to 60 = low > 60 to 90 = average > 90 to 120 = high > 120 to 150 = very high	= 1 = 2 = 3 = 4 = 5
Ladybirds	0 = no auxiliaries 1 = isolated adult(s) 2 = several individuals at any stage 3 = individual(s) with egg(s)	0 to 30 = very low > 30 to 60 = low > 60 to 90 = average > 90 to 120 = high >120 to 150 = very high	= 1 = 2 = 3 = 4 = 5
		Overall total of the presence levels of different types of auxiliaries	0 to 2 = very low > 2 to 4 = low > 4 to 6 = average > 6 to 8 = high > 8 to 10 = very high

2.6.6. A6: Observation methods for carabid beetles and earthworms

Carabid beetles

Carabid beetles appear to be rarer in tropical areas than in temperate climates, particularly in low-lying areas.

The Barber method is the method most commonly used to assess the presence of carabid beetles. Four plastic cups are buried in a line at ground level, separated by 5 to 10 m. They are half-filled with a mixture of equal parts water and white vinegar. Salt is added.



Source: http://agriculture-de-conservation.com/Evaluer-ses-populations-de-carabes,866.html

The beetles are harvested a week later and weighted or counted. Each cup collects carabid beetles from 25 m². The weight of the beetles found in the four cups is multiplied by 100 to obtain the population for a hectare.

Other references about the method:

- http://www.supagro.fr/ress-pepites/carabes/co/6_Echantillonage.html
- http://ephytia.inra.fr/fr/C/25129/jardibiodiv-Protocole-d-echantillonnage

Other sources of information about carabid beetles:

- http://www.ctifl.fr/ecophytopic/point_sur/PSCarabes.pdf
- http://documents.cdrflorac.fr/StageAccesLibre/RapportStageLPGENA2015_Maurouard.pdf
- http://www.agriculture-durable.org/wp-content/uploads/2014/03/carabesbiodivgc.pdf
- http://www.inra.fr/Grand-public/Agriculture-durable/Tous-les-magazines/Carabes-insectes-allies-de-la-biodiversite-et-de-l-agriculture
- http://www.biokids.umich.edu/critters/Carabidae/

Earthworms

- In the tropics, earthworms are very abundant in wet areas where recorded rainfall exceeds 1,000 to 1,100 mm. The dominant group in West Africa consists of geophagous earthworms which eat organic matter in the soil. http://books.openedition.org/irdeditions/3319?lang=fr
- In tropical regions, manual sorting is done in the same way as for the sampling of the total macrofauna in the soil (TSBF method http://www.supagro.fr/ress-pepites/OrganismesduSol/). All of the earthworms collected are counted (total abundance) and can be classified by ecological category. Weighing by ecological category enables determination of the density of earthworms in the soil.

Other methods used:

- http://www.supagro.fr/ress-pepites/OrganismesduSol/co/VDTQuantification.html
- https://ecobiosoil.univ-rennes1.fr/page/protocole-participatif-test-beche-vers-de-terre

2.6.7. A7: Assessment of farm agricultural practices

Source: adapted from "IBEA - A diagnostic tool for the impact of practices on the biodiversity of farms - Scientific manual - 1st version, March 2013".

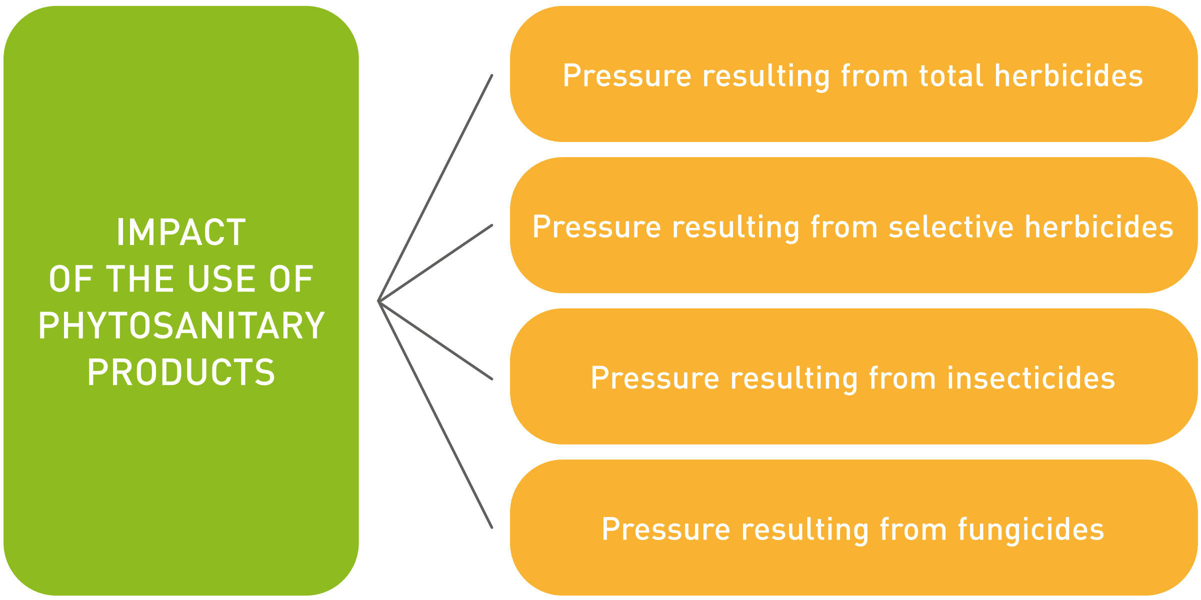
I. Technical itineraries of all cultivated areas

1. Impact of the use of phytosanitary products

For the purposes of simplification, only four major categories of pesticides are covered here (total herbicides, selective herbicides, insecticides and fungicides).

Several variables characterise the impact of pesticides on biodiversity, notably the proportion of the surface area treated with pesticides (or, inversely, that which isn't) and the average number of treatments (converted into certified doses) received by each hectare treated. Another variable is the ecotoxicity of the products used. All chemicals are not equally toxic and some are more virulent than others. The treatment period can also affect the impact of phytosanitary products on biodiversity.

Here, we only take into account the area being treated given the lack of data available on the effects of the quantity of pesticide used, the time of spraying on biodiversity and the complexity of a calculation including the ecotoxicity of the products. It is, however, obvious that reducing the quantities of pesticides used and selecting the products most suitable to the situation will be more positive for biodiversity.



1.1. Pressure resulting from total herbicides

The portion of the area treated with total herbicides (or, inversely, which is not treated) is a characteristic indicator of the pressure resulting from treatments with total herbicides. The number of treatments also has an impact on the environment in general (water, air, etc.) and on biodiversity in general. As the effect is difficult to quantify, and notably depends on the chemicals used, it is not used as an indicator here. However, it is clear that the greater the number of times a plot is treated, the greater the impact will be.

The pressure level is assessed by area treated with total herbicides during the year, as a percentage of the farm area cultivated. The 30% threshold set by experts is the limit beyond which the percentage that is not treated with total herbicides is too low for biodiversity.

Pressure level resulting from total herbicides	Description
Strong pressure	The area treated with total herbicides is greater than 30% ofthe cultivated area
Average pressure	The area treated with total herbicides is less than or equal to 30% of the cultivated area
No pressure	No cultivated area is treated with total herbicides

For vegetable farming in a tropical environment, it is suggested that the ratio be calculated as an average over the year. For example, for the crop schedule in Appendix 5 below, the % of the area (in red in the table) which received at least one total herbicide treatment during the year is calculated each month. The annual average is then calculated. This example yields 35.4%, a value considered to be high pressure.

Species	Variety	Month of the year (hectares planted)												Total
		1	2	3	4	5	6	7	8	9	10	11	12	
Tomato	Roma	2.5	2.5	2.5	2.5									10
Tomato	Xina	2.5	2.5	2.5	2.5									10
Tomato	Mongal F1					2.5	2.5	2.5	2.5					10
Tomato	Calinago					2.5	2.5	2.5	2.5					10
Okra	Clemson									5	5	5	5	20
Cabbage	KK Cross					2.5	2.5	2.5	2.5					10
Cabbage	Copenha-gen Market	2.5	2.5	2.5	2.5									10
Onion	Violet de Galmi	2.5	2.5	2.5	2.5									10
Maize	Local								2.5	2.5	2.5	2.5		10
Cucumber	Poinsettia					2.5	2.5	2.5						7.5
Cultivated fallow	Local legume									2.5	2.5	2.5	2.5	12.5
Totals														
Hectares	Cultivated area	10	10	10	10	10	10	10	10	10	10	10	7.5	Average % of total herbicides
%	Total herbicides	0	0	0	0	0	0	0	25	100	100	100	100	35.4%

1.2. Pressure resulting from selective herbicides

Likewise, and for the same reasons as for total herbicides, the indicator used to characterise the pressure due to selective herbicide treatments, is the percentage of the area which is treated with selective herbicides. Here again, treatment of a small percentage of the cultivated area and a low number of treatments is preferable.

The pressure level is assessed by area treated with selective herbicides during the year, as a percentage of the farm area cultivated. The 30% threshold set by experts is the limit beyond which the percentage which is not treated is too low for biodiversity.

Pressure level resulting from selective herbicides	Description
Strong pressure	The area treated with selective herbicides is greater than 30% of the cultivated area
Average pressure	The area treated with selective herbicides is less than or equal to 30% of the cultivated area
No pressure	No cultivated area is treated with selective herbicides

The same type of calculation is recommended for vegetable farming in a tropical environment.

1.3. Pressure resulting from insecticides

Likewise, and for the same reasons as for herbicides, the indicator used to characterise the pressure resulting from insecticide treatments, is the percentage of the area which is treated with insecticides or similar products (see below). Here again, treatment of a small percentage of the cultivated area and a low number of treatments is preferable.

The pressure level is assessed by area treated with insecticides and similar products during the year, as a percentage of the farm area cultivated. The 30% threshold set by experts is the limit beyond which the percentage which is not treated is too low for biodiversity.

In this case, all substances intended to fight animal kingdom pests (insects, molluscs, rodents, nematodes, etc.) are taken into account: insecticides, molluscicides, rodenticides, aphicides, nematicides, etc.

Treatments which use very little product per hectare such as seed treatments, spot treatment, traps, products authorised by organic farming and biocontrol products are not taken into account.

Pressure level of insecticides and similar products	Description
Strong pressure	The area treated with insecticides is greater than 30% of the cultivated area
Average pressure	The area treated with insecticides is less than or equal to 30% of the cultivated area
No pressure	No cultivated area is treated with insecticides

1.4. Pressure due to fungicides

Likewise, and for the same reasons as for other pesticides, the indicator used to characterise the pressure resulting from fungicide treatments, is the percentage of the area which is treated with fungicides. Here again, treatment of a small percentage of the cultivated area and a low number of treatments is preferable.

The pressure level is assessed by area treated with fungicides during the year, as a percentage of the farm area cultivated. The 30% threshold set by experts is the limit beyond which the percentage which is not treated is too low for biodiversity.

Treatments which use very little product per hectare such as seed treatments, spot treatments, traps, products authorised by organic farming and biocontrol products are not taken into account.

Pressure level of fungicides	Description
Strong pressure	The area treated with fungicides is greater than 30% of the cultivated area
Average pressure	The area treated with fungicides is less than or equal to 30% of the cultivated area
No pressure	No cultivated area is treated with fungicides

1.5. Overall assessment procedure (aggregation table)

The impact of the use of phytosanitary products is assessed based on the "Pressure resulting from total herbicides", "Pressure resulting from selective herbicides", "Pressure resulting from insecticides" and "Pressure resulting from fungicides".

The impact of total herbicides on biodiversity is more damaging than that of selective herbicides, insecticides and fungicides because the spectrum is broader and attacks the basis of the food chain. There is more emphasis on this impact for this reason.

	Pressure resulting from total herbicides	Pressure resulting from selective herbicides	Pressure resulting from insecticides	Pressure resulting from fungicides	Impact of phytosanitary product use
1	strong pressure	strong pressure	strong pressure	strong pressure	high impact
2	strong pressure	strong pressure	strong pressure	average pressure	high impact
3	strong pressure	strong pressure	strong pressure	no pressure	high impact
4	strong pressure	strong pressure	average pressure	strong pressure	high impact
5	strong pressure	strong pressure	average pressure	average pressure	high impact
6	strong pressure	strong pressure	average pressure	no pressure	high impact
7	strong pressure	strong pressure	no pressure	strong pressure	high impact
8	strong pressure	strong pressure	no pressure	average pressure	high impact
9	strong pressure	strong pressure	no pressure	no pressure	high impact
10	strong pressure	average pressure	strong pressure	strong pressure	high impact
11	strong pressure	average pressure	strong pressure	average pressure	high impact

	Pressure resulting from total herbicides	Pressure resulting from selective herbicides	Pressure resulting from insecticides	Pressure resulting from fungicides	Impact of phytosanitary product use
12	strong pressure	average pressure	strong pressure	no pressure	high impact
13	strong pressure	average pressure	average pressure	strong pressure	high impact
14	strong pressure	average pressure	average pressure	average pressure	high impact
15	strong pressure	average pressure	average pressure	no pressure	high impact
16	strong pressure	average pressure	no pressure	strong pressure	high impact
17	strong pressure	average pressure	no pressure	average pressure	high impact
18	strong pressure	average pressure	no pressure	no pressure	high impact
19	strong pressure	no pressure	strong pressure	strong pressure	high impact
20	strong pressure	no pressure	strong pressure	average pressure	high impact
21	strong pressure	no pressure	strong pressure	no pressure	high impact
22	strong pressure	no pressure	average pressure	strong pressure	high impact
23	strong pressure	no pressure	average pressure	average pressure	high impact
24	strong pressure	no pressure	average pressure	no pressure	high impact
25	strong pressure	no pressure	no pressure	strong pressure	high impact
26	strong pressure	no pressure	no pressure	average pressure	high impact
27	strong pressure	no pressure	no pressure	no pressure	average impact
28	average pressure	strong pressure	strong pressure	strong pressure	high impact
29	average pressure	strong pressure	strong pressure	average pressure	high impact
30	average pressure	strong pressure	strong pressure	no pressure	high impact
31	average pressure	strong pressure	average pressure	strong pressure	high impact
32	average pressure	strong pressure	average pressure	average pressure	high impact
33	average pressure	strong pressure	average pressure	no pressure	high impact
34	average pressure	strong pressure	no pressure	strong pressure	high impact
35	average pressure	strong pressure	no pressure	average pressure	high impact
36	average pressure	strong pressure	no pressure	no pressure	high impact
37	average pressure	average pressure	strong pressure	strong pressure	high impact
38	average pressure	average pressure	strong pressure	average pressure	average impact
39	average pressure	average pressure	strong pressure	no pressure	average impact
40	average pressure	average pressure	average pressure	strong pressure	average impact
41	average pressure	average pressure	average pressure	average pressure	average impact
42	average pressure	average pressure	average pressure	no pressure	average impact
43	average pressure	average pressure	no pressure	strong pressure	average impact
44	average pressure	average pressure	no pressure	average pressure	average impact
45	average pressure	average pressure	no pressure	no pressure	low impact
46	average pressure	no pressure	strong pressure	strong pressure	average impact

	Pressure resulting from total herbicides	Pressure resulting from selective herbicides	Pressure resulting from insecticides	Pressure resulting from fungicides	Impact of phytosanitary product use
47	average pressure	no pressure	strong pressure	average pressure	average impact
48	average pressure	no pressure	strong pressure	no pressure	average impact
49	average pressure	no pressure	average pressure	strong pressure	average impact
50	average pressure	no pressure	average pressure	average pressure	average impact
51	average pressure	no pressure	average pressure	no pressure	low impact
52	average pressure	no pressure	no pressure	strong pressure	average impact
53	average pressure	no pressure	no pressure	average pressure	low impact
54	average pressure	no pressure	no pressure	no pressure	low impact
55	no pressure	strong pressure	strong pressure	strong pressure	high impact
56	no pressure	strong pressure	strong pressure	average pressure	high impact
57	no pressure	strong pressure	strong pressure	no pressure	high impact
58	no pressure	strong pressure	average pressure	strong pressure	high impact
59	no pressure	strong pressure	average pressure	average pressure	high impact
60	no pressure	strong pressure	average pressure	no pressure	high impact
61	no pressure	strong pressure	no pressure	strong pressure	high impact
62	no pressure	strong pressure	no pressure	average pressure	high impact
63	no pressure	strong pressure	no pressure	no pressure	average impact
64	no pressure	average pressure	strong pressure	strong pressure	average impact
65	no pressure	average pressure	strong pressure	average pressure	average impact
66	no pressure	average pressure	strong pressure	no pressure	average impact
67	no pressure	average pressure	average pressure	strong pressure	average impact
68	no pressure	average pressure	average pressure	average pressure	average impact
69	no pressure	average pressure	average pressure	no pressure	low impact
70	no pressure	average pressure	no pressure	strong pressure	average impact
71	no pressure	average pressure	no pressure	average pressure	low impact
72	no pressure	average pressure	no pressure	no pressure	low impact
73	no pressure	no pressure	strong pressure	strong pressure	average impact
74	no pressure	no pressure	strong pressure	average pressure	average impact
75	no pressure	no pressure	strong pressure	no pressure	low impact
76	no pressure	no pressure	average pressure	strong pressure	average impact
77	no pressure	no pressure	average pressure	average pressure	low impact
78	no pressure	no pressure	average pressure	no pressure	low impact
79	no pressure	no pressure	no pressure	strong pressure	low impact
80	no pressure	no pressure	no pressure	average pressure	low impact
81	no pressure	no pressure	no pressure	no pressure	no impact

2. Impact of mechanisation

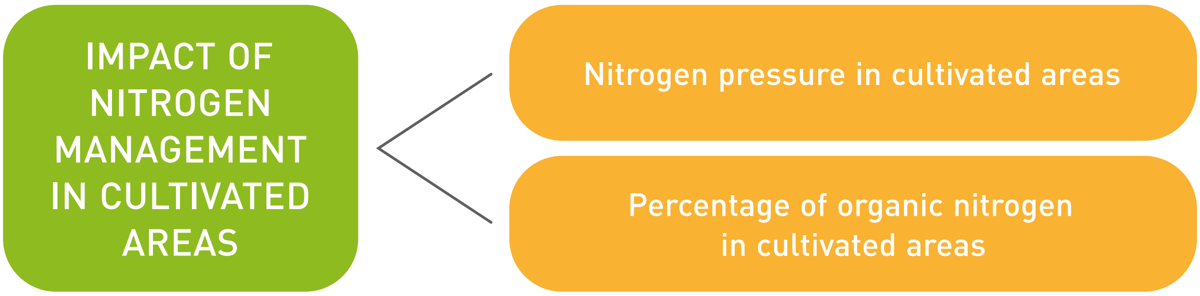
2.1. Percentage of land ploughed

At the regional level, as well as at the farm level, the percentage of ploughed surface area is characteristic of a degree of artificialisation of the environment. When ploughing accounts for under 20% of the area (of the farm and of the region), the impact on wild biodiversity is deemed to be weak or negligible whereas above 75%, its impact on the environment becomes very significant (no food sources for several months for many species, etc.).

This criterion is assessed by the percentage of land ploughed, i.e. turned over, compared to the total area cultivated.

Thresholds of ploughed cultivated land	Qualification	Negative impact of mechanisation
Greater than 75%	Area	high
Between 20% and 75%	Average	average
Under 20%	Limited	none or low

3. Impact of nitrogen management in cultivated areas



3.1. Nitrogen pressure in cultivated areas

In Europe, the threshold of 100 kg of nitrogen per hectare and per year (average for all cultivated land), and more so the 150 thresholds, are considered to be problematic for the local environment and for the water located at outlets in the case of field crops. In the case of tropical vegetable farms covered by this manual, we have used lower classification thresholds because the plots in tropical areas are often cultivated all year long and the needs over a year are therefore greater than in temperate areas.

The value of nitrogen pressure is calculated by counting all of the nitrogen compounds spread over cultivated areas of the farm (fertilisers, liquid manure, manure, composts, etc.) whether they are produced on the farm or not. Animal excretions in the fields are ignored given how imprecise these data are and how difficult it is to calculate them. This decision slightly biases the calculation without significantly modifying the nitrogen pressure and, therefore, the value of the indicator.

The level of nitrogen pressure is assessed based on the average amount of nitrogen (organic and mineral) spread per hectare for all of the plots farmed by calculating: the average dose of mineral nitrogen used per hectare (cultivated areas) (kgN/ha) and the average dose of organic nitrogen per hectare used (cultivated areas) (kgN/ha) whether produced by livestock or imported. The quantity of organic nitrogen which is not imported is estimated using livestock data.

Note:

- Calculations are in nitrogen units (NU), i.e. kg of nitrogen in the organic matter.
- The average dose per hectare is calculated by dividing the total doses spread on cultivated areas during the year by the area of all cultivated areas, whether or not they receive nitrogen.

Negative nitrogen pressure level	Description
Very high	Greater than 300 kgN/ha/year
High	Between 200 and 300 kgN/ha/year
Average	Between 100 and 200 kgN/ha/year
Low	Less than 100 kgN/ha/year

3.2. Percentage of organic nitrogen in cultivated areas

As opposed to mineral nitrogen, which is rapidly soluble in rain water, organic nitrogen, when not used in excess (in the form of manure or compost) is very positive for the organic activity of soils. On the other hand, nitrogen spread as liquid manure (in significant amounts) abruptly changes the carbon/nitrogen ratio in the soil, resulting in an acceleration of mineralisation and the turnover of organic matter. Liquid manure can also cause pedofauna asphyxiation problems, particularly for worms (Soltner, 2005).

The favourable effect level is assessed by the proportion of inputs of organic origin used on the cultivated areas of the farm excluding liquid manure due to its negative impact on soil-dwelling fauna (see above).

Favourable effect level	Percentage of organic nitrogen
Low	Percentage less than 20%
Average	Percentage between 20% and 50%
High	Percentage greater than 50%

Note: The fact that organic manure has been transformed (composting in particular) is not taken into account here because its impact on biodiversity has not been established.

3.3. Overall assessment procedure (aggregation table):

“Nitrogen management in cultivated areas” is assessed based on the “Nitrogen pressure in cultivated areas” and the “Percentage of organic nitrogen in cultivated areas”.

Nitrogen pressure is very important in nitrogen management, but the percentage is also important, notably for average nitrogen pressure. For low nitrogen pressure, the percentage of organic nitrogen is low and therefore has little impact. On the other hand, very high nitrogen pressure has such a significant impact on biodiversity that it isn’t really offset by organic nitrogen. The percentage of organic nitrogen therefore has an impact on average to strong pressure.

	Nitrogen pressure in cultivated areas	Percentage of organic nitrogen pressure in cultivated areas	Nitrogen management in cultivated areas
1	very high	low	**problematic**
2	very high	average	**problematic**
3	very high	high	**problematic**
4	high	low	**problematic**
5	high	average	**problematic**
6	high	high	**acceptable**
7	average	low	**acceptable**
8	average	average	**acceptable**
9	average	high	**favourable**
10	low	low	**favourable**
11	low	average	**favourable**
12	low	high	**favourable**

4. Assessment procedure of the impact of technical itineraries of all cultivated areas

In this case, the overall impact of choices made for crops on biodiversity is assessed.

The impact of the "Technical itinerary of all cultivated areas" is assessed based on aggregation of the "Impact of the use of phytosanitary products", the "Impact of mechanisation" and "Nitrogen management in cultivated areas". The impact of phytosanitary treatments is deemed preponderant in the effect of the technical itinerary on biodiversity.

	Impact of the use of phytosanitary products	Impact of mechanisation	Nitrogen management in cultivated areas	Technical itinerary of all cultivated areas
1	strong	high	problematic	problematic
2	strong	high	acceptable	problematic
3	strong	high	favourable	problematic
4	strong	average	problematic	problematic
5	strong	average	acceptable	problematic
6	strong	average	favourable	problematic
7	strong	low	problematic	problematic
8	strong	none or low	acceptable	problematic
9	strong	none or low	favourable	problematic
10	average	high	problematic	problematic
11	average	high	acceptable	poor
12	average	high	favourable	poor
13	average	average	problematic	poor
14	average	average	acceptable	poor
15	average	average	favourable	acceptable
16	average	none or low	problematic	acceptable
17	average	none or low	acceptable	acceptable
18	average	none or low	favourable	acceptable
19	low	high	problematic	poor
20	low	high	acceptable	acceptable
21	low	high	favourable	acceptable
22	low	average	problematic	acceptable
23	low	average	acceptable	acceptable
24	low	average	favourable	favourable
25	low	none or low	problematic	acceptable
26	low	none or low	acceptable	favourable
27	low	none or low	favourable	favourable
28	none	high	problematic	poor
29	none	high	acceptable	acceptable
30	none	high	favourable	acceptable
31	none	average	problematic	acceptable
32	none	average	acceptable	favourable
33	none	average	favourable	favourable
34	none	none or low	problematic	favourable
35	none	none or low	acceptable	favourable
36	none	none or low	favourable	favourable

II. Structure of perennial crops

1. Grass cover of perennial crops

Orchards, for example, mango orchards and other perennial woody crops or consisting of plants like banana and papaya trees clearly belong to cultivated areas, but due to their relative stability over time, they have specific characteristics vis-à-vis wildlife (nests, complex trophic networks, etc.). Contrary to ploughed areas which are re-seeded every year, this stability over time enables the development of a degree of biodiversity which is reinforced by ongoing grass cover. This technique is probably the most beneficial one for biodiversity and it has the benefit of providing shelter for auxiliaries (ESCo, Chapter 3, p. 41, 2008). Mechanical care of grass cover is preferable to chemical maintenance.

This criterion is assessed based on the percentage of the area of perennial crops with grass cover. This percentage is estimated by the farmer.

Note: a plot with grass cover on one row out of every two is considered to have cover on half of its area.

Grass cover level	Thresholds in % of grass cover
Low or no grass cover	< 20% of perennial area with grass cover
Partial cover	from 20% to 75% of perennial area with grass cover
Total grass cover	> 75% of perennial areas with grass cover

The area with grass cover must include sufficient species variability and density to be considered covered. In Guadeloupe[70] the grass cover must consist of minimum three species of grasses to be considered "validly" grassed. Optimally, 20 plant species should be used to ensure the ecosystemic services expected of grass cover.

The level of grass cover should be assessed during the favourable season, i.e. during the rainy season. To be valid, the grass cover must be in place during the entire favourable season and until the plants die off during the dry season.

2. Architecture of perennial crops

The presence in perennial crops of several strata which can be used by biological communities (spatial aspect) and their maintenance (temporal aspect) is potentially favourable to maintaining trophic networks and animal diversity (ESCo, 2008).

This criterion is assessed by the share of heterogeneous crops in strata and/or by age and/or by species and/or by varieties compared to the total area of perennial woody crops. The share also includes perennial woody crops over 30 years old which, due to their age, have increased in heterogeneity.

Criterion level	Description
Homogeneous	Heterogeneous share less than or equal to 50%
Heterogeneous	Heterogeneous share greater than 50%

70 Development of an indicator for the assessment of citrus cultivation orchards in Guadeloupe - End of study report on the Master 2 programme *Biodiversity management - Defended in September 2009 in Toulouse by Maxime Pfohl - Supervised by Fabrice Le Bellec, Agronomist at CIRAD Station, Vieux-Habitants*

3. Procedure for the overall assessment of the structure of perennial crops

This criterion assesses the impact of management choices on the complementarity of micro-habitats. Woody crops with grass cover and a heterogeneous architecture create a multitude of micro-habitats which facilitate the presence of a range of wildlife species.

The quality of the "Structure of woody perennial crops" is assessed by aggregating the "Grass cover of woody perennial crops and poplar groves" and the "Architecture of perennial woody crops". The architecture is considered to be slightly more important than the grass cover.

	Grass cover of perennial crops	Architecture of perennial crops	Structure of perennial crops
1	Low or no grass cover	homogeneous	**poor**
2	Low or no grass cover	heterogeneous	**acceptable**
3	partial grass cover	homogeneous	**acceptable**
4	partial grass cover	heterogeneous	**favourable**
5	total grass cover	homogeneous	**acceptable**
6	total grass cover	heterogeneous	**favourable**

2.6.8. A8: Assessment of the quality and deterioration/disruption of the AEI/AEU

Examples of assessment tables of the state of different types of AEI/AEU are provided below. The state of preservation (quality) of the AEI/AEU is assessed using several indicators for each of the three criteria (structure, composition and deterioration/disruption). The limits used to qualify the situation as good (A), average (B) or unfavourable (C) are provided for each criterion/indicator combination.

The final score given to the agroecological infrastructure is the score of the worse indicator of the list of assessments by AEI/AEU. All of the indicators must be assessed insofar as possible. If this is not the case, at least one indicator by category must be assessed. The diagnostic fits within the process of biodiversity improvement. Therefore, it must be possible to correct any deficient criterion at the end of the diagnostic.

An example of a table providing a compilation of the state of the AEI/AEU present on the farm is provided at the end.

Note: Some of the tables from the sources cited below have been freely adapted for this manual.

Sources:

- Natural Spaces Conservatory Languedoc Roussillon | SupAgro Florac, Diagnostic of the biodiversity on farms in Languedoc-Roussillon - Manual adapted within the framework of the Ecodiag Leonardo Da Vinci project innovation transfer work package no. 3.
- IBEA - A diagnostic tool for the impact of practices on the biodiversity of farms - Scientific manual - 1st version, March 2013

1. Natural and semi-natural hedge assessment help table

Definition: A natural or semi-natural hedge is considered to be a linear structure of minimum 10 m in length consisting of primarily local trees and/or bushes and shrubs.

If a hedge is interrupted for more than 20% of its length, the different sections must be considered separately.

Criteria	Indicators	State of conservation			Data observed
		A = Good	B = Average	C = Unfavourable	
Structure	Average hedge width (distance between the outside trunks)	> 2 m	1 to 2 m	< 1 m	
	Number of woody strata (trees: >3 m, high shrubs: 1.5 m to 3 m, low shrubs: <1.5 m) significant (at least 10% of the total length)	3	2	Less than 2	
	Average width of the grass strip on each side of the hedge	> 1.5 m	50 cm to 1.5 m	< 50 cm or no grass	
	Average number of types of small related structures: branch piles, trees with cavities, large-diameter trees (> 30 cm), piles of stones, low walls, walls, standing dead wood, stumps, etc. per 10 linear m	At least three different types	1 to 2 types	None	
Composition	Average number of woody species (low and high together, including vines) per 10 m section	More than 5	3 to 5	Less than 3	
	Average number of tree, bush and shrub species with fruit (berries or nuts) per 10 m section	More than 2	1 to 2	None	
	Average number of spiny shrub and bush species or trees characteristic of the local landscape per 10 m section	More than 1	1	None	
	Exotic species cover [%]*	Less than 1%	1-10%	> 10%	
Deterioration/ disruptions	Deterioration** [% of area impacted]	< 1	1-10	> 10	
	Average distance from the hedge to the closest treated or fertilised surface: distance of the trunk furthest outside to the edge of the treated and/or cultivated area	> 2 m	1 m to 2 m	< 1 m	

*List to be defined for each region
**Example: fill, waste, herbicide treatments, burning, ploughing or turning of the soil

2. Tree alignment assessment help table

Definition: Tree lines are leafy trees with high branches usually planted on the edge of a plot or road of minimum 30 m in length and consisting of at least five trees.

Criteria	Indicators	State of conservation			Data observed
		A = Good	B = Average	C = Unfavourable	
Structure	Average height	> 4m	between 2 and 4 m	< 2m	
	Average number of types of small related structures per 30 linear metres: branch piles, trees with cavities, piles of stones, low walls, walls, standing dead wood, etc.	At least three different types	1 to 2 types	No types	
Composition	Percentage of exotic** species excluding fruit trees	none	< 5%	< 5%	
Deterioration/ disruptions	Deterioration** [% of area impacted]	< 1	1-10	> 10	
	Average distance from the trunk to the edge of the treated and/or cultivated area	> 2 m	1 m to 1.5 m	< 1 m	

*List to be defined for each region
**Example: clear-cutting, excessive pruning, gravel or waste deposits, burning, weeding, ploughing or turning the soil, herbicide treatment, etc.)

3. Copse assessment help table

Definition: copses including small wooded areas of a surface area between 5 ares and 50 ares. Above 50 ares, the space should be considered a forest (see point 6) which can no longer be considered an AEI.

Criteria	Indicators	State of conservation			Data observed
		A = Good	B = Average	C = Unfavourable	
Structure	Number of trees with cavities, large-diameter trees, old tree per 5 ares	>/=2	1	0	
	Bare ground cover (excluding stones) [%]	< 10	10-20	> 20	
Composition	Exotic species cover* [%]	< 10	10-20	> 20	
	Cover with herbaceous plants instead of woody ones [%]	< 10	10-20	> 20	
Deterioration/ disruptions	Waste deposits or tracks [% of area impacted]	< 1	1-10	> 10	
	Cover damaged by fire (%)	< 10	10-20	> 20	

*List to be defined for each region

4. Grass strip assessment help table

Definition: there are two types of grass strips:

- Field borders are strips consisting of dense, established permanent herbaceous vegetation along one or more sides of a field (grass strips)
- buffers (filter strips, buffer strips or riparian zones), which are strips consisting of permanent herbaceous vegetation along waterways, ponds, sources and other wetlands.

Criteria	Indicators		State of conservation			Data observed
			A = Good	B = Average	C = Unfavourable	
Structure	Width [in m]	Buffer strips (along wetlands: waterways, streams, sources, ponds, etc.)	> 5	2-5	< 2	
Structure	Width [in m]	Grass strips (along cultivated areas, embankments, roads or other areas)	> 2	1-2	< 1	
Structure	Bare ground (excluding stones) [%]		< 10	10-20	> 20	
Structure	Cover consisting of young shrubs or bushes (> 30 cm high) [%]		< 25	25-50	> 50	
Composition	Exotic species [%]		< 1	1-10	> 10	
Composition	Ruderal species [%]*		< 1	1-10	> 10	
Composition	Average number of visible flowering plants (drawing auxiliaries) per 30 linear metres		> 10	5-10	< 5	
Composition	Perennial species cover* [%]		> 80	50-80	< 50	
Deterioration/ disruptions	Deterioration** [% area impacted]		< 1	1-10	> 10	

*List to be defined for each region
**Example: traces of herbicide treatments, burning, ploughing, etc.

5. Wetlands assessment help table

5.1. Risks of deterioration/disruption of wetlands

There is a risk of pollution and of deterioration of wetlands and/or aquatic environments from the farming practices used on neighbouring plots. The banks of wetlands protected by a wooded strip, by tree lines and with grass strips or non-fertilised, grazed or mowed natural meadows (with, ideally, development of water accesses to prevent deterioration of the environment by livestock) are the best agricultural technique for protecting water and wetlands from runoff and transfers of pollution. On the other hand, wetlands, for example a river bordered by crops without a buffer zone or too narrow a zone, are exposed to drifting pesticides and runoff (turbidity) and to abrupt flooding, which is always possible.

5.2. Ditch assessment help table

Definition: A ditch is a linear structure dug out to drain, collect or circulate water. All types of ditches are considered to be AEI/AEU except for those with built-on banks.

Criteria	Indicators	State of conservation			Data observed
		A = Good	B = Average	C = Unfavourable	
Structure	Bank slope < 60° (% linear]*	> 50	25 to 50	< 25	
	Presence of bare ground (excluding stones) [% of area]	< 10	10-25	> 25	
Composition	Exotic species** [%]	< 1	1-10	> 10	
Deterioration/ disruptions	Deterioration*** [% area impacted]	< 1	1-10	> 10	
	Average distance from the top of the bank edge to the edge of the treated and/or cultivated area	> 1 m	50 cm to 1m	< 50 cm	

*For more information about the measurement of vertical angles and slopes,
see http://www.fao.org/fishery/static/FAO_Training/FAO_Training/General/x6707f/x6707f04.htm
**List to be defined for each region
*** Example: gravel embankment deposits, traces of herbicide treatment, of burning, or ploughing, etc.

5.3. Marsh, backwater and pond assessment help table

Definitions: Small shallow ponds (mare) (perennial or not and natural or not). There are no precise criteria to differentiate between a large pond and a small pond. The latter generally don't have an outlet whereas other ponds are fed by a source or stream and have an outlet. Ponds are usually artificially created and blocked by a "roadway", a threshold or a reach (which can allow for emptying). A backwater is a small expanse of water with no outlet - a pond - often empty during the dry season. It can be a permanent pond or a branch of a river which gradually turns into small ponds which dry up and sometimes disappear.

Criteria	Indicators	State of conservation			Data observed
		A = Good	B = Average	C = Unfavourable	
Structure	Bank slope	Mostly < 30°	Mostly between 30 and 45°	Mostly > 45°	
Composition	Exotic species [%]*	< 1	1-5	> 5	
Deterioration/ disruptions	Deterioration** [% area impacted]	< 1	1-10	> 10	
	Distance from the top of the bank edge to the edge of the treated and/or cultivated area	> 5 m	2 to 5 m	< 2 m	

*List to be defined for each region

**Example: development, artificialisation of the source basin, catchments, draining, deposits, filling in, stamping by livestock or people, use by motorised vehicles, eutrophication

6. Forest quality

Forests which depend on management by the farmer (farmer forests) and which are generally used as a source for heating wood, stakes and timber, are an important biodiversity reservoir for many species which find diversified habitats and resources in this privileged environment. The "Forest quality" indicator is intended to assess the ability of forests to maintain a range of wildlife species via the assessment of their diversity in resources and in habitats. Forests greater than 5,000 m^2 are not taken into account in the AEI/AEU ratio calculation for farms, but their management must be optimised to obtain the greatest benefit of their biodiversity.

Note: Forests on the edge of a farm which do not belong to the farmer have an impact on the biodiversity of the farm itself. However, given that the farmer is not responsible for decisions about forest management they are not taken into account.

Calculation or assessment procedure:

The quality of a forest is assessed by its ability to maintain a range of wildlife species. This translates into a score allocated based on the following criteria:

- Significant presence (1) or absence (0) of shrubs
- Species mix: significant presence of 2 or 3 species (1), or of 4 or more species (2) or of a single dominant species (0) Significant age mix (balanced presence of spontaneous seeding, young shoots, small, medium and large trees) (1) or homogeneous tree age (0)
- Presence of dead wood: significant presence of dead wood on the ground (branches, trunks, etc.) or of standing dead wood (dead trees, dying trees, etc.) (2), or no dead wood (0)
- Significant presence of remarkable trees (1) or none (0) Significant presence of intra-forest ponds (1) or none (0)
- Significant presence of structured borders (1) or none (0) Significant presence of clearings (1) or none (0)

Quality	Overall forest score
Poor	Total score under 6 points
Average	Score between 6 and 7
Good to very good	Score between 8 and 9 or above 9

7. Summary compilation table of the state of the AEI/AEU

The different AEI/AEU inventoried and assessed within the farm can be summarised in a table as below. Measures can also already be recommended to improve their condition.

Assessment of agroecological infrastructure							
AEI/AEU type:		State of conservation				Observations	Measures recommended
AEI/AEU identification	Area occupied	Structure	Composition	Disruption	Score		
Total							
AEI/AEU type:		State of conservation				Observations	Measures recommended
AEI/AEU identification	Area occupied	Structure	Composition	Disruption	Score		
Total							
AEI/AEU type:		State of conservation				Observations	Measures recommended
AEI/AEU identification	Area occupied	Structure	Composition	Disruption	Score		
Total							
OVERALL TOTAL							

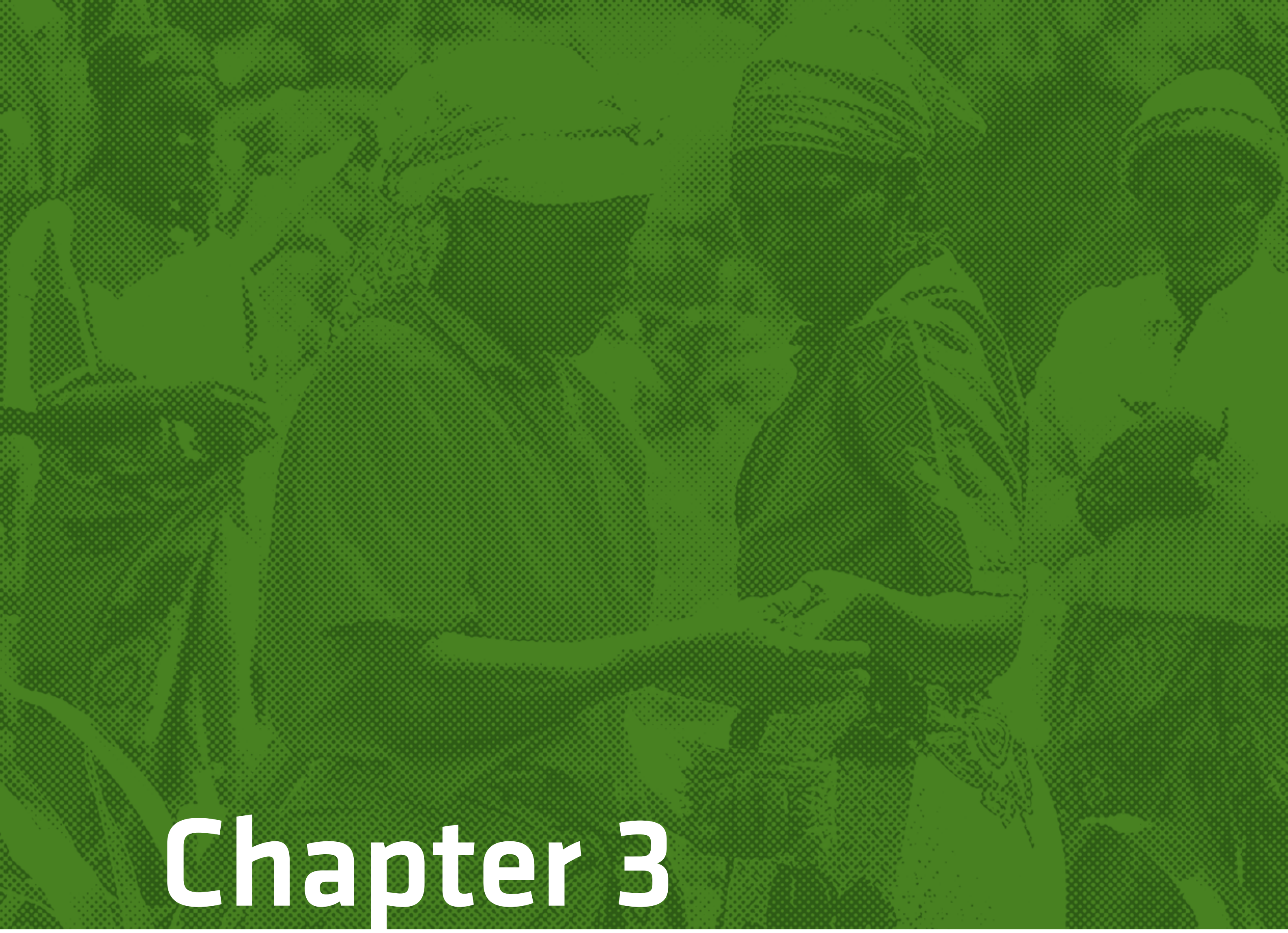
Example: a 5 ha farm with 4.5 ha of UAA

Assessment of the agroecological infrastructure							
AEI/AEU type:	Hedges	State of conservation					
AEI/AEU identification	Area occupied	Structure	Composition	Disruption	Score	Observations	Measures recommended
H1	50 m x 2.5 m = 125 m²	A	B	C	C		Remove non-organic waste and no longer make fires near the hedge
H2	25 m x 2 m = 50 m²	A	B	B	B		Decrease the number of exotic species and plant fruit bushes Move the cultivated plots 1 m away from the hedge
Total	175 m²						
AEI/AEU type:	Tree lines	State of conservation					
AEI/AEU identification	Area occupied	Structure	Composition	Disruption	Score	Observations	Measures recommended
AA1	200 m x 4 m = 800 m²	A	A	A	A		
Total	800 m²						
AEI/AEU type:	Grass strips	State of conservation					
AEI/AEU identification	Area occupied	Structure	Composition	Disruption	Score	Observations	Measures recommended
BE1	200 m x 2 m = 400 m²	A	C	A	C		Sow at least five species (preferably local) of flowering plants
BE2	200 m x 2 m = 400 m²	A	C	B	C		Sow at least five species (preferably local) of flowering plants Avoid driving the tractor on the strip
Total	800 m²						

AEI/AEU type:	Ponds	State of conservation				Observations	Measures recommended
AEI/AEU identification	Area occupied	Structure	Composition	Disruption	Score		
Ponds	20 m x 20 m = 400 m^2 (banks included)	A	B	C	C		Extend the area between the top of the bank and the edge of the cultivated plots to 3 m
Total	400 m^2						
OVERALL TOTAL	2,175 m^2						

The areas with isolated trees, i.e. 10 large trees on the farm, must be added to the overall total of 2,175 m^2 (10 large isolated trees in good health (not overly large) = 10 x 100 m^2 = 1,000 m^2).

This, therefore, totals AEI/AEU of 3,175 m^2 out of 45,000 m^2 which results in an AEI/AEU ratio of 7%, which is considered an average ratio. However, the area of this farm with hedges is not sufficient. Ideally, they should occupy at least 5% of the UAA (in this case, at least 2,250 m^2). To achieve this, the current length of the hedges should be increased at least 13 times. By adding these hedges to the farm, the overall AEI/AEU ratio would be 9.4%.



Chapter 3

Biodiversity Enhancement

3.1. WILD BIODIVERSITY ENHANCEMENT

3.1.1. Services provided

Agricultural production systems are based on a natural physical environment called an agroecosystem which consists of the land used for agriculture, livestock, pisciculture, forestry and grazing land. This environment creates a set of biotopes and biocenoses which are adapted and transformed according to the farming objectives and influence the environment's characteristics. Biodiversity is the foundation of many natural processes governing the functioning of agrosystems/ecosystems and the reason why the promotion of biodiversity is of capital importance to farmers and the community.

The main services provided by biodiversity within the context of agricultural activities are:

1. **Regulation services**: these are the benefits resulting from the regulation of ecosystemic processes, such as the regulation of air quality and soil fertility, the prevention of flooding and diseases and crop pollination.
2. **Support services** (also called self-maintenance or support services): are required for the production of all other ecosystem services. This consists in, for example, providing living spaces for plants and animals, enabling species diversity and preserving genetic diversity. Their effects on people are either indirect or appear over long periods of time.

Figure 1 shows the multiple services provided by agricultural biodiversity in a fictional landscape. It shows the services provided by biodiversity on different scales (cultivated plot, adjacent plots and at the, larger, landscape scale). It illustrates the fact that several services and benefits are provided by each element.

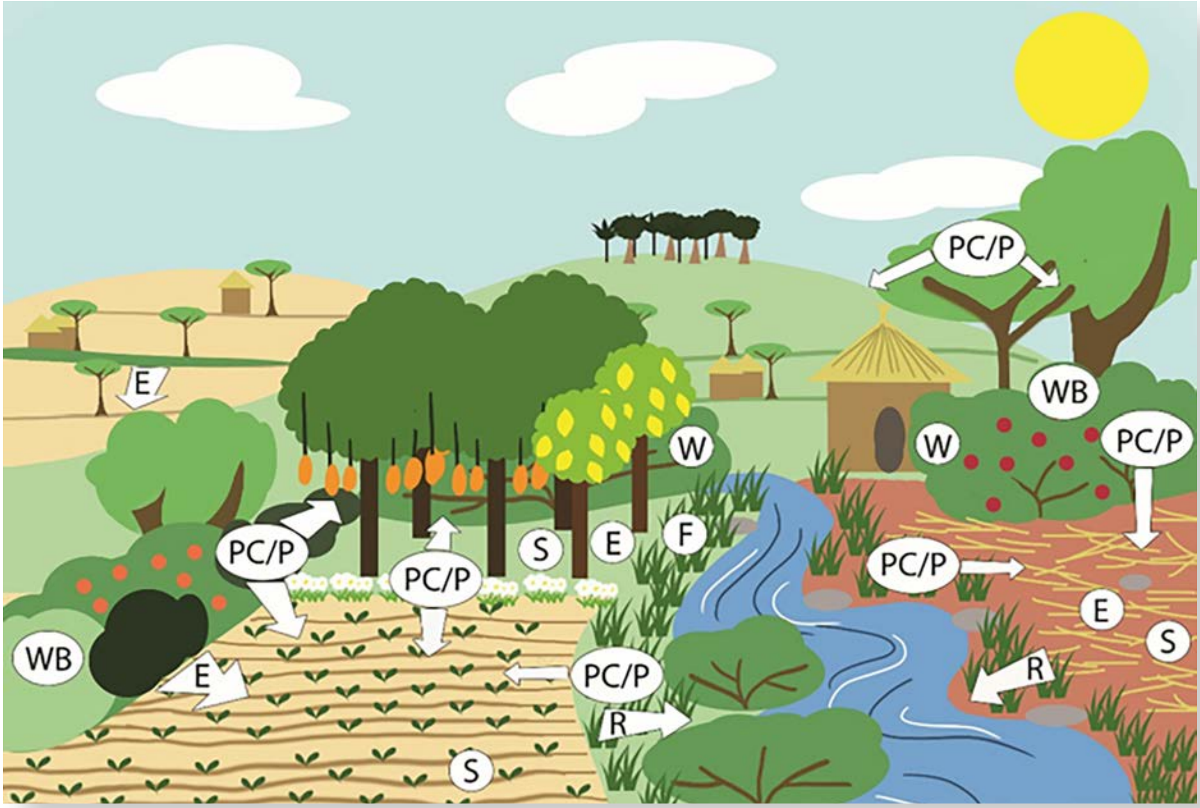


Figure 1: The multiple services provided by biodiversity to agriculture
Source: adapted from ELN-FAB, 2012[71]- drawing by Claire-Eliane Delhove

E. **Erosion prevention**: Hedges which follow contour lines prevent soil from eroding to the bottom of the hill. Grass cover in orchards prevents soil erosion by wind or torrential rains. Leaving harvest waste in the fields plays the same role.

F. **Flood prevention**: Leaving low river banks outside of the agricultural production zone covered with low vegetation provides room for overflowing and reduces water speed, protecting agricultural land downstream.

P. **Pollination**: Field borders with many flowers, river banks with vegetation, corpses and other areas provide habitats for a multitude of pollinating insects which are beneficial to crops.

PC. **Pest control**: Field borders with many flowers (selected species) and other semi-natural infrastructure provide a habitat for crop auxiliaries. Live hedges, copses, and other infrastructure also provide a habitat for predators and birds of prey which control small rodents.

R. **Reduced runoff**: strips of land without crops around fields capture excess fertiliser and pesticides and prevent them from flowing into rivers and ditches.

S. **The functions of soil structure**: Reduced ploughing, the presence of harvest waste on the ground and other measures which avoid unnecessarily disturbing the soil ensure an increase in soil biodiversity which improves soil structure and aeration as well as the capture and release of nutrients.

71 ELN-FAB (2012) Functional agrobiodiversity: Nature serving Europe's farmers. – Tilburg, the Netherlands: ECNC-European Centre for Nature Conservation.

W. **Water retention**: land with vegetation along rivers and copses act as sponges which hold water during floods and release it regularly over a long period of time.

WB. **Windbreaks**: aspects of the landscape such as hedges and lines of trees and orchards reduce wind speed. This reduces erosion and prevents sensitive crops from being damaged by violent winds. In some cases, agricultural yields are higher near windbreaks.

3.1.2. Regulation services

These services are benefits obtained via the regulation of ecosystem processes such as:

Micro- and macro-climate regulation:

ecosystems influence climate at both the local and global scales. For example, at the local level, changes in soil use can have an influence on both temperatures and the amount of rainfall. At the global scale, ecosystems can play an important role in the climate either by sequestering or emitting greenhouse gases.

Regulation of air quality:

Trees and other plants also play an important part in regulating air quality by eliminating pollutants from the atmosphere which can accumulate in crops.

Erosion control and ongoing soil fertility:

The vegetation cover prevents soil erosion and improves its fertility thanks to natural biological processes like nitrogen fixation. Soil erosion is a key factor in the soil deterioration process, declining fertility and desertification. This contributes to lower fisheries productivity downstream.

The fauna present in the soil (like earthworms and termites) plays a crucial role in its formation and fertility.

