A guide to identifying and adapting farming practices that enhance biodiversity for food and agriculture

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Imprint

As a federally owned enterprise, GIZ supports the German Government in achieving its objectives in the field of international cooperation for sustainable development.

Published by:
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn

Sector Programme Agriculture
Sector Programme Resilient Rural Areas

Friedrich-Ebert-Allee 32 + 36
53113 Bonn
T +49 228 44 60 – 0
F +49 228 44 60 – 17 66

E info@giz.de
I www.giz.de

Author:
Barbara Adolph

Design/layout:
now [nau], visual communicative design, Frankfurt/Main

Photo credits:
Title page: landscape © istock/618526126, portrait © GIZ/Faith Innocent, p. 5: © GIZ/Thomas Imo, p.14: both photos © CIAT/NeilPalmer, p.16: © GIZ/Ronny Sen, p.17: landscape © GIZ/Stella Marraccini, portrait © GIZ/Ranak Martin, p.24: both photos © GIZ, p.32: GIZ, p.38: photo in the middle © GIZ/Barbara Adolph, © Victoria Uwemedimo Agroecology Fund, portrait © GIZ/César Londoño, p.60: © GIZ/Martin Egbert, p.91: photos © GIZ/Andrés Verdezoto, p.92: © GIZ/Stella Marraccini, p.103: © istock/1061937346, p.104: © GIZ/Nguyen Duy Cong, p.116: GIZ/Ronny Sen, © GIZ/Nguyen Duy Cong, p.117: portrait: © GIZ/Nguyen Duy Cong, © GIZ / Andrés Verdezoto, p.130: woman and man © GIZ/Harsh Kamat, © GIZ/Joerg Böthling, p.139: © GIZ/Gaël Gellé, p.140: © GIZ/Ursula Meissner, p.152: © GIZ/Harsh Kamat, p.157: © GIZ Bolivien/Resilient Landscapes, p.158: both photos © GIZ/Madagascar, p.171: © GIZ/Harsh Kamat, p.181: © GIZ/Barbara Adolph, p.182: © GIZ/Harsh Kamat, p.194: © GIZ /PASSIP,, p.195: © GIZ/Barbara Adolph, p.207: © GIZ/Harsh Kamat, p.218: portrait woman © GIZ/Harsh Kamat, © GIZ/Scholz, p.225: desert landscape © istock/466266652, Mongolei landscape © GIZ/Dirk Ostermeier, p.237: portrait woman and man © GIZ/Harsh Kamat, portrait women © GIZ/Rossy Heriniaina, p.263: landscape © GIZ/Binh Dang, portrait © GIZ/Harsh Kamat

URL links:
Responsibility for the content of external websites linked in this publication alwayslies with their respective publishers. GIZ expressly dissociates itself from such content.

GIZ is responsible for the content of this publication.

Bonn, April 2026

A publication financed by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the Federal Ministry for Economic Cooperation and Development (BMZ)

Acknowledgements

The author would like to express her gratitude for all the support received in writing this report. The report has been written with the financial support of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the Federal Ministry for Economic Cooperation and Development (BMZ). Moreover, I benefitted from discussions with teams from GIZ on the structure and content of the report. A special thanks goes to Kathrin Cordes (GIZ), Liesa Nieskens (GIZ), Theresa Sänger (GIZ), Christine Wolf (GIZ) and Felicitas Röhrig (BMZ) for the initiative and support.

I also thank all participants of the focus group discussions (both GIZ and KfW) for their valuable input and especially Prince Asiedu, Rika Augustin, Olivier Joffre, Prof. Dr. Benno Pokorny and Regina Sánchez Sosa y Hernández (all GIZ) for their feedback on the guide and practice sheets.

All remaining errors are my responsibility. The views expressed are those of the author and do not reflect the official position of the institutions involved.

About this guide

Biodiversity is declining at an unprecedented rate. Agriculture sits at the heart of both the problem and the solution: As the world's largest user of land, agricultural systems depend fundamentally on healthy, functioning ecosystems, yet they are also a leading driver of their decline. Reversing current trends therefore requires a fundamental shift in how agricultural systems and landscapes are designed, managed and supported. **Biodiversity for Food and Agriculture (BFA)**, a concept advanced by the Food and Agriculture Organization of the United Nations (FAO), provides a holistic framework for this shift. It recognizes the diversity of species, genetic resources and ecosystems as a foundation for more resilient and sustainable agriculture and food systems.

However, implementing biodiversity-enhancing practices requires practical, context-specific knowledge: there is no "one-size-fits-all" solution, but rather a need for locally adapted biodiversity-enhancing practices that can be sustained and scaled. This guide supports practitioners in agricultural and rural development to identify, adapt and promote such practices through a structured yet flexible approach. It follows a learning cycle that combines systemic analysis, participatory prioritisation, practice selection and adaptation, and monitoring and learning.