Water regulation (low-flows and floods):

The recurrence and extent of runoff and flooding and the recharging of aquifers can be strongly impacted by changes in soil occupation and by modifications which can alter water storage potential at the ecosystem level. These changes can result from the transformation of wetlands or forests into farmland or of farmland into urban areas.

Water purification and waste management:

Ecosystems can put impurities in water but can also help filter and decompose organic waste introduced into wetlands, inland water sources and marine ecosystems.

Pollination:

Pollination via animals is an ecosystem service provided primarily by insects as well as by birds and bats. In agricultural ecosystems, pollinating agents are indispensable auxiliaries for fruit tree growing, horticulture and forage production, as well as for the production of seeds of many plants grown for their roots and fibre. Pollinating agents like bees, birds and bats account for 35% of global plant production (Klein *et al.*, 2007). From an economic standpoint, the value of pollination for human food production is estimated at €153 billion (9.5% of the commercial value of global food production for human consumption) (Programme Alarm, 2006-2009)[72].

Bees pollination

Bats pollination

Beetles pollination

Butterflies pollination

Figure 2: Examples of pollinators
Source:https://www.google.bj/search?q=photos+exemple+d%27insectes+pollinisateurs&tbm

The smallest change in an ecosystem can affect the distribution, abundance and effectiveness of pollination.

72 http://www.inra.fr/Grand-public/Ressources-et-milieux-naturels/Tous-les-dossiers/Abeilles-pollinisation-biodiversite-pesticides/Abeilles-pollinisation-et-biodiversite

Regulation of pests and diseases (people, plants and animals):

This refers to the activities of predators and parasites in ecosystems which contribute to the fight against harmful organisms and potential disease vectors.

Biological control is based on this principle:

it provides an elegant method for reducing the effects of a disruptive (or harmful) organism (animal or plant) by ensuring that it is eaten (or controlled) by one of its natural enemies. Insects are very important for biological control (BC). First as a target: bacteria, fungi, viruses, nematodes and, especially other insects, predators and parasites are used to control crop pests and disease vectors. Second, as biological control agents (or "auxiliaries") to destroy the destructive or disruptive (harmful) insects described above and to control unwanted plants which invade fields or canals.

(a) Adult Trichogramma parasitising borer eggs (photo INRA Antibes)

(b) Ladybird eating an aphid.

Figure 3: Examples of biological control agents
Source: (a) http://www.inra.fr/dpenv/hawlic16.htm;
(b) http://www.univers-nature.com/inf/inf_actualite1.cgi?id=3434

3.1.3. Self-maintenance services (support)

Wild biodiversity is essential to maintaining conditions favourable to life on Earth thanks to its role in the biogeoecolological cycles of the elements (nutritional or otherwise). It contributes to:

(a) the maintenance of local and global ecological balances
(b) the stability of atmospheric oxygen production and of the global climate,
(c) the formation and stability of soils,
(d) the cycle of the elements, and
(e) the habitats available to species.

Box 1: Example of self-maintenance services provided by hedges

The practice of planting windbreak hedges is an ancient agricultural practice to protect soils and market garden perimeters, crops, animals, buildings and roads and to secure rural concessions while marking off boundaries.

Examples of support services include the production of atmospheric oxygen, soil formation and retention, biogeochemical cycles, the water cycle and habitats and food, notably for crop auxiliaries. The supply of living space for plants and animals and the preservation of the diversity of plant and animal species are "**support services**" and are the foundation of all ecosystems and their services.

Figure 4: a Eucalyptus hedge enclosing a vegetable crop in Bujumbura (Burundi). Groupement ATUDI, Butere, Bujumbura- FAO-Project FBPP/GLO/013/BEL Source: photo Grégoire Mutshail, 2013.

Box 2: Example of self-maintenance services provided by termites

Together with earthworms, termites are the main members of soil fauna in tropical areas. Termites affect the physical properties of the soil, of the water on the soil and of the organic matter in the soil.

Termites make a significant contribution to most ecosystems:

- They are very important for the recycling of woody plants and other plant materials.
- The work they do in the soil contributes to its aeration and their activity results in a heterogeneous change and/or in the composition and fertility of the soil. Compact and hard soils cannot absorb water and, as a result, cannot support long plant life. As has been demonstrated in the Sahel in Africa, termites can contribute to repairing damaged soil.
- They also make a significant contribution to atmospheric gases. The production of carbon dioxide by termites is more pronounced in savannah covered with termite mounds than in zones without them (Konaté *et al.*, 2003). The recycling of carbon in the African savannah with grass cover, shrubs and trees is strongly impacted by termites.

While termites are sometimes a source of problems: physical barriers, crop destruction and damage to homes, they play an important role in the fertility of tropical soil and the structure and dynamics of ecosystems. This can have a positive impact on biodiversity and agricultural production.

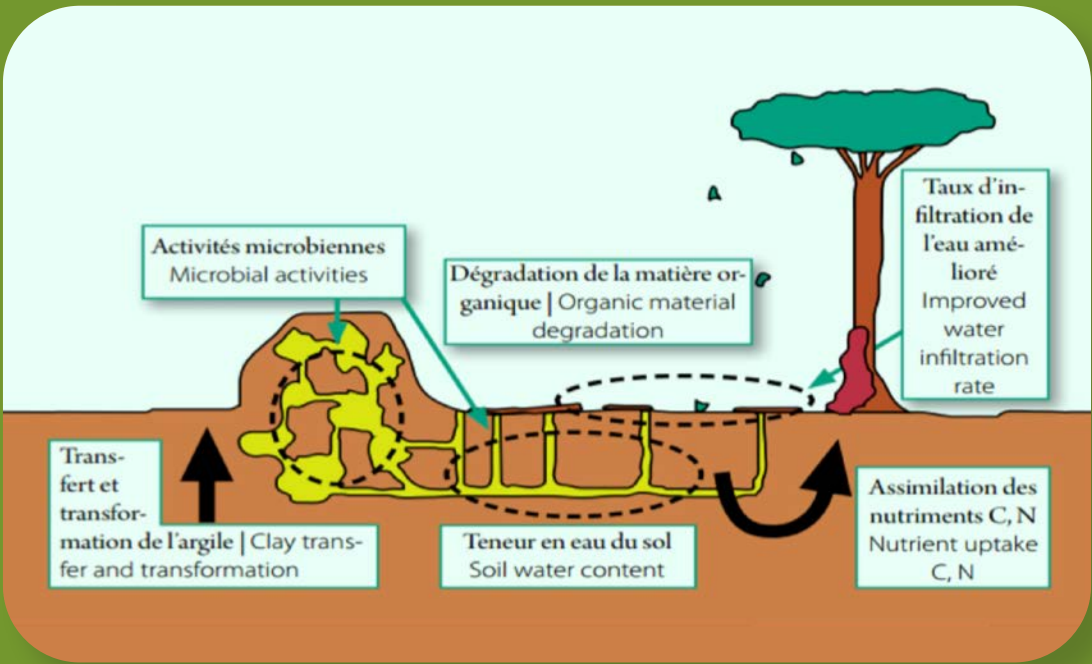


Figure 5: Conceptual model summarizing the role of termites as "ecosystem engineers", in the functioning of the Lamto savannah (Source: Konaté and Kampmann, 2010)

Box 3: Example of self-maintenance services provided by earthworms

Earthworms are considered an essential part of the functioning of the soil thanks to their impact on the formation, development and fertility of soils. Together with termites and ants, they are the primary macrofauna groups found in the soil of tropical countries (Lavelle, 2002). Earthworms are considered to be "ecosystem engineers" because they modify the functioning of soils through their activity.

There are three situations in which they can play the role of ecosystem engineers (Rossi, 1998):

1. they modify the soil's structure and, as a result, alter its porosity which constitutes a spatial resource for other organisms (microfauna, mesofauna) which are unable to move around or penetrate the soil's aggregates;
2. they act on the dynamics of organic material, in the short term in particular, and they contribute to the release of significant quantities of nutrients which are indispensable for plant growth;
3. they have an indirect effect on the flow of organic materials and of water in the soil via the changes they introduce in the soil structure and, therefore, contribute to the regulation of resource flows for various soil organisms.

The conversion of natural ecosystems into agricultural systems tends to reduce the density, the biomass and the biological diversity of earthworm populations. A return to fallow land generally results in an increase in their presence and diversity. The presence of certain species like the *Dichogaster baeri* can potentially provide an indication of soil quality (Tondoh *et al.*), 2010.

Some species of earthworms like the *Eisenia fœtida, Eisenia andrei* and *Eisenia hortensis* are useful for the production of worm compost. They digest compost and other organic and inert substances and contribute to enriching the soil with fertilisers which can be easily absorbed by plants, thereby contributing to sustainable soil fertility which is required to maintain biodiversity.

Figure 6: Earthworm specimens and signs of their activity: 1. *Millsonia omodeoi*; 2. *Hyperiodrilus afrcanus*; 3. Massive compact *Millsonia omodeo* casts; 4. Crumbly *Hyperiodrilus africanus* casts; 5. Quiescent earthworm specimen. Source: Konaté and Kampmann (2010).

3.2. DOMESTICATED BIODIVERSITY ENHANCEMENT

3.2.1. Definition

Domesticated biodiversity Includes all domesticated species and varieties and races used by humans. Over time, humans have succeeded in selecting plant and animal species to create varieties in the different categories of crops, fruits, vegetables, livestock and practically all domesticated species.

The domestication process has led humans to master the reproduction of several wild species and apply their own selection criteria. These criteria can be based on production (resistance, quality, productivity) or can be cultural (colour, shape, originality). By removing the species from natural selection. Natural selection is a process which promotes the adaptation of species by enabling the individuals best suited to their environment to reproduce.

Extensive diversity: hundreds of species and thousands of varieties:

- *Vegetables*
- *Fruits*
- *Roots and tubers*
- *Mushrooms*
- *Seasoning, aromatic (essential oils) and curative (medicinal) plants*
- *Ornamental plants*

Figure 7: the diversity of horticultural species/fruits and vegetables. Presentation workshop on the strategic horticulture framework of Burundi, FAO-Project FBPP/GLO/013/BEL, Bujumbura - Wilfried Baudoin, 2013.

Natural selection explains the adaptation of species to their environment. Humans have gradually created species which are different from wild populations, at least from a phenotype point of view (external aspect). While domestication is an ancient process, domesticated populations have sometimes virtually become an entirely different species. This means that domesticated populations can no longer reproduce with their wild cousins: the two populations are separate species.

There are three levels of diversity within a crop field or an orchard:

1. interspecific (or species) diversity: this is the best-known type because it is visible. It reflects the diversity of living species.
2. intraspecific (or genetic) diversity: is defined by the variability of genes within the same species, either between individuals or populations.
3. intravarietal diversity: is defined as genetic diversity within the same variety.

Diversity enables farmers to minimise the risks related to monocultures by cultivating different species and varieties. It increases the stability of crop yields thanks to intra-plot heterogeneity. In addition, some species can be complementary (associated crops). Generally speaking, this variability provides insurance against future adverse conditions and is a reservoir of potentially valuable resources for the future (FAO, 1997). Maintaining a high level of genetic diversity within an agroecosystem is, therefore, crucial for ensuring food security.

Farming which mixes varieties or species naturally increases crop protection by using the resistance attributes of each plant.

3.2.2. Promoting interspecific diversity

Figure 8: Combination (intercropping) of maize with carrots. Groupement TWIYUNGE MW'INTERABERE, Bugarama – Burundi, FAO-Project FBPP/GLO/013/BEL, photo Grégoire Mutshail, 2013.

The goal is to grow two or more species simultaneously in the same area for a significant period of their growth cycle (Willey, 1979). Combining several crops is a traditional practice in many tropical regions and, particularly, in Africa.

The combinations can provide **several benefits such as**:

3.2.2.1. A reduction in fertiliser use

In cereal/legume crop combinations, the legumes establish symbiotic relationships with the rhizobium micro-organisms in the soil which fix atmospheric nitrogen via the nodules of roots and provide plants with a significant proportion of their nitrogen needs. This ability, which is specific to legumes, enables them to bring to play a complementary nitrogen fixing process when they are associated with species which cannot fix nitrogen, like cereals. The gains in yields seen when combining cereals with legumes are often attributed to the complementarity of the two species in their use of nitrogen resources.

The better overall use of nitrogen also contributes to a reduction in lixiviation and limits the availability of N for the growth of weeds.

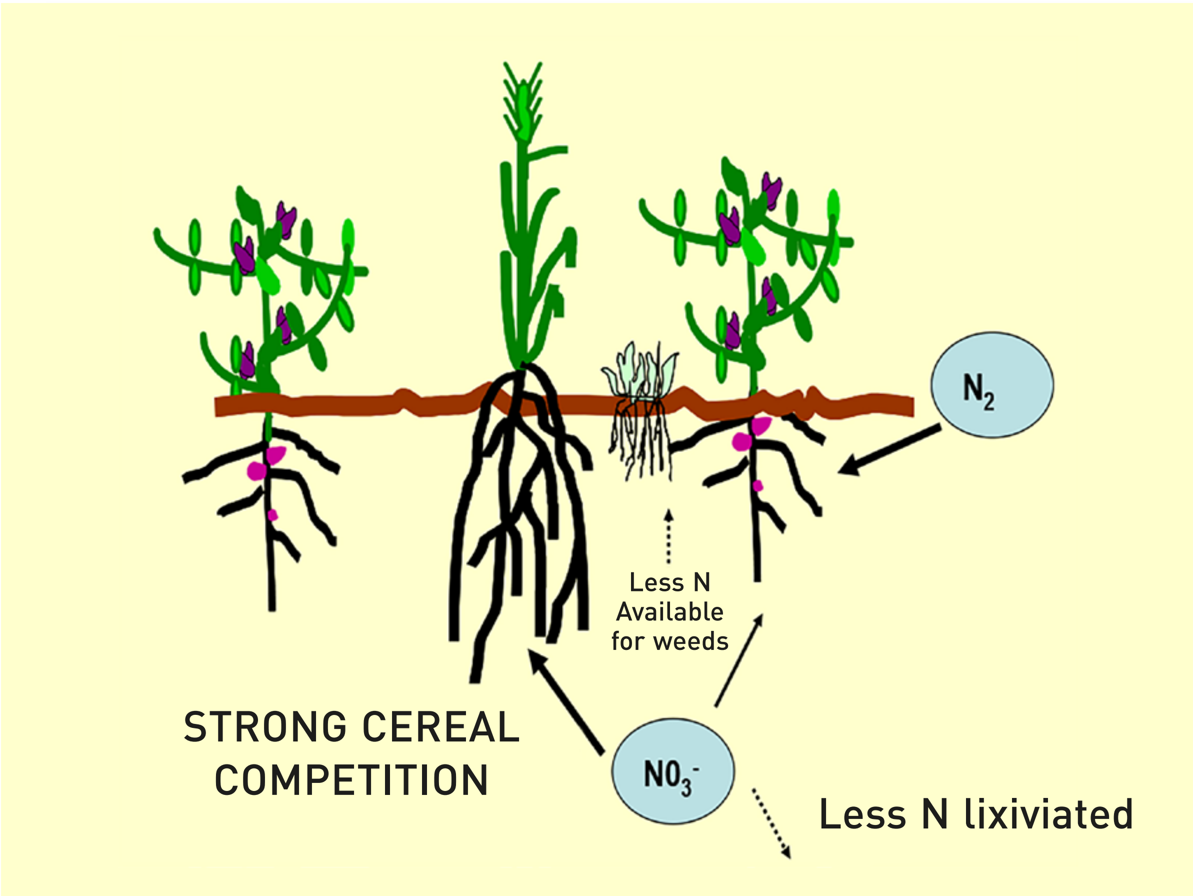


Figure 9: Diagram of N transfers between legumes and cereals
Source: http://inra-dam-front-resources-cdn.brainsonic.com/ressources/afile/246508-6e585-resource-article-inra-toulouse-cultures-associees.html

3.2.2.2. Repulsion and trapping of pests

The rate of attacks on a plant by pests is determined by many factors. The host plant's defences and its nutrition have long been considered the most important ones.

The concept of resistance by association states that, when planted near other plants, the host plant will benefit from the defences of neighbouring plants. The association of a sensitive plant with a resistant plant can reduce the density of pests on the sensitive plant.

Several mechanisms have been proposed to explain this phenomenon:

1. Companion plants which are less appetising for pests can make the entire plot less appealing. The mechanism involved is resistance by association with repelling plants. Experiences in fields have shown that *Myzus persicae* was less drawn to cabbage when it was surrounded by tomatoes or black mustard.
2. Plants emit repelling substances: This is also true of marigolds (*Tagetes*) which are very valuable for repelling insects which attack the aerial parts of plants and parasites which attack the roots. They have an acrid and pungent smell which many insects don't like. It is one of the best ways to repel white flies (*Aleyrodidae*), aphids and flea beetles.
3. Certain plants product insecticides, herbicides or nematicides. This is also the case for marigolds. They contain a substance in their roots which kills the nematodes that attack the roots of many plants. The giant marigold (*Tagetes minuta*) is used against couch grass and other weeds with starch-rich roots.
4. Refuge plants: Several insects which are harmful to vegetable crops are interested in, and drawn to, flowers which they take refuge in. This means that the vegetables and fruits are less infected. On the other hand, other flowers and aromatic plants can repel harmful insects or fortify the growth of vegetables to fight against certain cryptogamic diseases (mushrooms).

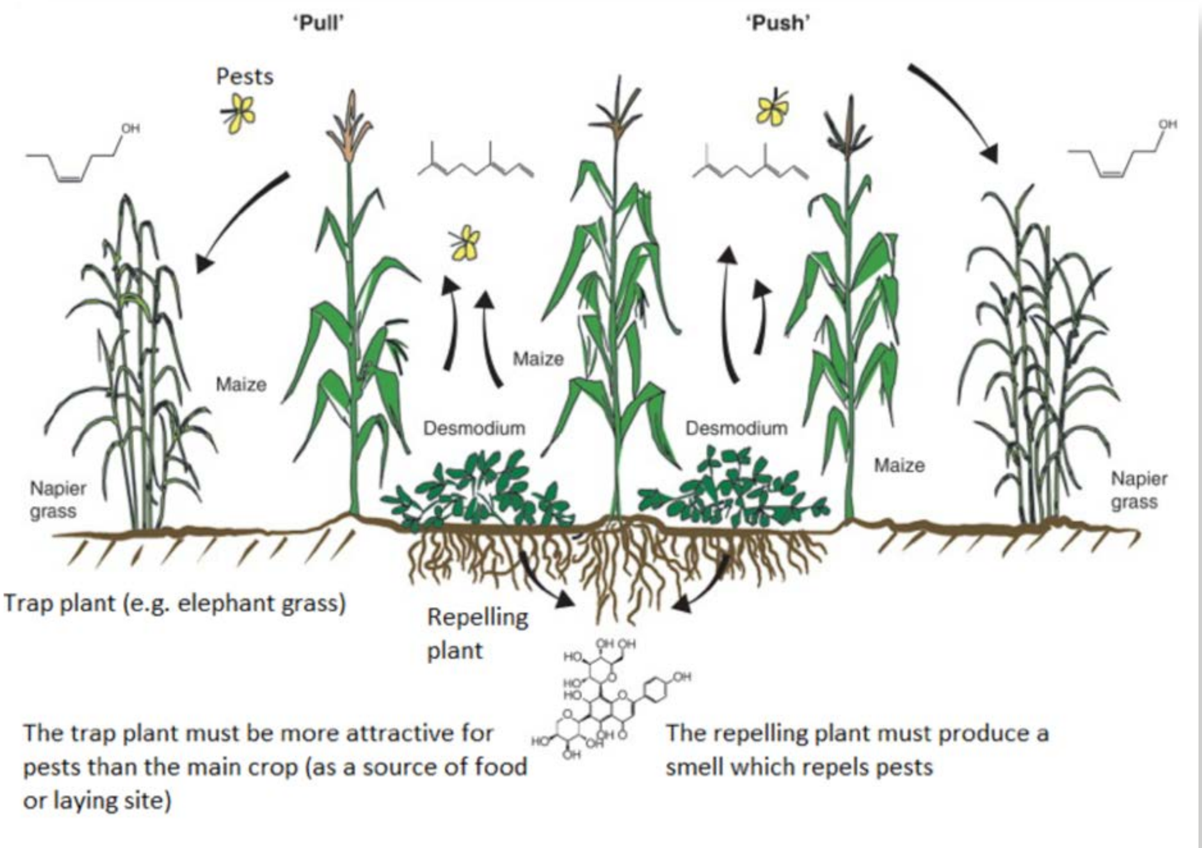


Figure 10: Push-pull technique for maize crops.
Pest and disease management in organic agriculture... TECA - FAO

3.2.2.3. Live stakes for plants

Some growing systems combine a climbing plant which needs a stake with herbaceous legumes which often have no immediate economic value. However, the herbaceous legumes play a major role in maintaining or restoring soil fertility and/ or for the management of certain parasites (weeds, nematodes, etc.).

One of the best-known examples is the use of the *Gliricidia sepium* as a live stake. It has been extensively described (Carsky *et al.*, 1998; Budelman and Defoer, 2000) and popularised in Benin (Doppler *et al.* 2000) and in Côte d'Ivoire (Kouame, 2001; Kouame and Kouao, 2001).

The use of *Gliricidia* to manage weeds reduces them in areas that are heavily infested. Kouame and Kouao (2001) demonstrated that fallow land with *Gliricidia* reduced weeding from four to two tours and reduced the biomass of weeds compared to natural fallow. *Gliricidia* also helps to:

- reduce competition between yams and weeds thanks to staking,
- accelerate the first stages of yam growth and cover the ground more quickly (Budelman, 1989),
- increase shade and the choking effect (thanks to the mulch from successive cuts (Kamara *et al.*, 2000).

Figure 10: Live yams staked using Gliricidia sepium after pruning in Benin Centre.
Source: https://agritrop.cirad.fr/533636/1/document_533636.pdf.

3.2.3. Promoting intraspecific combinations

"All" that is required to promote intraspecific combinations is to grow two or more varieties of the same species on the same plot. The increase in genetic intra-plot crop diversity can stabilise production quantities and quality when faced with biotic and abiotic stresses. However, the deployment of a diversity of genes involved in resistance mechanisms can improve the sustainability of the genes (Finckh, 2008). Many studies have demonstrated the impact on crop disease control of mixing several species or genotypes on the same plot of small-grain cereals (Wolfe, 1985; Finckh and *al.*, 2000; Finckh, 2008).

In addition to the impact of genetic diversity on production and disease resistance, the presence of increased cultivated genetic diversity in a plot may also promote the hosting of associated wild biodiversity thanks to the greater variability of phenotypes present. We present two examples of research on the impact of cultivating genetically diverse wheat crops (varietal combinations) on the following ecosystem services: (i) the regulation of pathogen populations and (ii) the biodiversity of associated communities of wild organisms.

3.2.3.1. Disease regulation

The impact of intraspecific diversity on the development of diseases has been studied extensively thanks to the interest of phytopathologists in varietal combinations and their use to control epidemics of certain pathogenic agents (phytopathogenic fungi and bacteria). In a varietal combination, there is increased resistance when the mixture contains a sufficient number of resistant varieties as a result of three main mechanisms, illustrated in Figures a, b and c (Finckh *et al.*, 2000):

- **Dilution effect:** the density of sensitive plants is lower in the plot which limits the propagation effectiveness of the disease.
- **Barrier effect:** resistant plants act as a barrier and trap spores when they are dispersed, therefore protecting sensitive plants.
- **Protection effect:** contrary to a single-variety plot, which only allows the development of strains which can attack the specific variety, a varietal mixture hosts a larger diversity of strains, some of which only develop in certain components of the mixture. When a strain attacks a plant and the variety has the corresponding resistance genes (non-virulent strain), the plant will implement a number of defence reactions which will protect it from later attacks by virulent strains for which it does not have any specific resistance genes.

These three mechanisms are complemented by two additional effects (Figures d and e):

- **Disruptive selection effect:** in a varietal combination, a polycyclic parasite (which completes several biological cycles over a year) will move from one variety to another and be confronted with a range of resistances in turn limiting the selection of a very aggressive strain.
- **Compensation effect:** a variety under heavy attack by a parasite will not be able to develop correctly (vegetative and root structures) and the space freed up can be colonised by resistant neighbouring plants which will, in turn, maintain the crop yield.

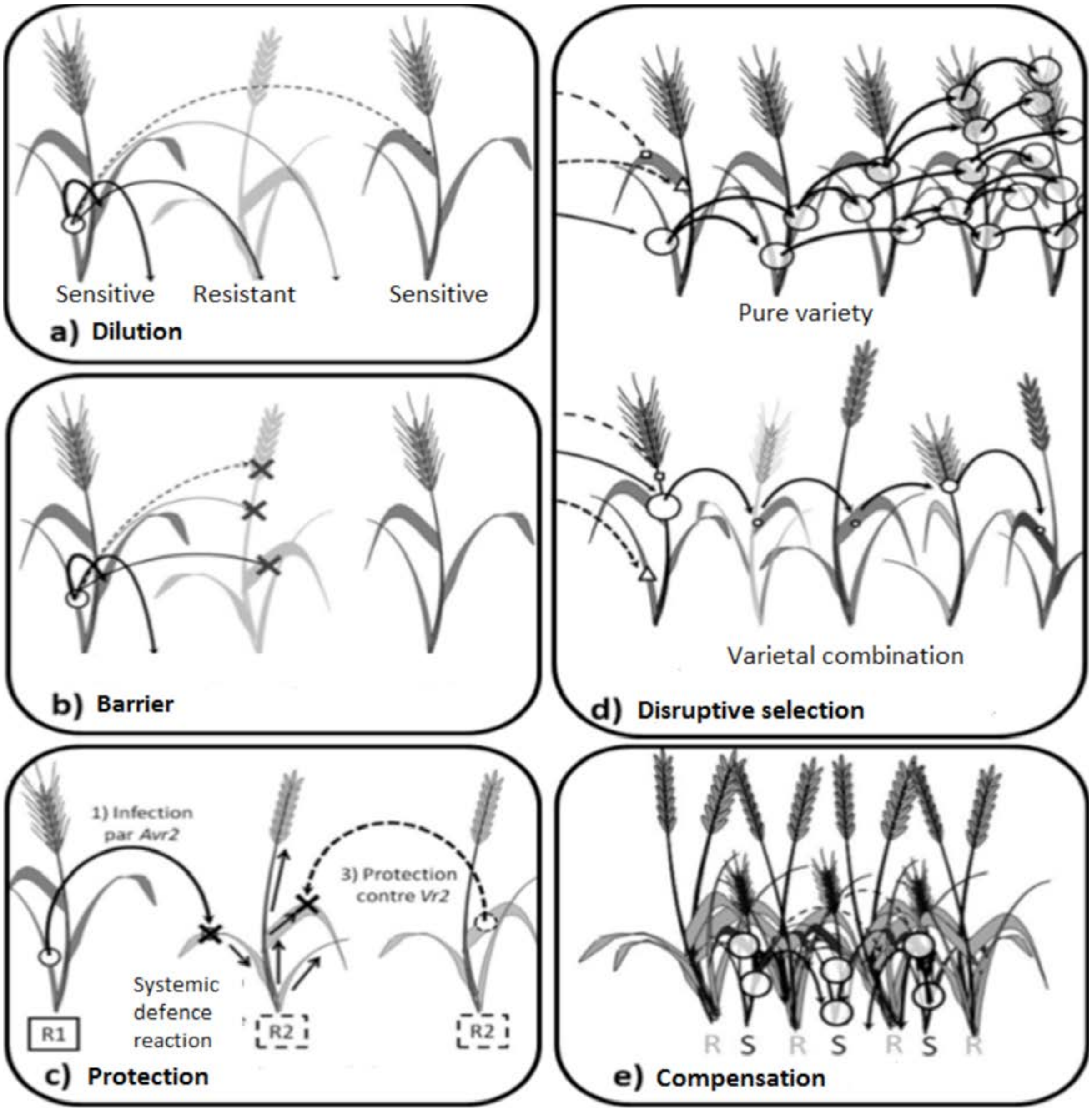


Figure 12: Mechanisms limiting epidemic progress in a varietal mixture.
Source: https://hal.archives-ouvertes.fr/hal-01277635

R = Resistant

S = Sensitive

The arrows, circles and crosses represent the migration, development and death of the pathogenic agent, respectively.

It's important to know that, while varietal combinations can be highly effective in controlling pathogenic agents whose epidemic explosion requires many reproductive cycles during the season (oidium rust, etc.), other diseases (lettuce mildew, etc.) are not significantly impacted by genetic diversity.

3.2.3.2. Biodiversity of associated wild organism communities

It has been demonstrated that the genotype of the individuals of the predominant species in a given ecosystem can influence the composition of the associated community of organisms (Whitham *et al.*, 2006).

An experiment was carried out in France on the relationship between the genetic and phenotypic diversity of a wheat crop and the biodiversity of the wild species associated with the crop at the plot level. Two varieties of wheat were sown on the same plot. The genetic differences were apparent in very significant differences in phenotypic diversity, notably at the level of plant architecture and phenology (Chateil *et al.*, 2013). However, no response to the sown diversity was detected in the wild plants.

Two explanations are possible:

1. either they were not sensitive to the diversity of the cultivated species;
2. or, their response could not be detected at the temporal and spatial scales of the experiment.

On the other hand, several arthropod taxons (collembola, spiders, predator beetles) sensitive to the architecture of the vegetation had a positive response to the genetic (and/or phenotypic) diversity of the wheat with more diverse communities in the mix than in the pure variety.

3.2.4. Promoting intravarietal diversity

Intravarietal diversity is diversity within the same variety. Modern selection has encouraged the creation of animal and plant varieties that tend to a "clonal" model in which all individuals are identical. This homogeneity is inspired by the industrial model. It makes the varieties extremely sensitive to the appearance of new diseases (notably cryptogamic fungi) and to weather events.

Intravarietal diversity is often considered on par with traditional varieties which maintain a genetic foundation which enables them to resist a range of environmental stresses, compared to improved varieties (Joshi *et al.*, 2018). The traditional varieties, called population varieties, are intended to avoid clonal issues and maintain the internal diversity of the variety which ensures that it is more resilient and has greater adaptive capacity, notably with respect to climate change Population varieties are generally produced by farmer seed selection, also called participatory seeds.

Intravarietal diversity is easily observed in cross-fertilised plants. On the other hand, genetic variability within crops which reproduce via vegetative reproduction, like yams, bananas and potatoes, is low. In grapes, whose seeds are obtained by vegetative reproduction, therefore asexually, spontaneous somatic mutations could create new alleles and be the source of new phenotypes (Savino *et al.*, 2017).

3.3. LANDSCAPE BIODIVERSITY

3.3.1. Definition

The word landscape usually designates an area the eye can see all at once. It appears as a single unit for the human brain. Its vegetation is organised in large groupings (tree and shrub density, short or high grass, etc.). For scientists, the landscape is an intermediate description level between habitat and ecosystem. It is an area composed of a mosaic of habitats which have functional relationships with each other: birds of prey living in the hedges (a habitat) hunt rodents which live in neighbouring meadows (another habitat). A landscape is the result of the interactions between natural factors and human development, which create a specific physiognomy.

From a functional standpoint, the heterogeneity of the landscape makes a significant contribution to the regulation and self-maintenance services provided by biodiversity. The homogenisation of landscape leads to the commoditisation of communities via a reduction in rare species and an increase in common species. This dynamic depends on the history of the landscape and, in particular, on the speed of change.

The different elements of the landscape include:

- Production zones: plots, meadows, fallow land, etc.
- Natural/wild zones: forests, waterways, dams, etc.
- Intermediate zones like hedges, grass strips, flower strips, etc.
- Urban zones: roads, habitats, etc.

In the next part of this section, we will only discuss intermediate zones in direct contact with a production zone and controlled by the producer.

3.3.2. Grass strips

Grass strips provide regulation, self-maintenance and supply services to producers:

1. **Water purification**: Growing along the edges of fields and waterways, they limit pollution by fertilisers and pesticides by purifying runoff water, trapping suspended matter (mud) and by facilitating the infiltration and breakdown of herbicides and insecticides (this is 62% effective for a strip six metres wide and 88% effective for a strip 18 meters wide). They also maintain water quality for aquatic fauna (fish, crustaceans, etc.) and for domestic use (drinking, clothes washing, baths, etc.).
2. **Erosion control**: Grass strips are located along contour lines to slow runoff water, increase infiltration and retain sediment. They also help prevent erosion. In addition, and contrary to mechanical structures (separators, small dykes), grass strips expand with sedimentation, ensuring water retention.
3. **A forage and construction material resource**: Local herbaceous plants (e.g. *Andropogon gayanus*, *Cymbopogon schoenateus*, *Vetivera nigritiana*) are sown or seedlings are planted at the start of the rainy season. The species of grass are chosen according to what the farmers want to use them for (straw, hay, mat weaving, roofing, construction of straw granaries, brooms, etc.) (GIZ, 2012). In cattle and sheep raising areas, the use of fodder plants can increase

interest in this technique and ensure wider acceptance. It is recommended that the development of grass strips be combined with assisted natural regeneration (woody species) or the planting of trees.

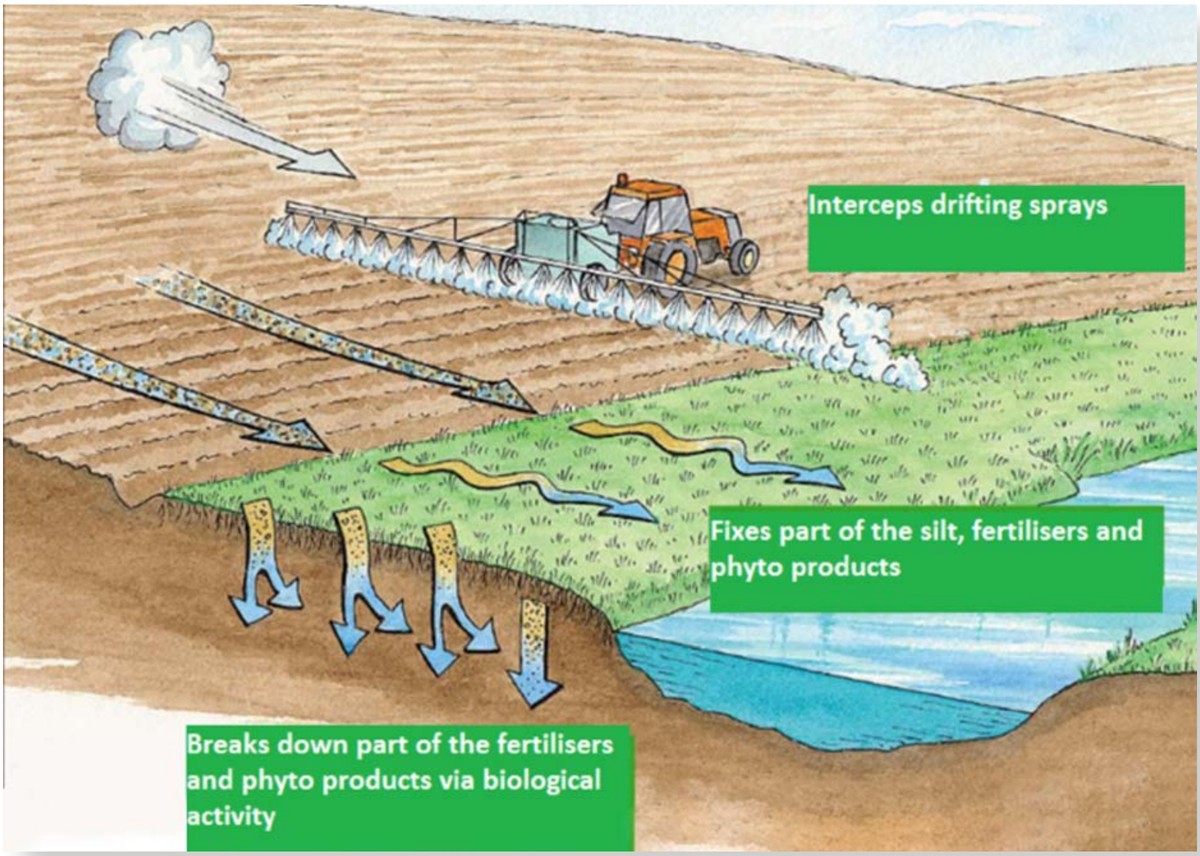


Figure 13: the role of grass strips around crops
Source: Drawing from the brochure "Grass strips and other bocage systems" by Dominique Soltner - www.soltner.fr

Figure 14: Grass strips protect water and potentially play an important role as a biological corridor (Source: http://www.ma.auf.org/erosion/chapitre1/VI.Lutte.html)

Le lien ne fonctionne pas

3.3.3. Hedges and copses

Hedges, copses, tree lines and isolated trees are among the main structuring elements of our landscapes. They play a part in creating a range of different landscapes. However, their benefits and uses go beyond simple viewing pleasure. Areas with trees play many important roles in the proper functioning, planning and development of our regions.

Hedges are plant and animal reservoirs where an equilibrium develops between the different species. As a result, hedge diversification can promote the presence of beneficial birds and insects.

For wild animals, hedges contribute to:

- food: networked food chains (berries, plants, insects, birds, carnivores),
- reproduction: nesting, laying eggs and raising chicks,
- shelter: protection and habitat,
- mobility: population exchanges through the corridors.

Hedges also have many benefits for producers:

Soil	Improved soil fertility: hedges limit erosion and increase crop yields. Looser (at the roots) and wetter soil.
Water	Water conservation: they prevent runoff and promote water infiltration and storage. Hedges maintain water quality through the breakdown of organic residue and phytosanitary products thanks to biological activity.
Insects	Pollination: hedges promote the development of varied flora which enables the development of pollinating insects. Control of bioaggressors: hedges provide shelter and food for crop auxiliaries (ladybirds, syrphid flies, chrysops, carabid beetles, etc.)
Other	Protection against stray domestic animals. Field property security.

In addition to these benefits, hedges provide a supply service:

- Wood production: Heating, stakes, sheets, ramial chipped wood (RCW).
- The production of fruits, flowers and vegetables.

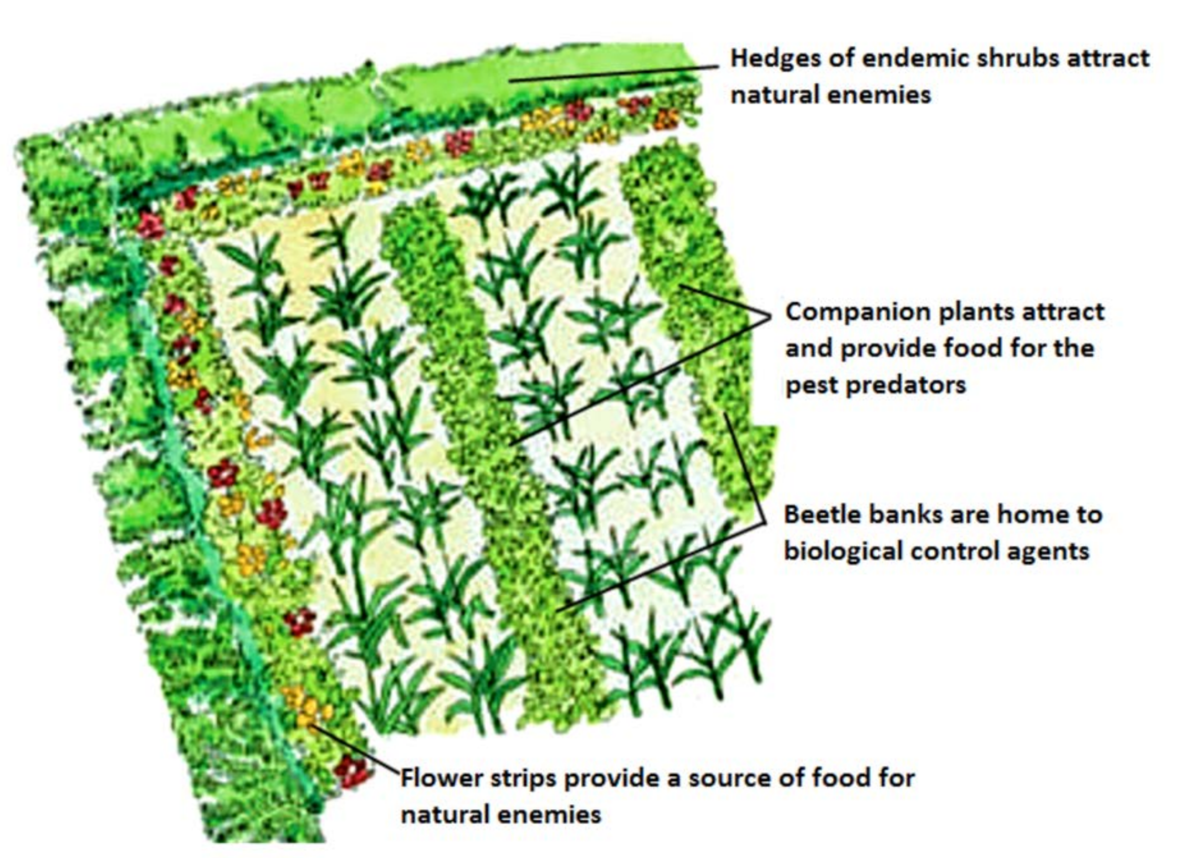


Figure 15: The function of hedges in pest and disease control
(Source TECA-FAO – https//teca.fao.org/fr/read/8575)

3.3.4. Flower strips

Flower strips consists primarily of perennial, herbaceous or woody flowering plants which can be located along wooded areas, hedges, fields and ditches. They are a source of abundant and diversified food for insects which are beneficial to farmers such as pollinators and the natural enemies of pests (predators and parasitoids).

Flower strips promote biodiversity and improve the production environment because:

1. They attract pollinating insects (bees, butterflies, etc.) which ensure plant reproduction and the production of most fruits and vegetables. According to the FAO (2016), about one third of the food we eat depends directly on these insects!
2. Grass strips shelter the enemies of pests which destroy crops. As a result, farmers can reduce their use of phytosanitary products.
3. They also enrich the earth with green fertiliser via the reserves of nutrients in the flowers on the ground.
4. They also prevent erosion.

The creation of flower strips must be well-thought out to attract the beneficial and pollinating insects of the crops nearby.

A flower strip isn't that easy to create if the species used are somewhat demanding and sensitive to competition. Several species can be used including *Achillea millefolium* which attracts true bugs, ladybirds and syrphid flies and *Pastinaca sativa* which attracts ladybirds. A list of recommended species is available on this website: http://arena-auximore.fr/wp-content/uploads/2014/10/Annexes.pdf.

Figure 16: Flower strips at the edge of fields.
Source: http://www.protectiondescultures.info/Agriculteurs/Les-bords-de-champs-preserver-la-biodiversite

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3.4. LINKS BETWEEN BIODIVERSITY AND OTHER ELEMENTS

3.4.1. Links between agricultural biodiversity and water

Water points constitute a special ecosystem at the intersection of aquatic- and land-based worlds. Sometimes natural, but usually created by humans, they are an important biodiversity reservoir. Their shallowness (less than 2 m) ensures that the entire depth of the water receives sunshine and enables plants to take root at the bottom. Their vegetation and soil are special and indicate the presence of water during part of the year at least. Water points are fed by rainwater, runoff or groundwater. They can be permanent or completely evaporate during the dry season. They are then said to be temporary.

Residents depend on the water points as much as on the adjacent landscape elements. Water points must therefore be created within a network of hedges, along roads, in meadows or in grass strips cut late in the season. Ditches and the edges of fields have spontaneous vegetation which enables fauna to move from one water point to another and to find food.

Figure 17: Kilobelobe pond, a reservoir of biodiversity and irrigation water. Groupement des maraichers de Kilobelobe, Lubumbashi, DRC, FAO-Project GCP/DRC/028/BEL, photo Grégoire Mutshail, 2006

Farm ponds have many other functions in addition to their role as biodiversity reservoirs:

- Domestic (water storage, fire control, fish pond for food).
- Agricultural (watering trough, cassava retting, irrigation, etc.).
- Water purification filters thanks to the vegetation which takes its food from the water (nitrates, phosphates, etc.).
- They are real "sponges" and contribute to regulating floods and recharging the water table. The recurrence and extent of runoff and flooding and the recharging of aquifers can be strongly impacted by changes in soil occupation and by modifications which can alter water storage potential at the ecosystem level.
- Water points act as brakes on surface water runoff and contribute to limiting agricultural land erosion.

Ponds also improve the overall living environment by facilitating the integration of buildings in the landscape and by enhancing farms.

3.4.2. Links between agricultural biodiversity and the soil

Soil contains several thousand animal species and several tens to hundreds of thousands of bacterial and fungus species. The quantity of living organisms present in the soil of a permanent meadow can amount to 1.5 tonnes per hectare of soil fauna, 2.5 tonnes per hectare of bacteria and 3.5 tonnes per hectare of fungi.

The soil and micro-organisms provide many services to farmers. They:

- maintain the soil structure,
- regulate soil hydrology processes,
- exchange gases and sequester carbon,
- purify the soil,
- cycle nutritional elements,
- decompose organic matter,
- control pests, parasites and diseases,
- are a source of food and medicine,
- maintain symbiotic and non-symbiotic relationships with plants and their roots,
- control the growth of plants (strengthening and elimination).

Any decrease in soil biodiversity will lead to a reduction in these services.

In addition to the well-known case of legumes which fix nitrogen, it has been demonstrated in many cereal crops, that the fungi *Fusarium oxysporum* (identified in Burkina Faso, Mali and Niger), transmitted through the soil, is very effective against witch grass, or striga (*Striga hermonthica* and *S. asiatica*). Other species of Fusarium (*F. nygamai*, *F. oxysporum* and *F. solani*), found in Sudan and Ghana are also very effective. The fungus can potentially be used by all farmers in the future to reduce the need for chemical herbicides.

How to promote soil organisms beneficial for agriculture? Several factors linked to agricultural techniques can influence the biodiversity of the soil[73]. They include:

- Ploughing: it has been demonstrated that ploughing disturbs soil fauna and leads to a reduction in biodiversity over the long term. Reducing this practice, or stopping it altogether to grow without ploughing, can be beneficial for the soil.
- Bare fallow: leaving soil bare is extremely harmful to its biodiversity. It is highly recommended that the ground be covered during fallow periods to reduce the risk of erosion and to promote soil fauna.
- The use of heavy machinery: this compacts the soil and destroys its porosity, which is harmful for its biodiversity.
- The use of phytosanitary products: pesticides kill crop pests and diseases as well organisms beneficial to the soil.
- Crop diversity: it has been proven that the weakest plant crops are the least favourable for soil life.

Some farming methods are already reducing these practices. They are detailed at the end of the chapter.

73 More information is available in the Coleacp "Sustainable soil management" manual.

3.4.3. Links between agricultural biodiversity and climate change

The dynamics of agricultural biodiversity and the climate are linked by the carbon, water and earth cycles. They have an interdependent relationship based on a fragile equilibrium nourished at both the local and the global levels. The climate is the source of current biological diversity and this biodiversity contributes to regulating the climate (fixing of CO_2, one of the main greenhouse gases, water retention, windbreaks, etc.).

The diversity of current ecosystems is due, to a large extent, to the climate and to the changes the Earth has experienced over its lifetime, including previous biodiversity collapses, which have enabled animal and plant species to weave links and evolve together to adapt to the environments in which they live. (MEA, 2005). The Economics of Ecosystems and Biodiversity, http://www.teebweb.org/.

According to the **2015 Climate Change Vulnerability Index**, seven of the ten countries most threatened by climate change are in Africa.

To counter the harmful effects and impacts of climate change, the promotion of biodiversity at the agricultural level will play an indispensable role, offering practical alternative mitigation activities to boost biodiversity in the fields and on the farm.

Therefore, to reduce the negative impact of climate change and improve their resilience, farmers must develop adaptation strategies which include changing the species they cultivate and mitigation options (e.g. planting a hedge to fix CO_2)[74].

Potential adaptation strategies include in situ and ex situ conservation of crop and livestock genetic resources which are essential for maintaining choice for future agricultural needs. The availability and accessibility of high-quality seeds are essential for strengthening the resilience of food production systems against unexpected threats and other shocks.

In situ conservation of biological agricultural diversity consists in ensuring the management of a wide range of crops by farmers located in the ecosystem in which the crops evolved. It ensures continuation of the evolution and adaptation of crops to their environment. Genetic diversity is also maintained in situ in home gardens and family plots, as illustrated in the figure below.

74 For more information, see the Coleacp "Agriculture, health and the environment" training manual.

Figure 18: Home garden with a variety of plants (Gbedomon *et al.*, 2015)

Ex situ conservation consists in preserving species outside of their natural habitat, for example, in seed banks and greenhouses.

3.4.4. Links between agricultural biodiversity and soil fertility indicators

Several plant species are recognised both by researchers and by farmers as indicators of impoverished or fertile soil. For example, the invasion of fields by cogongrass (*Imperata cylindrica*) in tropical areas is an indication of declining soil fertility.

During participative research in Cameroon, M'Biandoun *et al.* (2006) identified several indicator species for fertile and damaged soils. They are summarized in the following table.

Table: Indicator species by type of soil (M'Biandoun *et al.*, (2006))

Soils	Fertile soil indicator species	Damaged soil indicator species
Mafa Kilda	*Tribulus terrestris Linnaeus* *Amaranthus graecizans Linnaeus* *Indigofera hirsuta Linnaeus* *Portulaca oleracea Linnaeus*	*Triumfetta pentandra A. Rich* *Celosia argentea Linnaeus* *Digitaria argillacea (Hitchcock et Chase) Fernald* *Kyllinga tenuifolia Steudel*
Fignolé	*Alysicarpus ovalifolius (Schum. & Thonn.) Leon* *Brachiaria lata (Schum.) C.E. hubb.* *Amaranthus spinosus Linnaeus* *Waltheria indica Linnaeus*	*Panicum pansum Rendle* *Eragrostis turgida (Schum.) de Wild.* *Commelina subulata Roth* *Portulaca oleracea Linnaeus*
Gadas	*Celosia argentea Linnaeus* *Eleusine indica (L.) Gaertn* *Chrysanthellum americanus (L.) Vatke* *Tephrosia bracteolata Guill. & Perr*	*Hibiscus asper Hook. f* *Cassia mimosoides Linnaeus* *Indigofera hirsuta Linnaeus* *Chloris pilosa Schum*
Mowo	*Indigofera dendroïdes Jacq.* *Cyperus amabilis Vahl* *Ageratum conyzoïdes L. Subsp. conyzoides* *Cucumis melo L. Var. argrestis Naud.*	*Crotalaria retusa Linnaeus* *Cassia mimosoides Linnaeus* *Physalis micrantha Link* *Phyllanthus amarus Schum. & Thonn*

3.4.5. Links between biodiversity and agritourism

3.4.5.1. Definition

Agritourism, or agrotourism, sometimes also referred to as agricultural tourism or farm tourism, is a type of tourism based on the discovery of the farming know-how of a region and, by extension, of its landscapes, social customs and culinary specialities related to agriculture. This activity provides more or less significant economic development for the regions and farmers involved.

3.4.5.2. Appeal of agricultural landscapes for tourism

The diversity of species and varieties of cultivated plants and livestock races on all continents developed thanks to farmers who have adapted plants and animals to constantly updated selection objectives, different sites and changing climate conditions, a range of different crops and their individual preferences. They have been able to find a variety or race able to acclimatise to every plot of land. The extremely varied farming methods have led to diversified rural landscapes. Nowadays, however, farm landscapes are increasingly losing their diversity as a result of agricultural practices like monoculture. To halt this genetic erosion and promote the farming of ancient varieties and races, it is necessary to find incentives that will encourage farmers to practice in situ conservation. Agritourism, which is highly correlated with the quality of landscapes and the wealth of biodiversity, may provide a solution.

3.4.5.3. Prerequisite conditions for the development of agritourism

A number of conditions must be met to ensure that agritourism can develop. They include:

- A natural, mostly preserved landscape or small, highly structured farm landscapes. Major monocultures have little appeal.
- In addition to the beauty of the landscape itself, it must also have cultural, historical or natural appeal.
- A good communications network. Even very attractive regions will only draw tourists if they are connected to easily accessible centres.
- Infrastructure must be in place, e.g. transport, lodging and food.
- A stable political situation, without which even the most appealing sites will not draw any tourists.
- Acceptance by the local population, without which tourism cannot be successful.

Box 4: Example: the Songhai Centre, the heart of Benin's agritourism

Located at the heart of Porto-Novo, Benin's political capital, the Songhai Centre promotes greenery. Songhai is the name of an organic farm created in Porto-Novo by Godfrey Nzamujo, an American Dominican priest originally from Nigeria. The Songhai farms provide a model for autonomous and profitable development based on the intelligent use of resources. The Songhai Centre puts visitors at the heart of a biosphere in which nothing is thrown away and everything is transformed. It is totally autonomous, with hundreds of employees who raise chickens and fish, sell eggs, grow pineapple, produce natural fertilisers and make industrial tools. Chicken manure is transformed into biogas which runs the centre's kitchens. Plant matter and organic waste is recycled as compost and worm compost which are renewable resources for the sustainable management of soil fertility, essential for the preservation of biodiversity.

The spare parts of agricultural machinery are reused to make ingenious machines. Waste water is filtered with hyacinths. Songhai has been recognised as a "**Centre of Excellence for Agriculture**" by the United Nations. Make an appointment with nature and visit the Songhai Centre.

Songhai Centre: plastics recycling

Songhai Centre: worm farming

Songhai Centre: The promotion of biodiversity in agricultural practices and for the recycling of waste water
More information: http://www.songhai.org
Source: https://www.youtube.com/watch?v=TJMbj_qPlm8&feature=youtu.be

3.4.6. Links between biodiversity and the population's livelihood

Biodiversity provides support for the population's livelihood. Agricultural biodiversity in crops provides diversified agricultural products and contributes to the diversification of producer income sources. For example, the varieties most resistant to drought are grown to deal with irregular and insufficient rainfall. Varietal diversity also helps to control weeds. Field crops and broad-leaf varieties are better able to compete with weeds than small plants with narrow leaves. Some varieties inhibit and eliminate weeds whereas others tolerate them. For example, striga (*Striga sp.*) is a weed which causes many problems in Africa. When striga is present, it is recommended that maize or cowpea varieties, which are resistant and can compete with striga, be planted, otherwise there will be little or no yield.

Forests, which are rich in biodiversity, are essential for human survival and sustainable development. For example, wood is the primary energy source for heating and cooking for about 2.6 billion people. The World Bank has estimated that forests contribute directly to the survival of nearly 90% of the 1.2 billion people living in extreme poverty. The assessment of ecosystems for the millennium revealed that nearly 300 million people, mostly very poor, depend primarily on forest ecosystem services for their livelihood and survival. Many non-ligneous forest products produced by forest biodiversity such as wild cocoa, honey, resins, nuts, fruits, flowers, grains, rattan, mushrooms, meat and wild berries are essential for food, medicine and construction materials used by local and native communities to maintain their lifestyle, including their culture and religious or spiritual traditions.

3.4.7. Links between biodiversity and health

Biodiversity is essential for daily life. This fact is not always obvious or appreciated at its true worth. Health depends on ecosystem products and services (for example, the availability of drinking water sources, of food and of fuel) essential for good health and leading a productive life. Loss of biodiversity can have non-negligible direct consequences on health if ecosystem services no longer meet the needs of society.

Many communities use natural products from the ecosystem for medical and cultural purposes, as well as for food. Although there are many synthetic medicines for a range of purposes, natural products are still used as medicines and for biomedical research on plants, animals and micro-organisms in order to better understand human physiology and better assess and treat diseases. The World Health Organisation (WHO) estimates that approximately 80% of the population living in Africa uses traditional medicine for their healthcare needs.

3.4.8. Links between farming methods and biodiversity

Intensive agricultural techniques like deep and frequent ploughing, the intensive use of fertilisers and pesticides, fire, etc. reduce biodiversity and disrupt the natural equilibrium of ecosystems.

This is why we have seen the emergence of alternative production systems over the past years which are respectful of the environment. They enable the maintenance and/or restoration of soil fertility which preserves and promotes biodiversity while improving yields. Alternative production systems are used in agroforestry, conservation agriculture, permaculture, agroecology and climate-smart agriculture[75].

3.4.8.1. Agroforestry

Agroforestry is a resource management system which is dynamic, ecological, and natural. It integrates trees in the landscape, enabling diversified and sustainable production and providing farmers with increased social, economic and environmental benefits (Leakey, 1996). It is not a new or revolutionary agricultural method. In fact, it is one of the oldest farming methods. However, it was forgotten for a time because of the intensification of modern agriculture (Nair, 2007). Agroforestry has been practised for centuries in Africa, Latin America, China, India and Europe (Zou and Sanford, 1990; Nair, 1993).

Agroforestry trees which mark off cultivated plots and intraplot agroforestry trees spread food resources, habitats and travel zones throughout the farmed area. They provide diverse ecological niches when combined with a strip with several grass species (Poaceae (Gramineae), Fabaceae (legumes), Asteraceae, etc.). During the first years after planting, when trees are still young, the grass strip provides shelter and cover for wild fauna and auxiliaries and provides a travel corridor.

By creating a "border effect", hedges offer a wide range of living conditions which fauna use based on their needs: shade, light, cool, heat. They can be a temporary or permanent preferred space for field, forest and meadow animals. They provide more flowers and fruit than the forest.

Many species use the linear zones (hedges, grass strips, field borders, etc.) as a communication route. Fauna and flora are both protected and channelled. They can deploy throughout the networked area and take advantage of the many interlinked environments: woods, ponds, waterways, crops, etc. In addition to the biodiversity they contain, these linear zones also promote the equilibrium of animal and plant populations throughout the region and ensure the genetic mixing essential for the survival of species.

3.4.8.2. Conservation agriculture

The FAO (Food and Agriculture Organisation of the United Nations) defines conservation (of soils) agriculture as a farming system based on a significant reduction in, or the elimination of, tillage, permanent soil cover and diversification of plant species.

It is estimated that 100 million hectares of land are farmed using the conservation agriculture method. In Africa, the total number of conservation agriculture zones is still very small compared to the area cultivated using conventional farming methods and it accounts for less than 4% of the total area farmed.

75 All production systems presented in detail in the Coleacp Manual "Sustainable systems of production"

In West Africa, this type of agriculture may be a method to achieve the ecological intensification of production systems, subject to research producing more references about its effects at the farm level. Conservation agriculture is a crop production practice which uses resources effectively based on principles which improve biological processes on and under the soil. Its guidelines imply minimum or zero mechanical disturbance of the soil, permanent soil cover, either with a growing crop or crop waste mulch, and the diversification of plant species. In addition, farmers use traditional crop varieties without herbicides or varieties which are resistant to herbicides. Crop rotation is also used to manage harmful insects.

3.4.8.3. Organic farming

IFOAM, the International Federation of Organic Agriculture Movements defines organic agriculture as follows: "Organic agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic Agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved."

Organic farmers are both the guardians and users of biodiversity at all levels:

- at the genetic level: seeds and endemic races adapted to local conditions are preferred due to their greater resistance to diseases and their resilience in disruptive climate conditions;
- at the species level: various combinations of plants and animals optimise the cycle of nutritional elements and energy for the benefit of agricultural production.
- at the ecosystem level: the maintenance of natural zones within and around organic crop fields and the absence of chemical inputs create habitats which are favourable to wildlife. The use of organic methods to fight parasites preserves species diversity and prevents the appearance of pests resistant to chemical phytosanitary products.

3.4.8.4. Permaculture

Permaculture combines ethics, philosophy, science and a way of designing/laying out/planning and organising systems (and ecosystems). Its primary concerns are effectiveness, sustainability/regeneration and resilience. The term permaculture was coined in the 1970s by the Australians Bill Mollison and David Holmgren. It is a contraction of the words "permanent" and "culture". It is a vision and a framework for the relevant use of land, of the planet and of social groups to enable the construction of an infinity of realistic and creative solutions suited to each specific situation, always for the purpose of providing abundant societies to all which are sustainable/ regenerative, ecological and happy. Its goal is to create human societies which are respectful of nature and people via well-thought-out and effective design.

The benefits of permaculture include:

- soil fertilisation using green fertilisers (clover, etc.) and production are simultaneous,
- the maintenance or restoration of diversity enables better disease and pest control,
- crops and soil are in symbiosis and the soil is always covered to respect the life of the soil,
- the soil is less compacted and the earth is looser and lighter,
- the soil is less subject to weather erosion,
- gardeners and farmers have less work to do because they intervene as little as possible.

3.4.8.5. Climate-smart agriculture

Climate-smart agriculture is an approach designed to develop the technical, political and investment conditions necessary to achieve sustainable agriculture which meets the needs of food security within the context of a changing climate. CSA must be thought of as an ongoing and iterative process to combine food security, agricultural development and climate change.

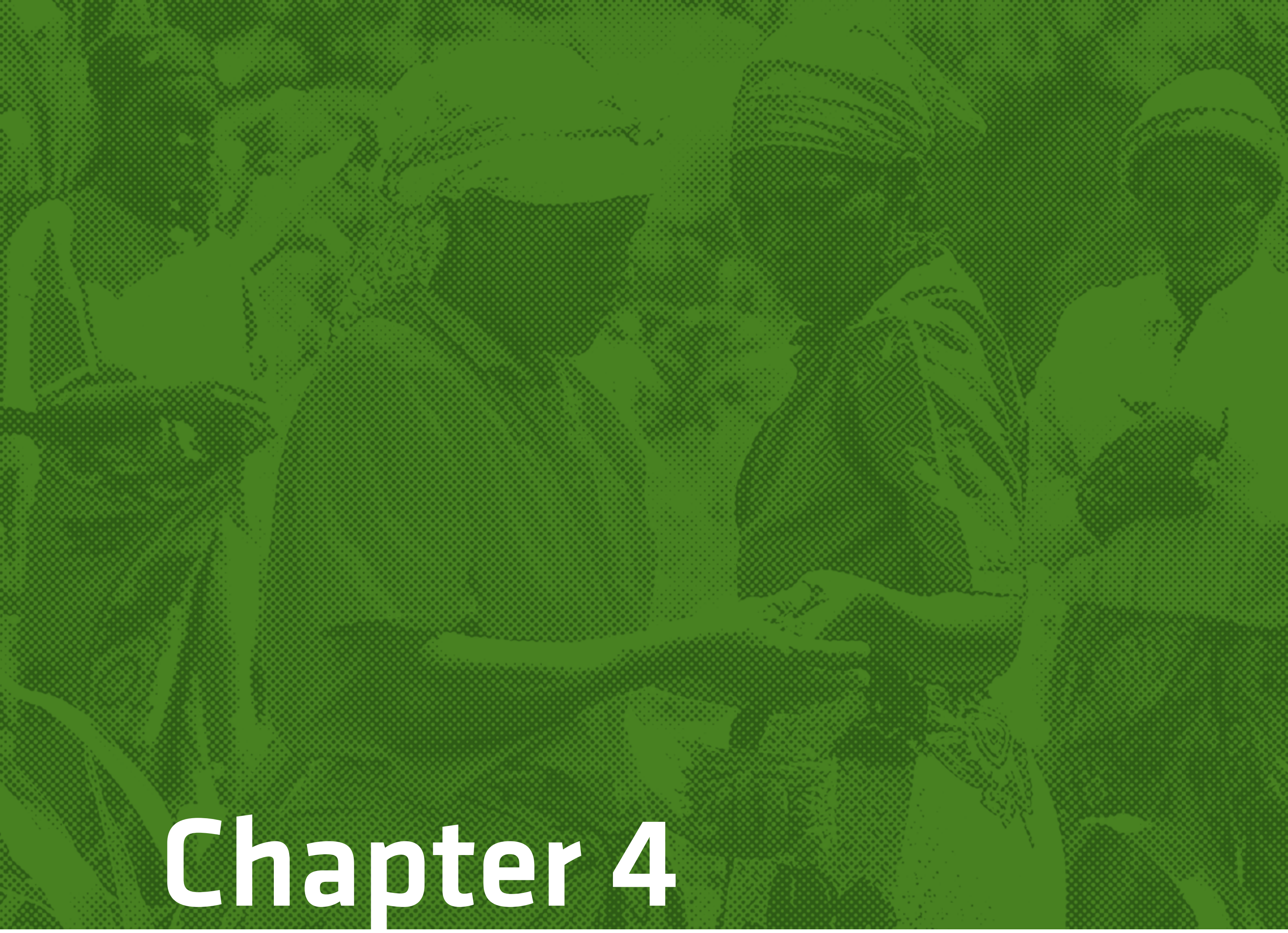
The Food and Agriculture Organization of the United Nations (FAO) defines climate-smart agriculture based on three major principles:

- Sustainably increase agricultural productivity and the income of farmers to reach national food security and development goals.
- Increase the resilience and adaptation of agriculture and food systems to climate change.
- Decrease greenhouse gas emissions and increase carbon absorption.

The combination of these three principles differentiates climate-smart agriculture from other approaches.

Its approach to agriculture is to identify endogenous options or practices which integrate food security, development and the climate change specific to each country.

It gives priority to better livelihoods by improving access to services, to knowledge, to resources (including genetic resources), to financial products and to markets; to seeking to identify opportunities for access to financing for the climate and includes traditional sources of funding for agricultural investment. It seeks to create favourable conditions through better harmonisation of policies, financial investments and institutional systems. It involves adaptation and strengthens resilience to shocks, in particular those related to climate change.



Chapter 4

Preservation and restoration of biodiversity

4.1. LAYOUTS AND CULTIVATION PRACTICES WHICH PROMOTE BIODIVERSITY

Agriculture leads to the destruction of natural habitats, but is also the source of a plethora of farmed animal and plant species. If the layouts and cultivation practices take into account the importance of preserving and restoring biodiversity, the agricultural landscapes created over many decades could yet offer many more secondary habitats which are rich in plant and animal species - both domesticated and wild. There are many layouts and cultivation practices, and they depend on the climatic zone, topography, soil type, technical abilities and available finances, etc.

All layouts and cultivation practices on a plot or in a landscape must contribute to the sustainable management of land and water resources, and seek synergy between plants, animals, insects and micro-organisms. The goal should be to adopt agroecological practices.

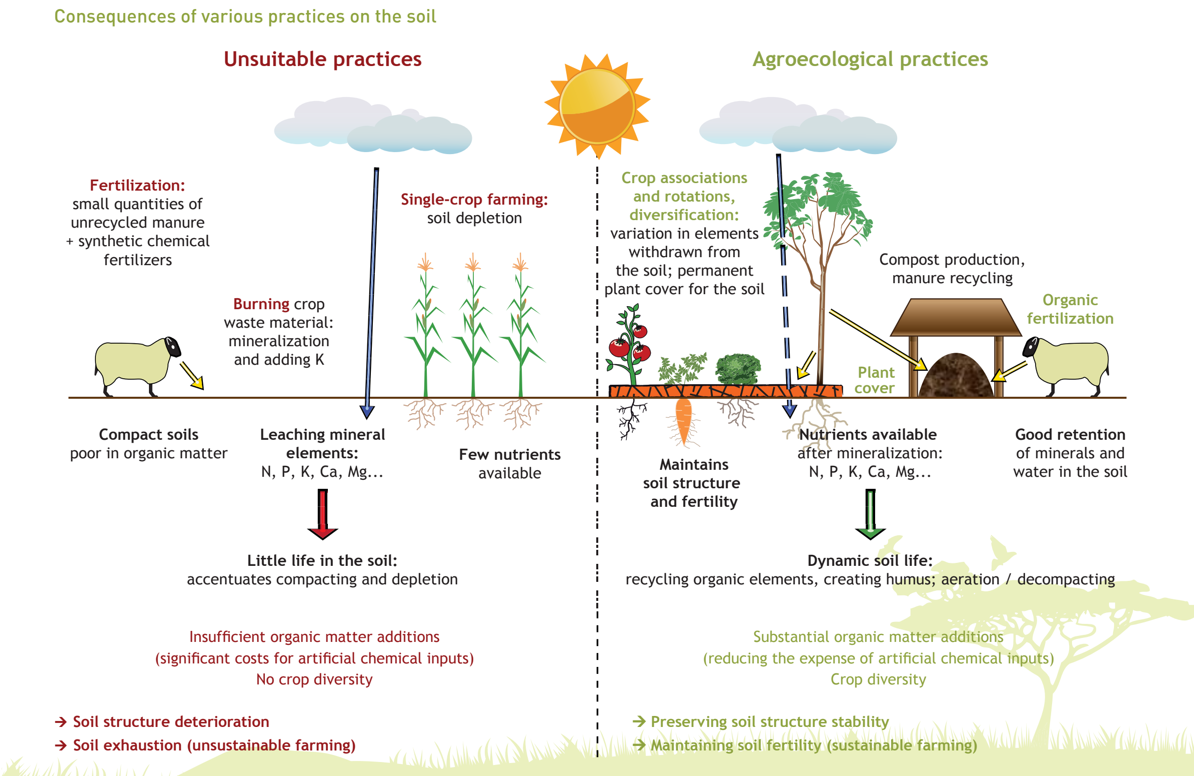


Figure 1: Effects of different agricultural practices on the landscape
(Source: AGRISUD INTERNATIONAL, 2010; http://www.agrisud.org/wp-content/uploads/2013/05/Guide_Anglais.pdf)

The layouts and cultivation practices must:

- aim to preserve or restore the land and water resources of the plot and landscape,
- produce enough aboveground and underground biomass in a large eco-volume made up of varied cultivated plant species,
- ensure a large volume of high-quality organic matter is efficiently managed and produced, by combining agriculture with diversified livestock farming,
- seek synergies between crops, trees, animals, insects, organisms and micro-organisms, etc.

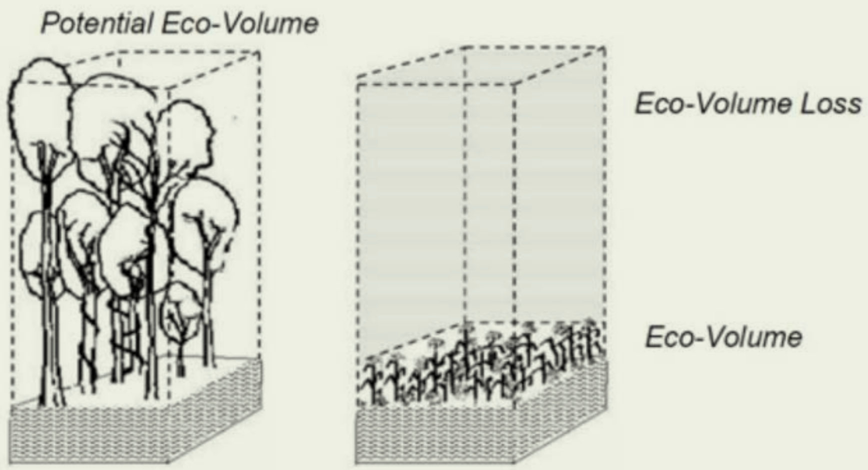


Figure 2: Potential eco-volume and loss in eco-volume
Source: JANSSENS, 2004 in TORRICO, 2006a cited by Baumert 2008)

The **advantages and disadvantages** of some practices, with **implementation examples** and **references, categorised by theme**, are presented below:

- ***Domesticated biodiversity on the farm***:
  - Livestock farming combined a production system.
  - Spatial crop layout techniques:
    - Crop allocations.
    - Combinations (intra-plot mixing).
  - Temporal crop layout techniques:
    - Rotations.
    - Catch crops.
  - Reserving a portion as large as possible of the farm for local patrimonial species and varieties.
- ***Wild biodiversity on the farm***:
  - Layouts and practices which promote the two types of wild biodiversity:
    - In terms of AEI/AEU.
    - In terms of Plant Protection Product use.
    - In terms of fertiliser use.
    - Particularly in terms of perennial crops.
  - Layouts and practices which more specifically promote wild para-agricultural biodiversity:
    - Flower strips.
    - Spatial-temporal diversity of cultivated species.
    - Grass cover of perennial crops.
    - Choice of Plant Protection Products.
  - Layouts and practices which more specifically promote the wild para-agricultural biodiversity of the soil:
    - Light soil work.
    - Permanent plant cover.
    - Rotations and combinations of crops with different root systems.
    - Organic conditioner.

4.2. HOW TO ENSURE OR IMPROVE DOMESTICATED BIODIVERSITY ON FARMS

Domesticated biodiversity is the collection and richness of plant and animal species and subspecies (races, varieties) domesticated and selected by humans over time. "*It is now agreed that a collapse of domesticated biodiversity has occurred over the course of the 20th century due to the disappearance of many varieties and races*" (Calame, M.).

The traditional production systems represented in many ACP countries by family-based production systems are confronted with a growing increase in intensive and commercial production systems which are responsible for the decline of biodiversity. However, these traditional systems developed and maintained a diversity of plants and animals over years through meticulous selection involving a large number of farmers and herders in different regions. Agricultural development models and initiatives which aim to maintain this poorly-appreciated richness are found in more and more ACP countries. The Songhai Centre[76] and "La Maison du paysan"[77] in Benin are good examples of models of domesticated biodiversity preservation. In addition, Paech, N. (2017)[78] confirms that this type of agroecological production system guarantees environmentally-friendly, sustainable agriculture.

The crop plants and agroforestry or reforestation trees selected must be able to leverage, conserve, reproduce and add value to existing varietal and genetic resources. Organising a network of seed or plant material producers is vital.

On a fruit and vegetable farm, domesticated biodiversity can be ensured through various practices. However, it must of course be ensured that the various products expected can be sold on the market and that the existing agroecological conditions allow for this diversification. On the other hand, it must be remembered that crop diversification generally entails more complex operation management, greater human resources and wider expertise.

4.2.1. Combining livestock farming with a production system

Global domesticated biodiversity on a farm can be improved by combining it with livestock farming, which can serve as a support service for plant production.

In addition, the integration of crops with livestock can increase the production of biomass, and the nutrients which come from it can recycled in an optimal manner (Altieri and Nichols, 2014, p. 44).

In fact, livestock farming is a balancing element in agricultural systems, through interchanges between the crops and animals (feed, restoring organic matter). It is therefore necessary to create and maintain the synergies between livestock and plant production activities.[79]

76 http://www.songhai.org/index.php/fr/

77 http://maisondupaysan.org/

78 Paech, N. (2017). Postwachstumsökonomie. Wohlstand ohne Wachstum in einer endlichen Welt. Videokonferenz an der Universität Bonn, 5.10.2017.

79 www.agrisud.org/wp-content/uploads/2013/05/Guide_Francais.pdf

Combining agriculture and livestock farming will add value to the interactions between them. It will also increase the farm's productivity. Broadly speaking, this happens by:

- adding value to crop residues by using them to feed cattle,
- adding value to animal faeces by using it to fertilise the soil and feed plants.

This agropastoral system can recycle nutrients in the soil and thereby sustainably manage its fertility. There are many combination methods. They depend greatly on the socio-economic conditions of the environment.

Livestock farming can be combined with agriculture or agroforestry, or the three can be combined. See technical sheet no. 11 - http://www.gret.org/wp-content/uploads/guide-pratique-agroecologie_pdf.pdf.

Advantages and disadvantages

Advantages	Disadvantages
• Manure production • Improves the total productivity of work and the land • Adds value to animal manure by using it to improve soil fertility • Adds value to crop residues by using them as fodder • Simultaneous intensification of agricultural production and livestock production • Uses plough farming • Strengthens the resilience of farms against climate change • Revenue is diversified • Household food security is strengthened • Strengthens erosion control by planting cover plants and trees for pastures or fodder production • Reduces the use of phytosanitary products and pesticides (low use)	• Requires more labour • Requires agricultural management expertise • Food is required for animals • Veterinary care is required for animals • Can result in competition for land between agriculture and livestock farming, sometimes difficult to remove • Requires more manpower • Poses a sanitary risk (zoonoses, roundworm, dysentery, etc.) • Requires a good recycling plan for waste, organic waste, etc. • Safety/security • Is difficult to adopt in regions where livestock farming is not/rarely practised

Examples and references

- Raising chickens produces droppings which are an excellent fertiliser, rich in nitrogen, phosphorus, potassium and calcium. An eco-friendly, low-cost and high-quality fertiliser can be quickly obtained thanks to a few chickens. The nitrogen found in chicken droppings is rapidly available to plants.[80]
- The following techniques use animal waste products as fertilisers after being transformed and help fight pests and diseases: sachi (bringing the animals onto the plot to be cultivated for an extended period of time, e.g. three months,

80 https://www.aujardin.info/fiches/fiente-poule-engrais-naturel-qualite.php

in order to fertilise it), bokashi (organic fertiliser based on animal manure, to which straw, ashes, molasses and liquid micro-organisms are added), biol liquid bio-fertiliser composed of various plants and manure) and slurry.[81]

- Horticulture and livestock farming integration at Jacaranda youth city and farm in Lubumbashi in Democratic Republic of Congo and at some urban horticulture farms. Fruit and vegetable crops are planted in proximity to poultry (chickens and ducks), pig, rabbit and goat farms. An area is also set aside for pisciculture. This ensures that activities are integrated: feeding cattle, recycling different kinds of farm and garden waste into manure and compost. This agropastoral production system can promote the use of composted manures as base fertilisers in fruit and vegetable production. Chicken and duck droppings are a good fertiliser choice for fruit and vegetable farmers, especially for crops such as tomatoes, amaranth and cabbage, thanks in particular to the nitrogenous elements they provide. Goat droppings are also used: after being soaked in water for two days, they are sprayed on vegetables as a liquid nitrogen fertiliser and provide other fertilising elements as well. Fruit and vegetable residues are used directly as food for ducks and rabbits and as supplements for chickens and *Tilapia nilotica* in pisciculture.
- Maintenance of spontaneous flora and/or flora spread in orchards by poultry in Martinique. Sheet no. 6 in: Tropical guide - Practical guide for designing tropical cultivation systems that are low in phytosanitary product use, http://agritrop.cirad.fr/578300/1/Guide+tropical+TBD+new.pdf.

4.2.2. Spatial crop layout techniques

Cultivated species and plant varieties can be diversified via different spatial crop layout techniques, such as a good crop allocation at the farm level and crop combinations at the plot scale.

4.2.2.1. Well thought-out crop allocation

Crop allocation consists of the geographic organisation of cultivated plots on an entire farm over the course of a given agricultural season.

This geographic distribution can have an influence on the spread of crop pests, in particular on those which can spread from one plot to another but do not necessarily have the ability to spread further, even if the plots aren't very far from each other.

This method can easily be used along with the choice of varieties and of the size and shape of plots. Its implementation is favoured by crop diversification on the farm, such as crop rotation.

81 http://ong-adg.be/index.php?lg=frb&rub=qui-sommes-nous&pg=publications&pub=l-agroecologie-reconnecter-l-homme-a-son-ecosysteme

It can also be taken into account at a larger scale if multiple farmers agree on the arrangement of crops. The limitations of the method are due to the possibility of needing complex rotations to spread the crops. For perennial crops, the solutions are more limited, but can also be partially implemented by juxtaposing varieties with different sensitivities.[82]

It's important to reduce the size of plots in order to maintain the biodiversity of agricultural areas. Researchers hypothesise that in a landscape with small plots, species can access the habitats located on the borders more easily. The biodiversity of the fields depends more on the AEI/AEU located on the edges of the fields than on the larger AEI/AEU such as forests and copses.[83]

The crop allocation of a farm is the result of various constraints, both technical and economic, and is intended to optimise the overall result. The economic criteria to be taken into account are the market, sale price, investments to be made, potential quota limits for regulated crops and subsidy limits. Broadly speaking, the technical factors include the rules of crop rotation, labour organisation, equipment availability and ecological factors (soil, climate, etc.). In addition, the farmer must take account of human resources in terms of quantity, qualifications and know-how.[84]

Advantages	Disadvantages
• Fights against certain plant diseases and soil parasites • Rational use of soil elements • Crop allocation is the arrangement of the area for crop rotation • Minimises/prevents the land erosion caused by monocultures • Adds to the value of the soil at different depths	• It can be difficult to meet sowing dates or weeding periods if manpower is a limiting factor of production • It can be difficult to apply specific fertilisers and phytosanitary products to each small plot • Management of plot irrigation is more difficult with small varied plots

4.2.2.2. Diversifying via intra-plot mixing

Intra-plot mixing consists of combining several species and/or varieties on a single plot. This consists of alternating rows of plants or of more complex combinations.

When multiple species are cultivated simultaneously on the same plot, they take part in competitive or complementary relationships for access to environmental factors. Three factors must be taken into account when determining combinations:

- the root system (e.g.: cabbage + lettuce);
- access to water and mineral elements (e.g.: fruit vegetables + leaf vegetables);
- light needs (e.g.: coriander, parsley, celery protected by beans or chilli peppers; ginger beneath papaya trees).

Le lien ne fonctionne pas

82 http://ecophytopic.fr/tr/pr%C3%A9vention-prophylaxie/gestion-des-cultures/assolement-parcellaire
83 http://www.osez-agroecologie.org/la-taille-des-parcelles-a-un-effet-plus-important-que-l-assolement-ou-les-iae-sur-la-biodiversite-des-champs-168-actu-82
84 https://fr.wikipedia.org/wiki/Assolement

In terms of agronomics, the most interesting combinations are those which add value to complementarities and limit competition between species in aboveground and underground areas. Furthermore, a certain level of diversity on the plot can prevent the spread of pathogens (Wolfe, 2000, in ESCo, 2008, Chapter 1).

It consists of promoting the combinations which ensure the protection of crops or which favour synergy between crops.[85]

Grass-legume combinations (which have a nitrogen effect, staking effect and enable weeds to be controlled) are well-known but many other combinations are also effective (shade plant in a dry climate, pest-trapping plant, stabilising plant, etc.).

Figure 3: Tropical agroforestry in Indonesia (eastern Java): during the dry season, rice paddies are farmed for vegetables with combined cabbage and bean crops under coconut trees. Source: http://www1.montpellier.inra.fr/safe/month/2008/april.htm

85 www.agrisud.org/wp-content/uploads/2013/05/Guide_Francais.pdf

Advantages and disadvantages

Advantages	Disadvantages

• Crop disease and pest prevention:
  ◦ Interferes with odours and disorientates harmful insects
  ◦ Parasitic pressure is distributed across multiple species and varieties; favours natural biological control.
  ◦ Parasites are concentrated on preferred plants
• Uses all of the plants' assets (stimulating ability) and their complementarities
• Optimises the use of nutritional substances available to plants
• Better occupies the root and air space
• Covers and protects the soil (erosion control) and can enrich it (leguminous plants)
• Makes better use of the soil over time (catch crops).
• Produces different crops in a single area (food security)
• Provides a staggered harvest of various products (food security and diversity)
• Limits the risks of harvest loss linked to climatic events, thanks to different crop development cycles
• Reduces the risk of lodging
• Fights weeds
• Soil structure and fertility are maintained
• Higher yields than monocultures in 70% of cases
	• Compatible plants sometimes have different needs (water, manuring, maintenance) from which crop management difficulties can arise. As a result, combinations are rarely practised in vegetable farming.
	• Requires good knowledge of plants and their interactions, in particular to avoid the risk of negative biochemical interactions
	• System is difficult to mechanise
	• Not all species are adapted
	• Labour must be organised to manage more species
	• Potential increase in the difficulty of the work.
	• It can be difficult to apply phytosanitary products targeted to one species
	• Cross-contamination between plants susceptible to the same parasites and diseases is possible

Examples of compatible/incompatible vegetable crop combinations

Table 1: Example combinations to avoid or implement
(Source: http://www.gret.org/wp-content/uploads/guide-pratique-agroecologie_pdf.pdf)

Crop	Compatible	Incompatible
Wheat	Beans, cucumbers, lettuce, melons, peas, potatoes, squash, sunflowers	Tomatoes
Beans	Broccoli, cabbage, carrots, cauliflower, celery, wheat, cucumbers, aubergines, peas, potatoes, radishes, tomatoes, strawberries, squash	Garlic, onions, chilli peppers, sunflowers
Cabbage	Beans, celery, cucumbers, lettuce, onions, potatoes, dill, kale, thyme, sage, spinach	Broccoli, cauliflower, strawberries, tomatoes
Aubergines	Basil, beans, lettuce, peas, potatoes, spinach	
Onions	Beets, broccoli, cabbage, carrots, lettuce, chilli peppers, potatoes, spinach, tomatoes	Beans, peas, sage
Cauliflower	Beans, beets, celery, cucumbers, sage, thyme	Broccoli, cabbage, strawberries, tomatoes
Cucumbers	Beans, broccoli, cabbage, cauliflower, wheat, peas, radishes, sunflowers	Melons, potatoes

Table 2: Crop combinations in Guyana – favourable combinations in green, unfavourable combinations in red.
Source: http://www.ecofog.gf/giec/doc_num.php?explnum_id=1742

Favourable combination (G) / Unfavourable combination (R)		Aubergines	Carrots	Celery	Cabbage (in general)	Salad cucumbers	Squash	Courgettes	Sweet cassava	Taro	Beans	Yams	Lettuce	Sweet corn	Turnips	Roselles	Watermelons	Sweet potatoes	Parsley	Chilli peppers	Sweet peppers	Bell peppers	Radishes	Tomatoes
Pineapples	X								G		G			G										
Aubergines		X			G						G								G	G	G		G	G
Carrots			X	R	G						G		G		G				G			G	G	G
Celery			R	X	G	G	G				G		R	R	G				R	G	G	G	G	G
Cabbage (in general)		G	G	G	X	G	G				G		G		R				R			G	R	G
Salad cucumbers				G	G	X		R		G	G		G	G									G	R
Squash				G	G		X				G		G	G									G	R
Courgettes								X			G												G	
Sweet cassava	G								X		G													
Taro						G				X	G	G		G										
Beans	G	G	G	G	G	G	G	G	G	G	X	G	G	G	G	G			R				G	R
Yams										G	G	X												
Lettuce			G	R	G	G	G				G		X	R	G				R				G	G
Sweet corn	G			R		G	G			G	G		R	X	G		G	G						
Turnips			G	G	R						G		G	G	X									G
Roselles											G					X		G						
Watermelons														G			X							G
Sweet potatoes														G		G		X						
Parsley		G	G	R	R						R		R						X				G	G
Chilli peppers		G		G																X				
Sweet peppers		G		G																	X			G
Bell peppers			G	G	G																	X		G
Radishes		G	G	G	R	G	G	G			G		G						G				X	G
Tomato			G	G	G	R	R				R		G		G		G		G		G	G	G	X

Figure 4: Combination of lettuce and onions on the Kaydara agroecological school farm in Senegal (Source: Gora Ndiaye).

Examples of combinations and references

- **Combinations for fighting crop pests**
  Source: Integrated Production and Protection applied to vegetable crops in Sudano-Sahelian Africa, FAO - Project GCP/RAF/244/BEL
  http://www.fao.org/3/a-az732f.pdf
    - Combining tomatoes and cabbage reduces Plutella xylostella attacks.
    - Amaranth combined with tomatoes attracts white flies and therefore reduces the risks of the TYLCV virus for the tomatoes. The amaranth can then be treated to reduce the white fly population in the field.
    - Roselle plants combined with tomatoes can reduce leaf miner infestations on tomatoes. Mining flies attracted by the roselles lay their eggs on them. The substances secreted by the plant prevent the eggs from developing.
- **Additional reference:** Vegetables: favourable and unfavourable combinations
  http://www.acd-serres.fr/fr-8825-4813-6891-sitemap-legumes-associations.html

- **Other examples of combinations -** Source: Technical sheet 17 "Rotations and combinations" in http://agritrop.cirad.fr/578300/1/Guide+tropical+TBD+new.pdf
  - Yams x cucumbers x beans x malanga in Guadeloupe.
  - Combination of maize x sweet potatoes x beans in Guadeloupe.
  - Combination of maize x beans x cucurbits in Martinique.
  - Combination of yams x yautia or taro or turban squash or okra or maize or beans in Martinique.
  - Combination of plantains x turban squash in Martinique.
  - Combination of young orchards x turban squash in Martinique.
  - Combination of bananas x pineapples in the Antilles.
  - Combination of vegetable crops x aromatic plants.

4.2.2.3. Forms of intra-plot mixing

Intra-plot mixing can be implemented in different ways, which are listed below and covered in detail afterwards:

a. The cultivation of non-ligneous plants in a mix, or "mixed intercropping".
b. Intercropping of several non-ligneous species or "row intercropping".
c. Cultivation of non-ligneous species in alternating rows or "strip intercropping".
d. Cultivation of grassy and ligneous species in combinations on the same plot.

Cultivating non-ligneous plants in a mix, or "mixed intercropping"

In this system, the bases of two or more plant species are grown simultaneously in the same plot without any specific spatial arrangement.

- **The difficulties of this type of intra-plot mixing**
  - Weed control is difficult to manage.
  - Low control over harvest staggering.
  - It can be difficult to adapt the seeds or the production of transplant seedlings in a way which uses available space well.
- **Examples and references**
  - Combination of maize, beans, squash - https://fr.wikipedia.org/wiki/Trois_s%C5%93urs_(agriculture).
  - Use of Welsh onion (Alium fistolum) to combat bacterial wilt in tomatoes in the Antilles – Technical sheet 2 Bio-disinfection of soils in http://agritrop.cirad.fr/578300/1/Guide+tropical+TBD+new.pdf.

Intercropping of several non-ligneous species, or "row intercropping".

In this system, rows of one species are alternated with rows of another, or of other species, on the same plot.

- **The advantages of this system**
  - Fertilisers and phytosanitary products are easy to spread
  - Easy weed control.
- **Examples and references**
  - Integrated Production and Protection applied to vegetable crops in Sudano-Sahelian Africa, FAO - Project GCP/RAF/244/BEL http://www.fao.org/3/a-az732f.pdf

    Vegetable farming is not very mechanised in many regions and still offers the possibility of working with species combinations which do not necessarily need to be planted or harvested at the same time.

    Combinations to avoid: As with crop allocations, not everything is recommended. As such, squash and potato combinations should be avoided because the humidity created by the former promotes mildew on the latter. Likewise, papaya trees do not combine well with many vegetable species due to the fact that they can harbour root-knot nematodes. Lastly, the transfer of polyphagous pests from a crop at a more advanced stage to one at a younger stage must be avoided to prevent early contamination. The experience gained by elders can be highly useful in this matter, but it must not be extrapolated to other regions before ensuring that the recipe works well within other contexts.

    One of the cultivated plants in the combination can also serve as a physical barrier. For example, windbreaks can be planted using maize or sorghum in vegetable micro plots. These barriers can, in addition, hamper the spread of certain diseases. Sometimes, however, resulting adverse effects have to be neutralised: since the rows of maize attract aphids (risk of virus transmission to watermelon crops), care should be taken to ensure that these windbreaks are treated with a suitable insecticide that does not risk leaving residues which are dangerous to people on the neighbouring crop.

    The combination plants can also release chemical substances which will cause certain insects to flee or become disoriented. Combining tomatoes with cabbage results in fewer diamondback moth (*Plutella xylostella*) attacks because their presence prevents the insect from finding the cabbage plants. Likewise, the presence of basil in a tomato crop will act as a deterrent to mining flies.

    The following also apply to tomatoes:

    - Intercropping rows of tomatoes with rows of plants which are not sensitive to *Pseudomonas solanacearum* slows down the spread of this bacteria.
    - A row of Mexican marigolds with yellow flowers (*Tagetes erecta*) every 16 rows of tomatoes serves as a trap plant for *Helicoverpa armigera*.

- Other examples of row combinations:
  - Nitrogen-fixing plants, such as beans and cowpeas combined with maize or sorghum.
  - Lettuce and leeks.
  - Maize and *Cucurbita moschata* squash (for leaf consumption).
- Combinations can also be made with a plant which is cultivated for some of its attributes rather than for the plant itself. Geranium can be combined with lemongrass (insect-repellent plants) or marigolds (nematicidal plants).

Cultivating non-ligneous species in alternating rows, or "strip intercropping"

This consists of planting, on a single plot, strips of two or more rows of one species and alternating each strip with strips of one or more cultivated species.

In terms of crop operations, implementing the combination in alternating rows is easier to manage. The orientation of the rows is important if one species is taller than another. An east/west orientation provides better sunlight to the lower crop.[86]

- **The advantages of this system**
  - Fertilisers and phytosanitary products are easier to spray compared to combinations a) and b).
  - Irrigation management is easier compared to a) and b).
- **Examples and references**
  - **Push-pull** – source Sheet 15 - http://agritrop.cirad.fr/578300/1/Guide+tropical+TBD+new.pdf

    Push-pull consists of introducing a repellent plant which pushes crop pests away and/or a trap plant which pulls crop pests away from the crop.

    Trap crops are planted near a crop or intercropped with it. These trap plants can attract pests (usually insects) and divert them away from the main crop. This limits the damage caused by pests on plots, with minimal recourse to chemical inputs.

    The repellent effect can be obtained either by planting repellent intercropped crops or by treating the main crop with a biopesticide such as neem extract.
  - **Planting maize on the edges** of vegetable crops in a tropical environment strongly limits the impact of flies on vegetables (e.g. In Réunion, as demonstrated by the CASDAR GAMOUR project).

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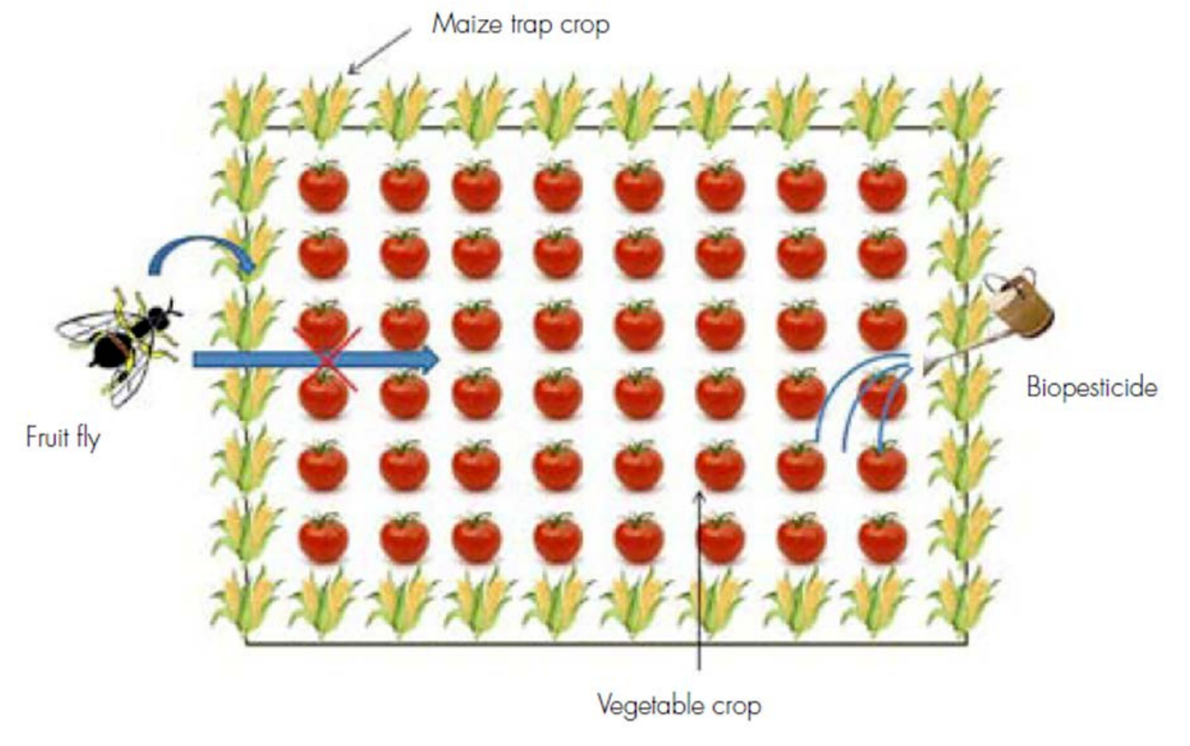
86 http://agritrop.cirad.fr/578300/1/Guide+tropical+TBD+new.pdf



Objective:

Pest control (Vegetable flies, Tephritidae) using the assisted Push-pull technique

Knowledge used:

Fly ecology, chemical ecology

Plant maize along the perimeter of the vegetable plot against fruit fly belonging to the Tephritidae family (such as Bactrocera or Dacus flies). The repulsive effect can be obtained either by treating vegetables with biopesticide or by intercropping them with repulsive plants.

Potential solutions researched:

- Agroecological engineering: (1) planting maize around cultivated plots; (2) spot application of Syneis-Appat on maize plants
- Integration in an agroecological package also including prophylaxis (augmentorium), sexual trapping with parapheromones, agronomic practices (vegetable cover) and conservation biological control.

The technique can fight against flies in the Tephritidae family, such as *Bactrocera cucurbitae*, *Dacus ciliatus* and *Dacus demmerezi*. These flies spend 90% of their lives away from crops and only emerge to lay eggs. Cultivating plants around the edges which can serve as shelter prevents them from laying eggs on the vegetables instead. They can be eliminated with a bio-insecticide on the trap crop. This avoids having to spread the bio-insecticide on the primary crop.

Maize doesn't only trap vegetable flies, it also attracts auxiliary organisms such as syrphid flies (natural predator of insects such as aphids).

Other source: Sheet no. 2 | Trap cropping and "push-pull farming systems" - Agroecological and agroforestry practices in tropical wet zones http://www.gret.org/wp-content/uploads/guide-pratique-agroecologie_pdf.pdf; in English - http://www.gret.org/wp-content/uploads/guide-agroecology-en-pdf.pdf

- Trap crops can either simply divert pests from the main crop or also stop the development of their larva, inhibit their appetite and so forth, thereby reducing the pest population on the plot.[87]

Cultivating grassy and ligneous species combinations on a single plot

Combining trees and crops provides more than just an economic benefit. Trees also provide a wide range of additional diversity which is beneficial to fauna and flora.[88]

Combining trees and vegetable crops is intended to optimise solar energy use by maximising the photosynthesis per unit of production surface area. The design of agroforestry vegetable farming systems is inspired by natural ecosystems. It results in agroecosystems which are viable and productive and which rely very little on inputs (fertilisation, phytosanitary protection).[89]

Specific advantages and disadvantages

Advantages	Disadvantages
• Creates beneficial micro-climates for plants, micro-organisms, insects and birds • Agricultural and ligneous production is diversified • Adapts to the harmful effects of climate change (e.g. heat waves) • Adds value to the soil minerals found at greater depths • Contributes organic matter to the soil • Makes rational use of soil water resources • Increases soil water retention capacity	• Crop pests are present • Combining crops with trees slightly reduces their productivity

Examples

Layered or multi-storey cultivation

The best-known combination with ligneous plants is **layered or multi-storey cultivation**, which is typical of forested regions but can also be found in dry areas such as oases.

87 http://www.infonet-biovision.org/PlantHealth/Intercropping-and-Push-Pull#simple-table-of-contents-5
88 https://culturesassociees.wordpress.com/tag/association-arbre-culture/
89 http://www.grab.fr/wp-content/uploads/2017/09/guide_verger-maraicher_smart_GRAB_web-1.pdf

Example 1: Household gardens

Household gardens can be defined as agroforesty ecosystems located near a plot or permanent dwelling and managed with family labour.[90]

The creole garden is typical of small-scale agriculture in the Caribbean. Combined crops follow one another in succession all year on plots near homes or nestled in the forest. Yams, sweet potatoes and taro share space with beans and other vegetable plants. Numerous fruit trees provide the garden with shade and revenue, supplemented by small pig and poultry productions, while banana trees contribute more directly to the household's food needs. Medicinal plants and spices are also present.[91]

In the figure below, the upper storey is occupied by large trees, such as *Inga feuillei*, *Mangifera indica*, *Persea gratissima* and *Artocarpus incisa.* These trees form a canopy which provides protection from the tropical sun and torrential rains. In addition, these trees provide food, their dead leaves contribute to the spontaneous regeneration of the soil and they help maintain relatively constant temperature and humidity levels. The next storey includes subsistence crops and fruits (e.g. *Musa* spp., *Carica papaya*). This storey is followed by a storey made up of shrub-height plants (cassava, maize, chilli peppers). The fourth storey is made up of ground cover or climbing plants (Cucurbits, beans) and tuber plants which round off the multi-storey structure.

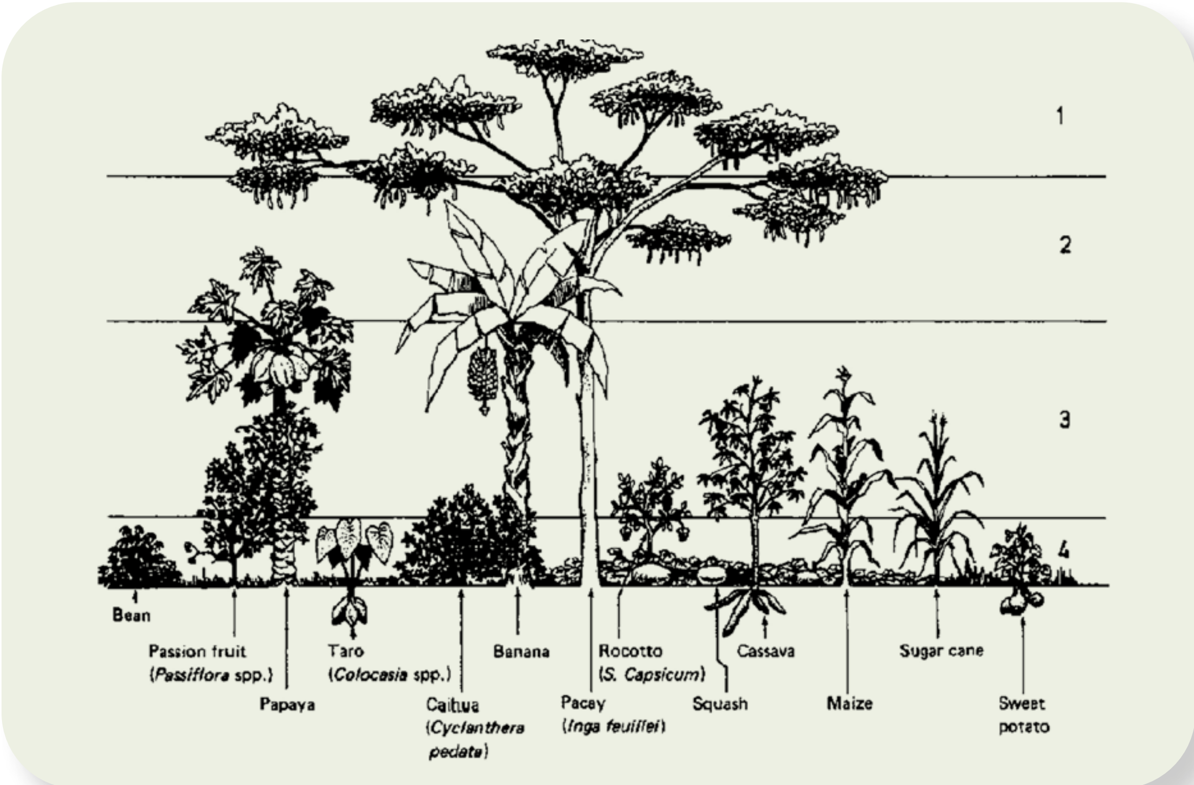


Figure 6: Typical Tropical Layered Household Garden

90 CREATION AND ORGANISATION OF HOUSEHOLD GARDENS IN WET FOREST AREAS IN CAMEROON, Mathurin TCHATAT e and 2), Henri PUIG e) & A. FABRE

91 Cultivating biodiversity - CIRAD

Example 2: Multi-storey cultivation in oases

The oasis cultivation system is organised in three storeys[92]:

- The date palm storey, which makes up the highest storey, serves as a windbreak and protects the other crops against the sun.
- The intermediate storey is made up of fruit trees (pomegranate, apricot, plum, mulberry, apple, etc.)
- The lower storey is occupied by vegetable, condiment or fodder plants (alfalfa).

With its crop storeys (upper stratum of date palms, middle stratum of various fruit trees and lower stratum of various vegetable, industrial and fodder plants), the Gabès oasis creates a favourable micro-climate for the development of a highly diversified flora and an exceptional landscape. The Gabès oasis is the only coastal oasis in the Mediterranean and one of the last examples of this type of oasis in the world. It is also a refuge for a fauna rich in small mammals, reptiles, molluscs and insects, and for a related fauna, still relatively unknown, made up primarily of trans-Saharan, migrating and wintering birds of international interest.