Key messages:

- Biodiversity for Food and Agriculture requires a systemic perspective that links farm practices with landscape dynamics, ecosystem functions and socio-economic drivers.
- Participatory approaches are essential to identify priorities and ensure practices are aligned with farmers' needs, capacities and livelihood strategies, including marginalized groups.
- No single practice is universally optimal; context-specific combinations of practices are needed to generate biodiversity, productivity and resilience benefits.
- Adoption depends on tangible co-benefits (e.g. income, food security, risk reduction), not biodiversity outcomes alone.
- Scaling requires more than replication of technologies and depends on enabling policies, institutions, knowledge systems and long-term investment.

- Coherence with national and global policy frameworks, alongside strong multi-stakeholder collaboration, is critical for sustained impact.
- Monitoring, evaluation and learning are integral to adapt practices, demonstrate results and support long-term system transformation.

Contents

Acronyms

ARD	Agricultural Research for Development
BFA	Biodiversity for Food and Agriculture
BHI	Biodiversity Habitat Index
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung *German Federal Ministry for Economic Cooperation and Development*
CBD	(United Nations) Convention on Biological Diversity
CSO	Civil Society Organisations
FAO	Food and Agriculture Organisation (of the United Nations)
FFS	Farmer Field School
GFAR	Global Forum on Agricultural Research
GIS	Geographic Information Systems
GIZ	Gesellschaft für Internationale Zusammenarbeit
HQ	Headquarters
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IPES-FOOD	International Panel of Experts on Sustainable Food Systems
IPM	Integrated Pest Management
ISFM	Integrated Soil Fertility Management
KfW	Kreditanstalt für Wiederaufbau *German Development Bank*
LEIA	Low External Input Agriculture
LPI	Living Planet Index
MEL	Monitoring, Evaluation and Learning
NbS	Nature-based Solutions
NCP	Nature's Contributions to People
NRM	Natural Resources Management
NTFP	Non-timber Forest Products
MSA	Mean Species Abundance
PES	Payment for Ecosystem Services
PID	Participatory Innovation Development
PLA	Participatory Learning and Action
PRA	Participatory Rural Appraisal
SDG	Sustainable Development Goal
SWC	Soil and Water Conservation
WEF	World Economic Forum
WWF	World-Wide Fund for nature

Glossary of key terms and definitions

Agricultural approaches: The diverse range of methods, techniques, and strategies used in agriculture to manage and optimise the production of crops and livestock. Common approaches that aim to address (aspects of) biodiversity enhancement include Agroecology, Permaculture, Regenerative Agriculture, Sustainable Intensification, Conservation Agriculture, Climate Smart Agriculture, Ecological Intensification and Organic Farming.

Agricultural practices: The methods and techniques used in farming to cultivate land, raise crops, and manage livestock. They encompass a wide range of activities from soil preparation and planting to harvesting and storage, and practices related to animal husbandry.

Agrobiodiversity: The variety and variability of animals, plants and micro-organisms that are used directly or indirectly for food and agriculture, including crops, livestock, forestry and fisheries. 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 agro-ecosystems (agricultural, pastoral, forest and aquatic) as well as the diversity of the agro-ecosystems. (→ FAO 2004)

Agroecology: FAO defines agroecology as a holistic and integrated approach that simultaneously applies ecological and social concepts and principles to the design and management of sustainable agriculture and food systems. It seeks to optimise the interactions between plants, animals, humans and the environment while also addressing the need for socially equitable food systems within which people can exercise choice over what they eat and how and where it is produced.[1]

Biodiversity or Biological Diversity: The UN Convention on Biological Diversity (CBD) defines biological diversity 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 (genetic diversity), between species, and of ecosystems.

1 ‣ https://www.fao.org/agroecology/overview/en/

Biodiversity for Food and Agriculture (BFA) is a more recent concept, similar to agrobiodiversity. It describes a subcategory of biodiversity that corresponds to the variety and variability of animals, plants and micro-organisms at the genetic, species and ecosystem levels that sustain the ecosystem structures, functions and processes in and around production systems, and that provide food and non-food agricultural products (→ FAO 2022a). The term is used throughout this guide, in line with more recent thinking on the interconnectedness of agroecosystems with wider ecosystems in an area.

Biodiversity-friendly practices: These are practices that can (if well adapted and managed) contribute to the conservation, restoration and sustainable use of biodiversity (→ FAO 2019a, → 2022a). There are countless individual practices that have been developed in specific contexts, making use of locally available resources and inputs. These practices can be grouped into broader categories, based on their main purpose and operating principles.

Bioeconomy: The bioeconomy is the production, utilisation, conservation, and regeneration of biological resources, including related knowledge, science, technology, and innovation, to provide sustainable solutions (information, products, processes and services) within and across all economic sectors and enable a transformation to a sustainable economy. The bioeconomy aims at reconciling the needs of humans and nature. Bioeconomy activities enhance economic, social, and ecosystem resilience, allowing both urban and rural communities to thrive especially during economic crises. (→ https://www.iacgb.net/GLOBAL).

Climate-smart agriculture: This approach integrates the three dimensions of sustainable development (economic, social and environmental) by jointly addressing food security and climate challenges. It is composed of three main pillars: 1. sustainably increasing agricultural productivity and incomes; 2. adapting and building resilience to climate change; 3. reducing and/or removing greenhouse gases emissions, where possible (→ FAO 2013a). These dimensions may contribute to the conservation and enhancement of biodiversity, but it is not its main goal.

Ecological intensification: This approach aims to harness ecosystem services to sustain agricultural production while minimising adverse effects on the environment. Ecological intensification is championed by scientists as a nature-based alternative to high-input agriculture (→ Kleijnet al. 2019). Conceptually, it sits somewhat between agroecology and sustainable intensification: Similar to agroecology, it focuses on using ecological processes to sustain or increase yields while reducing external inputs, but with less emphasis on the social and governance dimensions that are central to agroecology.

Ecosystem services: The benefits humans derive from ecosystems. These include provisioning, regulating, cultural and supporting services (→ Millenium Ecosystem Assessment 2005). They include

- **Cultural (ecosystem) services:** The non-material benefits people get from nature, such as spiritual enrichment, recreation, aesthetic enjoyment, cultural identity, and cognitive development, stemming from direct interaction with healthy ecosystems.

- **Provisioning (ecosystem) services:** The supply of goods of direct benefit to people, and often with a clear monetary value, such as timber from forests, medicinal plants, and fish from the oceans, rivers and lakes.

- **Regulating (ecosystem) services:** The range of functions carried out by ecosystems which are often of great value but generally not given a monetary value in conventional markets. They include regulation of climate through the storing of carbon and control of local rainfall, the removal of pollutants by filtering the air and water, and protection from disasters such as landslides and coastal storms.

- **Supporting (ecosystem) services:** These are not of direct benefit to people but essential to the functioning of ecosystems and therefore indirectly responsible for all other services. Examples are the formation of soils and the processes of plant growth. Some scholars frame supporting ecosystem services as ecosystem functions.

Low external input agriculture (LEIA): Intensive use of locally available, renewable resources, with few or no external inputs, generally for subsistence only (→ Kessler and Moolhuijzen 1994).

Nature-based solutions (NbS): Actions to address societal challenges through the protection, sustainable management and restoration of ecosystems, benefiting both biodiversity and human well-being → IUCN (2020)[2].

Nature's Contributions to People: A term that is broader than ecosystem services, used by the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES). It includes ecosystem services and embraces all the positive contributions, or benefits, and occasionally negative contributions, losses or detriments, that people obtain from nature (→ Pascual et al. 2017).

2 IUCN launched a revised version of their "Global Standard for Nature-Based Solutions" in October 2025. It is available at ‣ https://inbs.iucn.org.

Permaculture: Permaculture is a design system for ecological and sustainable living, integrating plants, animals, people, buildings, and communities. Permaculture is always a "cyclical" system that aims to return to the earth that which was taken from it. → **https://www.permaculturegardens.org/what-is-permaculture**

Production system: See → FAO (2013b) for the production-system classification used in this report (also shown in Annex 1).

Regenerative agriculture: Regenerative agriculture is an inclusive agroecosystems approach for conserving land and soil, biodiversity, and improving ecosystem services within farming systems. It focuses on the regeneration of living soil, improved micro hydrology, and conserving biodiversity at all levels while enhancing input use efficiency and ecosystem system services. The approach helps to achieve food and nutritional security with economically viable and ecological sustainable options (→ FAO 2021c).

Sustainable intensification: Sustainable intensification is defined as a process or system where yields are increased without adverse environmental impacts or cultivation of more land. This approach considers agricultural and uncultivated systems as interdependent and is mindful of the need for agriculture to directly contribute to the mitigation of major global challenges (→ **Campanhola and Pandey 2019**) – in particular, achieving the SDG "Zero Hunger". Sustainable intensification is relatively open, in that it does not privilege any particular set of technologies, or visions of agricultural production methods. It does not exclude the use of genetically modified crops, hybrid seeds, large scale mechanisation and the use of pesticides, but advocates for their responsible use.