Combining trees and fertilising shrubs

Examples:

- Combining trees such as *Faidherbia albida, Gliricidia sepium*, *Tephrosia candida* and *Sesbania sesbani* with crops significantly increases yields.
- The hedge species normally used on the edges of crops in the humid tropics are: *Cajanus cajan*, *Calliandra calothyrsus*, *Erythrina* spp., *Flemingia macrophylla*, *Gliricidia sepium*, *Inga edulis*, *Leucaena leucocephala*, *Paraserianthes* (*Albizia*) *falcataria*, *Sesbania sesban*. *G. sepium* and *L. leucocepahala* are two of the most suitable species for border crops because they can be sown directly, are resistant to repeated trimming, produce large quantities of biomass and nutrients and have a relatively long lifespan. *Flemingia macrophylla* provides a good yield in low-lying wetlands with acidic soil.
- Maize and pigeon pea - https://www.accessagriculture.org/fr/culture-intercalaire-du-mais-et-du-pois-cajan.
- Pigeon pea hedges - http://www.discoverlife.org/mp/20q?search=Cajanus+cajan.

Other references:

- Increasing the fertility of a field by combining *Faidherbia albida* with crops - http://www.gtdesertification.org/Publications/Augmenter-la-fertilite-d-un-champ-cultive-en-associant-Faidherbia-Albida-aux-cultures.
- Faidherbia parks - https://ur-forets-societes.cirad.fr/publications-et-communication/ressources-en-ligne/agroforesterie/les-parcs-a-faidherbia.

92 Common date production in the Gabès oases, in the context of climatic and economic uncertainties: operation, assets and constraints by Foued Ben Hamida. Agronomic institute of Tunisia - Master 2001 Gabès Oasis: Gabès Oasis - UNESCO World Heritage Centre, whc.unesco.org

Orchard/vegetable farms

This new type of production system combines fruit trees and vegetables on a single plot. It is part of the larger agroforestry category.

References:

- The rise of orchard/vegetable farms - http://www.agroforesterie.fr/base/presse/upload/2017/Vergers-maraichage-arboriculture-SMART-agroforesterie-RFL-n374-juil-aout-2017.pdf
- Combinations at initial planting of orchards - Integrated Production Guide for Mangoes in Réunion - https://reunion-mayotte.cirad.fr/content/download/7766/80992/version/1/file/obj_6900_file_Guide-PFI.pdf

Figure 7: Strawberries combined with onions under coconut trees at the Kaydara agroecological farm school in Senegal
Source: Gora Ndiaye

4.2.3. Temporal crop layout techniques

Species and varieties are also diversified at the temporal level on a farm via well-planned crop rotation and/or with catch crops, as follows.

4.2.3.1. A well though-out rotation

Crop rotation is intended to produce several crops on a single plot, staggered over time (a succession of crops on a plot). The objective is to maximise the use of the soil's mineral salts, prevent the spread of diseases and pests from one year to another and diversify production in order to reduce the risks of poor harvests. In addition, the permanent presence of crops in the plot prevents weeds from proliferating.

In general, to at least be effective against diseases and pests, the rotation takes place over the course a year minimum. However, producers without large land holdings can rarely carry out such lengthy rotations. Therefore, in vegetable farming, very short rotations of only a few months, repeated each year, season after season, are prevalent.[93]

Table 3: Examples of rotation systems in the upper Ouémé watershed in Benin

Village (Upper Ouémé)	Rotation system (examples)
Sérou	• Tuber plants (yams/cassava) • Cereals (sorghum/maize) • Cotton or cereal • Groundnuts or cotton • Cotton or groundnuts • Maize or cotton
Sonoumon	• Yams • Sorghum or maize • Cotton • Cotton • Maize • Beans
Wodora	• Yams • Sorghum or maize • Cotton • Maize or cotton • Fallow or cashews
Bodi	• Yams • Maize or sorghum • Cotton • Cotton • Cotton • Fallow or cashews

93 http://www.gret.org/wp-content/uploads/guide-pratique-agroecologie_pdf.pdf

Wéwé	• Yams • Maize or sorghum • Cassava + maize or sorghum • Groundnuts • Yams • Maize + sorghum
Sirarou	• Yams • Maize + sorghum • Cotton • Cassava • Fallow or cashews
Bassila	• Yams • Maize or sorghum • Cassava • Groundnuts • Bambara groundnuts • Fallow or cashews

Source: Mulindabigwi, 2005 - http://hss.ulb.uni-bonn.de/2006/0784/0784.pdf

Crops and their successions are planned according to the following rules:

- Avoid cultivating a plant from the same family twice in a row in order to limit the spread of pests and diseases, which are often specific to plant families.
- Avoid cultivating a plant for the same part (fruit, leaf, root) twice in a row so that the same minerals are not removed. The fertility of the soil is then enhanced and maintained and the soil structure is preserved.
- Plant nutrient-demanding crops at the start of the rotation to maximise the value of input organic matter, compost or recycled manure.
- Alternate between "cleaning" crops and "soiling" crops to limit the growth of grass on plots.
- Wait long enough before planting the same crop in the same spot again.

In addition to these rules, two important factors must be taken into account when planning successions:

- The preceding effect: the positive effects the harvested crop (preceding) can have on the next crop planted.
- E.g.: the positive effects of a leguminous plant on a tomato or squash crop;
- The sensitivity of the following crop: not all crops react the same way to the effects of the preceding crop.
- E.g.: planting onions after a legume is to be avoided.

For more details, see
www.agrisud.org/wpcontent/uploads/2013/05/Guide_Anglais.pdf

Advantages and disadvantages

Advantages	Disadvantages
• Production is staggered over time (food security) • Revenues are diversified and the risks linked to the loss of a harvest are reduced • The value of different soil elements is increased • Value is added to available agricultural labour • The concentration of parasites and pathogens on plots is limited by interrupting their reproduction cycles • The soil is used at different depths, by alternating between plant crops with different root systems: fascicular and pivotal. The soil structure is therefore maintained • The occurrence of weeds is reduced by making use of various control methods, depending on the crops: mulching, weeding, ridging • Good soil cover is ensured over time. Soil erosion is therefore limited and the development of soil micro-fauna is promoted	• In-depth knowledge of plants and their interactions is required in order to select the crops to grow • Understanding of the climate • Requires finding various profitable crops with commercial outlets • The workload may increase • Difficult to implement on small surface areas

Examples

- These are essentially problems caused by nematodes and by various soil fungi (Fusarium wilt, for example) which should be a concern if the rotation period is too short. Even a long rotation can lead to problems because many leguminous crops are susceptible to knot-root nematodes. Therefore, it should be ensured that tolerant species are introduced into the rotation. These include: sweet potatoes, strawberries, garlic, onions, maize, red amaranth (*Amaranthus cruentus*) and groundnuts. Cereal crops which don't attract nematodes or groudnuts which can trap certain species can also be alternated.
- Fallowing can also be considered on condition that the land is maintained properly (worked or pastured fallow land), because numerous species of weeds can promote the growth of nematodes and other diseases.
- For improved fallow land, one or more grass, tree or shrub species with enhancing properties are introduced into the field in combination with or as a catch crop of the primary crop, or after harvesting. Leguminous plants are particularly well-adapted due to their ability to fix atmospheric nitrogen in the soil. More information can be found in Technical sheet no. 7 of http://www.gret.org/wp-content/uploads/guide-pratique-agroecologie_pdf.pdf

- Bio-disinfection of soil: This consists of introducing service plants, which don't host target pests and/or reduce the development of certain diseases or telluric pests, into the rotation. Refer to Technical sheet 2 of http://agritrop.cirad.fr/578300/1/Guide+tropical+TBD+new.pdf
- A green fertiliser (such as Sorghum X Sudangrass, first cut on site, then buried) can reduce the infection potential of the soil for *Pseudomonas solanacearum*, *Pythium apharnidermatum* and nematodes and is very useful as part of a typical vegetable rotation in a tropical environment.
- Trap plants, such as a complete groundnut cycle or repeated plantings of tomatoes pulled 3 weeks after collection can reduce Meloidogyne populations in the soil.
- Examples taken from: Technical sheet 17 Rotations and combinations, in http://agritrop.cirad.fr/578300/1/Guide+tropical+TBD+new.pdf
  - Plants of interest to add to the rotation:
    - peas and beans to enrich the soil with nitrogen,
    - maize and sugar cane to cleanse the soil,
    - peanuts, radishes or turnips to trap nematodes,
    - marigolds (*Tagetes* sp.) to repel nematodes.
  - Examples of recommended rotations:
    - cucumbers/yams/rocket/chilli peppers,
    - parsley/bell peppers/radishes/beans,
    - tomatoes/lettuce/sweet potatoes/maize,
    - cabbage/radishes/peas/lettuce.
  - Examples of rotations to avoid:
    - aubergines/tomatoes,
    - nightshades/cucurbits

4.2.3.2. Catch crops

Planting catch crops from botanical families which are different from the main crops increases domesticated biodiversity" (Troussard, M. *et al.*)[94].

A first crop is planted. Then, when the first crop has reached a reproductive stage but has not yet been harvested, a second crop is planted (e.g. alfalfa + turnip). The second crop grows without being hindered after the first one is harvested. The planting of the second crop depends on the growth speed and cycle length of the first crop.[95]

Catch, double and intermediary crops are considered service plants. They are planted between two main rotation crops.

94 http://agropeps.clermont.cemagref.fr/mw/index.php/Implanter_des_cultures_d%C3%A9rob%C3%A9es_ou_double-cultures

95 www.agrisud.org/wp-content/uploads/2013/05/Guide_Francais.pdf

A catch crop increases the value of the production whereas an intermediary crop does not. The first crops are either short-cycle crops or crops with fodder value. The second are also short-cycle plants which should flower quickly and abundantly.

The objective of double crops is to limit the growth of weeds while allowing the cultivated plant to grow.

Advantages	Disadvantages
• Prevent the growth of weeds. • Contribute to providing permanent soil cover while producing an additional crop. • Contribute, as a potential shelter, to maintaining plant and animal biodiversity.	• Consume a portion of the water meant for the primary crop. • Additional crop operations for the catch crops (soil working, harvesting, etc.).

4.2.4. Reserving as large a portion of the farm as possible for local patrimonial species and varieties

The importance of local species and varieties for the balance and resilience of traditional agriculture has recently gained renewed interest. Although it was predicted in the 1970s and 1980s that "rustic" varieties would be quickly replaced by improved varieties better adapted to intensification, it is clear that this has not been the case in many situations. The use of a diversity of local species in agrosystems which are also diversified provides a guarantee of food production in an uncertain environment.[96]

Advantages and disadvantages

Advantages	Disadvantages
• "In situ" conservation of the genetic heritage • Resists the harmful effects of climate change • Socio-economic-cultural • Improved resistance to parasites and diseases	• Low yields • More labour • Requires sufficient available land for this type of species and varieties • Accessing certified or non-certified seeds is difficult

Examples and references

There are initiatives in place in several countries which bring together amateurs and professionals to conserve and cultivate traditional varieties "in situ". This practice preserves biodiversity.

96 Cultivating biodiversity to transform agriculture – Etienne Hainzelin coord. – Edition QUAE

4.3. HOW TO PROMOTE WILD BIODIVERSITY ON FARMS

In general, the efficient management of land resources (erosion control, organic fertilisation, crop rotation, crop combinations, etc.) and water resources (integrated management, eco-friendly phytosanitary treatment, etc.) is a precursor to preserving wild biodiversity. Measures intended to maximise the diversified production of biomass and eco-volume contribute to enriching wild biodiversity. Light soil work, agroforestry, organic matter management (no bush fires or stubble burning) and the reduced use of chemical products such as mineral fertilisers and pesticides have a significant positive impact on the preservation or restoration of the food chain.

Furthermore, the implementation of structures and measures to fight erosion (anti-erosion ditches, radical terracing, living fences, grass strips, stone barriers, fodder crops along anti-erosion structures, agroforestry, etc.) contributes very positively to the preservation and restoration of biodiversity.

Two major types of wild biodiversity must be promoted:

1. **Para-agricultural wild biodiversity**, which concerns the diversity of the living organisms which play an important role in agroecosystems. This consists primarily of crop auxiliaries and organisms which play an important role in soil fertility.
2. **Extra-agricultural biodiversity,** which concerns the organisms living on the farm which do not play an important role in agroecosystems. This is known as "patrimonial" biodiversity.

The two types of biodiversity can be promoted by taking action on the farm with respect to the AEI/AEU, Plant Protection Products and fertilisers in cultivated areas, and the areas occupied by perennial crops (orchards, etc.).

However, it must be noted that the layout of the environment must take into account the crops in place, the region and the climate. There is no single model. If there are no known experiences/examples in the production area, carrying out small-scale local observations and preliminary tests before any large application on the farm is advised.

4.3.1. Layouts and practices favourable to the two types of wild biodiversity at the AEI/AEU level

They are the most important elements on a farm for promoting wild biodiversity. Most are favourable to the two types of wild biodiversity previously mentioned. The different types of AEI/AEU are described in Chapters 2 and 3 of this manual. Among the most important are: natural and semi-natural hedges, copses, wetlands and grass strips.

4.3.1.1. Natural and semi-natural hedges

They are the most important agroecological infrastructures on a farm. Aesthetically as well as ecologically valuable, varied hedges provide shelter and a larder for numerous animals and birds, thereby contributing to the preservation of biodiversity. One major advantage is that maintaining open hedges is very easy because they do not require regular or repeated trimming.

Advantages and disadvantages

Advantages	Disadvantages
• Protect against water and wind erosion • Habitats/niches for insects and birds • Fodder for animals • Improved soil fertility • Promote soil aeration and improved microbial life in the soil • Pollination: hedges promote the development of varied flora, which enables the spread of pollinating insects • Preservation of water resources: prevent runoff and promote water infiltration • Habitats can be connected together • Provide plant material for mulching or composting • Wood production: Heating, stakes, sheets, RCW (Ramial Chipped Wood). • Provide various resources (fruits, bio-pesticidal plants) • Pest control: shelter area for crop auxiliaries (ladybirds, syrphid flies, lacewings, carabid beetles, etc.) • Protect crops from animal damage • Micro-climate regulation: windbreak effect, thermal regulation, shelter for cattle • Provide water savings (by reducing evapotranspiration) • Water quality: organic residues and phytosanitary products break down via biological activity • Hedges limit the pollution caused by fertiliser and phytosanitary inputs • Greenhouse gas: play an important role in carbon sequestration. • Landscape: emphasise topographical elements, increase diversity, heterogeneity and the tourist appeal of landscapes.	• Potential shelter for certain crop pests • Reduce the space available for crops • Require regular, however limited, maintenance • Require a fairly long planting period (1 to 2 seasons) • Represent a cost if the plants must be purchased • Require significant labour (planting, watering, trimming) • Require ownership of the land • Increase the competition between the edges of the plot and the layout

Examples and references

Some authors make a distinction between the following hedge types: windbreak hedges, protection hedges and biomass production hedges.

Example 1: Windbreak hedge:

the hedge is perpendicular to prevailing winds. Its purpose is to "break" the prevailing winds to protect the crops. A windbreak hedge protects a crop over a distance behind the hedge of roughly 10 to 20 times its height (i.e. 20 to 40 m for a 2 m high hedge). The windbreaks are planted in a single or double row. The spacing of the trees is generally wider than for protection hedges (1 plant per m^2). For a double row, the rows are planted in a quincunx pattern with spacing of 1.5 m between rows. Caution: an overly dense, and therefore impermeable, windbreak can cause damage to crops (can cause whirlwinds).

Example species: *Jatropha*, *Acacia*, *Azadirachta* (Neem), *Parkinsonia*, *Tephrosia*, etc. planted in combination.

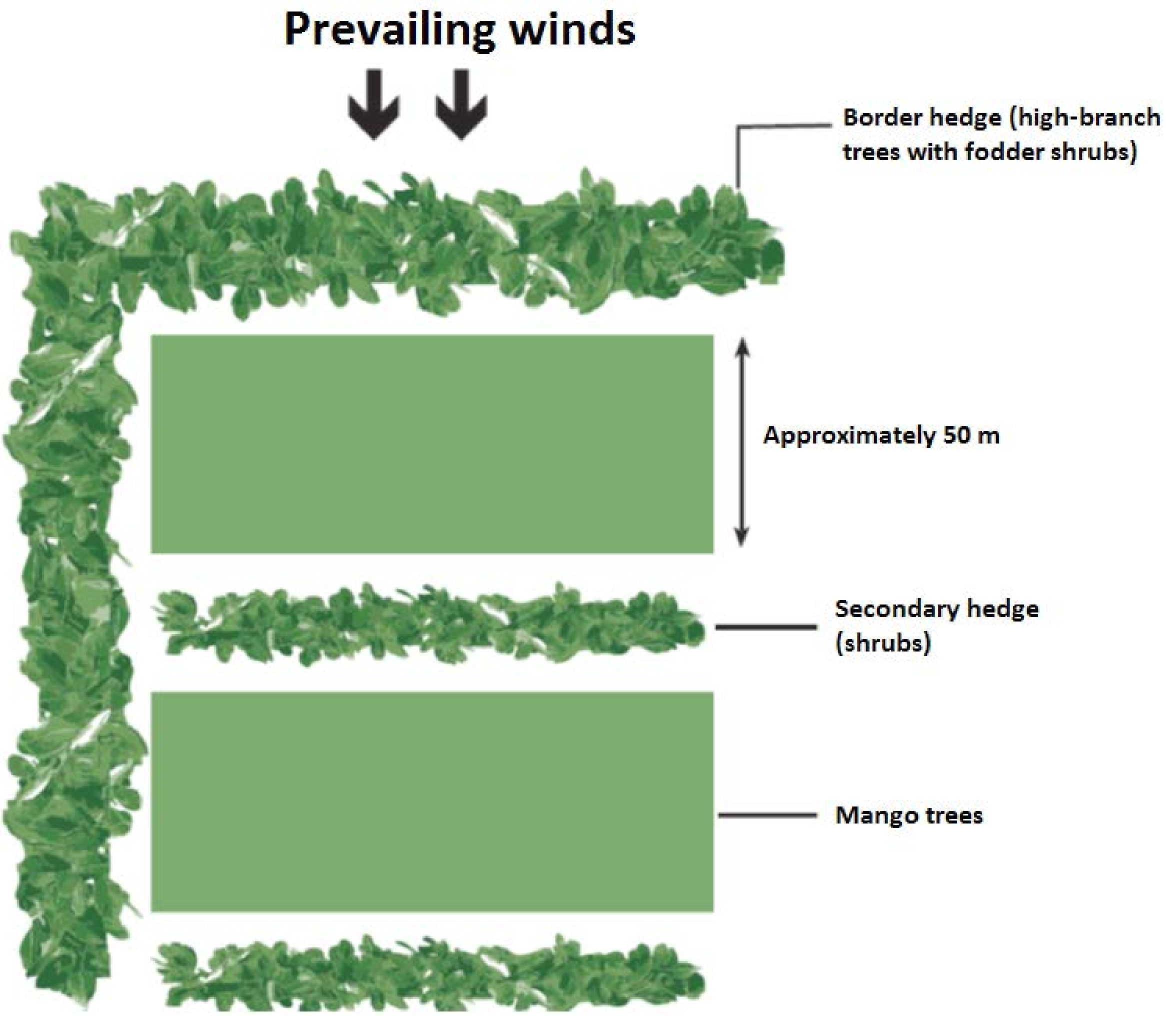


Figure 8: Arrangement of primary and secondary windbreaks in an orchard.
Source: Integrated Production Guide for Mangoes in Réunion
https://reunion-mayotte.cirad.fr/content/download/7766/80992/version/1/file/obj_6900_file_Guide-PFI.pdf

***Example 2: Protection hedge*:**

generally planted as a complement to barriers such as barbed wire and fencing. It is made up of thorny plants or species which are unpalatable to roaming animals. It is meant to prevent livestock from entering gardens.

Example species: *Acacia mellifera*, *Acacia nilotica, Acacia macrostachya,* Spurge (e.g. *Euphorbia tirucalli*), Gum acacia (*Acacia senegal*), Mesquite, Jujube, Cactus, Sisal, etc.

Here are a few examples of thorny hedges: monkeypod/Madras thorn (*Pithecellobium dulce*), Jerusalem thorn (*Parkinsonia aculeata*), Bengal currant (*Carissa carandas*), kei-apple (*Dovyalis caffra*), agave, yucca, etc.

Logwood (*Haematoxylum campechianum*) provides impenetrable hedges which are fragrant when flowering - http://uses.plantnet-project.org/fr/Haematoxylum_campechianum_(PROTA)

Table 4: *Examples of usable species for hedges in tropical climates*

Areas	Usable species
Dry area	*Acacia senegal* (gum acacia), *Prosopis africana*, *Parkinsonia aculeata*, *Calotropis procera*, *Agave sisalana* (sisal), *Azadirachta indica* (neem), *Jatropha curcas*
Humid area	*Crotalaria grahamiana*, *Cajanus cajan*, *Acacia dealbata*, *Dodonaea madagascariensis*, *Glyricidia sepium*, *Leucaena leucocephala*, *Sesbania rostrata*, *Tephrosia candida*, *Flemingia congesta*, *Acacia mangium* and*auriculiformis*

Source: www.agrisud.org/wp-content/uploads/2013/05/Guide_Francais.pdf

Example 3: Biomass production hedge:

generally planted in proximity to compost heaps or plots and regularly pruned. The trimmings are used to make compost or for mulching. They must be dense: 2 to 3 plants per linear metre. Young trees are planted at the rate of 1 plant per metre on 2 rows in a quincunx pattern. The two rows are spaced at 0.8 m.

Example species: leguminous shrubs, *Tephrosia*, *Leucæna*, *Flemingia*, *Glyricidia*, *Acacias*, etc.

Species selection

When planting these different types of hedges and when selecting the species, their other uses must be taken into account; such as, for example, the possibility of using the plants as insecticide plants or plants which favour crop auxiliaries.

- Examples of shrubby plants which can be used to produce bio-pesticides: neem, jatropha, *Tephrosia vogelii*.

  Neem can be used for service wood and heating wood production. However, its size requires that the producer control it on site or confine it to the outer areas as a wind-break.

Figure 9: A *Tephrosia vogelii* or Buba (Swahili) protecting fields of fruit and vegetables. Vegetable farmers use it as a bio-pesticide at the Greeze farm in Lubumbashi, Democratic Republic of the Congo. Source: Grégoire Mutshail Mutomb

- Examples of shrubby plants which attract crop auxiliaries and pollinators:
  - *Tithonia diversifolia* is a plant species from the Asteraceae family from Central America. It is often planted as an organised protective hedge

    It was introduced in several African countries as an ornamental plant and spread mostly along roadways. Its flowers attract various pollinating insects which are beneficial to agriculture. It is also used as a fertiliser plant (green manure) and for phytosanitation (fungicide, insecticide, nematicide).

Figure 10: A *Tithonia* sp. hedge protecting a celery crop at the Greeze farm in Lubumbashi, Democratic Republic of the Congo.Source: Grégoire Mutshail Mutomb

  - *Moringa oleifera*

    This tree's flowers are a good source of nectar for **bees** - https://abeillesetmiel.blogspot.com/2018/01/le-moringa-un-arbre-tres-mellifere.html
  - *Acacia mellifera*

    All acacias are honey plants to some degree; one is even called by the revealing name *Acacia mellifera*. Because they are often maintained on fallow land as multi-use trees, they can be a source of significant honey production. Overall, the Mimosaceae family contains many honey plant species[97].

97 Fallow land, harvest products and biodiversity. http://books.openedition.org/irdeditions/3320?lang=fr

References for the *Acacia mellifera*:

- *Acacia mellifera*. Agroforestry Database 4.0 (Orwa *et al.*2009) - http://www.worldagroforestry.org/treedb/AFTPDFS/Acacia_mellifera.PDF
- Exchange Centre for Information on Biodiversity in Niger. Convention on Biological Diversity (CBD) *Acacia mellifera* - http://ne.chm-cbd.net/biodiversity/la-diversite-biologique-vegetale/les-especes-vegetales-et-leurs-utilites/acacia-mellifera
- *Senegalia mellifera* subsp. *Detinens* - http://pza.sanbi.org/senegalia-mellifera-subsp-detinens

- Shrubby leguminous plants (agroforestry systems): leguminous plants enrich the soil with nitrogen (*Glyricidia, Acacia mangium and auriculiformis).*
- Fruit trees (complementarity of fruit/vegetable revenues): small trees are recommended for hedges at the interior of plots (e.g. guava, pomegranate, citrus), large trees are placed on the edges if space allows it (e.g. mango);
- Fodder trees (complementarity of crops/livestock): leguminous species should be favoured (*Faidherbia albida*, *Glyricidia*, *Leucaena*, etc.).
- Moringa: of particular interest because it can be regularly coppiced which makes it lower and gives it numerous branches which produce edible leaves. References: Complete information about organic Moringa cultivation https://www.moringa.biologique.bio/culture-plantation/; Moringa production and processing https://publications.cta.int/media/publications/downloads/1926_PDF.pdf.

Technical recommendations for use

In most cases, existing hedges in Africa are natural; therefore, before beginning to plant a new hedge, it is essential to remember that maintaining and improving existing hedges on the farm takes priority.

1. **Planting period**: identify planting periods outside of times of significant rainfall, dryness or waterlogging. For example, in climates with a pronounced dry season, hedges should be planted at the start of the rainy season (just after a good rainfall) to enable the seedlings to get a good start before the dry season.
2. **Soil preparation**: The soil must be worked in depth (subsoiling 60-80 cm deep, ploughing at least 25 cm deep, shallow ploughing) and completed by harrowing or motor-hoeing to break down the soil to a width of 2.5 m. This can be followed by mulching.
3. **Planting**: Hedge composition, species selection: the species must be selected for planting based on the soil, the climate and the objectives (width and height of the hedge). Local species which are more resistant to parasites and better suited to the soil and climate should be selected (a look around should be sufficient to identify which species will be best suited to the environment). These species will promote the presence of auxiliaries adapted to the crops.

It's important to combine species to create a composite or multi-species hedge by selecting trees with high branches, coppiced trees (i.e., cut at ground level so that the trees grow back with many new branches from their stumps) and shrubs, deciduous and evergreen species, berry-producing species and thorny species. It is essential to create shrubby and herbaceous strata. This type of combination meets the conditions required for the complete life cycle of many species, notably auxiliaries.

Planting tips:

Hedges can be placed by:

- direct seeding (groups spaced 50 cm to 1 m apart depending on the use of the hedge). E.g.: *Moringa*, *Acacia mangium* and *auriculiformis*, *Leucaena*;
- with cuttings (e.g.: *Glyricidia*);
- by planting plugs.

Young plants (1 to 2 years old; height = 40 to 120 cm) must be planted under mulch over 1, 2 or 3 rows for a wide hedge of 2 to 3 m. Trees with high branches must be separated by 5 to 10 m, coppiced trees by 2 to 5 m and shrubs by 0.5 to 1.5 m. The density of the trees should not interfere with crops. A width of 5 m for a hedge with 3 rows is considered optimal for biodiversity, but this can generally only be achieved in areas dedicated to rain-fed field crops.

For plug plants:

- Dig a hole of approximately 30 cm x 30 cm x 30 cm (depending on the future growth of the plant).
- Plant the seedling with the collar at ground level. Pack the earth to prevent air from entering and to promote earth/root contact. In dry areas, make a bowl to collect rainwater and maintain soil dampness. In wet areas, plant on mounds (make the bowl at the top of the mound).
- Water if there is little rainfall. The seedlings must be watered at least once a week (twice during the first few weeks). This will ensure that the seedlings will survive dry weather.
- Protect young plants which are not safe from stray animals (branches, nets, baskets, etc.).

Put down natural mulch: straw from cereals, *Imperata cylindrica* straw, wood chips, bark, if possible, or mulch made from plant leaves. Synthetic mulch or plastic should not be used because it is not biodegradable and must be removed at a later time. In addition, planting without plastic enables natural coppicing of the hedge and the growth of diversified flora. It is essential that the mulch be checked and weeds monitored during the first 3 years.

Add plants after a month or at the beginning of the rainy season of the following year. Experience has shown that a certain number of seedlings will die during the first year. It is therefore necessary to add new plants.

Caring for the hedge:

This will vary depending on the purpose of the hedge and the materials used. Each hedge must be cared for differently depending on its characteristics. Hedges must be cared for outside of key periods for wildlife like nesting and before the sap rises, once the berries have been eaten. It must be consistent to ensure that the branches do not become too large.

Prune the hedges based on the growth habit desired. See table below.

Table 5: Hedge pruning

Types of hedges	Typical growth habit	Pruning work
Protective living fence	Bushy	Pollard the plants to 1.2 to 1.5 m on a regular basis
Windbreak	Tall	Cut the excess branches to preserve 40% permeability to the wind (visual assessment)

Source: www.agrisud.org/wp-content/uploads/2013/05/Guide_Francais.pdf

Maintenance cutting (trimming) should generally be done at the start of the rainy season. However, in order to produce biomass and protect the site, trimming should be done on a regular basis depending on the hedge's growth.

It is recommended that the dead branches be left on the ground. It is recommended that some creepers be left as long as they do not weaken the trees or shrubs. It is recommended that the grass at the foot of the hedge be cut every year after the rainy season.

It is essential that dead and hollow trees used as habitat be kept. The damp cavities will provide something to drink for butterflies and the larvae of certain syrphid flies live in ageing trees, as do certain bat species and saprolyxic insects (insects which depend on the decomposition of dead or decaying wood or on associated organisms for at least part of their life cycle). In addition, they shelter mushrooms, mosses, lichens and ferns. Each piece of dead wood generates different biodiversity depending on the tree species, on the size and position of the piece of wood, on the amount of sun it receives, on its state of decomposition, its water content and the nature of the fungus which is causing the decay.

4.3.1.2. *Copses*

Copses are small wooded areas of a surface area between 5 ares and 50 ares. Above 50 ares, the space should be considered a forest, which can no longer be considered an AEI. See Appendix 10.

Advantages and disadvantages

Advantages	Disadvantages
• Habitats/niches for insects and birds • Ligneous production • Limit soil erosion • Pollination: promote the development of varied flora, which enables the spread of pollinating insects • Preservation of water resources: prevent run-off, promote water infiltration and soil drainage • Preservation of biological diversity: promote the development of fauna (habitat and food) and of diversified flora • Wood production: Heating, stakes, chips, RCW (Ramial Chipped Wood). • Fruit production • Pest control: shelter area for crop auxiliaries (ladybirds, syrphid flies, lacewings, carabid beetles, etc.) • Micro-climate regulation: windbreak effect, thermal regulation, shelter for cattle, etc. • Water quality: organic residues and phytosanitary products break down via biological activity Hedges reduce the pollution caused by fertilisers and phytosanitary inputs • Greenhouse gas: play an important role in carbon sequestration • Landscape: increase the diversity and heterogeneity of landscapes	• Reduce the space available for crops

Figure 11: Palmyra palms copse in Senegal
Source: Gora Ndiaye

Technical recommendations for use

1. **Planting period**: plant like a hedge, outside of times of significant rainfall, dryness or waterlogging. This will normally be at the start of the rainy season in the tropics.
2. **Soil preparation**: this is done before the rainy season. Ploughing isn't absolutely necessary for planting copses. However, the earth can be worked in depth (subsoiling 60-80 cm deep, ploughing at least 25 cm deep, shallow ploughing) and completed by harrowing or motor-hoeing to break the soil down.
3. **Planting**: copses on farms are normally planted in the areas which are less favourable for crops. Composition, species selection: Tree species must be selected based on the characteristics of the area where the copse will be planted. Exotic species should not be planted. Local species which are more resistant to parasites, adapted to the soil and the climate and which will best meet the food needs of the local fauna should be planted. Species which produce berries, fruit or nectar and which are favourable to the largest number of species possible should be selected. The appeal for fauna will depend on the species planted.

Planting tips

It is preferable to plant by modules. This option is more varied in terms of its composition and shape. It allows light into the copse which promotes the growth of diversified low vegetation. Random planting of trees and shrubs is recommended with denser and sparser areas to provide maximum diversity of biotopes. If planting is done in strips, they should be placed 1 m apart (with bands 80 cm wide). If the shape is square, the plants must be 80 cm to 1.50 m apart.

Plastic mulch should not be used for planting. Biodegradable mulch or no mulch is preferred.

Maintenance

Non-intervention is more beneficial to biodiversity in this type of environment. Maintenance, if required, must be performed as infrequently as possible. There should be no chemical weeding of the copse, grove or shrubs, even along the edges (a grass strip should be left, even if it is small).

It is essential that dead and hollow trees be left in place. They provide a habitat for tawny and little owls. The damp cavities will provide something to drink for butterflies and the larvae of certain syrphid flies live in ageing trees, as do bats and saprolyxic insects (insects which depend on the decomposition of dead or decaying wood or on associated organisms for at least part of their life cycle). In addition, they shelter mushrooms, mosses, lichens and ferns. Each piece of dead wood generates different biodiversity depending on the tree species, on the size and position of the piece of wood, on the amount of sun it receives, on its state of decomposition, its water content and the nature of the fungus which is causing the decay.

Figure 12: a copse in the middle of a maize field protected by farmers of the NGO CTD in Lubumbashi, Democratic Republic of the Congo
Source: Grégoire Mutshail Mutomb

4.3.1.3. Wetlands (ponds, ditches, etc.)

Wetlands aren't very popular with the general public, which sees them as festering areas infested with mosquitoes or, simply, as non-productive areas. Yet, wetlands play a fundamental part in regulating water and contain great diversity.

Advantages and disadvantages

Advantages	Disadvantages
• Efficient management/use of water resources • Limited irrigation • Fish production • Fish farming as a source of protein • Production of very rich compost in an anaerobic state at the bottom of the pond • Preservation of biological diversity: promote the development of fauna and flora reliant on wetlands • Water use: Ponds can be used to water herds • Ponds can also be used as water reserves against fires • Water level regulation: reduce runoff and limit flood cresting • Landscape: increase the diversity and heterogeneity of landscapes. • Ponds improve the living environment and enable educational, tourism and other activities.	• More labour • Malaria and other water-related diseases can develop • Risk of children drowning • Smells

Technical recommendations for ditches -

Adapted from: IBIS. Drainage and other ditches - http://www.hautsdefrance.chambres-agriculture.fr/fileadmin/user_upload/National/FAL_commun/publications/Hauts-de-France/Fosseesdrainageautres_OK.pdf

With respect to ditch maintenance: The depth of ditches must be maintained at 40 cm to 70 cm. Ditches must be maintained twice a year. When necessary (every 5 to 10 years), cleaning should be done in sections (less than 100 m) when ditches are dry. Only the bottom part of ditches should be cleaned by digging. The mud from cleaning should be spread out rather than stored in a heap. This will promote the recovery of vegetation from seeds or of the microfauna in the mud. The sediment should never be used to raise embankments and banks.

Layout and maintenance of the immediate surroundings: Differentiation is the key word for optimising the beneficial protective effects of ditches: differentiation of the planted or wild cover of the surroundings, differentiation in the times and types of work done. Ideally, a wooded riparian environment should be created with bulrushes, reeds or a grass strip at least 5 m wide. At a minimum, a strip of at least 1 m should be maintained. Wooded and non-wooded areas should be alternated to promote species diversity. The grass cover should be maintained, preferably by mowing. The residue should be removed or ground up, if possible, every two years, alternating between the banks to avoid obstructing the ditch downstream and to leave shelter for insects. The banks of ditches alongside meadows must be protected, with a fence if necessary, to prevent trampling of the banks and direct pollution of the ditch by organic matter.

Chemical treatments should never be used on the surrounding areas (herbicides, pesticides) and the use of fertilisers must be limited to facilitate the development of varied flora.

4.3.1.4. Grass strips

Grass strips provide multifunctional vegetation cover made up of flora adapted to the spatial characteristics of the plot, to its environment and to the needs of the farmer. This system has undeniable environmental value, notably in terms of water quality, soil erosion and the protection of fauna.

Different types of plants can be selected to promote a range of species such as auxiliary insects or small sedentary fauna. Vegetation can also be allowed to regrow spontaneously. The grass strip can provide shelter or a habitat for certain plant species. Wildlife can also be promoted depending on the species and their care requirements.

Grass strips enable the creation of areas where auxiliary insects can develop. However, this is also true of certain pests. These spaces can provide a "breeding ground" for the biological regulation of crop pests. In addition, a grass strip will enrich the soil with earthworms. Earthworms improve soil porosity and air and water circulation and provide an important source of food for many animals.

Advantages and disadvantages

Advantages	Disadvantages
• Soil fertility: reduce soil erosion, promote the development of soil microfauna, and improve the structure and porosity of the soil. • Pollination: improve the diversity of flora over time which is favourable for bees and other crop auxiliaries. • Preservation of water resources: improve water infiltration and retention and limit runoff. • Preservation of biological diversity: promote the development of fauna and flora and interconnect habitats. • Pest control: shelter area for crop auxiliaries (carabid beetles, syrphid flies, etc.) • Water quality: organic residues and phytosanitary products break down via biological activity • Greenhouse gas: carbon sequestration. • Landscape: grass strips increase landscape diversity and improve the image of agriculture.	• The crop area is reduced if it replaces a production area.

Technical recommendations

The plant species which will grow will depend on the environment and the history of the grass strip. They will depend on the species sown and on their density. It should be expected that the plant species present will evolve over time. The choice of plants grown in the grass strip can be directed by the crops on the adjacent plots and the species to be promoted: flowering covers will provide food for pollinators which will, in turn, provide food for insect-eating birds and their young. Seed-producing cover will provide food for granivorous birds. The density of the cover and its maintenance will also promote certain species or certain ecological needs over others.

Adapting the width of the grass strip (between 5 m and 10 m for field crops) to the characteristics of the plot and the region is key to its effectiveness, particularly with respect to intercepting runoff. Its width must be suited to the various elements of the landscape: the length and grade of the slope, the width of the river, rain characteristics, the intake area, the type of soil and crop. However, the best water quality results are obtained with a width of 10 m. This is only possible on large farms.

- **Flora characteristics**: A mixture of grasses and legumes is best for planting. To prevent weeds from spreading to the cultivated plot, the cover must have the following characteristics: easy and quick planting, regular occupation of the entire surface, vegetation density as regular as possible, resistance to invasions by plant species harmful to the plot and longevity. In addition, legumes are valuable in grass strips, especially in poor soils. They can fix the nitrogen in the air and, therefore, improve the concentration of nutrients available. Grasses will cover the ground quickly and limit the space and resources available for weeds.
- **Seeds**: For seed mixes, the ideal to ensure a regular planting of the cover is to sow twice, once for the grass seeds and once for the legume seeds. Legume seeds are looser than grass seeds and do not provide a homogeneous mixture of seeds.
- **Maintenance:** The grass strip must take well to ensure that weeds can't spread to the adjacent plot, and to prevent the growth of aggressive weed species. It is also recommended that the weeding programme be adapted by plot by monitoring the species that grow in the strip. Mowing and grinding times will depend primarily on the growth stage of the dominant weeds. Therefore, if damaging weeds are present, maintenance must be done to ensure that they cannot seed. Fertilisers and phytosanitary products are prohibited. It is better to mow and grind up the plants. It may be necessary to export the waste matter from cutting to ensure that the cover isn't choked out.

4.3.2. With respect to Plant Protection Products in cultivated areas

Phytosanitary treatments are believed to be one of the main causes of the decline in biodiversity in the agroecosystems of industrialised countries (ESCo, summary, p. 20, 2008). They are harmful to biodiversity because all of the biological links (plants, primary and secondary consumers, decomposers and all environments (air, soil, water, etc.) can be directly or indirectly impacted by pesticides.

Following its application on a field and depending on the chemical and its formulation, a certain portion of the solution spread will disappear quickly into the atmosphere and come down again elsewhere as rain. A portion enters the soil and is circulated in several different ways. A portion is absorbed by the plants, which may store it, transform it into metabolites which are potentially toxic, or transfer it to different organs. Another portion will enter the soil solution and can be metabolised by soil micro-organisms or percolate into groundwater. Last, another portion can be absorbed by the organic and mineral particles of the soil and follow a number of different paths: removal by erosion and runoff resulting in the release of the chemical in an aquatic environment and/or residual persistence of the product in the soil for a variable amount of time, depending on the environment and the chemical. Therefore, 10% to 70% of pesticides can be lost to the soil (Jensen, 2003) and up to 50% of products can be lost in the air in the form of droplets or gas (Van Den Berg *et al.*, 1999, in ESCo "Pesticides, agriculture and the environment", Chapter 3, p. 34, 2005). The products are dispersed outside of the fields by leaching, volatilisation, erosion or biological transfers (via food chains) and are now present in all habitats and ecosystems and constitute a real toxicological and ecotoxicological backdrop.

Broad-spectrum herbicides are designed to attack all of the vegetation present on a plot treated and therefore have a negative impact on the abundance and richness of plant species. However, they also act indirectly on many other taxons. Given that plants are at the start of the food chain, their systematic elimination is particularly disruptive to the equilibrium of the environment because it removes all trophic resources and impacts the pedofauna, including crop auxiliaries. The entomofauna (insects) of agroecosystems, in particular, are globally more affected by the indirect effects of herbicides (Way and Cammell, 1981, in ESCo, Chapter 1, p. 22, 2008). The application of broad-spectrum herbicides is, therefore, disastrous for the biodiversity of the plots treated.

Selective herbicides target a specific type of plant (for example, dicotyledons and grasses). As a result, they have a smaller impact than that of broad-spectrum herbicides. However, eliminating a type of plant from a plot decreases the biodiversity of the vegetation and creates an imbalance which can also be harmful to fauna biodiversity.

Insecticides, molluscicides, acaricides, raticides, etc. are intended to kill animal pests. This is harmful to the biodiversity of the fauna of the plot treated. In addition to the animals targeted, crop auxiliaries can also be affected, even when the chemicals target a specific type of pest. These unintended effects, which have been demonstrated by many studies, (ESCo, Chapter 1, p. 19) have serious consequences for biodiversity and the overall equilibrium of agroecosystems.

Fungicides probably impact less biodiversity than the other products. However, they are harmful to bacterial microflora (Ahmed *et al.*, 1998; Bunemann *et al.*, 2006 in ESCo, Chapter 1, p. 25, 2008) and to the fungi required for soil health.

Ideally, to prevent these products from impacting biodiversity, they should not be used at all, or only products which present a very negligible (or no) ecotoxicological risk should be used. Unfortunately, this is still often very difficult to achieve, at least in conventional agriculture. Most of the time, the risks related to the use of Plant Protection Products must be reduced by reducing the number of treatments and surfaces treated as much as possible. Below are some examples of practices which can reduce the disruptions of wild biodiversity caused by PPPs.

Buffer zones

These spaces adjacent to the cultivated plots are occupied by permanent vegetation. They can mitigate the negative effects of PPPs. These are called buffer zones.

They can be either grassy or wooded areas. They can protect water quality and preserve biodiversity.

The value of grass strips for reducing the hydric transfer of pesticides to waterways has been confirmed (Patty, 1997). How do they work? According to simulations of runoff in grassy and wooded buffer zones (Souiller, 2002, confirmed by Lacas *et al.*, 2005), it is primarily thanks to water infiltration in the buffer zone (and potentially somewhat to the absorption of chemicals with a high absorption capacity at the surface of the buffer zone).

Advantages and disadvantages

Advantages	Disadvantages
• Barriers to the free dissemination of soluble pesticides and fertilisers in nature • Control the aerial drifting of spraying to sensitive areas • Slow water runoff and facilitate its infiltration in the ground • Protect the soil against wind erosion • Retain the fertility of the plot • Prevent the silting of low-lying areas • Fertilise the plot when the grass strips consist of legumes • Can be productive (forage, other)	• Use space that could have grown crops • Require a significant amount of work to implement • Require technical knowledge • Maintenance costs

The implementation of buffer zones in a Catchment Area (CA) or basin is part of a more global approach based on a diagnostic of the vulnerability of the runoff areas and consultation with the players involved which ensures their effectiveness. Each type of buffer zone is more or less effective based on the type of runoff (drainage, diffuse or concentrated runoff) and the pesticides in question.

The use of PPPs should only be considered as a last resort. Preventive measures must first be implemented to reduce the risk that pests and diseases will appear. Whenever possible, the amount and frequency of treatment must be reduced, particularly for certain herbicides.

4.3.3. Fertiliser use in cultivated areas

4.3.3.1. Nitrogen pressure in cultivated areas

Contrary to calcium, phosphorous and potassium, nitrogen poses a particular problem because it isn't stored (absorbed) by the clay-humus complex of the soil and it is one of the first factors limiting plant biosynthesis. Nitrogen fertilisation is, therefore, often (over)abundant, resulting in significant loss through leaching (percolation deep into the ground), contamination of aquifers and/or surface water downstream (50% of the country is classified as vulnerable based on the 2007 "Nitrates Directive" mapping). The eutrophication of many waterways and the proliferation of algae in coastal waters (green tides, etc.) are major disruptions to aquatic ecosystems.

The amount of nitrogen (organic and mineral) spread per hectare and per year is a major indicator of the impact of agricultural practices on water (and, therefore, on the biodiversity of wetlands and aquatic environments). Too much nitrogen also weakens the plants grown (quick growth) making them more sensitive to attacks by pests (aphids) and results in the development of nitrophilic flora (weeds with little ecological value), which often leads to the use of pesticides). Overall, an increase in fertiliser use leads to the homogenisation of the environment and the disappearance of species adapted to areas which are poor in nutrients and the replacement of specialist species by generalist species. Mineral nitrogen fertilisation appears to be one of the main factors responsible for the decline in species richness in plots and in adjacent strips (ESCo, summary, p. 20, 2008).

Here are a few practical examples of ways to reduce disruptions due to nitrogen pressure on wild biodiversity:

Buffer zones

Buffer zones prevent the runoff of surface water which can be high in nitrogen content. The advantages and disadvantages of buffer zones were discussed above and examples and references were provided.

The contribution of N via the combination of legumes with crops

A typical example is the combination of cereals with legumes. The use of inputs has enabled a significant increase in the productivity of agroecosystems over the past decades. However, in the case of nitrogen (N) and phosphorous (P), this increase has been followed by a significant decline in the effectiveness of N and P. This is in part due to losses of N and P, resulting in a negative impact on the environment such as the eutrophication of surface water, the pollution of water tables and the emission of greenhouse gases. In order to maintain high agroecosystem productivity and stabilise it while minimising the negative impact on the environment, it is necessary to develop innovations to move toward "ecological intensification" of agroecosystems that make more efficient use of N and P resources in the soil. In a complex population combining several varieties of the same species, or several species, it should be expected that, if they are different enough from a functional standpoint, positive interactions (facilitation, complementarity) will override negative interactions (competition) between plants. The result can be better sharing of soil resources, as we have seen previously in the case of cereal/legume combinations.

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Advantages and disadvantages

Advantages	Disadvantages
• Decreased application of nitrogen fertilisers • Reduced risks from nitrogen pollution • Better ground cover	• Spatial overcrowding of intercropped legumes

Examples and references

- Combined crops. Cereals/Legumes - http://inra-dam-front-resources-cdn.brainsonic.com/ressources/afile/246508-6e585-resource-article-inra-toulouse-cultures-associees.html
- Potential Role of Cereal-Legume Intercropping Systems in Integrated Soil Fertility Management in Small holder Farming Systems of Sub-Saharan Africa - http://www.fao.org/family-farming/detail/en/c/329086/

Figure 13: Cowpeas under coconut trees and an anti-erosion strip of vetiver at the agroecological farm school at Kaydara in Senegal
Source: Gora Ndiaye

a. The proportion of organic nitrogen

An increase in the proportion of nitrogen provided by organic matter leads to a reduction in nitrogen pressure on the environment. See Chapter 2 of the manual for examples of the organic matter that can be used.

b. Localised application of fertilisers

Applying fertiliser as locally as possible, where it is best available to the plants, reduces the risk of negative impacts of the fertiliser on biodiversity.

For example, this can be done with:

- Suitable fertiliser-spreading equipment - http://www.slyfrance.com/pourquoi-localiser-lengrais/
- Via the irrigation system (fertigation).
- Microdoses to seeds - http://www.fao.org/fileadmin/user_upload/iarbic/doc/1_fiche_microdoses-2[1].pdf

c. The use of mycorrhiza

The vast majority of plants make multiple underground links with soil bacteria. Thanks to the micro-organisms, the plants can use the nitrogen in the air as well as the minerals they need to grow.

Mycorrhizal fungi also protect plants against a range of diseases and nematodes - http://www.supagro.fr/ress-pepites/sol/co/1_4_3mycorhizes.html.

Mycorrhiza are increasingly being sold in combination with wood pellets and/or composts.

4.3.4. With respect to areas planted with perennial crops (orchards, etc.)

Perennial crops which are heterogeneous by strata and/or by age and/or by species and/or by variety are more favourable to wild biodiversity. See the section of the document on multi-storey crops.

4.4. LAYOUTS AND PRACTICES WHICH MORE SPECIFICALLY PROMOTE WILD PARA-AGRICULTURAL BIODIVERSITY

Wild para-agricultural biodiversity in particular can be promoted by putting in flower strips, by ensuring maximum diversity of the species cultivated, by using Plant Protection Products which do not harm useful organisms and by maintaining perennial crops with grass strips.

See also http://www.agriculture-durable.org/wp-content/uploads/2014/03/amenagementauxiliairebiodivgc.pdf.

4.4.1. By putting in flower strips

The purpose of flower strips or islands is to provide abundant and diversified food sources for beneficial insects like pollinators and the natural enemies of pests (predators and parasitoids). The principle is relatively straightforward: simply install a strip or island consisting primarily of herbaceous or ligneous flowering plants at the edges of fields or along the borders of woods, hedges, fields, ditches, etc. By planting a linear strip of sufficient length within a field, the beneficial insects will be able to move along the "inhabitable motorways" and spread throughout the fields. Syrphid flies are the predominant predator auxiliaries seen in the flower strips.

Advantages and disadvantages

Advantages	Disadvantages
• Promote the presence of auxiliary insects (entomophagous and pollinators) • Act as trap plants for certain crop parasites • Preserve biological diversity: promote the development of fauna and flora • Limit soil erosion • Beautify the landscape • Landscape: increase the diversity and heterogeneity of landscapes	• Decrease the productive farm area if the cover replaces a crop area • Use irrigation water if need to be irrigated • Cost of labour (seedlings or seeds, light maintenance) • Cost of seedlings or seeds • The availability of seeds or of seedlings could be a problem for certain plant species which are not in high demand • Risk of hosting significant populations of slugs, rodents or other animals • Can be a source of an excessive amount of weed seeds • Very little experience in the tropics

Technical recommendations

Flower strips can be planted with annuals, biennials or perennials, wild or horticultural species. The choice, beyond the obvious value to biodiversity provided by wild species, will often depend on the availability of seeds and their cost.

The choice of species is currently problematic in the tropics because there are very few studies available.

A compromise needs to be found between a number of different species in order to optimise the flowering season and facilitate operations, particularly with respect to seeds. Installation should be done based on the soil and the previous growth. A false-seed bed will exhaust the seed stock of weeds and the regrowth of the previous growth. Any soil work done must then be superficial. The sowing of legumes should be done on a thin seed bed and consolidated soil. Rolling immediately after seeding will enable homogeneous germination. The density of seeds will depend on the mix. The cover should not be too dense, in any event.

Invasion by weeds which are harmful to neighbouring crops must be avoided, notably based on the seeds and species present.

The impact of the flower strip on the crop will vary depending on the parameters. For example, trials in France have shown that the impact of a flower strip on a neighbouring cabbage plot was significant up to 20 m away and lessened up to 50 m away.[98]

The following conditions must be present to create a successful flower strip:

- Species that will grow at different rates should be combined: a grass (5% by weight) will fill the area and prevent faster weeds from coming up.
- Perennial species will take over after the annuals.
- Broadcast seeding is generally used. The seeds should be mixed with coarse sand to better spread the seeds over the entire area.
- The soil must be kept wet during the first few weeks after seeding and watering must be planned depending on the situation.
- The maintenance of the flower strips is also important: if nothing is done, there is a significant risk that a dominant species will choke out the other ones and that, in the end, the flower diversity will suffer.

Examples and references

- The figure below shows the plant families that attract the most foraging insects in orchards in Martinique. This includes syrphid flies, whose larvae are important auxiliaries. Plants in the Asteraceae family are visited the most often. Among the most common Asteraceae in the tropics are: *Tithonia diversifolia,* Artemisia, pyrethrum, marigolds, *Bidens pilosa* (a medicinal plant), sunflowers, etc.