Wild foods: Food products obtained from non-domesticated species. They may be harvested (gathered or hunted) from within food and agricultural production systems or from other ecosystems → FAO (2019a)

1 Introduction

Introduction

1.1 Purpose of this guide

The aim of this guide is to **contribute to a better knowledge and understanding of agronomic and landscape practices that conserve, restore and sustainably use biodiversity for food and agriculture** (biodiversity-friendly or biodiversity enhancing practices) and support the mainstreaming of biodiversity into the agricultural sector and rural landscapes. It focuses on practical guidance to assist in the identification of suitable **practices for different agroecological contexts**. It complements existing guidance on the importance of biodiversity in agricultural systems (→ FAO 2022a, World Bank Group 2025), on the complementarity and synergies between biodiversity conservation, climate change adaptation and mitigation (→ Terton et al. 2024, GIZ 2022) and on ways of promoting biodiversity conservation through policies, communication and advocacy, business practices, and resource mobilisation (BMZ, KfW, GIZ 2016).

This guide is intended for experts involved in the planning and implementation of agriculture and rural development projects. It **offers orientation and practical steps for integrating biodiversity-enhancing practices into project design**. While the guide outlines key entry points and considerations, the recommended approaches need to be adapted to local contexts in close collaboration with project partners.

The guide consists of two parts. **The first part provides an overview of the connections between biodiversity and agriculture**, introducing different agricultural approaches aiming to make agriculture more sustainable, and outlines a process for the identification of suitable practices through a participatory and inclusive approach. The annexes list a range of specific methods and tools for the analysis of both agri-food systems overall, and biodiversity for food and agriculture (BFA) specifically.

The second part includes the "practice sheets" that provide a short description of each practice, the resources required to implement it, and the benefits to biodiversity enhancement that can be expected. The sheets also provide information about other potential benefits of the practice, as well as any challenges and trade-offs.

1.2 Materials and methods used

The guide draws on existing and openly available literature, as well as examples and suggestions from GIZ project and programme staff. It was developed using the following steps:

- Agreement on the purpose and scope of the guide with GIZ advisors from the Sector Project Agriculture, and the Sector Project Resilient Rural Areas
- Document review to identify biodiversity-enhancing agricultural approaches and practices, and selection of practices to include in the guide
- Development of a draft template to capture the main characteristics of each practice
- Focus group discussions with GIZ staff in Africa, Asia, Latin America and Germany to capture experiences with the integration of biodiversity-enhancing practices, identify knowledge and information needs of project staff and partners, and finalise practice selection and template design
- Reflection, analysis, writing, and peer review.

2

Biodiversity and agricultural landscapes

2

Biodiversity and agricultural landscapes

2.1 Importance of and trends in global biodiversity

Biodiversity underpins all life on earth. According to the United Nations Convention on Biodiversity (CBD)[3] , it is the foundation for the provision of food, fibre and water; it mitigates and provides resilience to climate change; it supports human health, and provides jobs in agriculture, fisheries, forestry and many other sectors. It is hence crucial in advancing human development, and especially for food security and sustainable agrifood systems, as enshrined in the Sustainable Development Goals (SDGs): SDG 14 on life below water and SDG 15 on life on land focus explicitly on biodiversity enhancement, as a basis for life on earth[4]. For SDG 2 Zero Hunger, ***"[t]here are critical biodiversity dependencies […],*** *including Target 2.4 relating to maintaining ecosystems and improvement of land and soil quality, and Target 2.5 on maintaining the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their wild species. Similarly, for SDG 8 on decent work and economic growth, biodiversity and healthy ecosystems are reflected in Target 8.4 on decoupling economic growth from environmental degradation and Target 8.9 relating to sustainable tourism."* (Secretariat for the Convention on Biological Diversity 2019).

Biodiversity is being lost at an alarming rate. The 2024 Nexus Assessment Report on the Interlinkages among Biodiversity, Water, Food and Health of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (→ IPBES 2024) noted a **2–6 % biodiversity decline per decade across all assessed indicators for the last 30–50 years**, with more than 50 % of the global population living in areas experiencing highest impacts from declines in biodiversity, water availability and quality and food security, and increases in health risks and negative effects of climate change. Similarly, the Worldwide Fund for Nature's Living Planet Report 2024 (→ WWF 2024) notes that, over the past 50 years (1970–2020), the average size of monitored wildlife populations has shrunk by 73 %, as measured by the Living Planet Index (LPI). The fastest declines have been seen in Latin America and the Caribbean (95 % decline), followed by Africa (76 %) and the Asia and the Pacific (60 %).

3 ‣ https://www.cbd.int/article/biodiversityforSDGs

4 ‣ https://www.stockholmresilience.org/research/research-news/2016-06-14-the-sdgs-wedding-cake.html and Secretariat of the Convention on Biological Diversity (2018)

Even the 2025 Global Risks Report of the World Economic Forum (→ WEF 2025) found the **top four most severe risks over the next ten years to be extreme weather events, biodiversity loss and ecosystem collapse, critical change to Earth systems and natural resources shortages**. They note that biodiversity loss will have *"severe consequences for the environment, humankind and economic activity due to destruction of natural capital stemming from species extinction or reduction, spanning both terrestrial and marine ecosystems".*

Agriculture is a main driver of biodiversity loss worldwide (→ IPBES 2019). Land and sea use changes, whereby natural habitats are converted to land for crops and livestock or degraded, or water overexploited for aquaculture/fisheries, cause damage to or loss of ecosystems. Industrial farming methods such as monocultures and the increasing use of agrochemicals (pesticides, mineral fertilisers) lead to pollution and over exploitation and harm terrestrial and aquatic life. Climate change is also an important driver of biodiversity loss. Major indirect drivers are demographic and dietary changes, unsustainable production and consumption patterns, impacts of technological innovations on nature, unsustainable international trade patterns and market preferences as well as inadequate governance (→ Bioversity 2017, → IPBES 2019, → DeClerck et al. 2021). The quest to increase food production in line with population growth and consumer preferences, whilst keeping food prices low, has resulted in predominant agricultural production models that are unsustainable (WWF 2021). By 2025, six of nine Planetary Boundaries[5] are being transgressed, with food systems as a dominant driver of global environmental change (→ te Wierik et al. 2025). → IUCN (2024) maps out in detail agriculture-related threats to biodiversity. In short: "It is important to acknowledge that the prevailing ways of growing food are choking the planet's ecosystems. This is driving and being compounded by biodiversity loss, land degradation, pollution and climate change." (→ CBD Statement on World Food Day 2025)

Food production is only one part of the global food system, which also includes transport, processing, retailing, consumption and waste of food – and the impact of these processes on nutrition, human health and well-being, and the environment. The EAT-Lancet commission report (→ Willett et al. 2019) concluded that *"Because much of the world's population is inadequately nourished and many environmental systems and processes are pushed beyond safe boundaries by food production, a global transformation of the food system is urgently needed."* Similarly, the GIZ Guiding Framework for the Transformation of Agriculture and Food Systems as well as the GIZ position paper on Agroecology emphasise that *"business as usual or gradual adjustments in sectoral silos are no longer an op-*

5 Planetary boundaries are human-determined values of control variables (such as temperature, ocean acidity etc.) set at a "safe" distance from a dangerous level (for processes without known thresholds at the continental to global scales) or from its global threshold (→ Rockström et al. 2009).

tion" (→ GIZ 2024a) and that *"a fundamental transformation of agricultural and food systems is needed"* (→ GIZ 2024b).

→ Benton et al. (2021) **identify three levers for food system transformation in support of nature: Dietary change, setting aside land for biodiversity, and adapting the way we farm the land.** A country-driven assessment of biodiversity and food (→ FAO 2019a) analysed eleven food and agriculture related drivers of change that impact biodiversity directly or indirectly[6]. It concluded that, while a range of drivers of change are having major negative impacts on biodiversity for food and agriculture (BFA) and the ecosystem services it delivers, some provide opportunities to promote more sustainable management. Specifically, *"many of the drivers that have negative impacts on BFA, including overexploitation, overharvesting, pollution, overuse of external inputs, and changes in land and water management, are at least partially caused by inappropriate agricultural practices".*

Some of the drivers of biodiversity loss require changes to global food systems (e.g., changes to demographic and food consumption patterns) that are beyond the remit of agricultural development projects. However, there are many ways that farming practices can be adapted to support biodiversity – and in turn these can translate into many benefits for food systems. The next section outlines some key contributions that biodiversity makes to sustainable and healthy agricultural and food production systems.

2.2 The role of biodiversity in agricultural systems

Agriculture relies heavily on biological diversity – including genetic, species and ecosystem diversity. In recognition of this crucial link, → FAO (2022a) developed a "Framework for Action on Biodiversity for Food and Agriculture", which identifies needs and possible actions for Biodiversity for Food and Agriculture (→ Box 1). The concept of Biodiversity for Food and Agriculture complements the more established term "agrobiodiversity", which focuses on the biodiversity within an agricultural production system, rather than the biodiversity of the wider system that impacts or is impacted by the agricultural and food system.

6 Population growth and urbanisation; markets, trade and the private sector; changing economic, sociopolitical and cultural factors; climate change; natural disasters; pests, diseases and invasive alien species; advancements and innovations in science and technology; changes in land and water use and management; pollution and external inputs; overexploitation and overharvesting; and policies.

Modern crop varieties and livestock breeds are the result of thousands of years of human selection, drawing on a gene pool of wild relatives. Genetic diversity within and among species provides a natural buffer against environmental changes. Because different crop varieties respond differently to stressors, they provide farmers with options to manage risks. When one crop fails, others can compensate, helping to safeguard harvests and livelihoods (→ Elouafi 2024). Natural ecosystems and biodiverse farming systems provide a source of genetic material that can be used for future crop breeding.