98 https://www.grab.fr/wp-content/uploads/2010/09/fiche-RMT-Auxiliaires.pdf

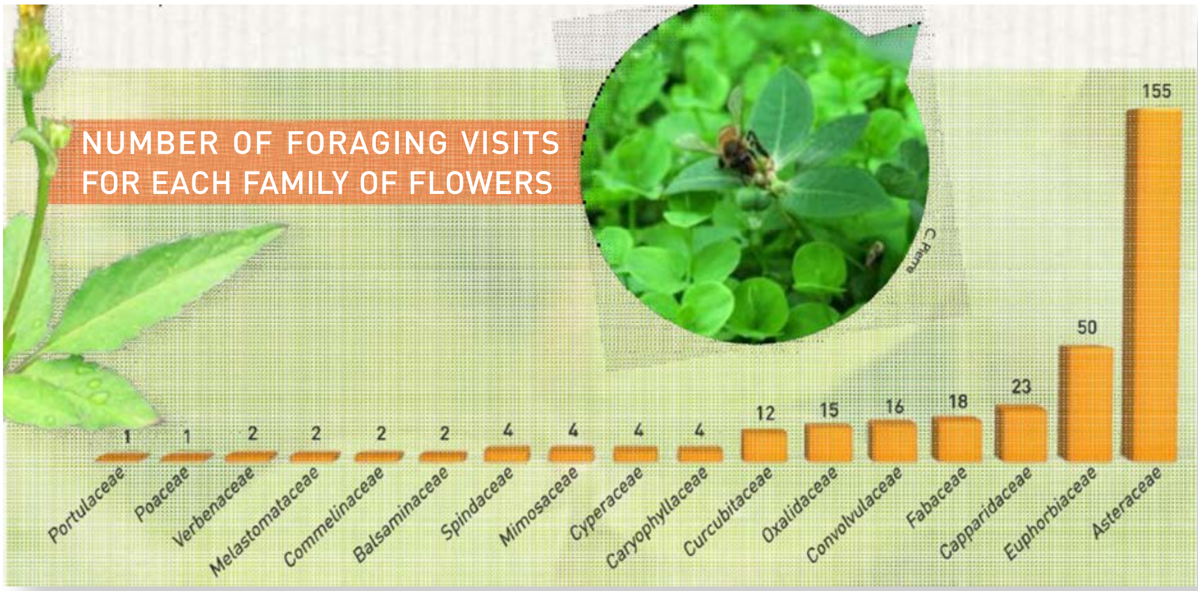

Figure 14: Number of foraging visits for each family of flowers
Source: http://cultures-tropicales.ecophytopic.fr/sites/default/files/InfoPointFede33_FREDON_PF_022016_abeilles.compressed.pdf

- Clumps or single marigolds and tagetes (*Tagetes spp.*) (host to predatory minute pirate bugs in the genus *Orius*). Also, the gliricidia (*Gliricidia sepium*), the pigeon pea (*Cajanus cajan*), basil (*Ocimum basilicum*), the sunflower (*Helianthus annuus*), the crotalaria (*Crotalaria* sp.) for their secondary prey, pollen, nectar, etc.[99]
- The Apiaceae (coriander, dill, fennel), the Asteraceae (marigolds, cosmos) and the Lamiaceae (basil, Hyptis, mint) are plant families that are well known for their production of a particularly rich nectar. Many spontaneous plants are also visited by auxiliaries for their nectar (Asteraceae, Euphorbiaceae) or their pollen (grasses). [100]

4.4.2. By providing spatial-temporal diversity of cultivated species

Crop allocation in as fine a mosaic as possible, intra-plot combinations and rotations are practices which promote the survival of abundant and varied wild para-agricultural biodiversity.

Below are a few examples and references specific to wild para-agricultural biodiversity

Examples and references

- Introduction of strips of sorghum and maize in a vegetable plot in Martinique to control *Aphis gossypii* aphids. For more information see – Technical sheet 9 "biological control by conservation" in http://agritrop.cirad.fr/578300/1/Guide+tropical+TBD+new.pdf, and http://ephytia.inra.fr/fr/C/23802/Tropileg-Exemples.

99 http://agritrop.cirad.fr/578300/1/Guide+tropical+TBD+new.pdf
100 http://www.ecofog.gf/giec/doc_num.php?explnum_id=1722

Figure 15: Strip of sorghum and okra crop (a) and sorghum seedlings between yam mounds (b)
Source: a) http://agritrop.cirad.fr/578300/1/Guide+tropical+TBD+new.pdf; b) Mulindabigwi (2006)

- Other examples from http://agritrop.cirad.fr/578300/1/Guide+tropical+TBD+new.pdf:
    - Introduction of single dill and coriander plants on the farm (hosts for parasitoid micro-hymenoptera, syrphid flies, lacewings and ladybirds).
    - Milkweed beds (*Asclepia curassavica*) (hosts for yellow aphids (*Aphis nerii*) which are eaten by ladybirds, syrphid flies and parasitoid wasps).

Other references

- Resilience in Agriculture through Crop Diversification: Adaptive Management for Environmental Change - https://academic.oup.com/bioscience/article/61/3/183/238071

4.4.3. By maintaining perennial crops with grass cover

Grass cover plays a primary role as a soil cover which can also reduce herbicide use. If the grass cover is sufficiently diversified in terms of plants beneficial to crop auxiliaries, it will also play an ecosystem service role in the fight against pests. In some cases, it can also contribute to limiting pathogenic agents by cleaning excess water on the ground and improve the soil. However, species selection and the rate of coverage must be taken into account to avoid problems such as competition or the development of other bio-aggressors helped by the cover. Lastly, the management of the cover must be able to limit its growth because it can also become a source of other undesirable effects.[101]

101 http://ecophytopic.fr/tr/pr%C3%A9vention-prophylaxie/techniques-culturales/enherbement-des-cultures-p%C3%A9rennes

Advantages and disadvantages

Advantages	Disadvantages
• Erosion control • Soil sanitation and improvement • Promotes crop auxiliaries • Reduces herbicide residue • Prevents soil packing • Promotes soil microflora and microfauna	• Requires trimming or mowing • Potential competition with crops • Potential source of pest infestation • Requires a good understanding of the plots and of their ability to host cover and knowledge of the characteristics of the weeds and cover plants. • Risks spreading if poorly managed, notably for perennial legumes

Examples and references

- Several types of service plants can be used to control weevils in banana plantations - www.cirad.fr/content/download/.../fiche+agroecologie+charançon+bananier-FR-4.pdf

Le lien ne fonctionne pas

- Alternative methods for controlling weeds such as cover plants or combinations with animals can be substituted for the use of herbicides, which are expensive and polluting. A judicious selection of plants can also promote auxiliaries - www.cirad.fr/content/.../10460/.../Agro-ecologie_cirad_controle_enherbement-FR.pdf
- Guide to using grasses in vineyards and orchards - https://www.barenbrug.fr/t%C3%A9l%C3%A9charger-2

In order to preserve para-agricultural biodiversity such as, for example, beneficial crop insects, the least harmful Plant Protection Products for these organisms must be selected, e.g. biocontrol products. For more information see point 5.5 "Selectivity of plant protection and respect for beneficial organisms" in Coleacp Manual "Sustainable Production System".

The following references can be helpful for product selection:

- Practical guide to pesticides and auxiliaries - https://www.astredhor.fr/data/info/43345-Pesticides_et_auxiliaires_complet.pdf
- Side effects manual - https://www.biobestgroup.com/fr/liste-des-effets-secundaires
- Application side effects - https://www.koppert.fr/effets-secondaires/
- Coleacp manual 10 Biological control and integrated crop protection: see 3.4.7. Pesticides and resistance management (IRAC groups)

4.5. LAYOUTS AND PRACTICES WHICH PROMOTE WILD PARA-AGRICULTURAL SOIL BIODIVERSITY

Light soil work, permanent plant cover, the rotation of crops with different root systems and significant organic conditioner is recommended to promote wild para-agricultural biodiversity of the soil. The first three are part of conservation agriculture, which was officially defined by the FAO in 2001 (see Chapter 3). It consists of three major principles which must be applied simultaneously: soil cover, no-till farming and crop diversification. Sowing is done under a quasi-permanent vegetation cover which protects the soil and manages weeds when there is no tillage.

4.5.1. Light soil work

Tillage causes major disruption to the environment. It results in the abrupt disappearance of a food resource for many species of vertebrates and invertebrates and it (temporarily) exposes pedofauna to the weather and predators. The abiotic factors (physical and chemical conditions) which interact with the soil micro-organisms (bacteria and fungi) also slip quickly from one equilibrium to another (for example, from an anaerobic environment without light to an aerobic environment with a lot of light). Deep ploughing aggravates these phenomena and is particularly harmful for soil macrofauna and, notably, for earthworms and the larvae of auxiliary insects which spend part of their life cycle in the soil. Likewise, frequent tilling aggravates the impact of soil work on biodiversity.

No-till farming or farming techniques which do not use ploughing or only work the soil superficially without turning it over, like SCT (Simplified Cultivation Techniques), are preferable.

Note: Tillage can have other harmful consequences which are less directly tied to biodiversity, like easier erosion, increased runoff, etc.

Why use SCT?

These techniques improve biodiversity and make the soil less sensitive to other deterioration processes. Avoiding the loss of structure caused by ploughing and allowing the crop waste to remain in the upper cm of the soil creates a habitat which is favourable for organisms, and all of the soil's properties are enhanced. The increase in organic matter in the first cm of soil provides an indispensable reserve of nutrients which enables the growth and activities of living beings. As a result, the entire food chain benefits when ploughing is eliminated.

Advantages and disadvantages

Advantages	Disadvantages
• Energy savings for soil work • Investment savings (machinery and tools) and lower maintenance and use costs • Preserves soil microfauna and microflora	• Makes weed control more complicated • The water consumption of crops can increase • Potential acidification of the soil

Technical recommendations

The move to SCT must be done gradually in order to adapt the crop work to the pedoclimate conditions of each plot. It is recommended that the technique selected be tested on a small area before generalising it to the farm. The earth must be worked when it is dry, both at the surface and in depth, to minimise compacting and to retain the benefits gained by eliminating ploughing. In addition, enhanced monitoring of the plots is required to detect pests and stricter management of the field edges is needed to limit weed invasions. It is also recommended that pH testing be done when switching to SCT to prevent any acidification due to the accumulation of crop residues and organic matter in the first centimetres of soil. Prior to transitioning to direct seeding, it is important to correct any drainage and levelling problems (the plots in wetter areas must be well managed).

Other key aspects must also be taken into consideration:

- Sowing

The significant presence of crop waste will have an impact on sowing conditions. The positioning of the seeds in the soil and the contact between soil and seed must be adequate to ensure that the crop takes.

- Weed control

Weed control is the main difficulty encountered by farmers when using simplified cultivation techniques. SCT encourage the development of plants with rhizomes without necessarily helping their dispersion. In this case, very superficial and localised soil work will eliminate the weeds. On the other hand, from a quality standpoint, there is a long-term impoverishment and specialisation of flora. Annual grasses normally benefit most from simplified cultivation techniques.

One solution to fight weeds is to create cover which competes with the weeds developing under the crop waste. Thanks to intercropping, which often solves the problem of excess nitrogen, weed control is better integrated in this sustainable farming system. The dynamics of populations evolve with the techniques selected. They will not be the same in a conventional "tillage" system as they are in a SCT or direct-seeding system.

- Residue management

Crop residue is essential to SCT because it enables the production of organic matter and, therefore, facilitates the development of all forms of soil fauna and flora. The harvesting method used also has a significant impact on the quantity and distribution of residue. Movement must be limited in the fields to prevent surface packing and reduce the impact of harvesting on the physical structure of the soil.

Examples and references

- Limiting soil erosion with conservation tillage - http://www.gtdesertification.org/Publications/Limiter-l-erosion-des-sols-grace-au-labour-de-conservation
- Minimum disruption of soil structure - http://www.fao.org/conservation-agriculture/in-practice/minimum-mechanical-soil-disturbance/fr/

4.5.2. Permanent plant cover

Permanent plant cover protects the soil from erosion, facilitates the presence of micro-organisms and insects in and on the soil and provides organic matter to the soil. The goal of every agricultural production system should be to have a very high leaf area index in both cultivated areas and fallow areas.

Permanent soil cover plays a key role in agricultural systems which are productive and respectful of the environment. In addition, it is important for:

- protecting the soil against the destructive effects of wind and the sun and for reducing runoff and erosion;
- sequestering carbon, therefore contributing to reducing the greenhouse effect;
- increasing the formation of humus and biological activity in the soil by protecting and providing food for the macro and micro-organisms living in it;
- creating a micro-climate favourable to the development and optimal growth of plant roots and the organisms living in the soil;
- limiting the decrease in the amount of organic matter in the soil.

Advantages and disadvantages

Advantages	Disadvantages
• Restructures the soil by improving porosity and facilitating the infiltration of water, therefore, meeting plant water needs • Reduces erosion >> decreases soil fertility degradation • Prevents the formation of a slaking crust • Protects the soil from high temperatures • Provides organic matter to the soil and nitrogen in the case of legumes • Increases the presence of organisms/ micro-organisms and beneficial insects in and on the ground • Stabilises yields over the long term • Controls weeds (makes soil work easier) • Reduces production costs and sustainably increases economic returns • Promotes carbon sequestration • Reduces deforestation by limiting slash-and-burn practices • Can provide fodder for animals • Can produce food for humans	• It's difficult to use mechanical methods to control the vegetation cover over large surfaces in hot and humid areas • Requires investment to implement and, if necessary, an understanding of cover plants • Creates a risk of water and soil pollution if herbicides are used • Can increase the time required for plant cover maintenance to prevent competition with crops • Sometimes involves the purchase of seeds to implement the plant cover, when they are not available locally • The fertilising effects of the plant cover are not evident immediately • Sometimes requires the use of inputs when the technique is first used

Examples and references

- **Permanent cover** is provided by live (cover plants) or dead plant mulch (straw). This can be achieved in different ways:
    - by leaving the waste from the previous crop on the ground,
    - with natural vegetation
    - with cultivated plants (intercropping or catch crops) which, in addition to their soil protection function, can also be used for human and livestock food production.
- **Cultivation Systems using Vegetation Cover (SVC)**

These systems consist in recreating forest ecosystems where litter continuously protects and fertilises the soil.

The humid tropical zone is essentially a fragile environment which can deteriorate quickly if the crop methods used are not suitable. SVCs provide a practical alternative to itinerant slash-and-burn agriculture. SVCs include all cultivation systems based on the fundamental principle of permanent soil cover. The practice has a dual protection and fertilisation purpose.

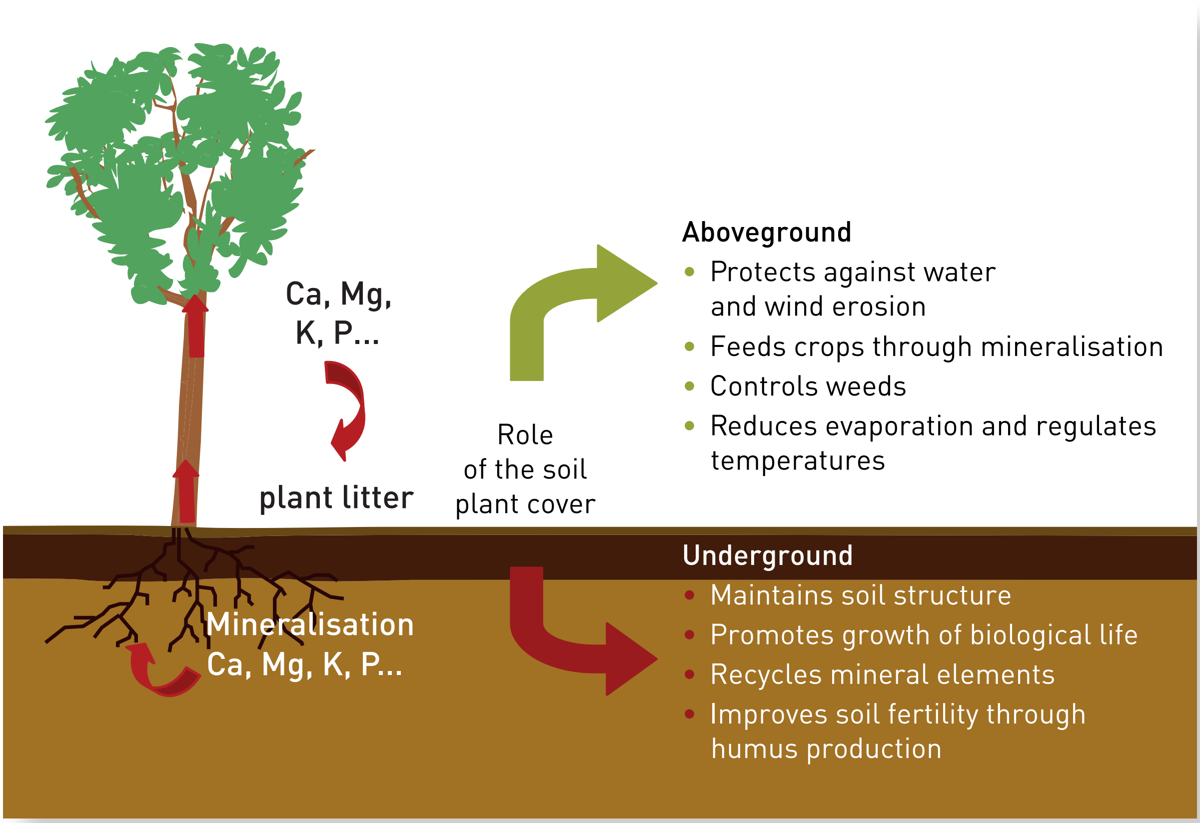

Figure 27: SVC principles
Source: www.agrisud.org/wp-content/uploads/2013/05/Guide_Francais.pdf

The vegetation cover can consist of dead mulch (mulch brought in or resulting from the in situ decay of cover plants) or a living plant (cover plant) associated with the main crop.

The use of SVC varies depending on the cultivation systems and depending on the provenance and production period of the vegetation cover. However, in all cases:

- the soil must always be covered;
- the soil should not be worked or tilled, or only minimally;
- sowing, transplanting and planting must be done directly in the dead or living vegetation cover.

Five systems are used:

- **SVC on harvest residue and weeds:** the vegetation cover is provided solely by the harvest residue and weeds which have grown during intercropping.
- **SVC with imported dead cover:** the ground is covered with straw from neighbouring plots.
- **SVC with dead cover produced on site:** the dead cover is produced immediately before or after the main crop. E.g. A maize crop on velvet beans.
- **SVC with permanent cover in alternating strips:** dead and live strips alternate on the same plot. The live strips are cut and the straw is spread over the dead strips. For example, a banana plantation on dead strips alternating with live Brachiaria strips.

- **SVC with permanent live cover:** the cover plant and the main crop are grown together on the same plot. For example, palm oil or rubber trees on Pueraria.

The cover plants used produce a significant amount of biomass and have a root system which structures the soil in depth. Depending on their characteristics, the cover plants can provide a range of benefits including nitrogen, feed for livestock, etc. The choice of cover plants is, therefore, not random. Brachiaria, Stylosanthes, Mucuna and Pueraria are among the main cover plants used in SVC.

- **Mulching**

Mulching consists of covering the ground with a dead cover as opposed to a live cover made up of soil-improving plants left in place.

Mulching has several benefits:

- No investment is required,
- Technical requirements are low.

Disadvantages include:

- The risk that the plot will be invaded by weeds if they are left in the field or brought with their seeds. They must be cut before fruiting.
- A risk of contamination if the crops are not rotated because the parasites from the previous crop can survive in the cut straw.

- **Rotations and combinations of crops with different root systems**

Thanks to the differences between the root systems of the crops used, crop rotation works like a biological pump given that it brings up and recycles minerals located in the deep soil layers. This function is important for limiting leakage outside of the cultivated system and to improve or restore poor soils to make them productive.

In addition, the rotation of several plant species diversifies soil flora and fauna because their roots secrete different organic substances which attract a range of bacteria and fungi. Micro-organisms then play an important role in transforming the substances secreted into nutritional elements for the plant. Crop rotation is important for phytosanitary control to the extent that it breaks down the transmission chains of the pathologies specific to certain plants.[102]

The advantages and disadvantages of crop rotation were covered in point 4.2.2.1.

Examples and references

- Plants draw elements from the soil in different ways depending on their root systems. Herbaceous plants with fasciculated roots (Allioideae, banana trees) explore the uppermost layers, herbaceous plants with pivotal roots (carrot, legumes) use a volume slightly lower down and perennial ligneous species (fruit trees, ligneous legumes) use the deep layers of the soil.[103]
- Utilising Differences in Rooting Depth to Design Vegetable Crop Rotations with High Nitrogen Use Efficiency (NUE) - http://orgprints.org/256/1/ActaHort_utilising_differences.pdf

102 http://www.fao.org/ag/ca/fr/1b.html

103 http://agritrop.cirad.fr/578300/1/Guide+tropical+TBD+new.pdf

Other references

- Indication of rooting depths in https://www.gardenorganic.org.uk/sites/www.gardenorganic.org.uk/files/resources/international/RotationsinVegetableProduction.pdf

4.5.3. Significant organic conditioning

The fertiliser used for horticulture should be primarily organic. This enables a better balance between fertilising elements and the gradual release of nitrogen. In addition, the increase in organic matter in the soil increases its ability to absorb water, its structure and, therefore, its aeration and its power to act as a buffer and mobilise minerals. Microbiological activity and diversity are also enhanced, including in terms of antagonistic microflora level which contributes to controlling soil disease agents and phytophagous nematodes. For example, doses of 100 t/ha of matter before each crop cycle in Morocco.[104]

Advantages and disadvantages

Advantages	Disadvantages
• Captures organic soil carbon • Helps to the reduce the CO_2 (greenhouse gas) in the air • Increases the soil's ability to retain water and nutrients • Increases microbiological activity and diversity	• Transport costs • Potential source of soil diseases • Difficult to obtain sufficient quantities • Heat can cause deterioration more or less quickly

Technical recommendations

While organic manure can have a positive impact on plant growth and help prevent phytosanitary problems, only high-quality manure or compost should be used, i.e. which has properly decomposed. Otherwise, there is a risk that the soil will be enriched with the seeds of weeds and a range of pathogenic bacteria. In the case of composting, this means that the matter must be aged properly (high temperature within the mass, the compost pile must be turned over to ensure consistent quality).

In tropical areas, the application of rich organic matter to provide fertilisers should normally be done before each sowing/planting because the mineralisation rate is elevated and quick. However, not too much should be used! Excessive use of fresh organic matter which is insufficiently decomposed or rich in nitrogen before planting can result in problems in the plants and in environmental pollution.

Some crops prefer fresh organic matter (Cucurbitaceae) while others don't (Allioideae, in particular). Generally speaking, after fresh manure has been applied, a wait period of 1 to 2 months is recommended before sowing or planting.

104 Integrated Production and Protection applied to vegetable crops in Sudano-Sahelian Africa - http://www.fao.org/3/a-az732f.pdf

Examples and references

- **Green fertilisers**

  Their purpose is to:

  - enrich the soil, notably by using legumes to fix atmospheric nitrogen;
  - provide organic matter by burying the green fertiliser in the ground. It then decomposes and creates humus;
  - structure the soil;
  - simultaneously eradicate certain weeds by turning over the earth;
  - control weeds throughout the growth of the green fertilisers through direct competition for light, nutrients and space,

    See technical sheet no. 10 http://www.gret.org/wp-content/uploads/guide-pratique-agroecologie_pdf.pdf and Sheet no. 2: Green fertilisers - http://www.ecofog.gf/giec/doc_num.php?explnum_id=1742

- **Ramial Chipped Wood (RCW).**

  Sheet n° 7 in - http://www.ecofog.gf/giec/doc_num.php?explnum_id=1742

- **Worm composting**

  - Video - https://www.accessagriculture.org/fr/les-merveilles-du-ver-de-terre
  - Sheets no. 5 and 6 - http://www.ecofog.gf/giec/doc_num.php?explnum_id=1742

4.6. HOW TO PRESERVE THE BIODIVERSITY OF AREAS NEAR THE FARM

The biodiversity in the areas surrounding the farm is protected primarily by planning areas which prevent potential disruptions resulting from the use of certain inputs such as Plant Protection Products and fertilisers. In some cases, continuity between natural areas surrounding the farm must also be ensured via corridors.

Sufficiently large grass strips (or wooded) are among the most important elements for avoiding disruptions.

In essentially agricultural areas, the landscape will be primarily influenced by the use made of the farms' UAAs. The types of crops grown and of AEI/AEU maintained on the farms will create the landscape. Farms taken individually will have little impact on the landscape; however, the landscape will be created by all of the farms together.

Farmland used to be subject to farming practices which were respectful of the landscape's biodiversity. The increase in demographic pressure on land and commercial and industrial farming have led to the disappearance of a large number of these practices. However, certain communities continue to use some of the traditional practices, despite the growing demographic pressure on land. Nearly all villages in Benin contain islands of "*sacred forest*". They are highly protected by the village residents. They are often used for offerings during traditional rites and ceremonies. They play an important role in the preservation of biodiversity by providing a natural habitat to a number of animal and plant species.

In Rwanda, agriculture is forbidden along roads, waterways and bodies of water. Although this measure is primarily intended to protect these sites, it also contributes to protecting and restoring biodiversity. The Assisted Natural Regeneration (UICN and MEDD, 2011) used in Burkina Faso on cultivated and non-cultivated areas is also a technique, which once put into practice, makes a substantial contribution to restoring biodiversity. The diversification of agricultural production and crop rotation are proven to improve biodiversity. Living fences, long-term fallow, flower fallow and windbreaks provide ecological habitats in agricultural landscapes. Fences, and notably barbed wire fences separating crop areas from natural areas, help to preserve biodiversity by preventing the expansion of cultivated land at the expense of natural areas.

Figure 28: Protection measures for natural areas vs. agricultural areas
a) 110 km barbed wire fence along the Akagera Park in eastern Rwanda, b) stone wall,
c) herding post by children, d) traditional beekeeping at the edge of the Virunga Park in northern Rwanda.
Source: https://www.researchgate.net/publication/280234192_The_effects_of_human-wildlife_conflict_on_conservation_and_development_a_case_study_of_Volcanoes_National_Park_northern_Rwanda

Resolution ACP-EU 3916/06/fin. of the Joint Parliamentary Assembly issued several recommendations regarding sustainable water management in ACP countries. A number of draft integrated water resource management projects have been prepared in several ACP country regions. However, the implementation of concrete actions on the plots has been slow. Efforts have been far more focused on strengthening institutional capacities. The laws and regulations of some countries provide for the protection of water points. The preparation and effective implementation of these laws will also contribute to preserving and restoring ecological habitats.

Beekeeping associated with agriculture, and particularly perennial crops like coffee, cocoa, cashews, mangoes, etc. helps to strengthen biodiversity and also improves agricultural productivity and food security.

4.7. OTHER LAND USE FOR A RANGE OF PURPOSES WHICH ALSO HAS A POSITIVE IMPACT ON BIODIVERSITY

Other land use for a range of purposes can also have a positive impact on biodiversity. These uses include:

- The prevention of flooding and silting (e.g. grass strips, living fences, measures to control erosion, prohibiting planting alongside waterways and bodies of water, etc.).
- Rainwater management (e.g.: rai nwater collection basins/ponds, measures to control erosion, vegetation cover, plot mulching, etc.).
- Water quality management (e.g.: wastewater treatment, phyto-purification or lagooning, water protection zones, etc.).
- Desilting of waterways and bodies of water.
- Reforestation of marginal or degraded land.

a) Rainwater collection in Kayonza/Rwanda

b) Phyto-purification (filtering of wastewater using plants) parc du chemin de l'île/France[105]

c) Radical terraces in Rwanda[106]

d) Mangrove reforestation in Senegal[107]

Figure 28: Layouts for water resource management
Sources: a) Mulindabigwi, V. 2008
b) https://www.aujardin.info/fiches/filtrage-eaux-usees-plantes.php
c) https://ec.europa.eu/avservices/photo/photoDetails.cfm?sitelang=fr&ref=028999#14
d) http://www.ideecasamance.net/index.php?page=activity

105 https://www.aujardin.info/fiches/filtrage-eaux-usees-plantes.php
106 https://ec.europa.eu/avservices/photo/photoDetails.cfm?sitelang=fr&ref=028999#14
107 http://www.ideecasamance.net/index.php?page=activity

The reforestation of marginal or degraded land or of mangroves, the desilting of water points and waterways, the protection of banks, the protection of waterways and water points against silting and/or pollution, the improvement of pastures and cultivated land via tree planting and the installation of windbreaks can have a positive and durable impact on biodiversity if the measures are based on a **regional land use master plan.** It is extremely important for the allocation of land for different uses (agriculture, livestock, housing, waterways and bodies of water, infrastructure, natural areas, etc.). When there is no plan, or it is not implemented, the result will unfailingly be the erosion of biodiversity due to demographic pressure on ecological habitats.

The UICN and the Burkina Faso Ministry for the Environment and Sustainable Development have jointly produced a catalogue of best practices for the adapting to climate change in Burkina Faso which are, in fact, also very effective practices for preserving and restoring biodiversity (UICN and MEDD, 2011). The catalogue describes and groups the practices in the following categories:

- Soil management (stone diguettes), filtering dykes, grass strips, zaï[108], half-moons, mulching, fixing of dunes, improved fallow, areas forbidden to livestock, development of low-lying areas)[109].
- Water management (micro-irrigation with basins, ramp systems, surface water retention: dams and reservoirs, rainwater collection or intake areas, wells and boreholes, fish ponds, digging out of natural ponds, protection of water point against silting).
- Forestry and agroforestry (controlled clearing, assisted natural regeneration, reforestation/afforestation, windbreaks, firebreaks, setting of banks, forest planning and management, arboretums and botanical conservatories).
- Agricultural inputs and techniques (improved seeds, no-ridge and tie-ridge tillage, scarifying, subsoiling, composting, crop combinations, crop corridors, off-season crops, combination of market gardening/arboriculture and vegetable gardens).
- Animal resources (mowing and storage of fodder, forage crops, livestock mobility and seasonal transhumance practices)[110].
- Energy (use of solar energy, solar energy conversion, improved cook stoves).

The list can also include other practices depending on the climate, topographical, pedological and geological conditions of each area: radical terraces, anti-erosion ditches, agriculture/livestock coupling, manure barns, animal improvement, seed and/or gene banks, bank protection, ravine treatment, protection of legally protected wildlife and plant species on the cultivated plots, etc.

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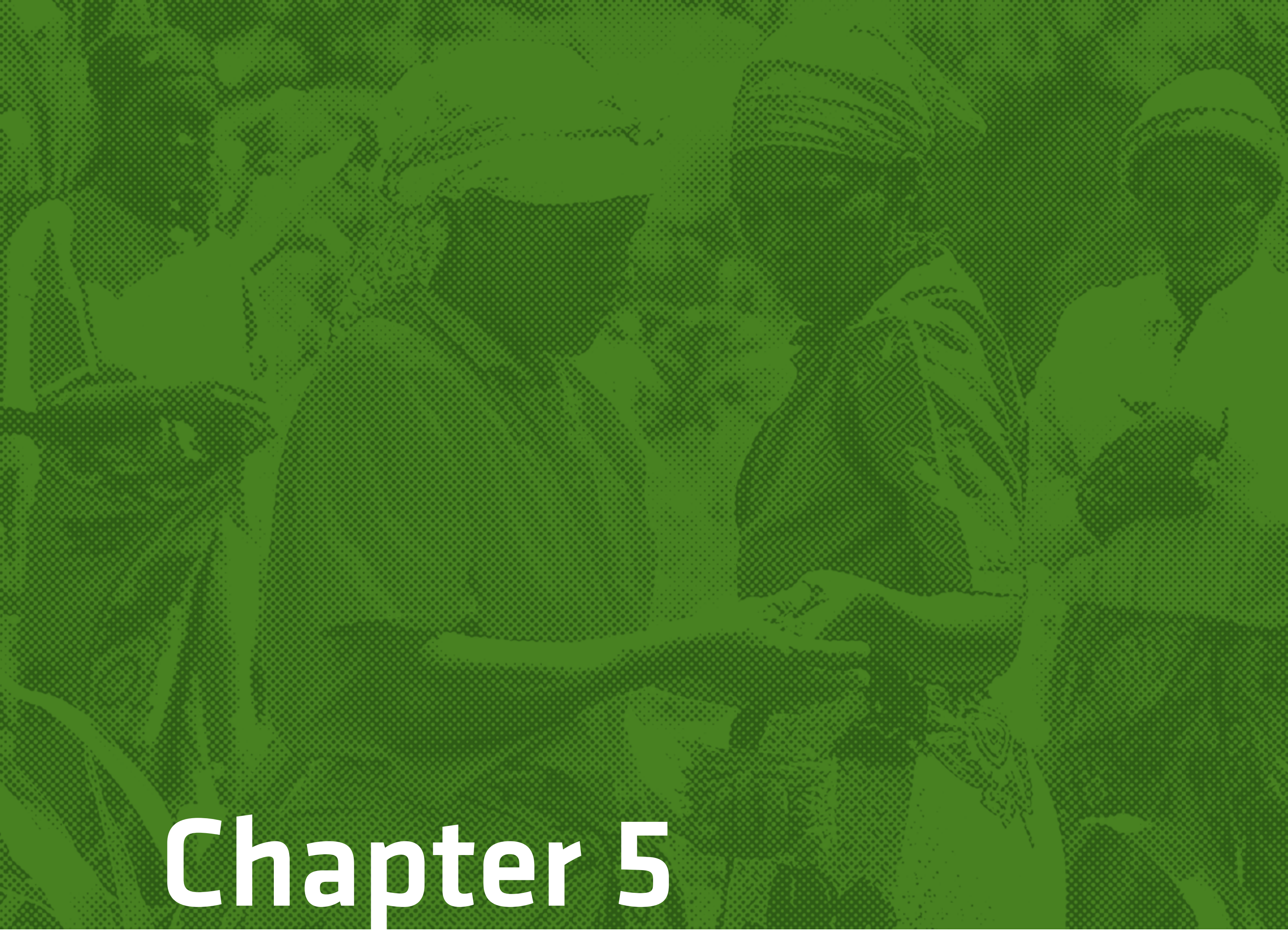
108 zaï: *"a farming technique particularly well-suited to 'zipellés', crusted pedological and significantly degraded surfaces. It was long considered anecdotal by researchers but is now a technique recognised by the Conservation des Eaux et des Sols (CES) (Water and Soil Conservation)".* https://fr.wikipedia.org/wiki/Za%C3%AF_(agriculture)

109 Other practices, such as radical terraces and anti-erosion ditches like those used in Rwanda can be included in the list.

110 Other practices can be added to enrich the list. They include manure barns, animal improvement, agriculture/livestock coupling.



Chapter 5

Case study

5.1. INTRODUCTION

Pedagogical objectives

From this case study, the trainee will learn to:

- Analyse a situation which closely reflects reality.
- Propose the observations, measurements or analyses to perform and determine the additional information necessary to complete an assessment of the biodiversity of a farm and its immediate surroundings.
- To create an assessment plan and carry it out based on the information available and following the methodology proposed in Chapter 2.
- To propose, based on the results of the assessment and acquired theoretical knowledge, a set of suitable solutions to sustainably preserve, restore or improve biodiversity based on the cases.
- Develop a coherent action plan to be implemented in order to achieve an acceptable level of biodiversity and its sustainable management.

5.1.1. A case study: why?

Why a case study?

Working from a theoretical case will never replace professional experience which was earned in the field, dealing with the realities of production. Nonetheless, **methodological principles can be learned from an example, drawn from previously encountered situations,** to analyse a situation, determine the nature and origin of certain problems encountered and propose an effective and profitable path forward which is compatible with sustainability objectives.

Here's a training exercise for you!

A case study must not offer a "simple recipe" in which the ingredients always result in the same solutions. On the contrary, it must enable you to **understand the complexity of the situations which can occur and require a case-by-case approach**, with suitable solutions adapted to each situation and the resources which are locally available. **You must be able to understand**, on your own, **the "why" behind your problems and determine "how" a sustainable improvement of the situation can be achieved** by assessing the cost-benefit relationship of each theoretically possible solution.

How can you benefit from this case study to review the various aspects of sustainable biodiversity management and apply what you have retained to a case which could be encountered in practice?

5.1.2. A case study: how is it carried out?

The case study includes **5 parts** which serve as steps in **the exercise to be completed**:

1. **Understanding the situation**: this consists in identifying, by reading a text, the information which is useful to understand a potential situation encountered by a horticultural company (in this case, regarding biodiversity).
2. **Drafting the biodiversity assessment plan:** The assessment must be a tool that assists in deciding on the actions to take to promote biodiversity. The assessment plan must be drafted depending on the situation described. In order to carry out the assessment, observations, measurements or analyses can be proposed and any additional information to be obtained must be listed.
3. **Carrying out the assessment and identifying the shortcomings regarding biodiversity management:** This consists of implementing the methodology, strictly speaking, proposed in Chapter 2. In this part, biodiversity management weaknesses should be identified and acceptable levels to attain should be proposed.
4. **Identifying suitable solutions**: this consists of taking stock of the solutions which would be suitable to rectify each separately identified situation and then seeing if each situation is: (1) effective; (2) profitable; (3) accessible; (4) sustainable.
5. **Proposing an action plan for the farm**: this consists of establishing an implementation strategy which integrates the solutions selected in order to sustainably improve the situation: preserve, restore, improve the biodiversity on the farm and the immediate surroundings.

To benefit from this case study, **you must follow the instructions and complete each step as a personal exercise.** Make use of the theoretical elements found in this manual and consult the websites and useful references cited.

This will provide you with instructions and a set of solutions for each step. You will see the following message:

"Have you completed your portion of the exercise? Bravo! Now compare your results with the proposed solutions, identify the differences and try and understand why your results differ from the proposed solutions. Have you designed a new and/or better proposal? Write out your analysis of the results and your personal insights in a few lines: this will help you retrace the logic behind your approach at the end of the exercise."

Advice before beginning: working with the printed pages of this Chapter and from Chapter 2 will make the task easier.

5.2. PART 1: UNDERSTANDING THE SITUATION

Instructions:

Carefully read this briefing of the difficulties which may be encountered by a horticultural farm. Identify the main elements in the situation described which will help you understand the nature of the farm's problems and have an initial idea of the state of its biodiversity.

If needed, print this page and reread it several times.

(Warning: this is a fictional case. Any resemblance to the situations described, the names or the company name are purely incidental).

5.2.1. Case briefing

Dieudonné Shamba has been the manager of the family-owned business FRUITVERTS sarl for the last 10 years, since the death of his father, who, like his father before him, was a market gardener. It's a mid-sized business (about 15 ha) established on the outskirts of a large city and near a few villages where a good portion of his vegetables are sold. The company produces some of its products on its own land (in particular, green beans and cherry tomatoes), but also works with numerous small local producers who provide fruit (mangoes) and some vegetables (okra, cabbage, chilli peppers, tomatoes, amaranth, etc.) over the course of the year. Products destined for the regional market and for export are sorted and packaged at his packaging plant. Some of the tomatoes purchased from local producers are also processed on site (dried) and packaged. Just 30 km separate the company from its main local market (in the city) and the major port from which luxury products (mangoes, filet green beans and cherry tomatoes) are shipped to Europe.

There are two crop zones on the FRUITVERTS land: one part of the farm (8 ha), furthest from the coastline, is made up of the higher elevation land which is fairly flat and divided into large patches separated by irrigation ditches. Up until now, the somewhat sandy-clay soils were fertile enough to plant export crops. Therefore, green beans (6 ha) for the French market and cherry tomatoes (2 ha) for the Dutch market, are grown each year between September and March-April. The crops are repeated on the same plots year after year. Maize is grown on the plots from May to August (rainy season).

Photo 1 - Crops planted on higher land (beans and cherry tomatoes)

The rest of the lands, which are quite sandy (about 7 ha), slope gently down towards the coastline. They are criss-crossed by channels carved by erosion. Since they are considered less fertile, various vegetable crops (especially tomatoes, chilli peppers and okra), destined for surrounding markets, are planted on the slope. Maize is also grown during the rainy season. The crops are distributed on small areas of a few ares, once separated by hedges which have mostly disappeared today. These small patches occupy the land from the top of the bank to the bottom of the slope where a large pond serves as a water reservoir to irrigate the crops. Dieudonné has planted several fruit trees on the slope to retain the earth and provide a bit of shade to his nurseries. As far back as he can remember, Dieudonné has always employed this crop distribution. The surrounding villages are spread along the coastline, following the major road which runs towards the city. Each villager owns a small orchard of mango trees and a few patches where vegetables (tomatoes, melons, aubergines, etc.), maize, sorghum and groundnuts are grown depending on the season.

Photo 2 - A small producer's cultivated patch

Dieudonné noticed, when examining his accounts, that the revenue he earned from his farm over the past two to three years fell significantly. However, sales prices have had the tendency to rise with the growth of the villages and the city, where there is a strong demand for fruits and vegetables. We must, therefore, conclude that his overall production has fallen! His company produced significantly fewer green beans and cherry tomatoes (the yields for these crops have fallen the most). For the other vegetables (tomatoes, okra or chilli peppers), the decline in production has not been as spectacular but it no longer reaches the levels of previous years despite repeated purchases of fertilisers and phytosanitary products. Unfortunately, the small producers have not been able to compensate for this production deficit, even though he has pushed them to produce as much as possible by increasing in size and has distributed compound fertilisers and phytosanitary products to them. Recently, European importers are requiring that Dieudonné follow specifications which aim for sustainable development and include a "biodiversity" component. The implementation of this biodiversity component requires that Dieudonné carry out a diagnosis (an assessment) and implement an action plan to improve the biodiversity on his farm and preserve the biodiversity of his farm's surroundings. Dieudonné recently visited a farm which practices agroecology. During the visit, the owner emphasised the importance of promoting biodiversity through suitable practices on the farm. Dieudonné was impressed by the yields obtained on this farm. He would also like to promote biodiversity on his farm, but doesn't quite know how to start.

To produce his green beans and cherry tomatoes, Dieudonné carefully prepares his land with a tractor, ploughing 30-40 cm deep to bury weeds and the residues from previous crops (notably, maize cultivated during the rainy season). Dieudonné also doesn't skimp on inputs. He increased the amounts of NPK fertilisers (10-10-30) applied in addition to fresh manure, which he ploughs under. He ensures that his crops are treated with phytosanitary products (insecticides, fungicides) multiple times during the season to hopefully increase yields. For two years now, he has even applied selective herbicides to the beans, tomatoes and maize (Atrazine) to keep the soil clean and limit competition from weeds. Lastly, he also increased irrigation water inputs over the last five years so that the beans and tomatoes could fully benefit from the fertilisers and phytosanitary treatments. He installed a large motor pump on the pond to irrigate the green beans and tomatoes more often by filling the ditches which criss-cross the fields. Nothing has improved.

His plants are sometimes affected by diseases (fusariosis, for example) which are treated with fungicides, but, in general, the leaves of the beans and tomatoes are a very dark green colour. On the other hand, during very hot periods, they have a tendency to wither more quickly. Dieudonné pulled some plants, but didn't find any traces of root-knot nematodes or collar rot on the roots. He doesn't understand what is happening.

Dieudonné's hard work has clearly not been rewarded. He needs help resolving his yield issues and ensuring the proper management of biodiversity on his farm. Can you help him?

Is there sufficient biodiversity on his farm? Does he need to change his practices to promote biodiversity? Will that enable him to reduce his input needs, improve his yields, reduce erosion problems, etc.? What must he do to respond to the importers' requirements?

- *On a sheet of paper, try to* ***sort*** *and* ***list*** *the information to retain from the briefing which will be useful for the analysis, such as the* ***problems and practices*** *(without reading further).*

5.2.2. Analysis of the situation described

Have you completed your portion of the exercise? Bravo! Now compare your results to the proposed solutions, identify the differences and try and understand why your results differ from the proposed solutions. Have you designed a new and/or better proposal? Write out your analysis of the results and your personal insights in a few lines: thiswill help you retrace the logic behind your approach at the end of the exercise.

Proposed solutions:

- *Information from the description*

General information:

- The company diversified its products and markets. It produces all year.
- The farm produces green beans and cherry tomatoes for export. It also produces maize, tomatoes, okra and chilli peppers for the local market.
- The company has existed for a long time.

- The soils are mostly soft and lightweight (clay-sand in the upper lands and sandy elsewhere). This is, a priori, favourable to bean and tomato crops, which prefer more lightweight soils.
- There is a large pond at the bottom of the farm.
- Hedges once delineated the small patches in the lower area of the farm, but have now almost entirely disappeared.
- A few fruit trees were planted on the sloped part of the land.
- The company purchases a portion of the production of small producers. They grow mangoes, tomatoes, okra, cabbage, chilli peppers, amaranth, melons and aubergines. During the rainy season they cultivate sorghum, maize and groundnut.
- The company pushes the small producers in the same direction in terms of practices (heavy use of chemical inputs).

Problems:

- Production has fallen. This is also the case for the small producers, where fertility has declined. The decline in production is regular and does not seem to be attributable to uncontrolled parasitic pressure.
- The sloping lands are subject to water erosion.

Farm practices:

- Crop diversity:
  - It is limited on the upper lands (beans or tomatoes/maize).
  - It is greater on the rest of the farm.
- Rotations:
  - The same crops often follow each other year after year on the same plots, and the cultivation practices do not change much.
  - On the upper lands, the annual rotation consists of a maize crop after tomatoes or green beans. The beans/tomatoes alternation is theoretically effective but since the proportion of green bean fields is significant (3/4), the alternation can only be carried out after a certain number of years.
- Plot size:
  - The upper lands are divided into large patches and the lower lands are divided into small patches of a few ares each.
- Use of Plant Protection Products:
  - Pesticide use is frequent and generalised due to crop repetition. It offsets the pressure from insects and diseases.
  - Herbicide treatments are carried out (in particular: Atrazine, selective herbicides for maize and other herbicides on green beans and tomatoes for export).

- Tillage:
    - Light ploughing is performed (tractor passes over the upper lands) each year.
- Conditioners:
    - Crop residues (maize) and fresh manure are buried when preparing the soil just before sowing/planting.
- Fertilisers:
    - High quantities of fertilisers are applied to the crops in the form of compound chemical fertilisers.
- Irrigation:
    - Large amounts of water are brought to the crops gravitationally, using a motor pump which pumps from the pond below.

Complementary analysis (area for notes)

- *Information from the description*

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5.3. PART 2: DRAFTING THE FARM'S BIODIVERSITY ASSESSMENT IMPLEMENTATION PLAN

5.3.1. Instructions

To improve the biodiversity on Dieudonné's farm and to preserve the biodiversity of the immediate surroundings, the existing level of biodiversity on the farm and the level of protection of the neighbouring biodiversity must first be evaluated. This consists of implementing the methodology proposed in Chapter 2 of this manual. Before completing this assessment, an implementation plan must be created, by following the steps listed and elaborated below.

Step 1: Begin by listing the necessary preliminary information.

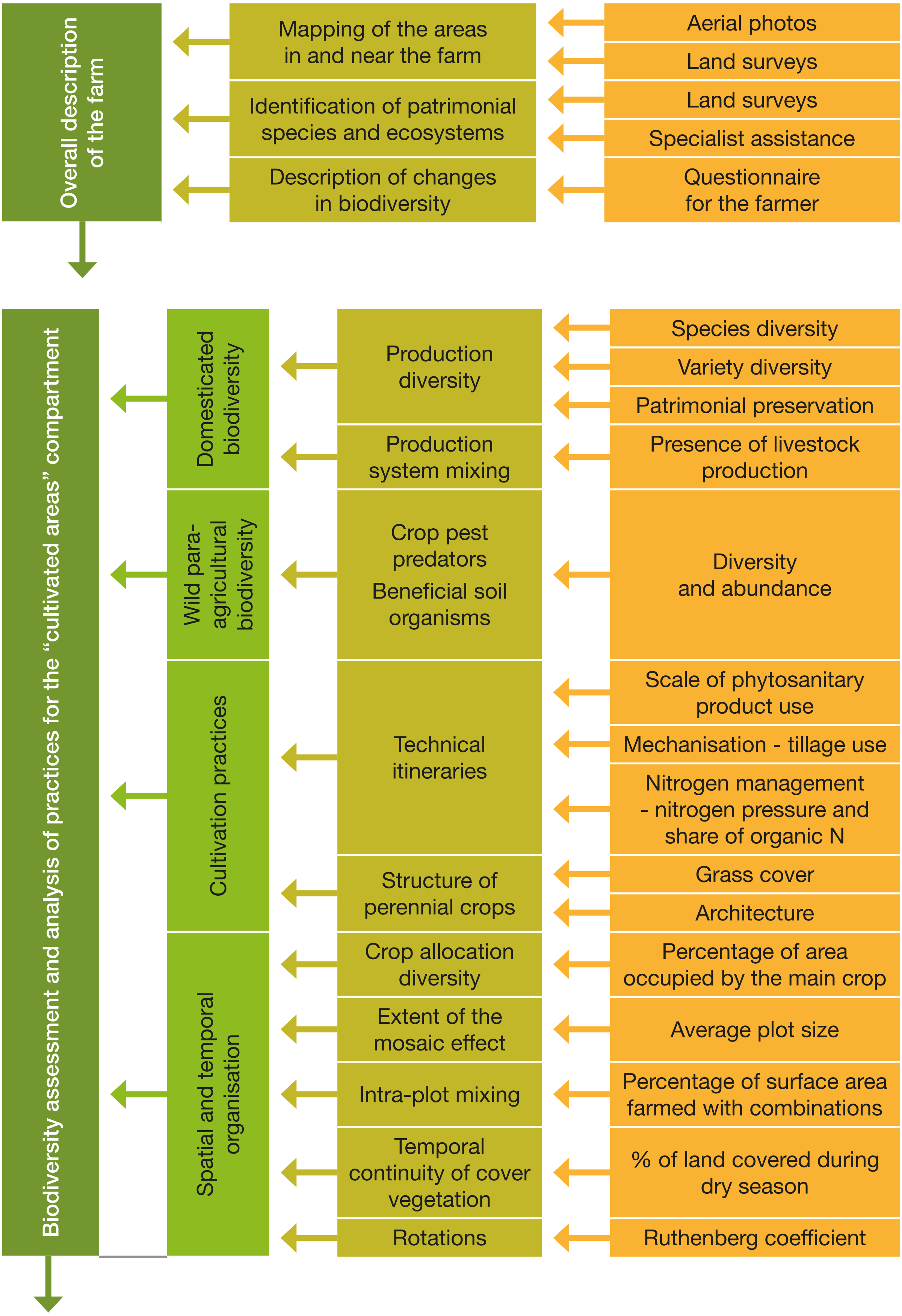
Step 2: Next, fill in the table, listing the types of areas to take into account to determine the assessments to be done (follow the order of the proposed methodology).