Healthy ecosystems support healthy food systems in many ways, providing essential services such as pollination, pest control, soil fertility, and clean water. These services support agricultural productivity and resilience. Biodiversity, as a key component of ecosystems, plays an important role in supporting food and agriculture – with → Box 1 outlining some of the main contributions. → Box 2 shows the different types of ecosystem services relevant for food and agriculture. In the context of the Intergovernmental Platform on Biodiversity and Ecosystem services (IPBES), ecosystem services are included in the concept Nature's Contributions to People (NCP) which embraces all the positive contributions, or benefits, and occasionally negative contributions, losses or detriments, that people obtain from nature (→ Pascual et al. 2017).

Bioeconomy – the production, utilisation, conservation, and regeneration of biological resources to provide sustainable solutions within and across all economic sectors – has been concerned with the extraction of goods from nature (e.g., food, energy, or biochemicals), potentially with detrimental impacts on NCPs (→ Bastos Lima et al. 2022). However, in recent years there has been a shift towards sustainable uses of biodiversity in bioeconomy strategies, either by mainstreaming biodiversity into dominant bioeconomy approaches[7] which have previously not considered biodiversity in much depth, and by giving the sustainable use of biodiversity a more central place in bioeconomy strategies (→ de Queiroz-Stein and Siegel 2023).

7 For example, the recently published "Strategic Framework for a Competitive and Sustainable EU Bioeconomy" proposes adding indicators on biodiversity to Product Environmental Footprint (PEF) methods and publishing a report on Member States' support schemes for biomass, including on biodiversity (European Commission 2025).

2

Box 1
The role of biodiversity for food and agriculture

Many components of Biodiversity for Food and Agriculture at genetic, species and ecosystem levels are key to the current and future productivity of all agricultural sectors:

- Plant, animal, aquatic and micro-organism and invertebrate genetic resources for food and agriculture and forest genetic resources – and their diversity at species and within-species (variety, breed, strain, etc.) levels – are vital to the current and future productivity and resilience of the crop, livestock, forest, aquaculture and fisheries sectors. Wild relatives of domesticated species have potential for domestication and provide a pool of genetic resources for hybridisation and selection.
- Associated biodiversity present in and around productions systems is essential to the supply of many ecosystem services that underpin agriculture and food production, including pollination, control of pests, maintenance of soil fertility, carbon sequestration and regulation of water supplies.
- Wild foods – a wide range of fungi, plants and animals, including invertebrates – are important for food security and nutrition in many countries. They are often harvested and consumed locally but are also traded over long distances. In the case of capture fisheries, they form the basis of a major sector of food and agriculture.

‣ **FAO 2019a**, ‣ **2022a**

Box 2
Types of ecosystem services for food and agriculture

Provisioning services

- Food and nutrition: Plants, animals, fungi, algae and bacteria that can be used as food. This includes cultivated and wild plants, and reared and wild animals, both terrestrial and aquatic. This is the ecosystem service that are most immediately contributing to the food system, but their productivity depends on the supporting and regulating services below.
- Medicines: These are often derived from wild plants, animals or other living organisms.

- Materials or energy: The range of natural resources used for materials or energy, such as timber/
- Water: Resources used for drinking, irrigation, and other agricultural uses (surface and groundwater).

Supporting services

- Pollination: Insects, birds, and bats pollinate crops, which is essential for fruit and seed production.
- Pest and disease control: Natural predators like insects and birds help control agricultural pests.
- Soil fertility and formation: Nutrient cycling and the breakdown of organic matter in the soil are critical for plant growth.
- Water regulation and purification: Ecosystems help regulate water flows and filter water, ensuring a supply of clean water for irrigation.

Regulating services

- Climate regulation: Biodiverse landscapes can store carbon (carbon sequestration) and influence local and regional climates positively, for the benefit of agriculture.
- Water quality: Healthy ecosystems help filter runoff from agricultural lands, protecting downstream water quality that is essential for irrigation and other food system uses.

Cultural services

- Recreation and tourism: Natural and managed landscapes can provide opportunities for recreation.
- Spiritual and aesthetic value: The cultural significance and beauty of landscapes and biodiversity.

Compiled based on ‣ **https://cices.eu/resources/** and ‣ **IPBES 2019**

If these ecosystem services are disrupted, agricultural systems are directly affected, with a knock-on effect on agricultural production, food and nutrition security, rural livelihoods and incomes. Whilst some of these impacts may take some time to materialise, the long-term consequences can be enormous – and very hard to reverse. Responsible development interventions therefore need to consider ways to enhance (conserve, restore and sustainably use) Biodiversity for Food and Agriculture before biodiversity loss causes irreversible damage to ecosystems[8] and people.

8 There are many documented cases for such (terrestrial or aquatic) ecosystem collapses related to biodiversity loss – resulting, for example, in desertification (‣ Mirzabaev et al. 2019). See also ‣ https://www.csis.org/analysis/seeding-security-why-agrobiodiversity-loss-threatens-national-security for a discussion of the impacts of agrobiodiversity loss on food security.

3

Agricultural approaches and practices for biodiversity enhancement

Agricultural approaches and practices for biodiversity enhancement

3.1 Framing agricultural sustainability

Over the past decades, a multitude of concepts and approaches for sustainable agriculture have been developed, promoted and, in some cases, discarded. Depending on the specific focus of an organisation or a group of actors, and the emerging new challenges and insights, these approaches have usually emphasised or prioritised some aspects, at the expense of others.

For example, the concept "Sustainable Intensification" emphasises the need for productivity increases to feed a growing world population, whilst minimising negative impacts on the environment. It has been particularly popular with some actors promoting (and having a stake in the promotion of) the use of external inputs (improved crop varieties, inorganic fertilisers, pesticides). Similarly, "Regenerative Agriculture" emerged in response to the perception that "sustainable" describes the current status, whereas most agricultural systems require restoration and improvement. New insights into soil health[9] and the role of soil organisms supported the emerging focus on soils as the foundation for a healthy agroecosystem, with somewhat less attention to other components of the system. "Agroecology", which has its origins in both ecological sciences and social movements, has gained traction with international research and development actors (notably the FAO). Agroecological principles have been integrated into agricultural policies of many countries (including France, Senegal, Uganda and Cuba). → IPES-FOOD (2022) provides an interesting account of the political economy dimensions of three main agricultural approaches with a biodiversity focus: Agroecology, Regenerative Agriculture and Nature-Based Solutions. Bioeconomy is not an agricultural approach as such, but can be applied to agricultural systems with the aim of conserving and restoring biodiversity (→ Gomez San Juan et al. 2022) and has therefore been included here.

Whilst researchers and development practitioners have grouped existing or new practices into agricultural approaches with specific priority objectives, there is in practice a large overlap between different agricultural approaches with regards

9 Soil health has been defined as the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal, and human health (‣ Pankhurst et al. 1997)

to the specific agricultural practices that they promote. At plot and farm level, different agricultural practices have always been combined to achieve the desired results, considering the available resources (labour and knowledge; land and other natural resources; social, physical and financial capital). Farmers have experimented to adapt the mix of practices to suit their needs, paying little attention to the conceptual debates.

3.2 Biodiversity-enhancing agricultural practices

Agricultural practices can have both positive and negative impacts on biodiversity, creating a need for management systems that protect both food production and environmental health. Biodiversity-friendly practices such as using cover crops, crop rotation, and maintaining hedgerows can enhance ecosystem services. Intensive practices such as heavy pesticide use, monoculture, and excessive tilling can lead to soil degradation, water pollution, health issues and loss of biodiversity and thus a degradation of ecosystem services.

Practices that promote the health of ecosystems can help agriculture become more resilient to stresses such as climate change. Incentives for farmers can help support the adoption of these practices, ensuring the continued provision of both food and other ecosystem benefits.

Practices that are universally emphasised (across nearly all approaches) and can thus be considered as the **"core biodiversity toolkit"** include the following five practices embedded in both ecological and productivity-focused paradigms:

- **Crop rotation** – a foundational practice for soil health, pest management, and productivity in virtually all sustainable systems.
- **Soil and water conservation** – universally prioritised for resilience, yield stability, and climate adaptation.
- **Agroforestry** – strongly promoted in most approaches for biodiversity enhancement, carbon sequestration, and livelihood diversification.
- **Organic soil amendments** – widely valued for restoring soil fertility and microbial activity.
- **Integrated Pest Management (IPM)** – a central, cross-cutting practice balancing ecological and economic pest control.

Practices prominent in **ecologically grounded approaches** that strengthen functional biodiversity and community autonomy (hallmarks of agroecology and permaculture), but are often seen as "context-specific" or "optional" in climate-smart or sustainable intensification strategies, include:

- **Intercropping**
- **Conservation and use of local crop varieties and livestock breeds**
- **Integrated fish-crop-livestock systems**
- **Community-managed/assisted natural regeneration**

Practices that emphasise **soil carbon, ecosystem function, and productivity**, often with measurable climate or yield outcomes, and that are most associated with soil regeneration and climate focus, include:

- **Minimum/zero tillage**
- **Sustainable rangeland and herd management**
- **Agroforestry** (shared with ecologically based approaches).

Practices with selective or **niche integration** that are context-dependent and often adopted through incentive or conservation programmes rather than being core framework principles include:

- **Bee keeping** – valued mainly for pollination and income diversification; strong in permaculture but secondary elsewhere.
- **Landscape features for biodiversity** (hedgerows, wetlands, etc.) – gaining traction in regenerative, climate-smart, and intensification programmes that work at landscape scale.