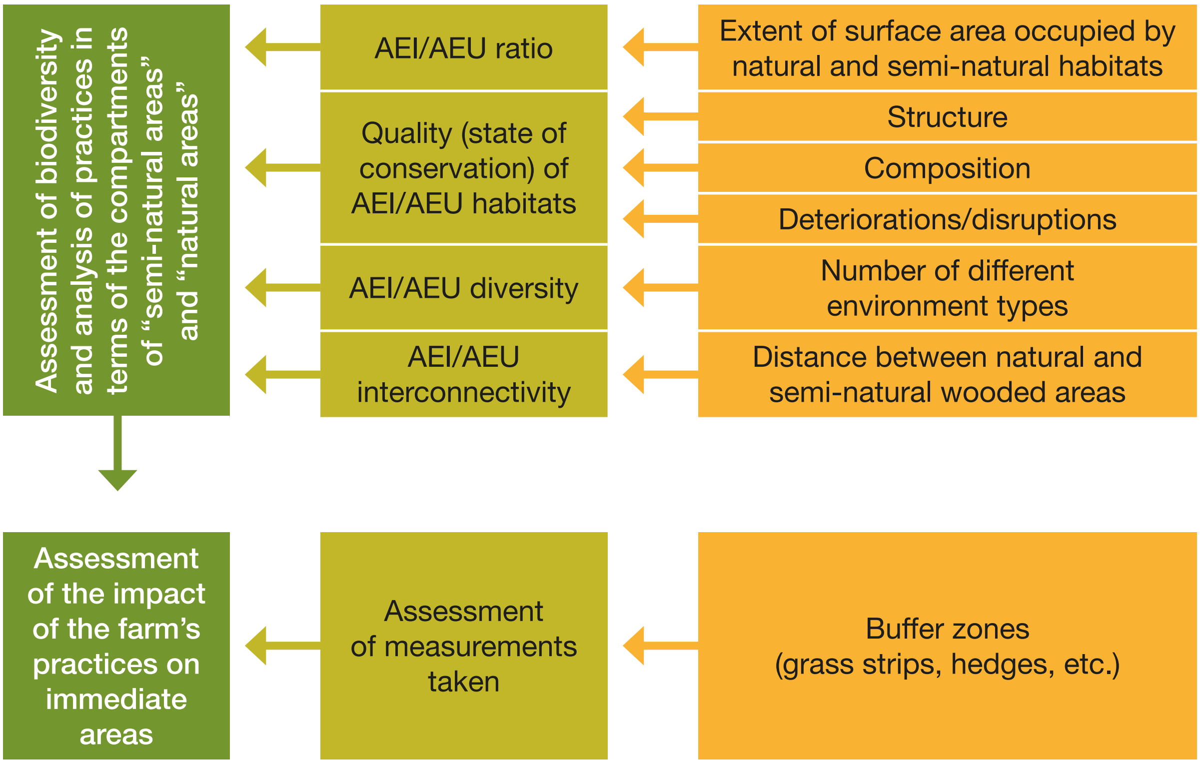
Step 3: Next, for each type of assessment, create the indicator aggregation diagrams and identify the data and information missing in order to carry out the assessment.

Step 4: When finished, list the information and data to be obtained by categorising them and indicating the analyses, measurements and observations to perform.

The small farmers who supply Dieudonné are not taken into account here. They must each be analysed separately or by group if they occupy adjacent land.

The methodology proposed in Chapter 2 is illustrated schematically in the flowchart below.





- ***Step 1: Preliminary information***

  Preliminary information is required to complete the following table in step 2. List them (without looking at the solutions), then compare them (solely for the preliminary information) with the solutions proposed further down in Point 5.4.2.2.

- ***Step 2: Creating the table of assessments types to be done***

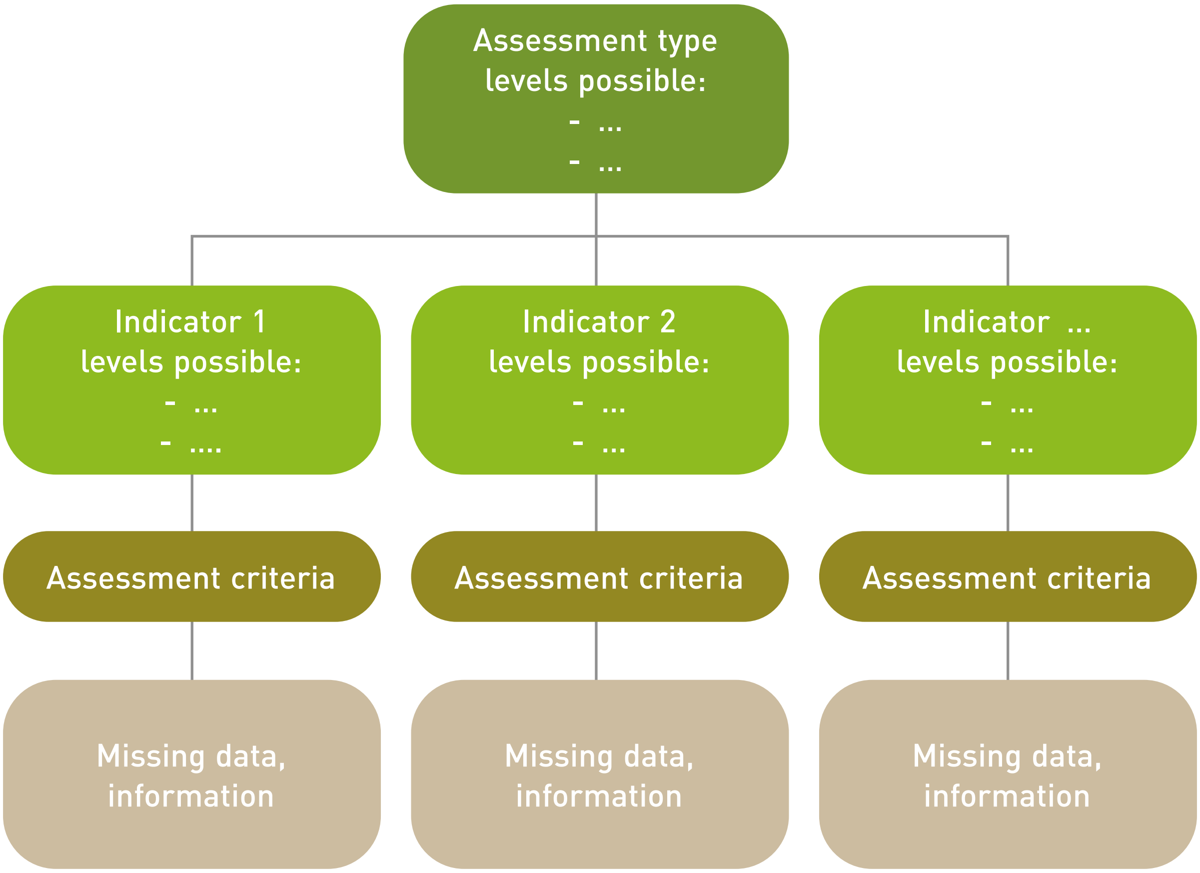
  Based on the information provided in Part 5.4.2.3., regarding the results from the preliminary information, fill out the table using the model below (if necessary, add rows to the table). This will make it possible to determine the types of assessments to carry out depending on the areas found on and near the farm belonging to the different compartments.

Table (example to print and complete)

Compartment type	Area type	Type of assessment to complete

- ***Step 3: Establishing the diagrams by assessment type***

  Based on the previous table, establish an indicator aggregation diagram for each assessment type retained. Using the model provided below, enter the name of the assessment type and the indicators and include the various levels possible each time. Then, for each indicator, provide the assessment criteria and the data/information missing in order to carry it out.



- ***Step 4:** Lastly, make a categorised list of the **observations, analyses and measurements which would need to be performed** and/or the **additional information** which would need to be obtained before the next step, which is the actual assessment of the biodiversity on the farm.*

  The categorisation should be done by compartment (compartment of cultivated areas, compartment of natural and semi-natural areas, compartment of areas in the farm's immediate surroundings), and then by type of biodiversity or practices to be assessed.

5.3.2. Proposed solution

Have you completed your portion of the exercise? Bravo! Now compare your results to the proposed solutions, identify the differences and try and understand why your results differ from the proposed solutions. Have you designed a new and/or better proposal? Write out your analysis and your personal insights in a few lines: this will help you retrace the logic behind your approach at the end of the exercise.

5.3.2.1. Proposed solutions: preliminary information (Step 1)

1. Describe the farm overall using the **mapping of the plot** and **measure the areas occupied by AEI/AEU.**
2. Collect information on the **history of biodiversity management** on the farm and its evolution.
3. Ask what the **primary pests of the main crops** are and during which times of the year they are most present.

5.3.2.2. Proposed solutions: table of assessment types to be carried out (Step 2)

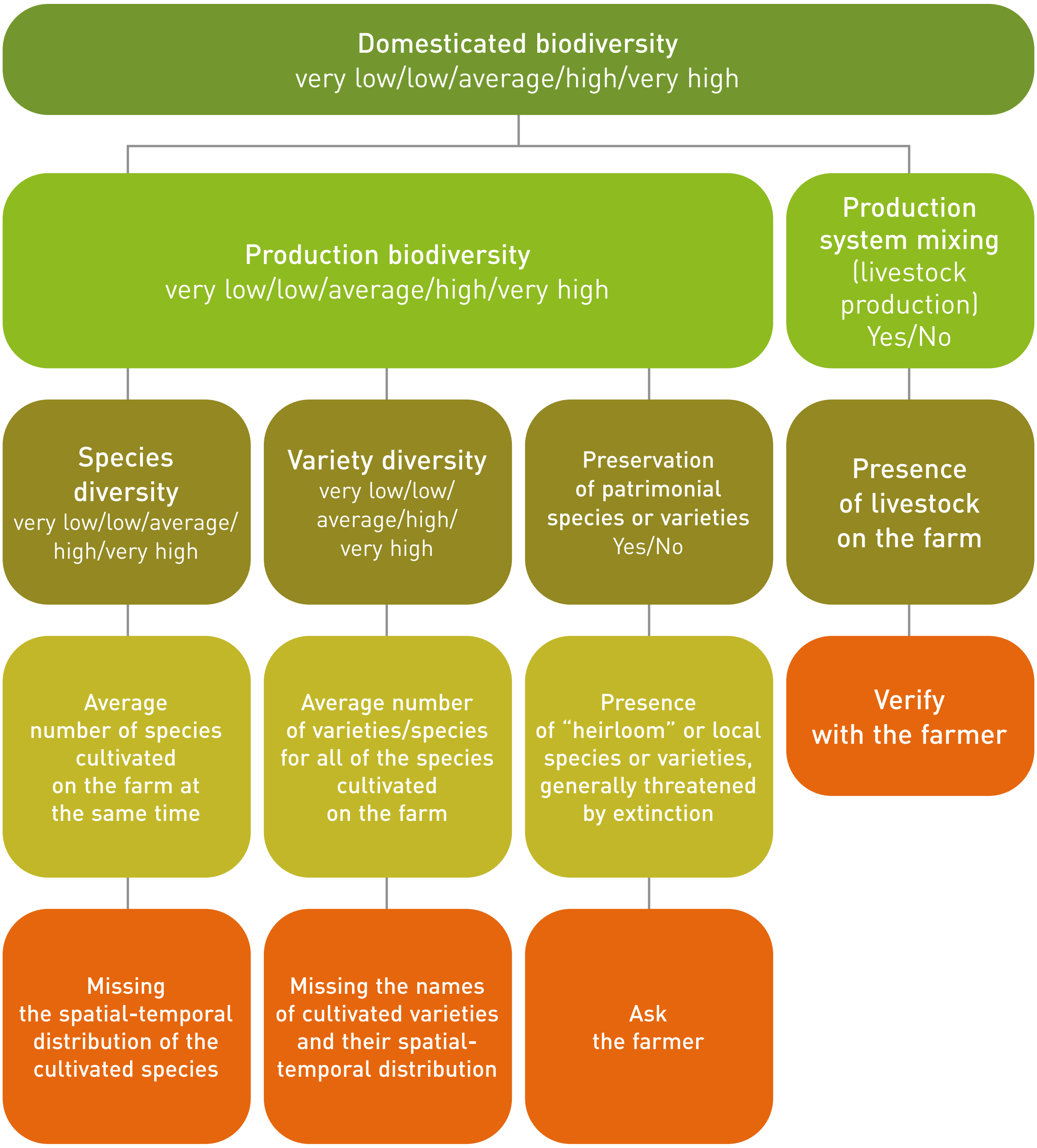
<table>
<tr><th>Compartment type</th><th>Area type</th><th>Type of assessment to be done</th></tr>
<tr><td>Cultivated lands on the upper part</td><td>Annual crops</td><td rowspan="2">Domesticated biodiversity
• Species diversity
• Variety diversity
Wild para-agricultural animal biodiversity
• Soil organisms in the large patches and small patches
• Presence of auxiliaries on plants for: aphids on green beans, spider mites on tomatoes, aphids on okra
Technical itineraries
• Use of phytosanitary products
• Mechanisation
• Nitrogen management
Spatial organisation and temporal management
• Crop allocation diversity
• Mosaic effect
• Intra-plot mixing
• Temporal cover management
• Rotations</td></tr>
<tr><td>Lands cultivated on lower part</td><td>Annual crops</td></tr>
<tr><td>Lands cultivated on lower part</td><td>Perennial crops (isolated fruit trees)</td><td>Domesticated biodiversity
• Species diversity
**</td></tr>
<tr><td>AEI/AEU</td><td>All of those found on the farm</td><td>AEI/UAE ratio
AEI/AEU diversity
AEI/AEU interconnectivity</td></tr>
<tr><td>AEI/AEU</td><td>Ponds</td><td>Quality</td></tr>
<tr><td>AEI/AEU</td><td>Hedges</td><td>Quality</td></tr>
<tr><td>AEI/AEU</td><td>Grass strip</td><td>Quality</td></tr>
<tr><td>Off-farm</td><td>Forest reserve</td><td>Presence and quality of the buffer zone</td></tr>
</table>

Off-farm	Field crops	Presence and quality of the buffer zone
Off-farm	Vegetable crops	Presence and quality of the buffer zone
Off-farm	Temporary waterway	Presence and quality of the buffer zone
Off-farm	Road	Presence and quality of the buffer zone

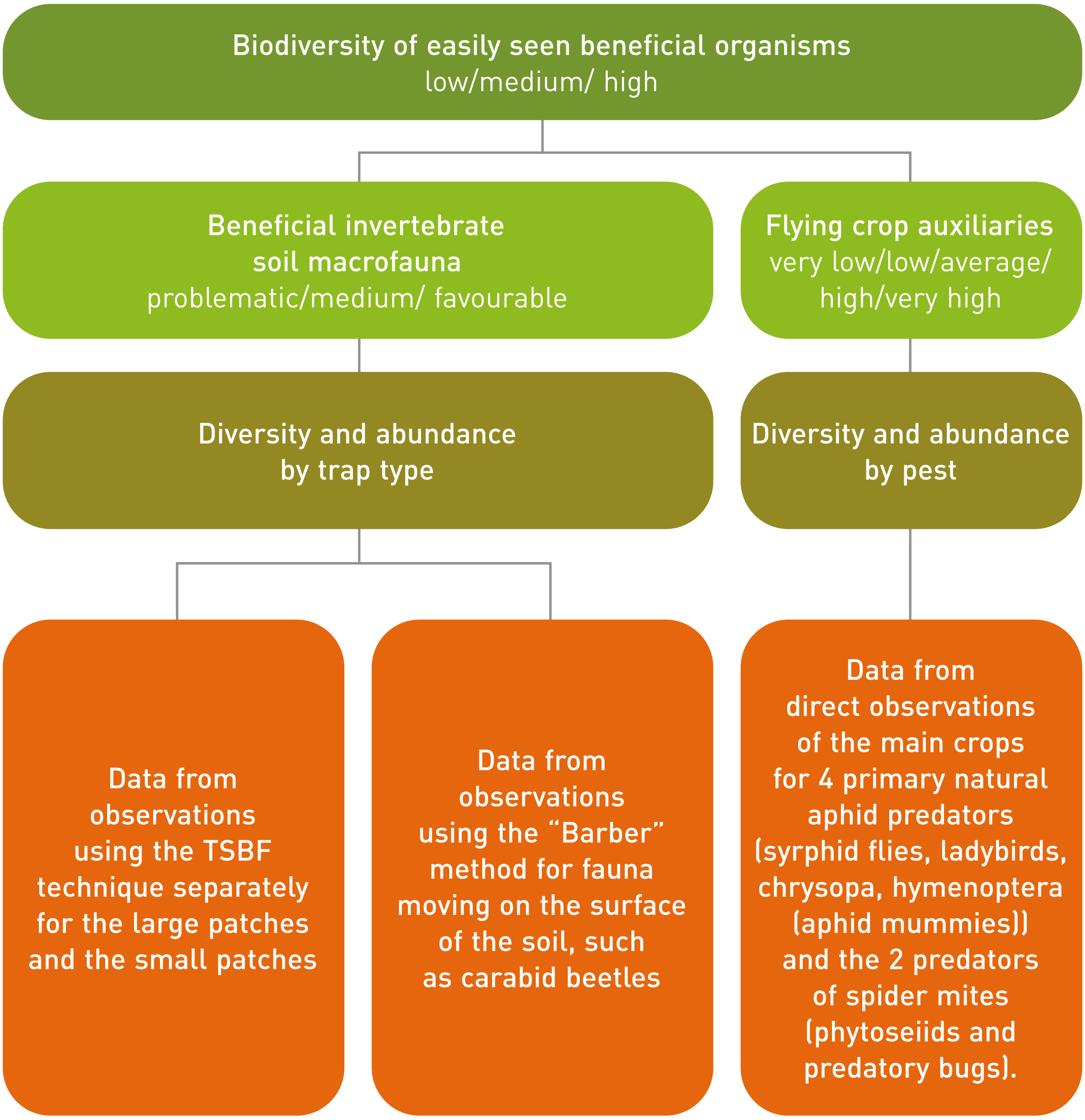
**Since the fruit trees are few in number and isolated, no assessment needs to be carried out for the other aspects mentioned in Chapter 2 of the manual.

5.3.2.3. Proposed solutions: diagrams of the assessments to be carried out (Step 3)

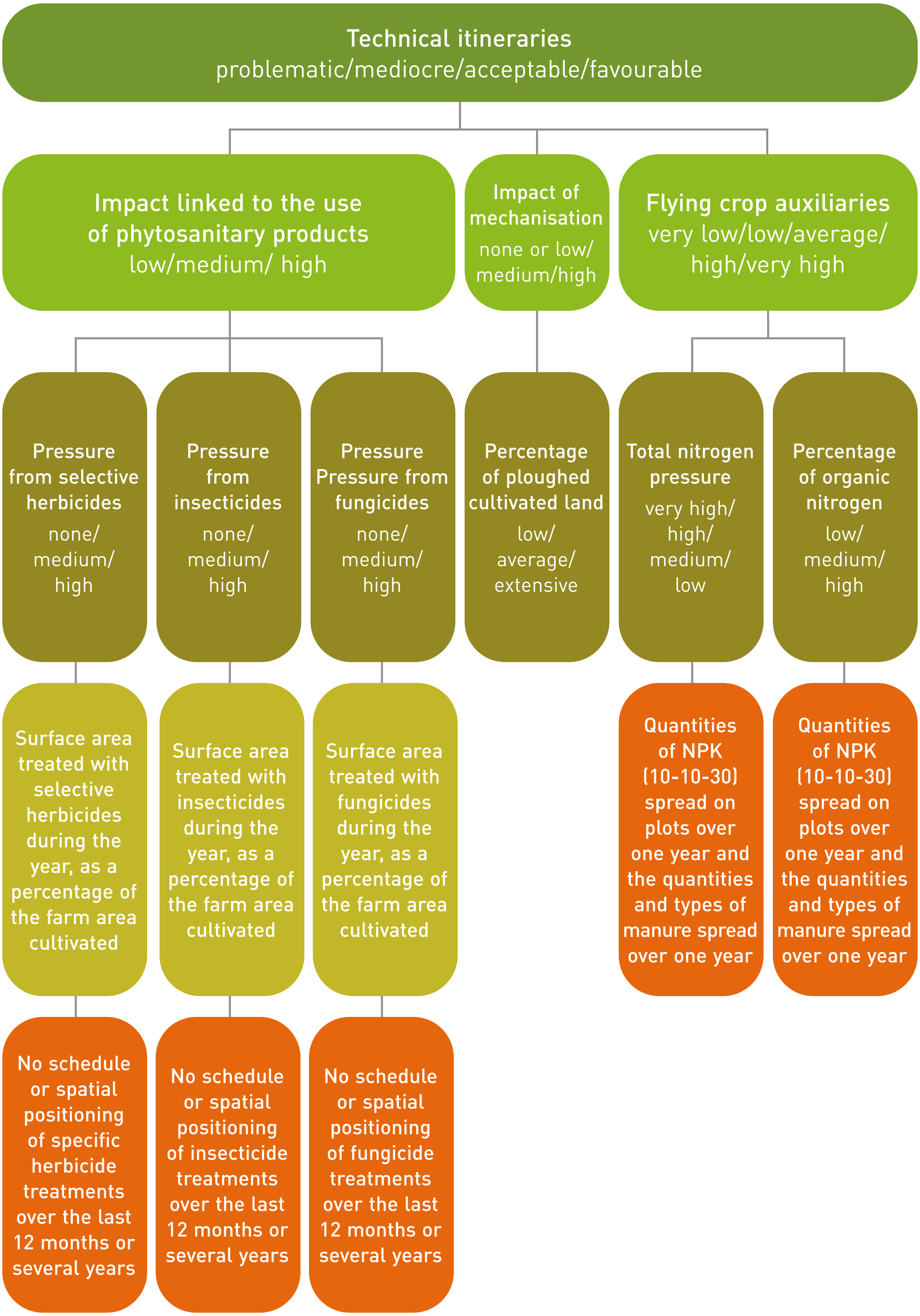
Domesticated biodiversity



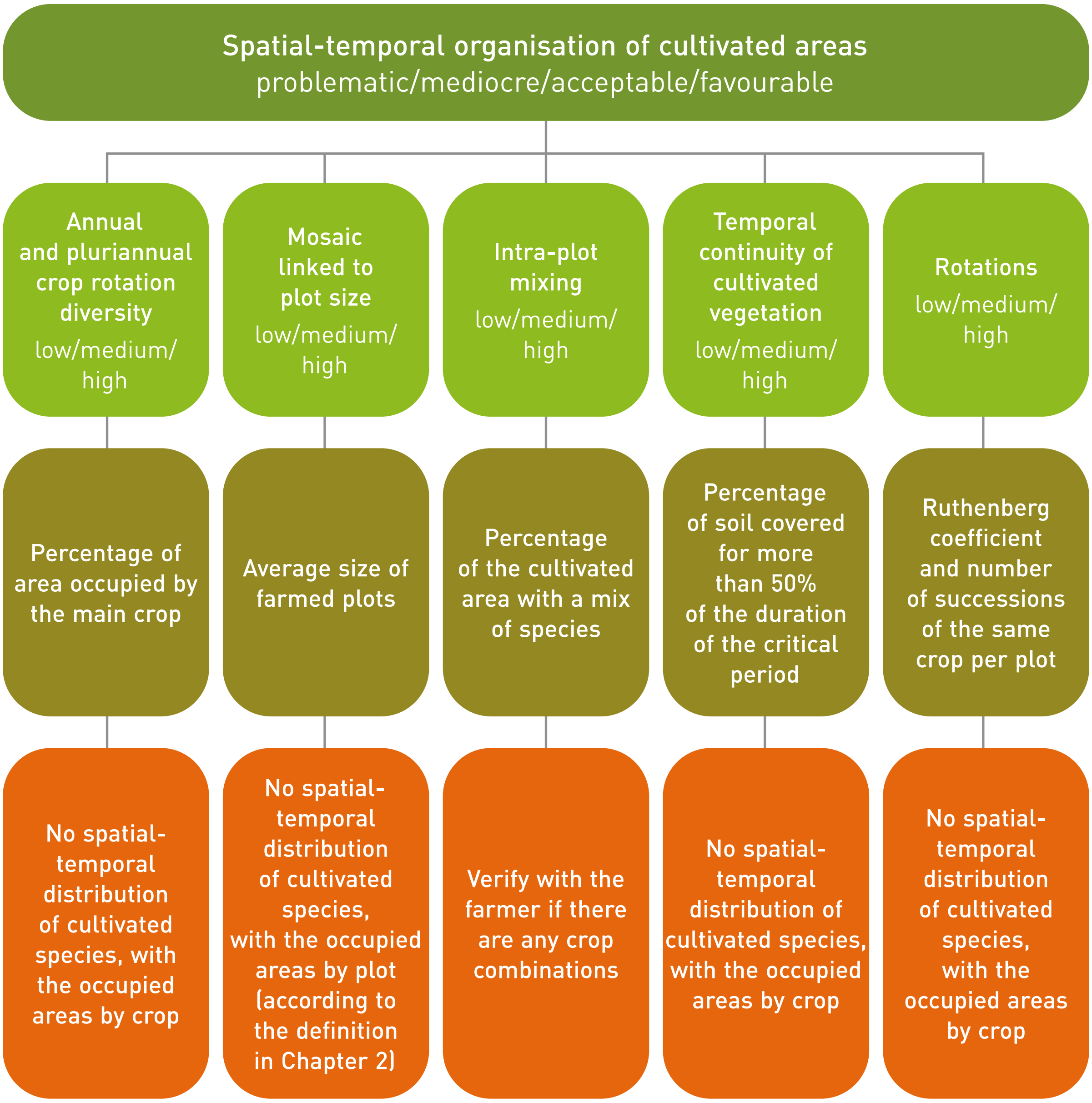
Wild para-agricultural animal biodiversity



Technical itineraries

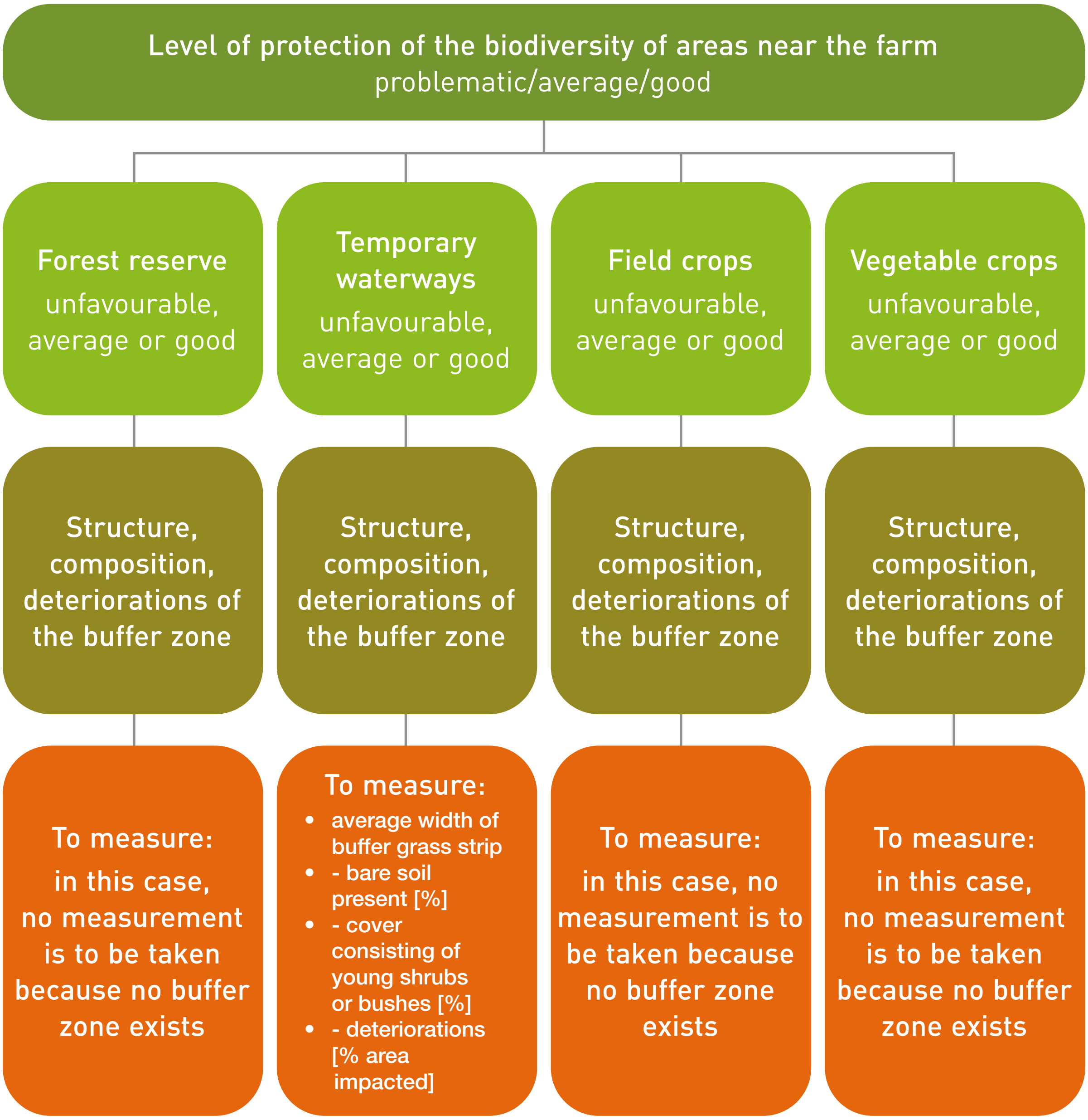


Spatial organisation and temporal management of cultivated areas



AEI/AEU biodiversity

Protection of the biodiversity of the farm's immediate surroundings



5.3.2.4. Proposed solutions: categorised list of observations, analyses and measurements to perform and/or additional information needed (Step 4)

- For the compartment of cultivated areas:
  - In terms of domesticated biodiversity.
    - Spatial-temporal distribution of cultivated areas based on the model of Appendix 2 of Chapter 2 to calculate the average number of cultivated species and the average number of varieties/species.
    - Ask the farmer if there are endangered "heritage" or local species or varieties present on the farm.
    - Ask the farmer if livestock production is present on the farm.
  - In terms of wild para-agricultural biodiversity.
    - Complete a sampling of the soil macrofauna using the TSBF method and the Barber trap.
    - Obtain the auxiliary count data for the auxiliaries for aphids on green beans and okra and the auxiliaries for spider mites on tomatoes.
  - In terms of technical itineraries.
    - Ask the farmer for a schedule and the spatial positioning of the applications of specific herbicides, insecticides and related products, and fungicides over the last 12 months or several years in order to calculate the percentage of surface area treated compared to the cultivated area.
    - Ask the farmer about the quantities of NPK (10-10-30) and quantities and types of manure applied on the plots over one year in order to calculate the quantity of N applied per ha and per year on the farm and the share of organic N.
  - In terms of spatial organisation and temporal management.
    - Spatial-temporal distribution of the cultivated spaces to calculate the percentage of surface area occupied by the main crop, the average size of the cultivated plots, the percentage of soil covered and for the rotations: the Ruthenberg coefficient and the score based on the number of successions of the same crop.
    - Ask the farmer if there are any crop combinations.
- For the compartment of natural and semi-natural areas on the farm:
  - In terms of AEI/AEU quality.
    - Obtain the measurements identified in the diagram as necessary for assessing the different areas, namely:

      For the hedges:

      - average width of the hedge,
      - number of significant ligneous strata,
      - average width of the grass strip on each side of the hedge,

- average number of associated small structure types,
- average number of ligneous species,
- average number of fruit-bearing tree, shrub and bush species,
- average number of spiny shrub and bush species or trees characteristic of the local landscape,
- exotic species cover [% of surface area],
- deteriorations [% area impacted],
- average distance hedge/closest fertilised or treated surface.

For the pond:

- average bank slope,
- % of the bank surface occupied by exotic species,
- % surface area impacted by deteriorations,
- distance from the top of the bank edge to the edge of the treated and/or cultivated area.

For the grass strip:

- average width of buffer grass strip,
- bare soil present [%],
- cover consisting of young shrubs or bushes [%],
- exotic species cover [%],
- ruderal species cover [%],
- average number of plant species with visible flowers,
- perennial species cover [%],
- deteriorations [% area impacted].

- For the compartment of areas surrounding the farm
  - In terms of the quality of protection by buffer zones.
    - Obtain the following measurements for the buffer zone located along the waterway:
      - average width of buffer grass strip,
      - bare soil present [%],
      - cover consisting of young shrubs or bushes [%],
      - deteriorations [% area impacted].

Complementary analysis (area for notes)

- *Preliminary information*

- *Table*

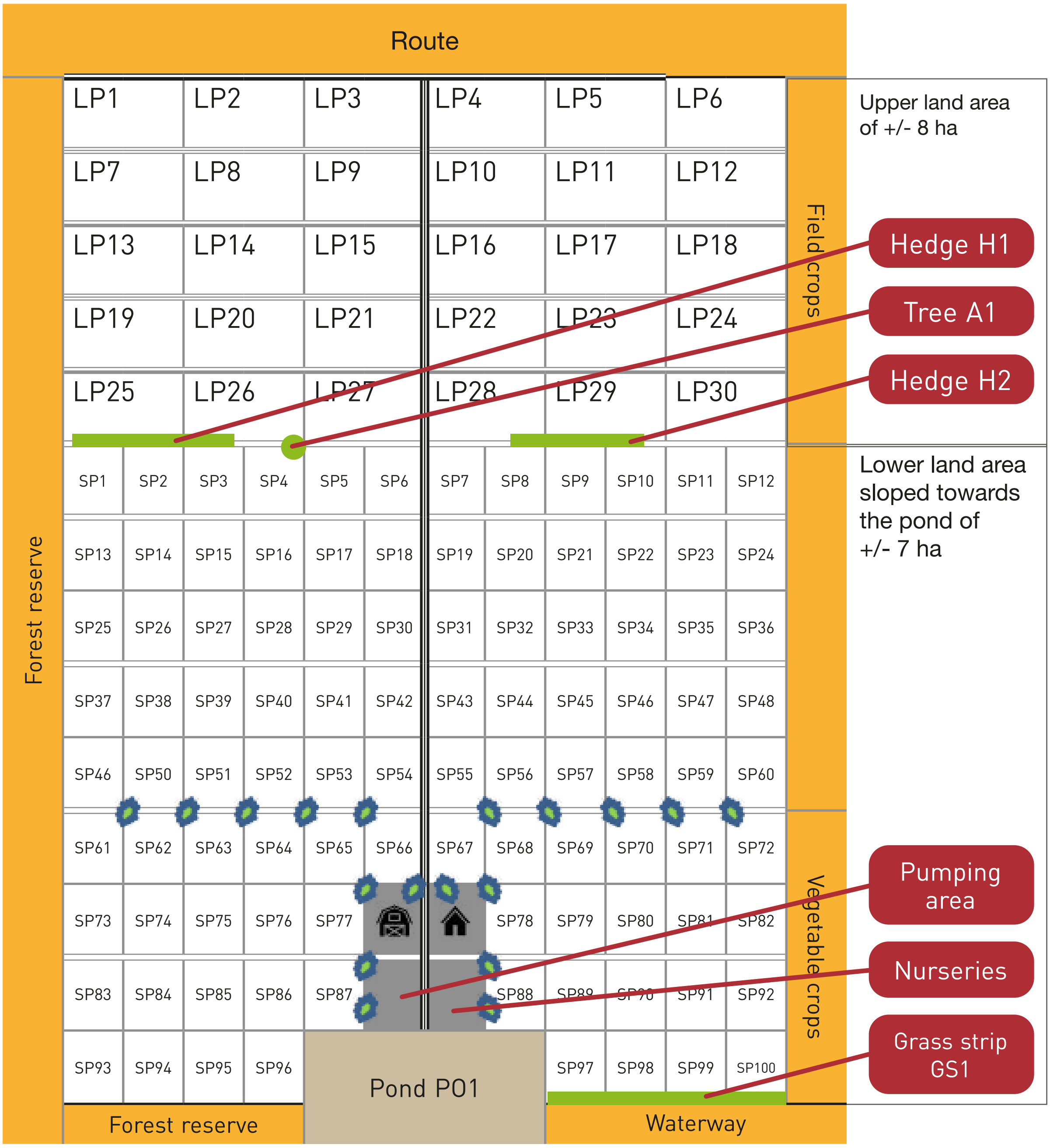
- *Diagrams*

- *Observations, analyses and measurements to perform and/or additional information to obtain*

5.3.3. Results of the analyses, measurements, observations and additional information obtained

5.3.3.1. Preliminary information

Mapping of the plot and areas occupied by AEI/AEU



Legend

- Boundary of plots
- Trail with water line
- Narrow path with canal l
- Wide path with canal
- Wide path with water line
- Hedge
- Exceptional tree
- Planted fruit tree
- Inhabited plot
- Plot with agricultural buildings
- 25 m
- Uncultivated

Identified AEI/AEU and surfaces they occupy

Assessment of the agroecological infrastructure							
AEI/AEU type:	Hedges	State of conservation				Observations	Measures recommended
AEI/AEU identification	Area occupied	Structure	Composition	Disruption	Score		
H1	60 m x 2.5 m = 150 m²						
H2	60 m x 2.5 m = 150 m²						
Total	300 m²						
AEI/AEU type:	Isolated trees	State of conservation				Observations	Measures recommended
AEI/AEU identification	Area occupied	Structure	Composition	Disruption	Score		
A1	100 m²						
Total	100 m²						
AEI/AEU type:	Grass strips	State of conservation				Observations	Measures recommended
AEI/AEU identification	Area occupied	Structure	Composition	Disruption	Score		
BE1	100 m x 3 m = 300 m²						
Total	300 m²						
AEI/AEU type:	Ponds	State of conservation				Observations	Measures recommended
AEI/AEU identification	Area occupied	Structure	Composition	Disruption	Score		
MA1	25 m x 100 m = 2,500 m² (banks included)						
Total	2,500 m²						
OVERALL TOTAL	3,200 m²						

UAA = 150,000 m² – 2,500 m² of built areas and farmyards = 147,500 m²

History of biodiversity management and its evolution

Guide questions	Answers (from the farmers)	Since when?
What wild plants (grasses, shrubs, trees, etc.) are no longer found on the farm?	Trees: Baobab, **Acacia senegalenis**, **Acacia albida** Shrubs: **Combretum micranthum**	Since the allocation of the large patch zone for export crops
What cultivated plants are no longer found on the farm?	Millet and cowpeas in the large patch zone Cabbage and African aubergines in the small patch zone	Since the allocation of the large patch zone for export crops
What new wild plants are growing on the farm?	None were seen	/
What new plants are cultivated on the farm?	Green beans	Since the allocation of the large patch zone for export crops
What flying and non-flying insects are no longer found on and in the farm's soil?	Unknown	/
What new flying and non-flying insects are found on and in the farm's soil?	None seen	/
What animals (e.g. rodents) are no longer found on the farm?	None	/
What new wild animals are found on the farm?	None	/
What combinations of crops no longer exist?	Millet + cowpeas	Since the allocation of the large patch zone for export crops
What crop rotation systems (succession of crops and fallow land on the farm) no longer exist?	/	/
What are the other changes with respect to plants, insects, animals and crop systems?	Semi-natural hedges delineated groups of individual plots in the small patch zone. There was a hedge roughly every 50 metres. Only the remainders of these hedges still exist.	Since the restructuring of the site since export production began
What are the reasons behind these observed changes?	Restructuring of the site since export production began	/
What are the consequences of these changes?	/	/
What are the responses provided by the farmer(s)?	/	/
What is the impact of these responses on biodiversity?	/	/

Main pests

Crop	Pest	Period of heavy infestation
Green beans	aphids	February
Tomatoes	spider mites	March
Okra	aphids	April

5.3.3.2. Additional data and information obtained

- ***For the compartment of cultivated areas - in terms of domesticated biodiversity***

Spatial-temporal distribution of cultivated areas

Annual crops															
Plot	Species	Variety	Hectares occupied per month												Total
			1	2	3	4	5	6	7	8	9	10	11	12	
LP1 to LP24	Green beans	Paulista	6	6									6	6	
LP25 to LP30	Tomatoes	Datterino	2	2	2							2	2	2	
LP1 to LP30	Maize	Local						8	8	8	8				
SP1 to SP36	Tomatoes	Xina				2.5	2.5	2.5	2.5						
SP1 to SP36	Maize	Local								2.5	2.5	2.5	2.5		
SP1 to SP36	Okra	Clemson	2.5	2.5	2.5									2.5	
SP37 to SP84	Tomatoes	Roma		3	3	3	3								
SP37 to SP84	Maize	Local						3	3	3	3				
SP37 to SP84	Okra	Local	3									3	3	3	
SP85 to SP100	Chilli peppers	Safi	1	1	1	1							1	1	
SP85 to SP100	Maize	Local					1	1	1	1					
Perennial crops: there are 18 mango trees on the farm (9 Kent variety and 9 Keitt variety). These are isolated trees.															

- *Presence of endangered "heritage" and local species or varieties*

  According to the farmer, the local okra variety is generally being grown less and less.

- *Livestock farming present on the farm*

  No, there is no livestock production on the farm.

- *For the compartment of cultivated areas - in terms of wild para-agricultural biodiversity*
  - *Soil macrofauna*
    a. *Data obtained with the TSBF method*

Average abundance of earthworms (per m^2 and at a depth of 30 cm)

	Large patches	Small patches	Average
Earthworms (all species combined)	10	70	40

The organisms best known to the farmer were also surveyed when using the TSBF method. For some groups, distinctions were made between species without being able to name the species. The species are therefore identified by a number.

Average abundance of underground macrofauna (per m^2 and at a depth of 30 cm)

		Large patches	Small patches	Average
Myriapods (millipedes/ centipedes)	Species 1	6	27	
	Species 2	1	10	
	Total	7	37	22
Ispotera (termites)	All species combined	20	100	60
Isopods (woodlice)	All species combined	3	12	7.5
Spiders	Species 1	6	3	
	Species 2	1	2	
	Species 3	1	2	
	Total	8	7	7.5
Ants	Species 1	10	100	
	Species 2	5	80	
	Species 3	5	20	
	Total	20	200	110
Beetle larvae	Species 1	10	30	
	Species 2	1	10	
	Species 3	1	8	
	Total	10	48	29

Adult beetles	Species 1	7	12	
	Species 2	2	8	
	Total	9	20	14.5

Calculation of the Shannon H' and evenness E indices

	Large patches		Small patches		Average	
	H'	E	H'	E	H'	E
Myriapods (millipedes/centipedes)	0.41	0.59	0.58	0.84	0.49	0.71
Spiders	0.74	0.67	1.08	0.98	0.91	0.82
Ants	1.04	0.95	0.94	0.86	0.99	0.95
Beetle larva	0.57	0.52	0.92	0.84	0.74	0.63
Adult beetles	0.53	0.76	0.76	0.97	0.64	0.86

b. ***Data obtained with Barber traps***

Average abundance of captures per week over 4 weeks
(collected from traps once a week)

		Large patches	Small patches
Carabid beetles	Species 1	2	10
	Species 2	1	5
	Species 3	0	5
Other beetles	Species 1	2	4
	Species 2	0	1

These data are not directly usable because there are no references for the abundance categories in Chapter 2 of this manual. They can, nevertheless, be useful for assessing the evolution of the carabid beetle population following the implementation of new practices. This is, of course, on condition that the traps are set under weather conditions which are similar each year and at a same station.

- *Auxiliaries on plants*
    a. *Natural predators of aphids on green beans in the large patch zone*

Table of observations from 15 February 2017

Auxiliaries	Sum of the scores for the 50 fruiting bodies observed (10 locations x 5 bodies per location)	Presence scores
Ladybirds	40	2
Syrphid flies	50	2
Chrysops	0	1
Hymenoptera parasitoids	40	2
	Sum of the scores for the presence levels of the different types of auxiliaries	7

b. *Natural predators of aphids on okra in the small patch zone*

Table of observations from 15 and 22 April 2017

Auxiliaries	Average of the sum of the scores for the 50 fruiting bodies observed on two the observation dates (10 locations x 5 bodies per location)	Presence scores
Ladybirds	50	3
Syrphid flies	70	2
Chrysops	20	1
Hymenoptera parasitoids	70	3
	Sum of the scores for the presence levels of the different types of auxiliaries	9

Data could not be obtained for the natural predators of spider mites. Due to the large number of preventive treatments performed, large populations of spider mites never occur on the tomatoes.

- *For the compartment of cultivated areas - in terms* of technical itineraries
    - *Use of specific herbicides, insecticides and similar products, and fungicides.*

Plots treated in 2017

Treatment type	Large patches	Small patches	Total surface area treated
Selective herbicide	LP1 to LP30: 2 treatments = 8 ha	No treatment	8 ha
Insecticide/ acaricide	LP1 to LP30: 4 to 6 treatments (tomatoes: 4 treatments, green beans: 2 treatments, maize: 2 treatments) per plot = 8 ha	SP1 to SP36: 2.5 ha (okra 4 treatments, maize 0) SP37 to SP84: 3 ha (tomatoes 3 treatments, okra 3 treatments, maize 0) SP85 to SP100: 1 ha (chilli peppers 6 treatments, maize 0) = 6.5 ha	14.5 ha
Fungicide	LP1 to LP30: 2 treatments (tomatoes: 2 treatments, green beans: 2 treatments, maize: 0) per plot = 8 ha	SP1 to SP100: no fungicide	8 ha

- ***Quantities of NPK (10-10-30) and quantities and types of manure spread on the plots over one year***

NPK (10-10-30) applications over one year

Crop	Quantity of NPK fertilisers/ha	Cultivated area	Total NPK fertilisers/year
Large patches			
Maize	300 kg/ha for base and 200 kg/ha for maintenance before 10 leaves = 500 kg/ha	8 ha	4,000 kg
Green beans	200 kg/ha for base and 300 kg/ha for maintenance	6 Ha	3,000 kg
Tomatoes	400 kg/ha for base and 200 kg/ha x 4 applications for maintenance = 1,200 kg/ha	2 ha	2.400 kg
Small patches			
Maize	300 kg/ha for base and 200 kg/ha for maintenance before 10 leaves = 500 kg/ha	6.5 ha	3,250 kg
Tomatoes	200 kg/ha for base and 200 kg/ha x 4 applications for maintenance = 1,000 kg/ha	5.5 ha	5,500 kg
Okra	200 kg/ha x 3 applications = 600 kg	5.5 ha	3,300 kg

Chilli peppers	300 kg/ha for base and 150 kg/ha x 5 applications for maintenance = 1,050 kg/ha	1 ha	1,050 kg
		Total over the 14.5 ha	22,500 kg

Cow manure applications per year

Crop	Quantity spread per ha	Cultivated area	Total manure/year
Large patches			
Maize	10 t/ha	8 ha	80 t
Green beans	10 t/ha	6 ha	60 t
Tomatoes	20 t/ha	2 ha	40 t
Small patches			
Maize	10 t/ha	6.5 ha	65 t
Tomatoes	10 t/ha	5.5 ha	55 t
Okra	10 t/ha	5.5 ha	55 t
Chilli peppers	10 t/ha	1 ha	10 t
		Total over the 14.5 ha	365 t

- *For the compartment of cultivated areas - in terms* of the spatial organisation and temporal management of cultivated areas
  - *Spatial-temporal distribution of cultivated areas*

    The spatial-temporal distribution of the cultivated areas was provided in the Manual.
  - *Species mix*

    The farmer confirms that there are no crop combinations on the farm.
- *For the compartment of natural and semi-natural areas on the farm - in terms of AEI/AEU quality*

For the hedges

	H1	H2
Structure		
Average width	2.5 m	2.5 m
Number of ligneous strata	2 (upper and lower)	2 (upper and lower)
Average width of grass strip	1 m	1 m
Average number of associated small structure types	2 (piles of branches and dead standing wood)	2 (piles of branches and dead standing wood)
Composition		
Average number of ligneous species	3	3
Average number of fruit-bearing tree, shrub and bush species	1	1
Average number of spiny shrub and bush species or trees characteristic of the local landscape	1 (Jujube)	1 (Jujube)
Exotic species cover	0%	0%
Deteriorations/disruptions		
Deteriorations	15% (burning)	15% (burning)
Average distance hedge/closest fertilised or treated surface	1.5 m	1.5 m

For the pond

Structure	
Average bank slope	30°
Composition	
% of the bank surface occupied by exotic species	0%
Deteriorations/disruptions	
% of area impacted by deteriorations	8% catchments
Distance from the top of the bank edge to the edge of the treated and/or cultivated area	0.5 m

For the grass strip

Structure	
Average width of buffer grass strip	3 m
presence of bare soil [%]	25%
cover consisting of young shrubs or bushes [%]	30%
Composition	
exotic species cover [%]	0%
ruderal species cover [%]	0%
average number of plant species with visible flowers	To complete*
perennial species cover [%]	To complete*
Deteriorations/disruptions	
deteriorations [% area impacted]	15% (burning)

*this observation is to be done at a time which favours the growth of grasses in the area

- ***For the compartment of areas surrounding the farm - in terms of the quality of protection by buffer zones***
  - ***For the buffer zone located along the waterway:***
    - average width of the buffer grass strip,
    - bare soil present [%],
    - cover consisting of young shrubs or bushes [%],
    - deteriorations [% area impacted].

Same data as above

Average width of the buffer grass strip	3 m
presence of bare soil [%]	25%
cover consisting of young shrubs or bushes [%]	30%
deteriorations [% area impacted]	15% (burning)

There are virtually no buffer zones protecting the other exterior areas. Only a strip of 1.5 m is left fallow along the perimeter fence.

5.4. PART 3: OVERALL ASSESSMENT AND IDENTIFICATION OF BIODIVERSITY SHORTCOMINGS

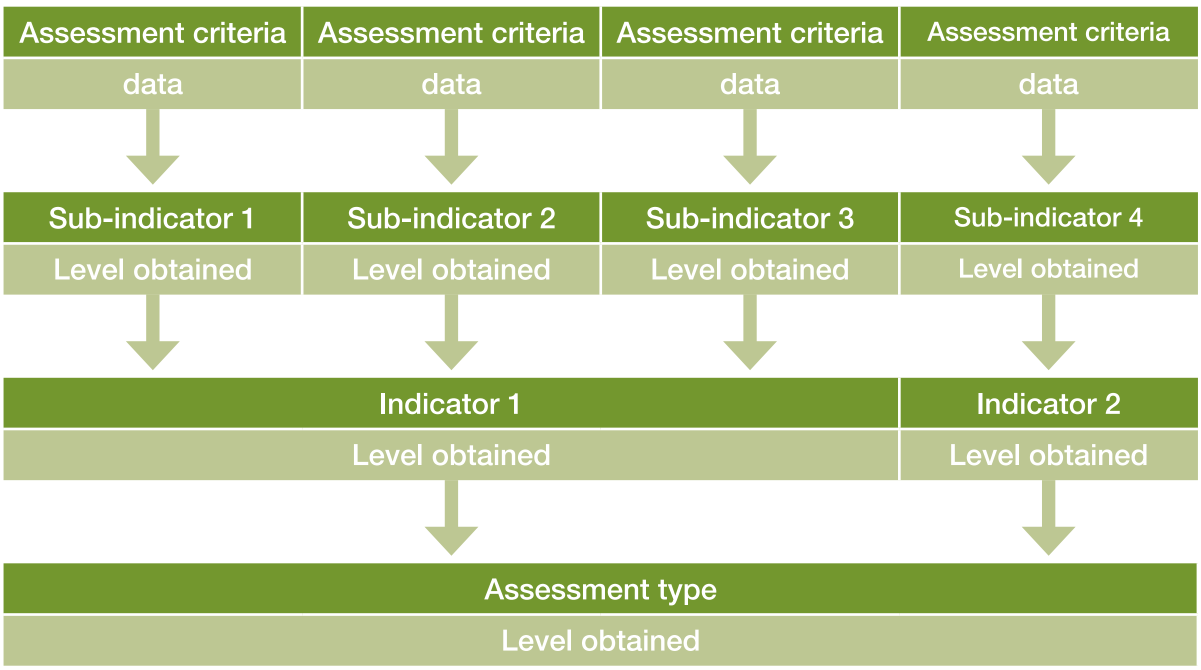
5.4.1. Instructions

Instructions:

You now have the information/data necessary to carry out the actual assessment of the biodiversity on the farm and identify any shortcomings. Now complete the different types of assessments, one after another, by following the aggregation diagrams established in Part 3.2 and by taking into account the information available in Part 3.3. and the grading methods explained in Chapter 2. When necessary, perform the last calculations to obtain the necessary values, based on the raw data available. Go through the base diagrams from bottom to top and reiterate them as procedures (see the outline to follow below). Indicate the values available and the levels which result from them.

At the end of each procedure, mention the shortcomings identified and the levels which must be reached for a status which is satisfactory overall. Identify any missing elements which could allow the assessment to be refined.

Process outline



5.4.2. Proposed solutions

Have you completed your portion of the exercise? Bravo! Now compare your results to the proposed solutions, identify the differences and try and understand why your results differ from the proposed solutions. Have you designed a new and/or better proposal? Write out your analysis of the results and your personal insights in a few lines: this will help you retrace the logic behind your approach at the end of the exercise.

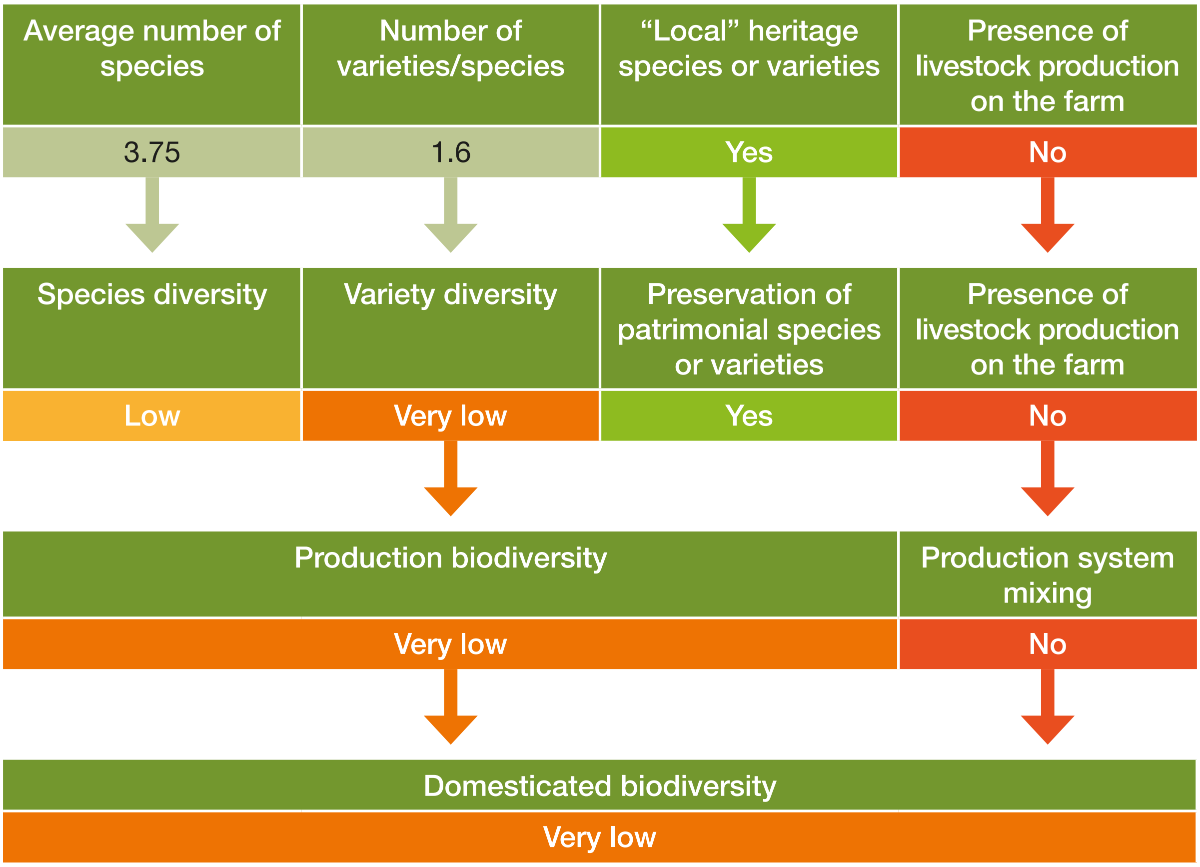
5.4.2.1. Domesticated biodiversity

a. **Calculation of the values allowing the level of indicators to be established**

Number of species and number of varieties per species

Plot	Species	Variety	Hectares occupied per month												Total
			1	2	3	4	5	6	7	8	9	10	11	12	
LP1 to LP24	Green beans	Paulista	6	6									6	6	
LP25 to LP30	Tomatoes	Datterino	2	2	2							2	2	2	
LP1 to LP30	Maize	Local						8	8	8	8				
SP1 to SP36	Tomatoes	Xina				2.5	2.5	2.5	2.5						
SP1 to SP36	Maize	Local								2.5	2.5	2.5	2.5		
SP1 to SP36	Okra	Clemson	2.5	2.5	2.5									2.5	
SP37 to SP84	Tomatoes	Roma		3	3	3	3								
SP37 to SP84	Maize	Local						3	3	3	3				
SP37 to SP84	Okra	Local	3									3	3	3	
SP85 to SP100	Chilli peppers	Safi	1	1	1	1							1	1	
SP85 to SP100	Maize	Local					1	1	1	1					
Totals for annual crops															
	Hectares	Area	14.5	14.5	8.5	6.5	6.5	14.5	14.5	14.5	13.5	7.5	14.5	14.5	
	Number	Species	4	4	3	2	2	2	2	1	1	3	5	4	33
	Number	Varieties	5	5	4	3	3	2	2	1	1	3	5	5	39
	Perennial crops: there are 18 mango trees on the farm (9 Kent variety and 9 Keitt variety)														
	Number	Species	1	1	1	1	1	1	1	1	1	1	1	1	12
	Number	Varieties	2	2	2	2	2	2	2	2	2	2	2	2	24
	Average number of species per month		33+12/12 = 3.75												
	Average number of varieties per species		8/5 = 1.6												

b. **Domesticated biodiversity assessment diagram**



c. **Conclusions and shortcomings identified**

For the domesticated biodiversity to be acceptable, an average number of species of at least 6 and a number of varieties per species of at least 3 must be attained. If, in addition, a bit of livestock farming is taking place on the farm, the level of domesticated biodiversity could be considered high.

5.4.2.2. Wild para-agricultural animal biodiversity

a. **Calculation of the values allowing the level of indicators to be established**

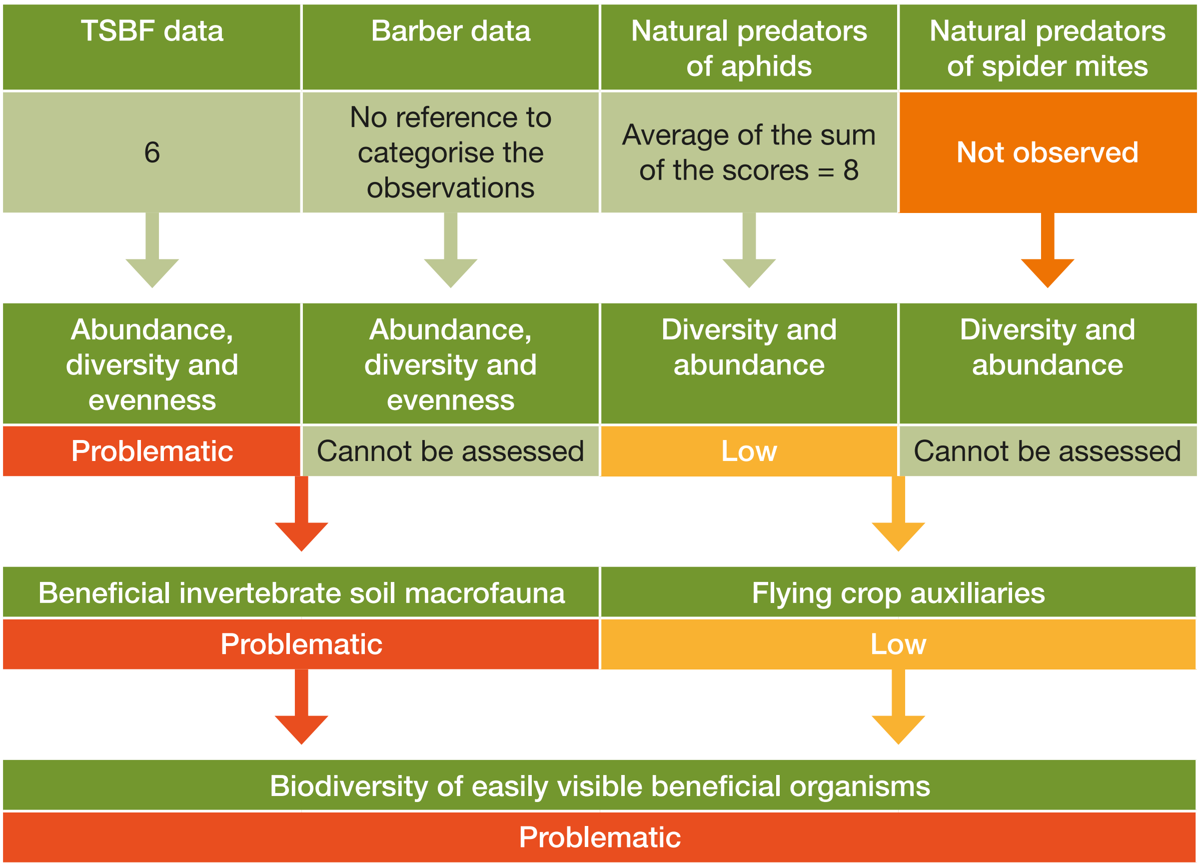
- *Values of TSBF data for 4 taxa (those for which the abundance categories are proposed in Chapter 2)*

Organism	Abundance	Diversity (H')	Evenness (E)	Total overall assessment
Earthworms	2	/(1)	/(1)	4
Myriapoda	2	1	2	5
Termites	4	/(2)	/(2)	8
Ants	2	2	3	7
Global TSBF data score				24/4 = 6

- *Average score for natural aphid predators*

  On average, the score for the farm is 8 ((9 (green beans) + 7 (okra))/2).

b. **Wild para-agricultural animal biodiversity assessment diagram**



c. **Conclusions and shortcomings identified**

Based on what was observed, wild para-agricultural biodiversity is, overall, problematic on the farm. As for the natural predators of aphids, the overall average score should be higher than 8 to be acceptable. With respect to soil macrofauna, the biodiversity of earthworms, myriapods and ants is particularly low. To have an acceptable level of biodiversity, the abundance would need to be at least doubled for earthworms, tripled for ants and quintupled for myriapods.

Analysis of the raw data shows that the situation is especially critical for the large patches.

5.4.2.3. Technical itineraries

a. **Calculation of the values allowing the level of indicators to be established**

- *Percentage of surface area treated with Phytosanitary Products*

  Percentage of surface area treated with herbicides: 8/14.5 x 100 = 55.2%

  Percentage of surface area treated with insecticides: 14.5/14.5 x 100 = 100%

  Percentage of surface area treated with fungicides: 8/14.5 x 100 = 55.2%

- *Calculation of kgN/ha/year*

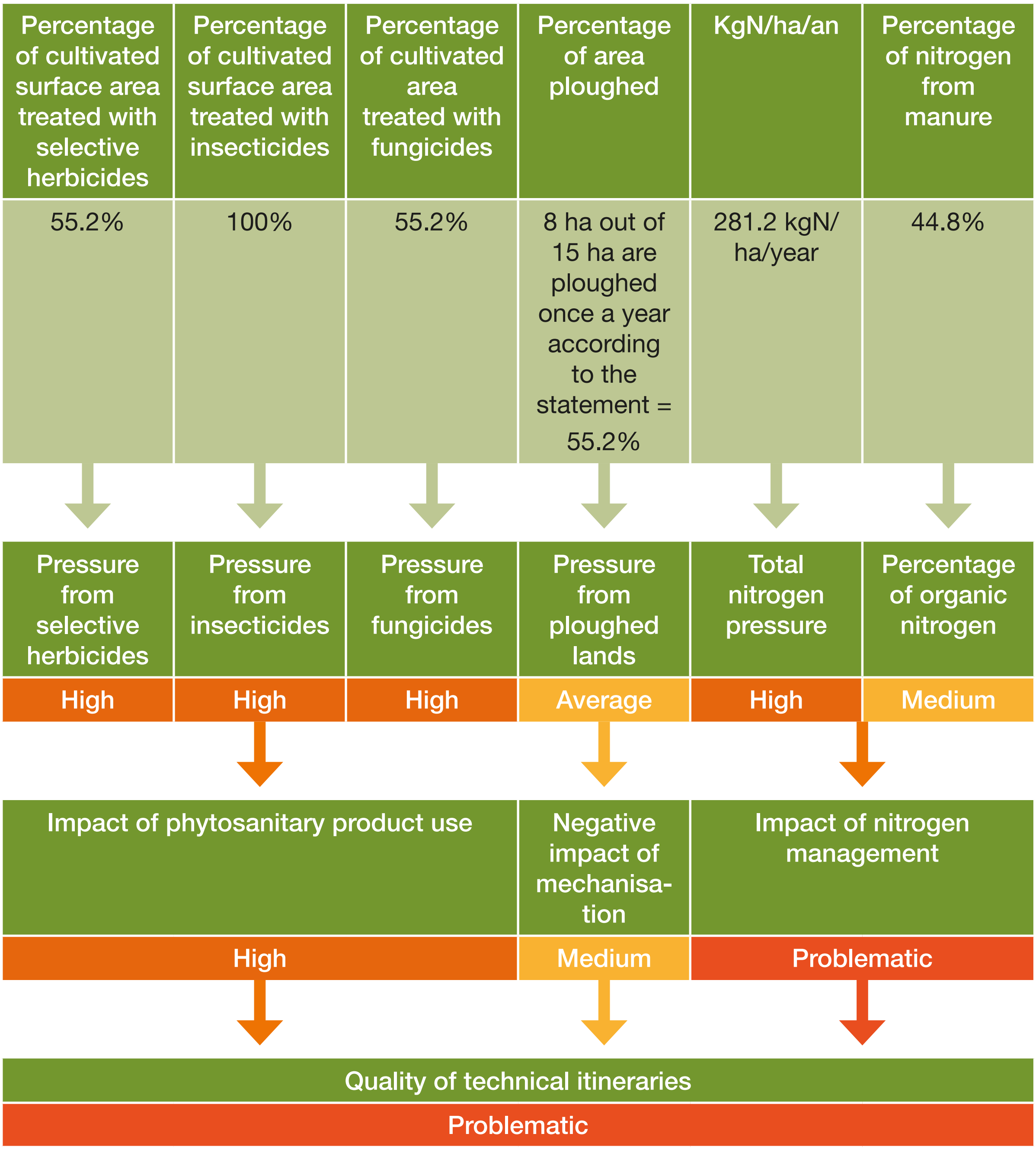
  22,500 kg of NPK (10-10-30) over 14.5 ha/year = 1,552 kg/ha/year = 155.2 kgN/ha/year

  + 365 t of cow manure over 14.5ha/year = 25.2 t/ha/year; based on 5 kg of N per ton of manure: 126 kgN/ha/year = total of 281.2 kgN/ha/year

- *Calculation of the percentage of nitrogen from manure*

  126/281.2 x 100 = 44.8%

b. **Assessment diagram for the quality of technical itineraries**



c. **Conclusions and shortcomings identified**

The quality of the technical itineraries is problematic in particular due to excessive nitrogen pressure and overuse of phytosanitary products.

The quantity of nitrogen applied via mineral fertilisers and manure must be reduced in order to reach a maximum value of 200 kgN/ha/year while maintaining a sufficient percentage of N originating from organic manuring.

The pressure due to phytosanitary products must be reduced by lowering the percentage of treated surfaces. A maximum percentage of 30% should be aimed for. However, a more in-depth analysis of phytosanitary product use is necessary to be able to propose alternatives (notably biocontrol products which should not be taken into account for the calculation of treated surfaces).

An improvement can also be achieved by reducing the areas which are subject to overturning tillage.

5.4.2.4. Spatial organisation and temporal management of cultivated areas

a. **Calculation of the values allowing the level of indicators to be established**

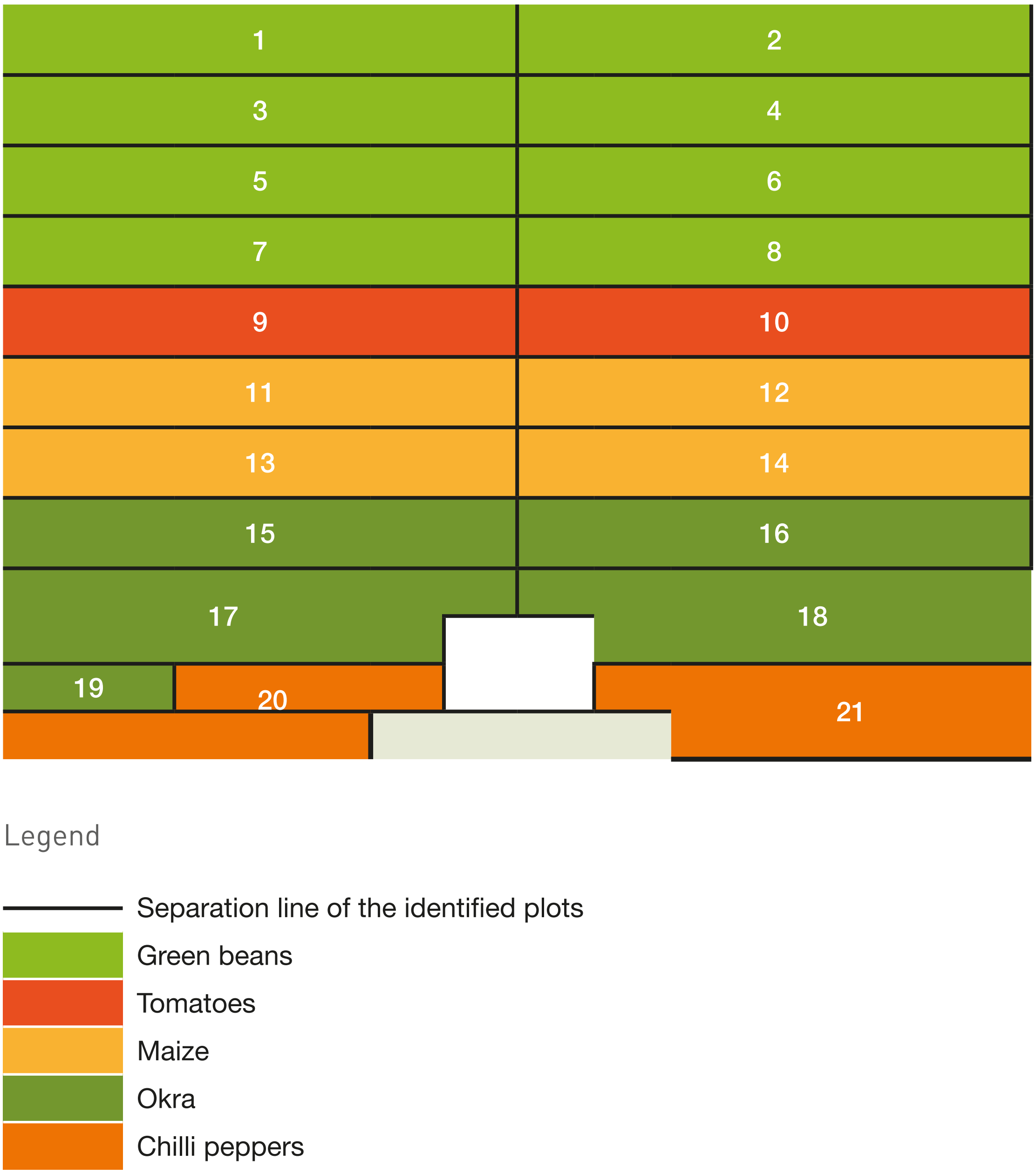
- *Percentage of area occupied by the main crop*

Calculation table for the percentage of area occupied by the main crop

Plot	Species	Variety	Hectares occupied per month											
			1	2	3	4	5	6	7	8	9	10	11	12
LP1 to LP24	Green beans	Paulista	6	6									6	6
LP25 to LP30	Tomatoes	Datterino	2	2	2							2	2	2
LP1 to LP30	Maize	Local						8	8	8	8			
SP1 to SP36	Tomatoes	Xina				2.5	2.5	2.5	2.5					
SP1 to SP36	Maize	Local								2.5	2.5	2.5	2.5	
SP1 to SP36	Okra	Clemson	2.5	2.5	2.5									2.5
SP37 to SP84	Tomatoes	Roma		3	3	3	3							
SP37 to SP84	Maize	Local						3	3	3	3			
SP37 to SP84	Okra	Local	3									3	3	3
SP85 to SP100	Chilli peppers	Safi	1	1	1	1							1	1
SP85 to SP100	Maize	Local					1	1	1	1				
	Totals													
	Hectares	Area	14.5	14.5	8.5	6.5	6.5	14.5	14.5	14.5	13.5	7.5	14.5	14.5
	Percentage of main crop (%)		41.4	41.4	58.8	84.6	84.6	82.8	82.8	100	100	40	41.4	41.4
			Average		66.6%									

- *Average size of cultivated plots*

  Considering the definition provided in Chapter 2, that paths and trails also constitute physical separations of the plots and taking into account the information on spatial-temporal distribution on page 292, we can determine the number of plots for each month of the year as illustrated in the diagram below for the month of November, for example.



The number of plots identified for the year as a whole is compiled in the table below from which the average size of the plots is calculated.

Plot	Species	Variety	Number of plots identified by month of occupancy											
			1	2	3	4	5	6	7	8	9	10	11	12
LP1 to LP24	Green beans	Paulista	8	8									8	8
LP25 to LP30	Tomatoes	Datterino	2	2	2							2	2	2
LP1 to LP30	Maize	Local						10	10	10	10			
SP1 to SP36	Tomatoes	Xina				4	4	4	4					
SP1 to SP36	Maize	Local								4	4	4	4	
SP1 to SP36	Okra	Clemson	4	4	4									4
SP37 to SP84	Tomatoes	Roma		5	5	5	5							
SP37 to SP84	Maize	Local						5	5	5	5			
SP37 to SP84	Okra	Local	5									5	5	5
SP85 to SP100	Chilli peppers	Safi	2	2	2	2							2	2
SP85 to SP100	Maize	Local					2	2	2	2				
	Totals and averages													
	Hectares	Area	14.5	14.5	8.5	6.5	6.5	14.5	14.5	14.5	13.5	7.5	14.5	14.5
	Number	Plots	21	21	13	11	11	21	21	21	19	11	21	21
	Average plot size	Area in ha	0.69	0.69	0.65	0.59	0.59	0.69	0.69	0.69	0.71	0.68	0.69	0.69
	Average size over 12 months		0.67 ha = 6,700 m^2 4.6% (6,700/145,000 x 100) compared to the cultivated surface area											

- *Plant cover continuity and rotations*

  Table for rotation analysis and plant cover continuity established on the basis of the table on page 292.

Plot	Surface area (ha)	Occupation per month											
		1	2	3	4	5	6	7	8	9	10	11	12
		Dry season						Rainy season				Dry season	
LP1 to LP24	6	Green beans	Green beans				Maize	Maize	Maize	Maize	*	Green beans	Green beans
LP25 to LP30	2	Tomatoes	Tomatoes	Tomatoes			Maize	Maize	Maize	Maize	Tomatoes	Tomatoes	Tomatoes
SP1 to SP36	2.5	Okra	Okra	Okra	Tomatoes	Tomatoes	Tomatoes	Tomatoes	Maize	Maize	Maize	Maize	Okra
SP37 to SP84	3	Okra	Tomatoes	Tomatoes	Tomatoes	Tomatoes	Maize	Maize	Maize	Maize	Okra	Okra	Okra
SP85 to SP100	1	Chilli peppers	Chilli peppers	Chilli peppers	Chilli peppers	Maize	Maize	Maize	Maize	*	*	Chilli peppers	Chilli peppers

Note: The boxes in red indicate the absence of plant cover (no crop or spontaneous vegetation or crop waste (litter))
*For September and October, it is assumed that the uncultivated land is naturally covered with vegetation due to the rainy season

- *Table for the analysis of plant cover continuity.*

Ratio of covered area per month											
1	2	3	4	5	6	7	8	9	10	11	12
Dry season						Rainy season				Dry season	
100%	100%	5!.6%	44.8%	44.8%	100%	100%	100%	100%	100%	100%	100%

Average percentage of soil covered over the 8 months of the dry season = 80.15%

- *Quality level of rotations*

  R = 100 for all of the plots since there is no fallow on all of the plots.

  The table of occupancy per month above shows that the same crops do not follow each other on all of the plots.

  The Ruthenberg coefficient (R) and the number of successive crop cycles with the same crops are the same for all of the plots. In this case the weighting explained in Chapter 2 is not applied since all of the plots have the same status. All of the plots receive a score of 2.

b. **Assessment diagram for the spatial organisation and temporal management of the cultivated areas**

Percentage of area occupied by the main crop	Average plot size	Percentage as a mix of species	Percentage of soil covered	Ruthenberg coefficient and crop cycle successions
66.6%	4.8% compared to the cultivated area	No species mix	80.15%	Average score = 2
↓	↓	↓	↓	↓
Crop allocation diversity	Mosaic	Intra-plot mixing	Plant cover continuity	Rotations
Low	High	Low	High	Medium

Spatial-temporal organisation
Acceptable

c. **Conclusions and shortcomings identified**

The spatial-temporal organisation is acceptable overall but the allocation diversity should be improved, if possible, by reducing the share dedicated to main crops and practising intra-plot mixing (crop combinations) on at least a portion of the farm. In terms of rotations, fallow periods, even short ones, must be introduced for the large patch zone in particular (plots LP1 to LP30) from March to May. In the small patch zone, it is recommended that fallow periods be introduced each year during the rainy season on a portion of the plots.

5.4.2.5. In terms of AEI/AEU.

a. **Calculation of the values allowing the level of indicators to be established**

Overall state of the AEI/AEU: For each AEI/AEU, the scores are provided based on the information obtained in Point 3.3.2 and the thresholds of the categories specified in Chapter 2. The scores obtained for structure, composition and deteriorations/disruptions are carried over into a global table and critical points are indicated.

For the hedges

	H1		H2	
	Data	State	Data	State
Structure				
Average width	2.5 m	A	2.5 m	A
Number of ligneous strata	2 (upper and lower)	B	2 (upper and lower)	B
Average width of grass strip	1 m	B	1 m	B
Average number of associated small structure types	2 (piles of branches and dead standing wood)	B	2 (piles of branches and dead standing wood)	B
Overall score		B		B
Composition				
Average number of ligneous species	3	B	3	B
Average number of fruit-bearing tree, shrub and bush species	1	B	1	B
Average number of spiny shrub and bush species or trees characteristic of the local landscape	1 (Jujube)	B	1 (Jujube)	B
Exotic species cover	0%	A	0%	A
Overall score		B		B

Deteriorations/disruptions				
Deteriorations	15% (burning)	C	15% (burning)	C
Average distance hedge/ closest fertilised or treated surface	1.5 m	B	1.5 m	B
Overall score		C		C

For the grass strips

	Data	State
Structure		
Average width of the buffer grass strip	3 m	B
Presence of bare soil [%]	25%	C
Cover consisting of young shrubs or bushes [%]	30%	B
Overall score		C
Composition		
exotic species cover [%]	0%	A
ruderal species cover [%]	0%	A
average number of plant species with visible flowers	To be completed*	/
perennial species cover [%]	To be completed*	/
Overall score		A
Deteriorations/disruptions		
deteriorations [% area impacted]	15% (burning)	C
Overall score		C

For the pond

	Data	State
Structure		
Average bank slope	30°	B
Overall score		B
Composition		
% of the bank surface occupied by exotic species	0%	A
Overall score		A
Deteriorations/disruptions		
% of area impacted by deteriorations	8% catchments	B
Distance from the top of the bank edge to the edge of the treated and/or cultivated area	0.5 m	C
Overall score		C

Global AEI/AEU table

Assessment of the agroecological infrastructure						
AEI/AEU type:	Hedges	State of conservation				Observations
AEI/AEU identification	Area occupied	Structure	Composition	Disruption	Score*	
H1	60 m x 2.5 m = 150 m²	B	B	C	C	Heavy deterioration following the burning of crop waste
H2	60 m x 2.5 m = 150 m²	B	B	C	C	Heavy deterioration following the burning of crop waste
Total	300 m²					
AEI/AEU type:	Isolated trees	State of conservation				Observations
AEI/AEU identification	Area occupied	Structure	Composition	Disruption	Score*	
AA1	100 m²	/	/	/	/	/
Total	100 m²					
AEI/AEU type:	Grass strips	State of conservation				Observations
AEI/AEU identification	Area occupied	Structure	Composition	Disruption	Score*	
GS1	100 m x 3 m = 300 m²	C	A	C	C	Too much bare soil Heavy deterioration following the burning of crop waste
Total	300 m²					
AEI/AEU type:	Ponds	State of conservation				Observations
AEI/AEU identification	Area occupied	Structure	Composition	Disruption	Score*	
MA1	25 m x 100 m = 2,500 m² (banks included)	C	A	C	C	Cultivated area too close to the top of the pond bank
Total	2,500 m²					
OVERALL TOTAL	3,200 m²					

*The final score given to the agroecological infrastructure is the score of the worst indicator on the AEI/AEU assessment's list. The diagnostic is part of the process of biodiversity improvement. Therefore, it must be possible to correct any deficient criteria via the management recommended at the end of the diagnostic. The overall score for all of the AEI/AEU follows the same principle and is therefore C in this case.

b. Biodiversity assessment diagram in terms of AEI/AEU

Surface area occupied by the AEI/AEU and UAA	Overall state of the structure/ composition/ deterioration of the AEI/AEU	Number of AEI/AEU types	Distance between natural and semi-natural wooded areas
3,200 m²/ 147,500 m² x 100 = 2.2%	C score	4 (hedges, isolated tree, pond, grass strip)	According to the mapping, most of the wooded areas are over 100 m away
AEI/UAE ratio	AEI/UAE quality	AEI/AEU diversity	AEI/UAE connectivity
Poor	Unfavourable	Average	Poor

Global AEI/AEU value for biodiversity
Problematic

c. Conclusions and shortcomings identified

The percentage of surface area occupied by the AEI/AEU is very low and should be increased by at least 4 times to be at an acceptable ratio.

Overall, the few AEI/AEU on the farm are in a poor state, especially due to deteriorations caused, in particular, by burning crop waste nearby.

To improve their condition, disruptions must be reduced to a maximum of 10% of the AEI/AEU surface area in question. The disruptions should, preferably, be avoided completely.

The grass strip cover must also be improved because there is too much bare soil.

The main issue with the pond is that the cultivated plots are too close. The distance between the top of the bank and the crops should be at least 2 m or, if possible, more than 5 m in order to avoid potential disruptions to the pond from agricultural practices.

The connectivity between the AEI/AEU is also poor and must be improved, notably by planting more hedges to ensure that there is never more than 100 m between wooded areas. The ideal distance is 50 m or less.

5.4.2.6. Protection of the biodiversity of the farm's immediate surroundings

a. Calculation of the values allowing the level of indicators to be established

Assessment of the state of the buffer zone along the waterway

	Data	State
Structure		
Average width of the buffer grass strip	3 m	B
Presence of bare soil [%]	25%	C
Cover consisting of young shrubs or bushes [%]	30%	B
Overall score		C
Deteriorations/disruptions		
deteriorations [% area impacted]	15% (burning)	C
Overall score		C
	General state*	C

*The final score given to the agroecological infrastructure is the score of the worst indicator on the assessment list.

b. Assessment diagram for the protection of biodiversity in the areas surrounding the farm

Structure, composition, deteriorations of the buffer zone along the forest reserve	Structure, composition, deteriorations of the buffer zone along the waterway	Structure, composition, deteriorations of the buffer zone along the neighbouring field crops	Structure, composition, deteriorations of the buffer zone along the neighbouring vegetable crops
No buffer zone	C score	No buffer zone	No buffer zone
↓	↓	↓	↓
Level of protection of the forest reserve	Level of protection of the temporary waterway	Level of reciprocal disruptions with neighbouring field crops avoided	Level of reciprocal disruptions with neighbouring vegetable crops avoided
Poor	Poor	Poor	Poor

↓

Level of protection of the biodiversity of areas near the farm
Problematic

c. **Conclusions and shortcomings identified**

The protection of the areas surrounding the farm is very problematic.

The level of protection of the waterway by the grassy area is poor overall because there is too much bare soil and the percentage deteriorated by burning is too high. Burning must be prohibited and the grassy area must be replenished with perennial plants in order to have less than 10% bare soil.

There are virtually no buffer zones protecting the other areas located near the farm. Buffer zones must be created everywhere.

My additional analysis (space for notes):

5.5. PART 4: PROPOSED IMPROVEMENTS

5.5.1. Instructions

To help Dieudonné, he must be provided with suitable solutions to improve the biodiversity on his farm. Work using a two-step approach for each of the 6 following topics covered in Part 3:

1. *domesticated biodiversity;*
2. *wild para-agricultural animal biodiversity;*
3. *technical itineraries;*
4. *spatial organisation and temporal management of cultivated areas;*
5. *AEI/AEU biodiversity;*
6. *protection of the biodiversity of the farm's immediate surroundings.*

Step 1: For each shortcoming identified:

- a) *a) describe and grade the current situation as well as the objective to be reached while indicating potential constraints and comments;*
- b) *b) briefly list the possible solutions and mention the other improvements which they could provide to the level of biodiversity management on the farm*

Step 2: next verify if, for each topic, these solutions to the shortcomings can be considered effective, profitable, accessible and sustainable. For each solution, assess these 4 criteria and give them a score from 1 to 4 (1: poor; 2: average; 3: good; 4: excellent).

Note that the score will, of course, be quite subjective and sometimes difficult to give because it will depend on several factors which may not be well known or mastered. Nevertheless, it should make it possible to identify the solutions whose implementation should be prioritised.

Based on the scores obtained, establish 4 priority groups to identify the solutions whose implementation should be prioritised in the action plan in Part 5.

Lastly, compile a summary table of the Priority 1 solutions (in green) and Priority 2 solutions (in blue) for all of the shortcomings identified. Carry over the indicator improvements each of the solutions provides to the table based on the information entered in the tables in Step 2. This will facilitate identification of the main priorities when creating the action plan in Part 5 of this chapter.

The tables to be completed at each step are presented below:

Table 1 from Step 1

Shortcoming identified	Current situation	Objective
Constraints/comments		

Table 2 from Step 1

Proposed solutions	
Solution	Probable impact on other biodiversity indicators
S1:	
S2:	

Table from Step 2

Proposed solution	Effective	Profitable	Accessible	Sustainable	Total score
Shortcoming:					
S1:					
S2:					

Priority groups based on the scores obtained

Priority	Score	Colour code
1		
2		
3		
4		

Effective: effectiveness for resolving the shortcoming and improving the diversity in question while taking into account other positive impacts on other aspects of biodiversity. Or effectiveness for resolving the negative impact of certain cultivation practices.

Profitable: economically viable and worth the effort (productive)

Accessible: implementation of the solution is possible given the availability of the required inputs, equipment and technical knowledge and the complexity of the implementation

Sustainable: sustainability of the solution, in other words: long-term, beneficial to local development, low dependency on exogenous inputs, no negative impact on local natural resources or the environment.

Compilation table

All of the Priority 1 and 2 solutions for each shortcoming and the indicators favourably impacted.

Solution	Indicators																			
	Species diversity	Variety diversity	Presence of livestock production	Beneficial soil macrofauna	Flying auxiliaries	Herbicide pressure	Insecticide pressure	Fungicide pressure	Ploughing pressure	Nitrogen management	Crop allocation	Mosaic	Intra-plot mixing	Cover continuity	Rotations	AEI/AEU ratio	AEI/AEU quality	AEI/AEU diversity	AEI/AEU connectivity	Protection of external biodiversity
Shortcoming:																				
S1:											☺									
S2:											☺	☺								

☺ Favourable impact of a Priority 1 solution

☺ Favourable impact of a Priority 2 solution

5.5.2. Search for suitable solutions: proposed results

Have you completed your portion of the exercise? Bravo! Now compare your results to the proposed solutions, identify the differences and try and understand why your results differ from these solutions. Have you perhaps thought of a new and/or better solution? Write out your analysis of the results and your personal insights in a few lines: this will help you retrace the logic behind your approach at the end of the exercise.

5.5.2.1. Domesticated biodiversity

a. **Number of cultivated species**

Shortcoming identified	Current situation	Objective
Insufficient average number of species cultivated per month	3.75	At least >5
Constraints/comments		
Dieudonné wants to maintain the production of two species (tomatoes and green beans) on the large plots. Importers are asking for them and they are his most profitable crops. Diversification will therefore be aimed at the small patches intended for the local market and the rainy season crops on the farm as a whole.		

Proposed solutions	
Solution	**Probable impact on other biodiversity indicators**
S1: 3 different crops instead of maize only during the rainy season, by replacing a portion of the cultivated area with 2 other crops	• Increased crop allocation diversity • Mosaic increased
S2: 2 crops grown together with the maize	• Crop allocation diversity increased Intra-plot mixing increased
S3: S1 and S2 concurrently	• Crop allocation diversity increased Intra-plot mixing increased • Mosaic increased
S4: Plots SP1 to SP36 cultivated with 4 crops instead of 2 during the dry season	• Crop allocation diversity increased • Mosaic increased
S5: Plots SP1 to SP36 cultivated combining tomatoes and okra with another crop	• Crop allocation diversity increased Intra-plot mixing increased
S6: S4 and S5 concurrently	• Crop allocation diversity increased Intra-plot mixing increased • Mosaic increased

b. Number of varieties cultivated

Shortcoming identified	Current situation	Objective
Insufficient average number of varieties cultivated per species	1.6	At least 3
Constraints/comments		
For the two export species, tomatoes and green beans, the varieties are decided by the importer. As a result, species diversity will be hard to reach on the farm due to this external constraint. Diversification will, therefore, only be possible on the small plots intended for the local market and those cultivated during the rainy season in order to have at least 3 varieties cultivated each year for each crop.		

Proposed solutions	
Solution	**Probable impact on other biodiversity indicators**
S1: change from 1 variety of maize to 4 varieties over the year	Increased mosaic
S2: change from 2 to 4 tomato and okra varieties over the year	Increased mosaic
S3: change from 1 to 3 varieties of chilli peppers	Increased mosaic
S4: plan at least 3 different varieties for "new" crops which will be planted over the year	Increased mosaic

c. Livestock production on the farm

Shortcoming identified	Current situation	Objective
No livestock production on the farm	None	Present
Constraints/comments		
The space available on the farm is limited		

Proposed solutions	
Solution	**Probable impact on other biodiversity indicators**
S1: Poultry farming	The droppings provide increased organic matter and contribute to: Improving nitrogen management Improving the biodiversity and soil macrofauna

d. **Proposed solutions: analysis of solutions to increase domesticated biodiversity**

Proposed solution	Effective	Profitable	Accessible	Sustainable	Total score
Number of species cultivated					
S1: 3 different crops instead of maize only during the rainy season, replacing part of the cultivated area with 2 other crops	2	4	4	4	14
S2: 2 crops grown together with the maize	3	3	3	3	12
S3: S1 and S2 concurrently	4	2	3	2	11
S4: Plots SP1 to SP36 cultivated with 4 crops instead of 2 during the dry season	2	4	4	4	14
S5: Plots SP1 to SP36 cultivated by combining tomatoes and okra with another crop	3	3	3	3	12
S6: S4 and S5 concurrently	4	2	3	2	11
Number of varieties cultivated					
S1: change from 1 variety of maize to 4 varieties over the year	4	4	4	4	16
S2: change from 2 to 4 tomato and okra varieties over the year	2	3	3	3	11
S3: change from 1 to 3 varieties of chilli peppers	3	2	2	3	10
S4: plan at least 3 different varieties for "new" crops which will be planted over the year	4	4	3	3	14
Livestock production on the farm					
S1: Poultry farming	4	4	3	3	14

Four groups of priorities are apparent based on the scores:

Priority	Score	Colour code
1	15 and 16	
2	13 and 14	
3	11 and 12	
4	10	

5.5.2.2. Wild para-agricultural animal biodiversity

a. Invertebrate macrofauna beneficial to the soil

Shortcoming identified	Current situation	Objective
Insufficient earthworm, myriapod and ant biodiversity	Score = 6	Score > 7
Constraints/comments		
The eight months of dry weather during the year are not favourable to earthworms and myriapods. Analysis of the raw data shows that the situation is particularly critical in the large patches.		

Proposed solutions	
Solution	**Probable impact on other biodiversity indicators**
S1: Increase the organic matter in the soil	• Improved nitrogen management
S2: Improve the soil cover while crops are growing by combining with another crop	• Decrease in herbicide pressure • Increased intra-plot mixing • Increased domesticated biodiversity • Increase in flying auxiliaries
S3: Improve the soil cover while crops are growing by mulching	• Decrease in herbicide pressure
S4: Improve the continuity of soil cover between crops by using fallow fields and/or catch crops	• Increase in the percentage of soil covered • Increased species biodiversity • Decrease in herbicide pressure • Increase in flying auxiliaries
S5: Change to soil work without overturning	• Decrease in the negative impact of mechanisation
S6: Ensure greater crop diversity at the spatial level	• Increased species biodiversity • Increased crop allocation diversity • Improved mosaic • Increase in flying auxiliaries
S7: Ensure greater crop diversity at the temporal level	• Increased domesticated biodiversity • Improved rotations • Increase in flying auxiliaries
S8: Reduce the use of insecticides harmful to the macrofauna	• Lower herbicide pressure • Increase in flying auxiliaries

b. Flying crop auxiliaries

Shortcoming identified	Current situation	Objective
Insufficient presence of natural aphid predators	Score = 8	Score > 8

Constraints/comments
More information is required about the pesticides used to be able to assess their incidence on the natural aphid predators.

Proposed solutions	
Solution	**Probable impact on other biodiversity indicators**
S1: Reduce the use of insecticides harmful to flying auxiliaries	• Lower herbicide pressure • Increase in soil macrofauna
S2: Install grass strips with flowers	• Increased AEI/UAE ratio • Increase in certain soil macrofauna
S3: Install hedges with plants favourable to flying auxiliaries	• Increased AEI/AEU ratio and connectivity • Increase in certain soil macrofauna
S4: Ensure greater crop diversity at the spatial level	• Increased species biodiversity • Increased crop allocation diversity • Improved mosaic • Increase in flying auxiliaries
S5: Ensure greater crop diversity at the temporal level	• Increased domesticated biodiversity • Improved rotations • Increase in flying auxiliaries

c. **Proposed solutions: analysis of solutions to increase wild para-agricultural biodiversity**

Proposed solution	Effective	Profitable	Accessible	Sustainable	Total score
Invertebrate macrofauna beneficial to the soil					
S1: Increase the organic matter in the soil	3	4	3	4	14
S2: Improve the soil cover while crops are growing by combining with another crop	4	3	3	3	13
S3: Improve the soil cover while crops are growing by mulching	3	3	3	2	11
S4: Improve the continuity of soil cover between crops by using fallow fields and/or catch crops.	4	2	4	3	13
S5: Change to soil work without overturning	3	3	3	3	12
S6: Ensure greater crop diversity at the spatial level	2	2	2	3	9
S7: Ensure greater crop diversity at the temporal level	3	2	2	3	10
S8: Reduce the use of insecticides harmful to the macrofauna	3	3	2	2	10
Flying crop auxiliaries					
S1: Reduce the use of insecticides harmful to flying auxiliaries	4	3	2	2	11
S2: Install grass strips with flowers	3	2	1	2	8
S3: Install hedges with plants favourable to flying auxiliaries	3	3	2	4	12
S4: Ensure greater crop diversity at the spatial level	3	2	2	3	10
S5: Ensure greater crop diversity at the temporal level	3	2	2	3	10

Four groups of priorities are apparent based on the scores

Priority	Score	Colour code
1	13 and 14	
2	11 and 12	
3	9 and 10	
4	8	

5.5.2.3. Technical itineraries

a. **Phytosanitary products**

Shortcoming identified	Current situation	Objective
Overuse of phytosanitary products	Percentage of the area treated with herbicides = 55.2% Percentage of the area treated with insecticides = 100% Percentage of the area treated with fungicides = 55.2%	< 30% for each

Constraints/comments
A more in-depth analysis of the use of phytosanitary products is required to be able to provide alternatives, notably biocontrol products which will not be taken into account for the calculation of treated surfaces and which will, therefore, enable a reduction in the percentage of area treated, and which we will refer to as alternative products. The decrease in the percentage of area treated will probably be difficult to implement given that the area is considered to have been treated after a single treatment with a chemical product.

Proposed solutions	
Solution	**Probable impact on other biodiversity indicators**
S1: Practice mechanical weeding instead of chemical weeding	
S2: Mulch	• Increase in soil macrofauna
S3: Combine cover plants with the crops	• Increase in soil macrofauna • Decrease in nitrogen pressure when legumes are used
S4: Seed directly in the dead or living vegetation cover	• Increase in soil macrofauna • Decrease in the percentage of land tilled
S5: Use alternative pesticides against the main pests (aphids, spider mites)	• Increase in flying auxiliaries • Increase in soil macrofauna
S6: Use alternative fungicides depending on the main diseases present	• Increase in soil macrofauna

b. Nitrogen pressure

Shortcoming identified	Current situation	Objective
Too much nitrogen applied per ha/year	281.2 kgN/ha/year Percentage of organic N = 44.8%	< 200 kgN/ha/year*
Constraints/comments		
The amount of nitrogen applied should be decreased while keeping a sufficient percentage of N from organic manure or, ideally, by increasing it to over 50%. *Between 200 and 300 kgN/ha/year may also be acceptable on condition that the percentage of organic N is greater than 50%.		

Proposed solutions	
Solution	**Probable impact on other biodiversity indicators**
S1: Decrease overall mineral base fertiliser use	
S2: Use other fertilisers without N as the mineral base fertiliser	
S3: Decrease overall mineral base and maintenance fertiliser use as well as organic manure use and apply it more locally	
S4: Increase organic manure use and decrease mineral base and maintenance fertiliser use	• Increase in soil macrofauna
S5: Cultivate legumes in combinations	• Increase in soil macrofauna • Decrease in herbicide pressure • Increased species biodiversity

c. Tillage

Shortcoming identified	Current situation	Objective
Use of deep-ploughing with soil overturning on too-large an area	55.2%	< 20%
Constraints/comments		
Eliminating deep-ploughing with soil overturning will require a radical change and a fairly significant investment in labour and equipment: either farmers must use a cultivation system using vegetation cover (SVC) or they must subsoil and work the soil superficially.		

Proposed solutions	
Solution	**Probable impact on other biodiversity indicators**
S1: Deep-ploughing without soil overturning (sub-soiling)	Increase in soil macrofauna
S2: Superficial tillage (maximum 10 cm deep)	Increase in soil macrofauna
S3: No tillage - seeding/planting in the vegetation cover	Increase in soil macrofauna

d. **Proposed solutions: analysis of solutions to decrease the pressures caused by the technical itinerary practices**

Proposed solution	Effective	Profitable	Accessible	Sustainable	Total score
Phytosanitary products					
S1: Practice mechanical weeding instead of chemical weeding	4	3	4	3	14
S2: Mulch to prevent weeds	3	3	3	2	11
S3: Combine the crops with cover plants to prevent weeds	3	4	3	3	13
S4: Seed directly in the dead or living vegetation cover to prevent weeds	3	4	3	4	14
S5: Use alternative pesticides against the main pests (aphids, spider mites)	4	4	2	3	13
S6: Use alternative fungicides depending on the main diseases present	4	3	2	3	12
Nitrogen pressure					
S1: Decrease overall mineral base fertiliser use	2	3	4	2	11
S2: Use other fertilisers without N as the mineral base fertiliser	3	3	3	2	11
S3: Decrease overall mineral base and maintenance fertiliser use as well as organic manure use and apply it more locally	3	4	3	3	13
S4: Increase organic manure use and decrease mineral base and maintenance fertiliser use	4	3	2	4	13
S5: Cultivate legumes in combinations	4	3	3	4	14
Tillage					
S1: Deep-ploughing without soil overturning (sub-soiling)	4	2	3	2	11
S2: Superficial soil work (maximum 10 cm deep)	4	3	3	3	13
S3: No tillage - seeding/planting in the vegetation cover	4	4	2	4	14

Four groups of priorities are apparent based on the scores:

Priority	Score	Colour code
1	14	
2	13	
3	12	
4	11	

5.5.2.4. Spatial organisation and temporal management of cultivated areas

a. Crop allocation

Shortcoming identified	Current situation	Objective
The percentage of the area occupied by the main crop is too large on average	Main crop percentage: 66.6%	Maximum 50%
Constraints/comments		
The export market constraint does not allow for the reduction of the area occupied by green beans, which is the main crop during several months. Analysis of the table on page 306, shows that maize and tomatoes are the dominant crops at two different times. The overall average percentage of the main crop can be reduced by diversifying the plots occupied by these crops.		

Proposed solutions	
Solution	**Probable impact on other biodiversity indicators**
S1: 3 different crops instead of maize only during the rainy season, replacing part of the cultivated area with 2 other crops	• Increased number of species cultivated • Increased mosaic • Increase in flying auxiliaries
S2: Plots SP1 to SP36 and SP37 to SP84 cultivated with 2 or 3 different crops instead of tomatoes alone from March to May	• Increased number of species cultivated • Increased mosaic • Increase in flying auxiliaries

b. Intra-plot mixing

Shortcoming identified	Current situation	Objective
The practice of combining crops is not used on the farm	No combinations	On average, at least 5% of the area cultivated uses combinations
Constraints/comments		
Crop combinations will be more difficult in export tomato and bean plots because the producer cannot afford to reduce the size of these particular crop areas. Intra-plot mixing should be done with the farm's other crops.		

Proposed solutions	
Solution	Probable impact on other biodiversity indicators
S1: 2 crops grown together with the maize	• Increased number of species cultivated • Increase in flying auxiliaries
S2: Plots SP1 to SP36 cultivated by combining tomatoes and okra with another crop	• Increased crop allocation diversity • Increase in flying auxiliaries
S3: Combined with cover plants	• Increase in species diversity • Increase in soil macrofauna • Decrease in herbicide pressure • Increase in flying auxiliaries

c. **Rotation**

Shortcoming identified	Current situation	Objective
The farm doesn't fallow its fields	No fallow R = 100	R < 66.7 (fallow 4 months out of 12)
Constraints/comments		
The rotations implemented are globally good but could be improved by decreasing the Ruthenberg coefficient, i.e. by introducing sufficiently-long fallow periods. However, this is difficult to achieve with vegetable crops for which it is more difficult to fallow than for field crops.		

Proposed solutions	
Solution	Probable impact on other biodiversity indicators
S1: Start using fallow periods (even short ones) or catch crops, notably in the large patch areas (plots LP1 to LP30) from March to May and from September to October in plots SP85 to SP100	• Increase in soil macrofauna • Increase in flying auxiliaries • Improved cover continuity • Increase in the diversity of crops cultivated • Decrease in herbicide pressure
S2: Fallow some of the plots every year during the rainy season	• Increase in the diversity of crops cultivated • Decrease in herbicide pressure

d. **Proposed solutions: analysis of solutions to improve the spatial organisation and temporal management of cultivated areas**

Proposed solution	Effective	Profitable	Accessible	Sustainable	Total score
Crop allocation					
S1: 3 different crops instead of maize alone during the rainy season, replacing part of the cultivated area with 2 other crops	4	3	4	4	15
S2: Plots SP1 to SP36 and SP37 to SP84 cultivated with 2 or 3 different crops instead of tomatoes alone from March to May	3	2	3	3	11
Intra-plot mixing					
S1: 2 crops grown together with the maize	4	3	4	3	14
S2: Plots SP1 to SP36 cultivated by combining tomatoes and okra with another crop	3	3	3	2	11
S3: Combined with cover plants	4	2	3	4	13
Rotation					
S1: Start using fallow periods (even short ones) or catch crops, notably in the large patch areas (plots LP1 to LP30) from March to May and from September to October in plots SP85 to SP100	2	3	2	3	10
S2: Fallow some of the plots every year during the rainy season	1	1	3	3	8

Four groups of priorities are apparent based on the scores:

Priority	Score	Colour code
1	14 and 15	
2	12 and 13	
3	10 and 11	
4	8 and 9	

5.5.2.5. AEI/AEU biodiversity

a. AEI/UAE ratio

Shortcoming identified	Current situation	Objective
Ratio much too low	2.2%	> 5% (ideally at least 10%)
Constraints/comments		
The farm had hedges which separated the oldest plots Restoring them would raise the AEI ratio of the farm		

Proposed solutions	
Solution	**Probable impact on other biodiversity indicators**
S1: Install new hedges and restore earlier hedges	• Increased connectivity between wooded areas • Improved protection of areas around the farm • Increase in flying auxiliaries • Increased mosaic
S2: Install grass strips, e.g. between cultivated areas and the top of the banks of the pond	• Increase in flying auxiliaries • Increase in soil macrofauna • Increased mosaic
S3: Install windbreaks around the farm	• Increased connectivity between wooded areas • Improved protection of areas around the farm • Increase in AEI/AEU diversity • Increase in flying auxiliaries

b. AEI/UAE quality

Shortcoming identified	Current situation	Objective
Problematic quality of the 3 types of existing AEI/AEU	Score of C for the 3 types	Score of B for the 3 types
Constraints/comments		
To improve their condition, disruptions must be decreased to a maximum of 10% of the surface area of the AEI/AEU in question. They should be avoided entirely, if possible. The grass strip cover must also be improved because there is too much bare soil. The main issue with the pond is that the cultivated plots are too close. The distance should be at least 2 m or, if possible, over 5 m to avoid the potential disruptions of agricultural practices on the pond.		

Proposed solutions	
Solution	**Probable impact on other biodiversity indicators**
S1: Stop burning waste near the hedges and on the grass strips; grind up and/or compost the organic waste or use it as mulch.	• Increase in flying auxiliaries • Increase in soil macrofauna
S2: Replant the bare sections of the grass strips	• Increase in flying auxiliaries • Increase in soil macrofauna
S3: Create a grass strip at least 2 m wide between the cultivated plots and the top of the bank of the pond	• Increase in flying auxiliaries • Increase in soil macrofauna • Increase in the AEI/AEU ratio

c. **AEI/AEU connectivity**

Shortcoming identified	Current situation	Objective
The distance between wooded areas is too great	> 100 m	50 m
Constraints/comments		
The farm had hedges which separated the oldest plots Restoring them would increase connectivity on the farm.		

Proposed solutions	
Solution	**Probable impact on other biodiversity indicators**
S1: Plant hedges to separate production plots	• Increase in the AEI/AEU ratio • Increase in flying auxiliaries • Increased mosaic
S2: Plant windbreaks or hedges around the farm	• Increase in the AEI/AEU ratio • Increase in flying auxiliaries

d. **Proposed solutions: analysis of solutions to improve AEI/AEU biodiversity**

Proposed solution	Effective	Profitable	Accessible	Sustainable	Total score
AEI/UAE ratio					
S1: Install new hedges and restore earlier hedges	4	3	3	4	14
S2: Install grass strips, e.g. between cultivated areas and the top of the bank of the pond	2	3	2	2	9
S3: Install windbreaks around the farm	4	3	4	4	15
AEI/UAE quality					
S1: Stop burning waste near the hedges and on the grass strips; grind up and/or compost the organic waste or use it as mulch.	4	4	3	4	15
S2: Replant the bare sections of the grass strips	4	3	2	2	11
S3: Create a grass strip at least 2 m wide between the cultivated plots and the top of the bank of the pond	4	2	2	2	10
AEI/AEU connectivity					
S1: Plant hedges to separate production plots	4	3	3	4	14
S2: Plant windbreaks or hedges around the farm	4	3	4	4	15

Four groups of priorities are apparent based on the scores:

Priority	Score	Colour code
1	14 and 15	
2	12 and 13	
3	10 and 11	
4	9	

5.5.2.6. Protection of the biodiversity of the farm's immediate surroundings

a. Grass strip along the waterway

Shortcoming identified	Current situation	Objective
Too much bare soil and too much has been deteriorated by burning	Score C	Score B
Constraints/comments		
The weather during the long dry season makes it difficult to maintain the grass strips and requires finding the perennial plants best-suited to these conditions, preferably among local plants. The absence of a composting area makes it difficult to avoid burning plant waste.		

Proposed solutions	
Solution	**Probable impact on other biodiversity indicators**
S1: Stop burning waste on the grass strips; grind up and/or compost the organic waste or use it as mulch.	• Increase in flying auxiliaries • Increase in soil macrofauna
S2: Replant the bare sections of the grass strips	• Increase in flying auxiliaries • Increase in soil macrofauna

b. Protective infrastructure of the other areas surrounding the farm

Shortcoming identified	Current situation	Objective
Practically no buffer zone	No buffer zone	Quality buffer zones everywhere (minimum score of B)
Constraints/comments		
Virtually none of the other areas located near the farm are isolated by a buffer zone. Buffer zones must be created everywhere. The ideal protection for the external zone would normally be a hedge or windbreak which is sufficiently wide and well structured. If there is no hedge, a wide enough grass strip buffer can also be used to prevent disruptions in the outer areas.		

Proposed solutions	
Solution	**Probable impact on other biodiversity indicators**
S1: Install windbreaks along open areas like roads and the crops surrounding the farm	• Increase in the AEI/AEU ratio • Increase in AEI/AEU diversity • Increase in flying auxiliaries • Increased connectivity between wooded areas
S2: Install hedges along the closed-in areas like the forest surrounding the farm	• Increase in the AEI/AEU ratio • Increase in flying auxiliaries

c. **Proposed solutions: analysis of solutions to improve the protection of biodiversity in the farm's immediate surroundings**

Proposed solution	Effective	Profitable	Accessible	Sustainable	Total score
Grass strip along the waterway					
S1: Stop burning waste on the grass strips; grind up and/or compost the organic waste or use it as mulch.	3	3	3	4	13
S2: Replant the bare sections of the grass strips	2	2	2	4	10
Protective infrastructure of the other areas surrounding the farm					
S1: Install windbreaks along open areas like roads and the crops surrounding the farm	4	3	3	4	14
S2: Install hedges along the closed-in areas like the forest surrounding the farm	3	2	3	4	12

Four groups of priorities are apparent based on the scores:

Priority	Score	Colour code
1	13 and 14	
2	12	
3	11	
4	10	

5.5.2.7. Summary of the minimum objectives to be achieved per shortcoming identified

Domesticated biodiversity		
Shortcoming identified	**Current situation**	**Objective**
Insufficient average number of species cultivated per month	3.75	At least > 5
Insufficient average number of varieties cultivated per species	1.6	At least 3
No livestock production on the farm	None	Present
Wild para-agricultural animal biodiversity		
Shortcoming identified	**Current situation**	**Objective**
Insufficient earthworm, myriapod and ant biodiversity	Score = 6	Score > 7
Insufficient presence of natural aphid predators	Score = 8	Score > 8
Technical itineraries		
Shortcoming identified	**Current situation**	**Objective**
Overuse of phytosanitary products	Percentage of the area treated with herbicides = 55.2% Percentage of the area treated with insecticides = 100% Percentage of the area treated with fungicides = 55.2%	< 30% for each
Too much nitrogen applied per ha/year	281.2 kgN/ha/year Percentage of organic N = 44.8%	< 200 kgN/ha/year keeping or increasing the percentage of organic nitrogen Between 200 and 300 kgN/ha/year is also acceptable on condition that the percentage of organic N is greater than 50%.
Use of deep-ploughing with soil overturning on too-large an area	55.2%	< 20%

Spatial organisation and temporal management of cultivated areas		
Shortcoming identified	**Current situation**	**Objective**
The percentage of the area occupied by the main crop is too large on average	Main crop percentage: 66.6%	Maximum 50%
The practice of combining crops is not used on the farm	No combinations	On average, at least 5% of the area cultivated uses combinations
The farm doesn't fallow its fields	No fallow R = 100	R < 66.7 (fallow 4 months out of 12)
AEI/AEU biodiversity		
Shortcoming identified	**Current situation**	**Objective**
Ratio much too low	2.2%	> 5% (ideally at least 10%)
Problematic quality of the 3 types of existing AEI/AEU	Score of C for the 3 types	Score of B for the 3 types
The distance between wooded areas is too great	> 100 m	50 m
Protection of the biodiversity of the farm's immediate surroundings		
Shortcoming identified	**Current situation**	**Objective**
Too much bare ground and too much of the grass strip along the waterway has been deteriorated by burning	Score C	Score B
Practically no buffer zone on the edge of the farm	No buffer zone	Quality buffer zones everywhere (minimum score of B)

5.5.2.8. Compilation table of the priority solutions (priority 1 and priority 2 groups) and improved indicators

Solution	Indicators: Species diversity	Variety diversity	Presence of livestock production	Beneficial soil macrofauna	Flying auxiliaries	Herbicide pressure	Insecticide pressure	Fungicide pressure	Tillage pressure	Nitrogen management	Crop allocation	Mosaic	Intra-plot mixing	Cover continuity	Rotation	AEI/AEU ratio	AEI/AEU quality	AEI/AEU diversity	AEI/AEU connectivity	Protection of external biodiversity
Number of species cultivated																				
S1: 3 different crops instead of maize alone during the rainy season, replacing part of the cultivated area with 2 other crops	☺										☺	☺								
S4: Plots SP1 to SP36 cultivated with 4 crops instead of 2 during the dry season	☺										☺	☺								
Number of varieties cultivated																				
S1: change from 1 variety of maize to 4 varieties over the year		☺										☺								
S4: plan at least 3 different varieties for "new" crops which will be planted over the year		☺										☺								
Livestowck production on the farm																				
S1: change from 1 variety of maize to 4 varieties over the year			☺	☺						☺										

Solution	Species diversity	Variety diversity	Presence of livestock production	Beneficial soil macrofauna	Flying auxiliaries	Herbicide pressure	Insecticide pressure	Fungicide pressure	Tillage pressure	Nitrogen management	Crop allocation	Mosaic	Intra-plot mixing	Cover continuity	Rotation	AEI/AEU ratio	AEI/AEU quality	AEI/AEU diversity	AEI/AEU connectivity	Protection of external biodiversity
Invertebrate macrofauna																				
S1: Increase the organic matter in the soil										☺										
S2: Improve the soil cover while crops are growing by combining with another crop	☺			☺	☺	☺							☺							
S3: Improve the soil cover while crops are growing by mulching				☺		☺														
S4: Improve the continuity of soil cover between crops by using fallow fields and/or catch crops.	☺			☺	☺	☺								☺						
S5: Change to soil work without overturning				☺					☺											
Auxiliaries																				
S1: Reduce the use of insecticides harmful to flying auxiliaries				☺	☺		☺													
S3: Install hedges with plants favourable to flying auxiliaries				☺	☺											☺			☺	
Phytosanitary products																				
S1: Practice mechanical weeding instead of chemical weeding						☺														
S3: Combine cover legumes with crops to prevent weeds				☺		☺				☺										
S4: Seed directly in the vegetation cover to prevent weeds				☺		☺			☺											
S5: Use alternative insecticides				☺	☺		☺													

Solution	Species diversity	Variety diversity	Presence of livestock production	Beneficial soil macrofauna	Flying auxiliaries	Herbicide pressure	Insecticide pressure	Fungicide pressure	Tillage pressure	Nitrogen management	Crop allocation	Mosaic	Intra-plot mixing	Cover continuity	Rotation	AEI/AEU ratio	AEI/AEU quality	AEI/AEU diversity	AEI/AEU connectivity	Protection of external biodiversity
Nitrogen pressure																				
S3: Decrease mineral fertiliser use as well as organic manure use and apply it more locally										☺										
S4: Increase organic manure use and decrease mineral base and maintenance fertiliser				☺						☺										
S5: Cultivate legumes in combinations	☺			☺		☺				☺										
Soil work																				
S2: Superficial soil work				☺					☺											
S3: No tillage - seeding/planting in the vegetation cover				☺					☺											
Crop allocation																				
S1: 3 different crops instead of maize alone during the rainy season, replacing part of the cultivated area with 2 other crops	☺				☺						☺	☺								
Intra-plot mixing																				
S1: 2 crops grown together with the maize	☺				☺								☺							
S3: Combined with cover plants	☺			☺	☺	☺							☺							
AEI/AEU ratio																				
S1: Install new hedges and restore earlier hedges					☺							☺				☺			☺	☺
S3: Install windbreaks around the farm					☺											☺		☺	☺	☺

Solution	Species diversity	Variety diversity	Presence of livestock production	Beneficial soil macrofauna	Flying auxiliaries	Herbicide pressure	Insecticide pressure	Fungicide pressure	Tillage pressure	Nitrogen management	Crop allocation	Mosaic	Intra-plot mixing	Cover continuity	Rotation	AEI/AEU ratio	AEI/AEU quality	AEI/AEU diversity	AEI/AEU connectivity	Protection of external biodiversity
AEI/UAE quality																				
S1: Stop burning waste near the hedges and on the grass strips; grind up and/or compost the organic waste or use it as mulch.				☺	☺												☺			
AEI/AEU connectivity																				
S1: Plant hedges to separate production plots					☺							☺				☺			☺	
S2: Plant windbreaks or hedges around the farm					☺											☺			☺	
Protection of the biodiversity of the farm's immediate surroundings																				
S1: Stop burning waste on the grass strips; grind up and/or compost the organic waste or use it as mulch.				☺	☺															☺
S1: Install windbreaks along open areas like roads and the crops surrounding the farm					☺											☺		☺	☺	☺
S2: Install hedges along the closed-in areas like the forest surrounding the farm					☺											☺				☺

Complementary analysis (area for notes):

5.6. PART 5: ACTION PLAN

5.6.1. Instructions for the presentation of an action plan

To help Dieudonné, he must be provided with an "Action plan" to implement solutions, beginning with those given priority.

The "Action plan" must be prepared taking into account the priorities listed in point 5.6.2.7. Priority will first be given to Group 1 solutions then to Group 2 solutions which have a positive impact on at least 3 indicators (acting on one indicator to generate an effect can simultaneously address another shortcoming). The other solutions should be considered less urgent and taken into account last.

The "Action plan" should be presented based on a three-year implementation schedule. It should state what can be put in place immediately, what needs preliminary testing, what requires additional information prior to implementation, etc.

Work with the table below as an example to describe the implementation steps. Use one table per step (year).

In the table, provide the N solutions to be implemented (general description of the objective) and the N actions required to achieve the result sought. The N solutions should be grouped in four groups in each table: product diversification, cultivation practices, phytosanitary practices and AEI/AEU layout/management practices. In addition, for steps 2 and 3 (years 2 and 3), new and ongoing actions should be separated for each group. Create a summary table (see example below) briefly stating the main actions to be carried out each year for each solution.

You should also plan to monitor changes in biodiversity to check if it is improving following the actions taken to address the shortcomings. Propose a biodiversity assessment programme specifying the indicators to be taken into account based on the model below.

Model action plan table (example to be used)

Step… - … year	
1. Product diversification	
Solution	Actions planned and comments
Actions to be carried out or modified depending on the experience of the previous year(s).	
New actions	
2. Cultivation practices	
Solution	Actions planned and comments
Actions to be carried out or modified depending on the experience of the previous year(s).	
New actions	
3. Phytosanitary practices	
Solution	Actions planned and comments
Actions to be carried out or modified depending on the experience of the previous year(s).	
New actions	
4. AEI/AEU layouts	
Solution	Actions planned and comments
Actions to be carried out or modified depending on the experience of the previous year(s).	
New actions	

Action plan summary model

Solution	Year 1	Year 2	Year 3
Product diversification			
Cultivation practices			
Phytosanitary practices			
AEI/AEU layout			

Indicator assessment schedule model

Indicators	Year 1	Year 2	Year 3
Domesticated biodiversity			
Wild para-agricultural animal biodiversity			
Technical itinerary			
Spatial organisation and temporal management of cultivated areas			
AEI/AEU			
Buffer zones in areas surrounding the farm			

Make your own, complete "Action plan". Next consult the proposed solutions and compare them with your plan.

5.6.2. Develop an action plan: proposed results

Have you completed your portion of the exercise? Bravo! Now compare your results to the proposed solutions, identify the differences and try and understand why your results differ. Have you designed a new and/or better proposal? Write out your analysis of the results and your personal insights in a few lines: this will help you retrace the logic behind your approach.

Proposed solutions: proposal for an action plan in three tables (3 steps, 1 year per step).

Step 1 - year 1 Priority 1 Group solutions to be implemented first and actions to be implemented the first year	
1. Product diversification	
Solution	Actions planned and comments
3 different crops instead of maize alone during the rainy season, replacing part of the cultivated area with 2 other crops	Replace part of the maize crop with **sorghum and millet crops.** Grow at least 3 varieties for each "new crop" from the start, if possible.
Four varieties of maize over the year instead of one.	**Sow after selecting the maize varieties** based on the planting and market periods (grain maize, Oaxacan Green corn, etc.)
2. Cultivation practices	
Solution	Actions planned and comments
Increase the input of organic matter in the soil	First, **increase manure applications by at least 50%** before planting the crops. The manure must be composted before use. **Install a composting area** which will also be used to compost the farm's plant waste.
Crop combinations with a preference for legumes	At first, depending on the season, **combine** crops like **cowpeas and squash with maize, sorghum and millet.**
Fallow and/or catch crops	This practice can only be used for plots when a sufficiently long period is possible between two crops. This is only the case for the section of the farm with large plots. However, the period during which this can be done is dry and very hot and is not favourable to plants for fallow or for a catch crop without irrigation. **Preliminary tests are required. Cowpeas or other plants can be tested as a catch crop** with irrigation at the start of the cycle only.
Sowing and transplanting directly in the vegetation cover	This is only possible for crops planted immediately following the rainy season crop. It should have a vegetation cover reinforced with a combination crop or a catch crop. **Preliminary tests are required.**

3. Phytosanitary practices	
Solution	**Actions planned and comments**
Use mechanical weeding instead of chemical weeding	Herbicides are only used on the large fields. In order to reduce the surface area weeded chemically, **a mechanical weeding test** must be done on **50% of the land cultivated in the large patches.** The goal is to achieve a ratio of chemically weeded land of less than 30% for the entire farm.

4. AEI/AEU layout/management	
Solution	**Actions planned and comments**
Do not burn waste near the hedges or on the grass strips; grind up and/or compost organic waste or use it as mulch.	**Eliminating burning** is fairly easy to achieve on condition of being able to easily move the plant waste and take it to a composting area. The priority is to **create a composting area** on the farm and to **have equipment to grind/shred** the largest waste.
Hedges favouring plants which are beneficial to flying crop auxiliaries	Hedges must be planted with several strata which will vary depending on the size of the plots and the space available. They must include a wide range of plants and favour flowering plants which are beneficial to bees and auxiliaries. Local plants suited to the climate are preferred. Hedges on small plots should be planted every 50 m perpendicularly to the slope of the land. Hedges for large plots should be planted along transversal roads at about 50 m from each other. Ideally, hedges should be planted at the start of the rainy season The **following actions are required the first year prior to planting**: • Selection of species for the composition of the hedges and a planting plan. • Orders based on availability or own seedlings. • Potential for irrigation after planting, if required.
Windbreaks around the farm	The windbreaks should ideally consist of several strata like hedges, but should also include more tall trees. Local species which do not require much water should be preferred. Planting should be done at the start of the rainy season. The **following actions are required the first year prior to planting**: • Selection of species for the composition of the windbreaks and a planting plan. • Orders based on availability or own seedlings. • Potential for irrigation after planting, if required.

Step 2 - second year Solutions to be implemented second and actions to be implemented the second year Priority 2 Group solutions with an impact on at least three indicators which were not already initiated in step 1 Priority 1 Group solutions whose actions have already been started and are being continued	
1. Product diversification	
Solution	Actions planned and comments
Actions to be carried out or modified depending on the experience of the first year	
3 different crops instead of maize alone during the rainy season, replacing part of the cultivated area with 2 other crops	Replace part of the maize crop with **sorghum and millet crops**. Grow at least 3 varieties for each "new crop", if possible.
Four varieties of maize over the year instead of one	**Seed after selecting the maize varieties** based on the planting and market periods (grain maize, Oaxacan Green corn, etc.)
New actions	
Plots SP1 to SP36 cultivated with 4 crops instead of 2 during the dry season.	In addition, the plots should include **round cabbage when tomatoes are being grown and onions during the okra growing season.** Grow at least 3 varieties for each "new crop" from the start, if possible.
Poultry farming	**Set up poultry farming after the feasibility study and the facilities required have been built.**
2. Cultivation practices	
Solution	Actions planned and comments
Actions to be carried out or modified depending on the experience of the first year	
More organic matter in the soil	Continue to increase **applications of manure by 50%** before planting the crops if this wasn't completed in year 1. Continue or begin to compost the farming plant waste in the **composting area.**
Crop combinations with a preference for legumes	Depending on the season, **continue/change/expand** the crop combinations like **cowpeas and squash with maize, sorghum and millet.**
Fallow and/or catch crops	If necessary, **continue the preliminary tests or implement more extensively** if the test results were positive.
Sowing and transplanting directly in the vegetation cover	If necessary, **continue the preliminary tests or implement more extensively** if the test results were positive.
New actions	
Preferably cover plants combined with legumes	If possible, **use cover plants** for all of the farm's crops **or carry out preliminary tests, if necessary.**

3. Phytosanitary practices	
Solution	**Actions planned and comments**
Actions to be carried out or modified depending on the experience of the first year	
Use mechanical weeding instead of chemical weeding	**Put into practice and/or continue testing** weeding alternatives to chemicals.
New actions	
Reduced use of insecticides harmful to auxiliaries	Analyse the treatments used (profile of the active substances used, treatment targets, etc.) and based on the results, **identify the products authorised in the country which it would be preferable to use.** **Test the products** on part of the area of each crop.
Use alternative insecticides to avoid chemical products (biocontrol products, etc.)	

4. AEI/AEU layout	
Solution	**Actions planned and comments**
Actions to be carried out or modified depending on the experience of the first year	
Do not burn waste near the hedges or on the grass strips; grind up and/or compost organic waste or use it as mulch.	**Continue to avoid burning** waste. After grinding the waste, **compost it** in the composting area created for this purpose. **Potentially** use part of the ground up and non-composted **waste** to **mulch** certain crops.
Hedges favouring plants which are beneficial to flying crop auxiliaries	**Plant** the plants available for the priority hedges and carry out the required maintenance **at the start of the rainy season**.
Windbreaks around the farm	**Plant** the plants available for the priority windbreaks and carry out the required maintenance **at the start of the rainy season**.
New actions	
Hedges along the closed-in areas like forests around the farm	Hedges must be planted with several strata which will vary depending on the space available. The large tree stratum must be sufficiently dense to ensure that the desired screen effect is optimal. They must include a wide range of plants and favour flowering plants which are beneficial to bees and auxiliaries. Local plants suited to the climate are preferred. The **following actions are required the first year prior to planting**: • Selection of species for the composition of the hedges and a planting plan. • Orders based on availability or own seedlings. • Potential for irrigation after planting, if required.

Step 3 - third year Solutions to be implemented last and actions to be implemented the third year Priority 2 Group solutions with an impact on at least three indicators which were not already initiated in step 2 Priority 1 Group and Priority 2 Group solutions whose actions have already been started and are being continued	
1. Product diversification	
Solution	Actions planned and comments
Actions to be carried out or modified depending on the experience of the two previous years	
Plots SP1 to SP36 cultivated with 4 crops instead of 2 during the dry season.	Continue to plant the plots with the four crops: **round cabbage, tomatoes, onions and okra.** Change the crops or diversify even more with other additional crops.
Poultry farming	**Continue raising poultry** or change the type of livestock production, if necessary.
Three different crops instead of maize alone during the rainy season, replacing part of the cultivated area with 2 other crops	If not already done, continue to replace part of the maize crops with **sorghum and millet crops or change the choice of crops.** Grow at least 3 varieties for each “new crop”, if possible.
Four varieties of maize over the year instead of one	**Potentially change the maize varieties** depending on the planting and market periods (grain maize, Oaxacan Green corn, etc.)
New actions	
Plant at least 3 new varieties of each “new” crop over the year if this hasn’t already been done.	**Sow after selecting the varieties** based on the planting and market periods. If required, first carry out a preliminary test on small areas.
2. Cultivation practices	
Solution	Actions planned and comments
Actions to be carried out or modified depending on the experience of the previous years	
More organic matter in the soil	Continue to increase **applications of manure by 50%** before planting the crops if this wasn’t completed in year 2. Continue to compost the farming plant waste in the **composting area.**
Crop combinations with a preference for legumes	Depending on the season, **continue/change/expand** the crop combinations like **cowpeas and squash with maize, sorghum and millet.**
Fallow and/or catch crops	**If necessary, continue the preliminary tests or implement more extensively if the test results were positive.**

Sowing and transplanting directly in the vegetation cover	**If necessary, continue the preliminary tests or implement more extensively if the test results were positive.**
Preferably cover plants combined with legumes	If possible, **use cover plants** for all of the farm's crops **or carry out preliminary tests, if necessary.**
New actions	
Improved soil cover with mulching	**To be implemented**, in particular, for crops which are not suited to the use of cover plants.
More localised application of mineral fertilisers and organic manures.	This technique saves on inputs and reduces nitrogen pressure. **To be implemented for as many crops as possible** if the technique is known and perfected. Otherwise carry out **tests.**
Higher proportion of organic manure compared to mineral base and maintenance fertilisers.	**This should be done for the greatest number of crops possible,** for full or localised spreading.
Superficial soil work without overturning	To be implemented if cultivation cannot be done under a vegetation cover on the entire farm. **Find the appropriate equipment**
3. Phytosanitary practices	
Solution	Actions planned and comments
Actions to be carried out or modified depending on the experience of the previous years	
Reduced use of insecticides harmful to auxiliaries Use alternative insecticides to avoid chemical products (biocontrol products, etc.)	**Use products** which had positive test results. Continue to analyse the treatments used (profile of the active substances used, treatment targets, etc.) and based on the results, **identify the products authorised in the country which it would be preferable to use.** **Test the products** on part of the area of each crop.
New actions	
None	/

4. AEI/AEU layout	
Solution	Actions planned and comments
Actions to be carried out or modified depending on the experience of the first year	
Hedges along the closed-in areas like the forest surrounding the farm	Hedges must be planted with several strata which will vary depending on the space available. The large tree stratum must be sufficiently dense to ensure that the desired screen effect is optimal. They must include a wide range of plants and favour flowering plants which are beneficial to bees and auxiliaries. Local plants suited to the climate are preferred. The **following actions are required the first year prior to planting**: • Selection of species for the composition of the hedges and a planting plan. • Orders based on availability or own seedlings. • Potential for irrigation after planting, if required.
Do not burn waste near the hedges or on the grass strips; grind up and/or compost organic waste or use it as mulch.	**Continue to avoid burning** waste. After grinding the waste, **compost it** in the composting area created for this purpose. **Potentially** use part of the ground up **waste** to **mulch** certain crops.
Hedges favouring plants which are beneficial to flying crop auxiliaries	**Continue to plant** the plants available for the priority hedges and carry out the required maintenance **at the start of the rainy season.**
Windbreaks around the farm	**Continue to plant** the plants available for the priority windbreaks and carry out the required maintenance **at the start of the rainy season.**

The summary table below provides a better understanding of the different steps required to implement the actions for each solution.

Solution	Year 1	Year 2	Year 3
Product diversification			
3 rainy season crops instead of maize only	• Plant maize, sorghum and millet	• Plant maize, sorghum and millet or change the crop selection	• Plant maize, sorghum and millet or change the crop selection
4 varieties of maize over the year instead of one	• Select the varieties • Sow	• Select the varieties • Sow	• Select the varieties • Sow
4 crops instead of 2 on SP1 to SP36	/	• Grow round cabbage, onions, tomatoes and okra	• Continue with these crops or change and/or diversify more
Poultry farming	/	• Feasibility study • Layouts • Start up	• Continue the poultry farming
At least 3 varieties per species farmed	/	/	• Increase the number of varieties cultivated per crop*
Cultivation practices			
Increased organic matter	• Increase the contribution to the soil by 50% • Create a composting area**	• Continue to increase the contribution to the soil by 50% • Compost	• Maintain the increase in the contribution to the soil by 50% • Continue to compost
Crop combinations	• Combine cowpeas and/or squash with cereal crops	• Continue/change/extend the combinations	• Continue/change/extend the combinations
Fallow/catch crops	• Preliminary tests on large fields	• Implement and/or continue testing	• Implement and/or continue testing
Direct sowing/transplanting under vegetation cover	• Preliminary tests	• Implement and/or continue testing	• Implement and/or continue testing
Combined with cover plants	/	• Implement and/or test	• Implement and/or test
Mulch	/	/	• Implement
Localised manure	/	/	• Implement and/or test

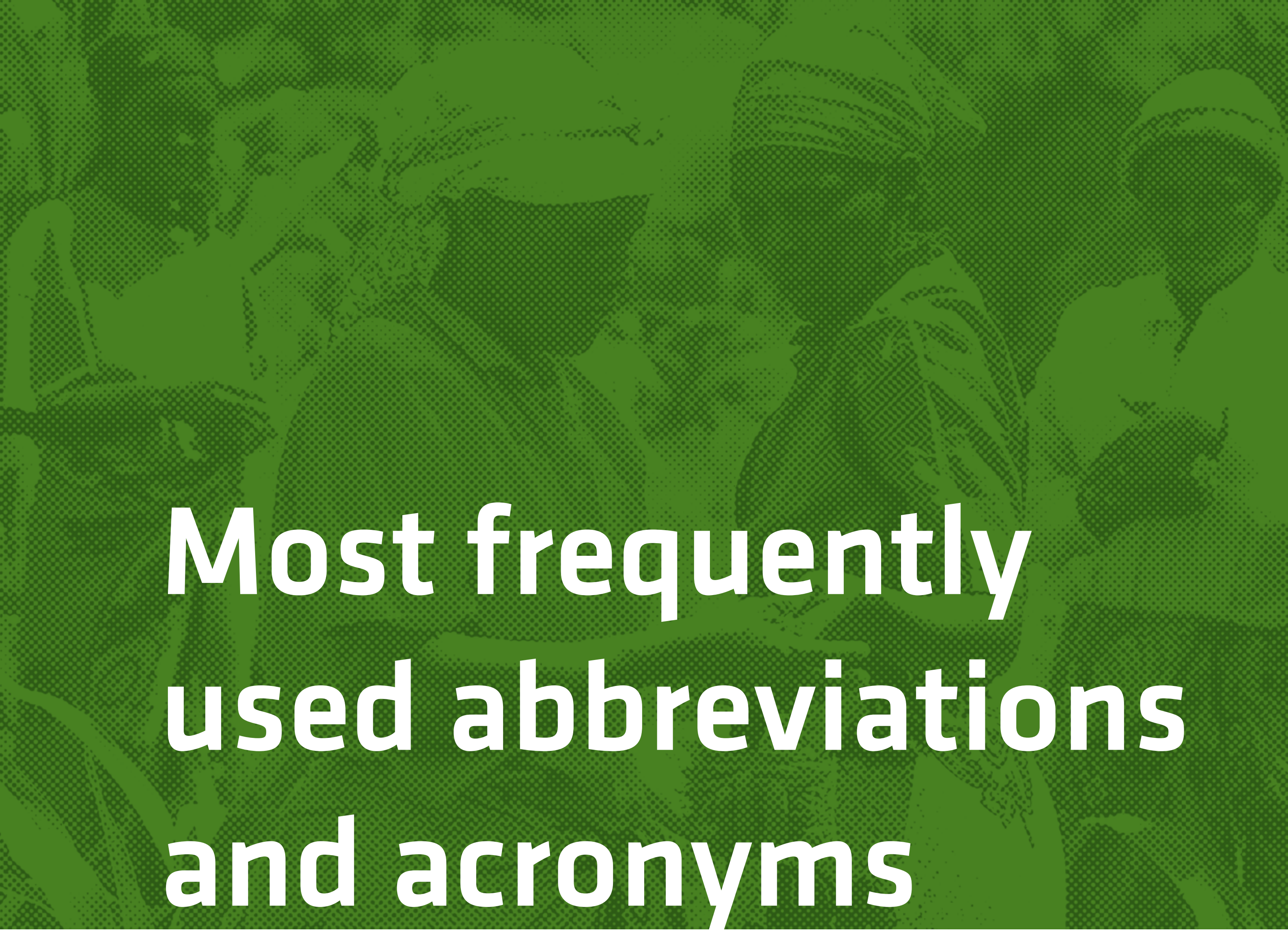
High percentage of organic manure	/	/	• Implement and/or test
Superficial soil work without overturning	/	/	• Find out if appropriate equipment is available
Phytosanitary practices			
Alternative weeding	• Alternative weeding test on 50% of the large patch land	• Implement and/ or continue testing	• Implement and/or continue testing
Alternative insecticides and respect for auxiliaries	/	• Analyse practices • Identify the alternative products available • Test the products	• Implement the products with positive test results • Continue the analyses and tests
AEI/AEU layouts			
Do not burn waste	• Immediately stop burning any organic waste	• Continue the ban	• Continue the ban
Hedges between plots	• Select species • Draw up a planting plan • Produce or order the seedlings	• Plant	• Plant • Maintain
Windbreaks	• Select species • Draw up a planting plan • Produce or order the seedlings	• Plant	• Plant • Maintain
Hedges around the farm	/	• Select species • Draw up a planting plan • Produce or order the seedlings	• Plant

* preferably to be done the first year
** composting will also enable better management of the AEI/AEU by avoiding the burning of plant waste on the farm

The monitoring of changes in biodiversity on the farm can be done by assessing the indicators on a regular basis (for example, once a year) and using the following programme in which the level expected each year can be indicated

Indicator	Year 1	Year 2	Year 3
Domesticated biodiversity			
Number of species cultivated	X	X	X
Number of varieties cultivated		X	X
Presence of livestock production		X	X
Wild para-agricultural animal biodiversity			
Invertebrate soil macrofauna			X
Flying crop auxiliaries			X
Technical itinerary			
Percentage of the area with herbicides			X
Percentage of the area with insecticides			X
Percentage of the area with fungicides			X
Nitrogen total/ha/year		X	X
Percentage of organic N		X	X
Percentage of area ploughed in depth			X
Spatial organisation and temporal management of cultivated areas			
Main crop percentage	X	X	X
% of the area cultivated in combination		X	X
Rotations (Ruthenberg coefficient)			X
AEI/AEU			
AEI/AEU ratio		X	X
AEI/UAE quality	X	X	X
AEI/AEU connectivity			X
Buffer zones in areas surrounding the farm			
Quality		X	X
Presence			X

Complementary analysis (area for notes)



Most frequently used abbreviations and acronyms

MOST FREQUENTLY USED ABBREVIATIONS AND ACRONYMS

ACP	Africa Caribbean Pacific
CSA	Climate-Smart Agriculture
AFD	Agence Française de Développement (French Development Agency)
COP	Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC)
ESCo	Expertise Scientifique Collective (Collective Scientific Expertise)
FAO	Food and Agriculture Organization of the United Nations
FiBL	Research Institute of Organic Agriculture
GHG	Greenhouse Gas
IFOAM	International Federation of Organic Agriculture Movements
INRA	French National Institute for Agricultural Research
AEI	Agro-Ecological Infrastructure
GMO	Genetically Modified Organism
UNEP	United Nations Environment Programme
DRC	Democratic Republic of the Congo
GIS	Geographical Information System
UAA	Utilised Agricultural Area
CBDS	Secretariat of the Convention on Biological Diversity
SCV	Cultivation Systems using Vegetation Cover
BPS	Biodiversity Promotion Surfaces
TSBF	Tropical Soil Biology and Fertility
AEU	Agro-Ecological Units
IUCN	International Union for Conservation of Nature

Glossary

GLOSSARY

Direct genetic action	Genetic improvement or modification through the creation of new varieties or genetically-modified organisms.
Anthropisation	The conversion of an environment by human action which furthers it from its natural state.
Water supply catchment area	Area over which water infiltrates and supplies the catchment area.
Crop allocation	Distribution of crops on a farm over a specific year. Crop allocation is the division of agricultural land into multiple plots which support various crops.
Auxiliary	Predator or parasitoid animal which, due to its mode of living, assists in destroying harmful crop pests.
Doline	Small natural funnel, generally in a calcareous soil, into which surface water disappears. Artificial well or sump for absorbing rainwater.
Biocenosis	Collection of living organisms coexisting in an ecological area and their organisation and interactions.
Biodiversity	Biodiversity is the variability among living organisms and the ecological structures they are a part of, including diversity within species (genetic diversity), between species (species diversity) and in ecosystems (ecosystem diversity).
Domesticated biodiversity	Domesticated biodiversity includes the collection and richness of species and subspecies (races, varieties) domesticated by humans and subjected to artificial selection. The term "domesticated biodiversity" is also used to express the global decline in the diversity of cultivated and raised species in recent years.
Wild biodiversity	Wild biodiversity exists spontaneously, is often not directly managed by humans but is greatly influenced by human activity. Wild biodiversity can be exceptional or ordinary. It is *exceptional* when it is made up of living organisms and habitats which are rare or at risk of disappearing. In this case, it can be regulated. In the opposite case, it's known as ordinary.
Biotope	In ecology, a biotope (from Ancient Greek) is a living place defined by relatively uniform physical and chemical characteristics. This environment hosts a collection of life forms which make up the biocenosis: flora, fauna, fungus (mushrooms) and micro-organisms. It's an ecosystem component formed by its physical, chemical and spatial dimensions.

Bocage An enclosed landscape, defined by a dispersed habitat combined with individual farms surrounded by their farmlands, often enclosed by hedges or shelterbelts and generally combining pastures and livestock production.

Rural region where the cultivated fields and prairies are enclosed by raised earth or banks with hedges and coppices, and more or less continuous lines of trees and bushes.

Functional characteristics Tangible, objective and observable attributes linked to functioning.

Clearance cairn Pile of stones collected from de-stoning fields.

Commensal A commensal organism gains benefits from another host organism without causing it harm.

Competition for resources and space Rivalry between species which depend on the same limited resources (food, shelter, nesting areas). It can be interspecific (between different species) or intraspecific (between individuals of the same species).

Conservation To conserve or maintain intact or in the same state. Also designates the state of being conserved.

Declivity Refers to the slope of the terrain.

Dehesa Wooded pastures found in the south west of the Iberian peninsula, where the climate and vegetation constitute a habitat which is ideal for raising Iberian pigs and producing premium Spanish ham.

Genetic drift Evolutionary process which results in the creation of new species from populations of individuals. This process consists of the random variation in allele frequencies within a population and over the course of generations.

Stubble burning Stubble burning is a traditional agricultural practice which consists of pulling and then burning the vegetation and upper layer of humus in small piles, then spreading the ashes on the land to enrich it with additional nutrients.

Ecosystem An ecosystem is the dynamic collection of living organisms (plants, animals and micro-organisms) which interact with each other and the environment (soil, climate, water, light) in which they live. It's a structured collection formed by a biocenosis and a biotope.

Ecotone Transition area between two communities (= border between two ecosystems).

Ecovolume	The volume of uniform aboveground vegetation and its composition and height, in which the biotic and abiotic components coexist and interact with each other. This concept demonstrates the interrelation between the species which live within a volume and links a biocenosis to specific conditions in a given location.
Prunings	Trimmed and pruned branches. Pruning: The removal of certain branches from a tree or shrub to give it a desired shape, eliminate a diseased or broken section or stimulate growth.
Evenness	Even character.
Ruderal species	Ruderal plants are plants which grow near or on debris, fallow or banks of rubble.
Vivacious species	A plant which lives more than three seasons (a *perennial* plant is one which appears to live indefinitely).
Outlet	Furthest point downstream in a hydrographic network where all of the run-off water drained by the basin passes.
Function	All of the operations contributing to a same result executed by an organ or group of organs. Also the role played by an element of a whole.
Fallow	Fallow is land which no longer maintains its function or purpose (whether it is the original one or not): urban fallow, industrial fallow, commercial fallow, agricultural fallow. Momentarily abandoned, these areas can provide an opportunity to rethink the layout of the land, both in rural and urban environments. The situation is not irreversible: fallow can be reassigned to a similar activity or to a different activity (old factories re-purposed into housing or offices; slag heaps into recreational areas, etc.). It often consists of a period of waiting and a transition between two uses.
Genotype	A genotype is composed of all of an individual's hereditary characteristics

Natural habitats of community interest

The natural habitats of community interest are listed in Annex I of the EU Habitats Directive.

They were selected based on the following criteria:

- they are in danger of disappearing from their natural distribution area;
- they have a reduced natural distribution area following their decline or due to their intrinsically restrained distribution area;
- they are exceptional examples, belonging to a European biogeographic region and representative of the European Union's ecological diversity.

Ichthyology

Ichthyology designates the branch of zoology entirely dedicated to the study of fishes. This includes bony fishes (osteichthyans) and cartilaginous fishes (chondrichthyans) such as sharks. Certain aquatic animals, vertebrates without jaws or agnathans, are sometimes incorrectly described as fish.

Indicator

An indicator is an assessment and decision-making support tool.

Broadly speaking, an indicator is a summary of complex information which allows for dialogue between different players (scientists, administrators, politicians and citizens). A biodiversity indicator must enable the quantification of biodiversity and its spatial-temporal distribution variations. It must assist in quantitatively and qualitatively assessing the state of health and richness of the living world. Nevertheless, an indicator will always be a *model* of reality, not reality itself, which is why it must always include qualitative information and comments.

Intraspecific and interspecific

The term "intraspecific" refers to any relationship established between individuals belonging to a single and same species. The term "interspecific" refers to any relationship established between individuals belonging to different species.

Liquid manure

Liquid mix of animal droppings, water and possibly litter residues.

Soil litter

Plant litter consists of all of the dead leaves and plant debris decomposing on the ground. It hosts an ecosystem of decomposers which gradually transform it into humus.

Leaching

Leaching refers to the transport in the soil cover, downwards and towards aquifers, of dissolved substances (nitrates, phosphates, pesticides, etc.) resulting from the movements of the liquid phase of the soil or substrate. Stated more simply: the movement of soluble elements in (or out) of the soil cover or the substrate.

Ecological interconnection Ecological interconnection is the network of connections between green or aquatic areas which facilitates all types of biological exchanges. The communication areas which create ecological continuities (connections between ecosystems) are known as wildlife or ecological corridors. Re-establishing ecological interconnection entails recreating the connections between ecosystems in order to compensate for the effects of landscape fragmentation (re-establishment of the biological corridors between ecosystems).

Matorral Shrubby formation with small and spaced stunted trees (carob, mastic), located especially in Castile. A degraded form of holm oak forest.

Habitat modification This is one of the main causes of the disappearance of species. Humans fragment the landscape and natural habitats by building roads and housing.

Parasitoid Parasitic organism which, during its growth, systematically induces the death of its host. This differs from the strict definition of parasitism, in which the classic parasite tends to preserve its host, since its death does not benefit it.

Rangeland Designates lands grazed by livestock. This name, derived from ancient rural laws, has become a technical term in modern agriculture which refers to uncultivated or low-yield lands which are used to raise livestock for profit.

Dry grassland A calcicolous dry grassland is a grassland which develops on dry calcicolous soils. This term also includes a variety of environments whose management must be adapted depending on the flora and fauna present, as well as the farmer's production constraints.

Phenotype All of the observable and apparent characteristics of an individual or organism resulting from hereditary factors (genotype) and changes caused by the surrounding environment.

Physiological Relating to the functioning of organs and tissues in living organisms.

Ecological plasticity Ability to adapt to diverse ecological conditions.

Direct predation Antagonistic interaction which is unilaterally harmful between a species called a predator and several species called prey on which the "harmful" species depends in an opportunistic or compulsory way from a trophic standpoint. For example, a wolf which eats a hare or a lion which eats a gazelle.

Consolidation Consolidation is an agricultural term which refers to a specific land arrangement. It consists of grouping small plots into larger-sized fields. This technique often increases the profitability of crops. Consolidation gives rise to agricultural landscapes without any tall vegetation. It is a cause of bocage destruction.

Ecological network An ecological network is a "collection of habitats which is likely to provide a temporary or permanent living environment to plant and animal species and which fulfils their vital requirements and ensures their long-term survival". It is designated as a green infrastructure in some EU documents.

Trophic network All of the food relationships between species in a community and by which energy and matter circulate. All of the trophic chains which link the organisms of a biocenosis.

Ecosystem services The commonly accepted definition of ecosystem or ecological services is found in the Millennium Ecosystem Assessment, which states that they are the benefits humans draw from ecosystems. For the sake of simplicity, we say that the ecosystems "yield" or "produce" "services".

Private standard A standard is a norm for national or international use published by a private entity which is not, or is not approved by, a national or international standardisation body.

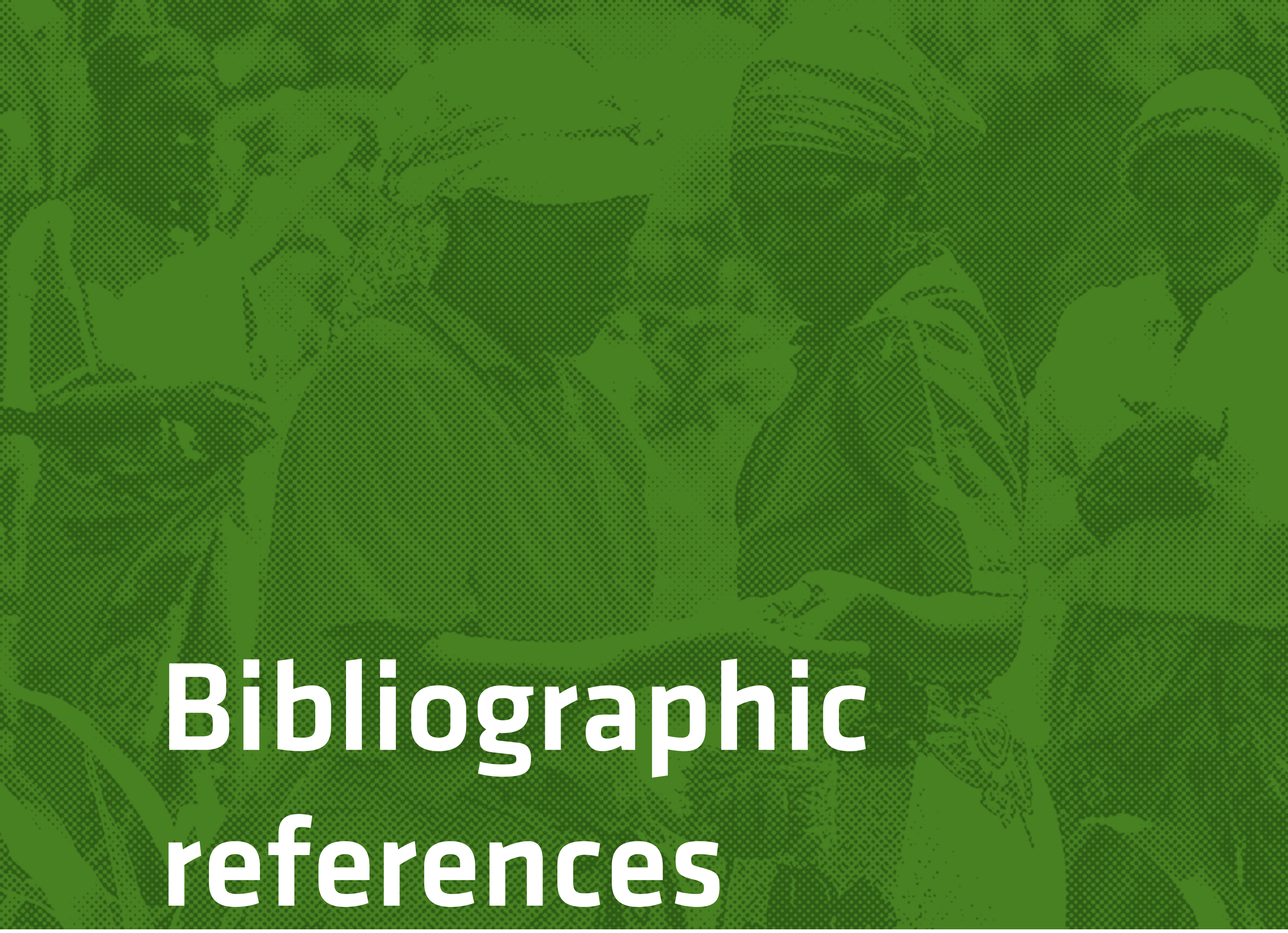
Utilised Agricultural Area (UAA) Total area of the farm excluding the areas occupied by buildings and farmyards.

Symbiont In the broadest sense, an organism which has entered into a symbiotic relationship. This means there are two symbionts.

More specifically, the organism contained in the organs of a larger host and nourished by it is called an endosymbiont. E.g.: bacteria which generate bio-luminescence in certain deep ocean fishes.

Taxon A group of fauna or flora corresponding to a given systematic identification level: class, order, genus, family, species.

Hybrid varieties Hybrid varieties are plants resulting from the crossing of two genetically different and pure varieties, generally to increase the value of one or more specific characteristics including colour, size, resistance to disease or climate conditions, etc.



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Documents for further exploration

DOCUMENTS FOR FURTHER EXPLORATION

GENERAL DOCUMENTS ABOUT BIODIVERSITY

Agroecology dictionary. Diversification of crop rotations
https://dicoagroecologie.fr/encyclopedie/diversification-des-assolements/

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https://books.google.it/books?isbn=2759219011

La Production et Protection Intégrées appliquée aux cultures maraîchères en Afrique soudano-sahélienne FAO -Projet GCP/RAF/244/BEL
http://www.fao.org/3/a-az732f.pdf

La gestion des ravageurs et des maladies en agriculture biologique
http://teca.fao.org/fr/read/8575

La gestion et la planification des cultures en agriculture biologique
http://teca.fao.org/read/8561 Le lien ne fonctionne pas

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www.agrisud.org/wp-content/uploads/2013/05/Guide_Francais.pdf

La grande muraille verte -
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Guide des pratiques agroécologiques - Département de Mbour, Sénégal
http://www.agrisud.org/wp-content/uploads/2016/03/REFSA-Guide-Fr-VF.pdf

Pratiques agroécologiques et agroforestières en zone tropicale humide
http://www.gret.org/wp-content/uploads/guide-pratique-agroecologie_pdf.pdf

Gestion de la biodiversité dans les écosystèmes agricoles
https://www.bioversityinternational.org/uploads/tx_news/Gestion_de_la_biodiversite%CC%81_dans_les_e%CC%81cosyste%CC%80mes_1699_02.pdf

Guide Pratiques (Source: Site internet IBIS) - Fiches Pratiques agricoles et Biodiversité
http://www.ecophytopic.fr/sites/default/files/IBIS_Guide%20Pratiques.pdf

Kit pédagogique pour les pays situés en zones sèches.
Une approche créative de l'éducation à l'environnement.
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Pôle ERR - Agriculture-Forêt. Mettre en place des infrastructures agroécologiques (IAE) sur son exploitation agricole : pourquoi ? comment ?
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Amélioration de la fertilité des sols par des moyens naturels
http://terredesjeunes.org/sites/terredesjeunes.org/files/AmeliorationFertiliteDesSols-1.pdf

Guide de conception de systèmes de production fruitière économes en produits phytopharmaceutiques - https://www.gis-fruits.org/Actions-du-GIS/Guide-Ecophyto

Guide pratique pour la conception de systèmes de culture légumiers économes en produits phytopharmaceutiques
http://agriculture.gouv.fr/guide-pratique-pour-la-conception-de-systemes-de-culture-legumiers-economes-en-produits

Effet des plantes de service sur les bio-agresseurs des Cultures
http://open-library.cirad.fr/files/2/56__etude_bioagresseurs_quaranta.pd

Guide tropical - Guide pratique de conception de systèmes de culture tropicaux économes en produits phytosanitaires
http://agritrop.cirad.fr/578300/1/Guide+tropical+TBD+new.pdf - https://cosaq.cirad.fr/outils-d-aide-a-la-decision/guide-tropical

Guide de Production Intégrée de mangues à la Réunion
https://reunion-mayotte.cirad.fr/content/download/7766/80992/version/1/file/obj_6900_file_Guide-PFI.pdf

E-TIC AgriGuide
http://www.agriguide.org/agriguide/files/etic_agriguide_fr_20120830.pdf
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Les pratiques agroécologiques dans les exploitations agricoles urbaines et périurbaines pour la sécurité alimentaire des villes d'Afrique subsaharienne
http://savoirs.usherbrooke.ca/bitstream/handle/11143/8877/Gravel_Andreane_MEI_2016.pdf?sequence=1

Cultivons autrement : exemples locaux de techniques agro-écologiques
http://www.ecofog.gf/giec/doc_num.php?explnum_id=1742

Training manual - Module 9: Crop Management
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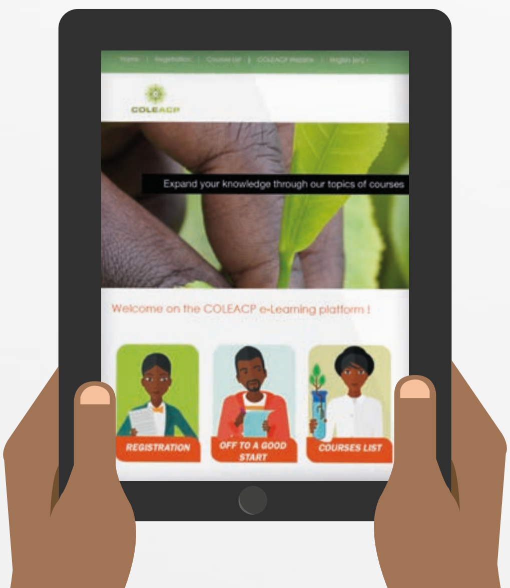

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