For the purpose of this guide, the focus is on the actual practices and not on the associated agricultural approaches. Nevertheless, for conceptual clarity, Table 1 shows the overlap between the main agricultural approaches, in terms of the specific practices they generally promote.

Table 1 Biodiversity-friendly agricultural practices promoted by different agricultural approaches Source: Author's own

Agricultural practices with the potential to enhance biodiversity	Agricultural approaches (3 = key component of the approach, 2 = optional component, 1 = not normally promoted as part of this approach)									
	Agro-ecology	**Regenerative agriculture**	**Conservation agriculture**	**Permaculture**	**Organic farming**	**Low external input agriculture**	**Climate-smart agriculture**	**Sustainable intensification**[10]	**Ecological intensification**	**Bioeconomy**[11]
Crop rotation	3	3	3	2	3	3	2	3	3	3
Intercropping	3	2	2	3	2	3	2	2	3	3
Conservation and use of local crop varieties	3	2	1	3	3	3	2	2	3	3
Conservation and use of local livestock breeds	3	2	1	3	3	3	2	2	2	3
Bee keeping	2	2	1	3	2	2	2	1	2	2
Organic soil amendments	3	3	2	3	3	3	2	2	3	3
Minimum/zero tillage	2	3	3	2	2	2	3	3	3	3
Soil and water conservation	3	3	3	3	2	3	3	3	3	3
Integrated fish-crop-livestock system	3	3	1	3	2	3	2	2	2	3
Sustainable rangeland and herd management	3	3	2	2	2	3	3	3	3	3
Agroforestry	3	3	2	3	2	3	3	3	3	3
Community-managed / assisted natural regeneration	3	3	2	3	2	3	3	2	2	2
Integrated Pest Management (IPM)	3	2	2 [12]	2	3	3	2	3	3	3
Landscape features to create biodiverse habitats	3	3	3	3	3	3	3	3	3	2

10 See Chapter 2.4 Sustainable intensification in FAO 2019a.

11 There is no agreed list of bioeconomic agricultural practices. The scoring is based on the author's assessment of the potential of each practice to contribute to the objectives of bioeconomy as e.g. outlined in Gomez San Juan et al. (2022).

12 Conservation agriculture sometimes uses synthetic herbicides, in particular glyphosate ("Roundup"), which has detrimental impacts on biodiversity.

This guide describes the resources required at farm level to implement the 14 practices, the potential impacts of each practice on Biodiversity for Food and Agriculture, and any potential co-benefits and trade-offs resulting from the practice (with regards to other desirable environmental, economic and social outcomes). **Table 2** explains the different aspects of each practice sheet.

Table 2 Elements of the practice sheets explained

Context/suitability	
Farm or landscape level	Whether a practice can be adopted at the level of an individual farm or requires implementation at a larger scale. Most practices will be more effective if implemented at scale, but they may still be suitable for adoption at individual farm or plot level (for example, crop rotation or intercropping). Where practices require implementation at scale (for example, soil and water conservation at community or watershed level), collective action may be required for establishment / initial adoption and maintenance/continuation of the practice.
Relevant production system (FAO classification, see FAO 2013b)	The production system(s) that the practice is suitable for.
Resource requirements/cost implications	
There will be large variations in resource requirements and costs, depending both on the nature of the practice implemented (e.g., whether soil conservation involves earthen or stone bunds, or whether a landscape feature is a pond or a hedgerow), and the specific context in which the practice is being applied. The information here is indicative, to act as a "checklist", and would need to be verified at local level.	
Land and other natural resources	The type and extent of land and water resources required, and any other natural resources.
(financial and physical) Capital / implements	Both initial investments and ongoing operational costs, including any specialised equipment
Labour (qualitative and quantitative/skills etc.)	A breakdown of the main activities requiring labour (family or hired), as well as the specific knowledge and skills required to implement the practice.

Expected impacts on biodiversity (and in what timeframe these impacts may occur/become observable)

The focus in these sections is on potential impacts. The actual impacts depend on a wide range of parameters, related to how suitable the practice is for the specific context in which it is implemented, and how well it is designed and managed. A practice that is in principle well suited to the local context may still have negative impacts, in particular if it is poorly designed and implemented. Negative impacts can to some extent be mitigated by "tweaking" the design and implementation or improving monitoring and follow-up.

Genetic diversity Species diversity Ecosystem diversity	Indication of the dimension of biodiversity (potentially) being impacted by the practice.
More detailed description of impacts on biodiversity.	This section outlines in some detail the potential positive and negative impacts of the practice on the three dimensions of biodiversity.

Co-benefits, trade-offs, synergies and challenges

<table>
<tr><td>Co-benefits and trade-offs for climate change mitigation and adaptation:</td><td rowspan="7">The co-benefits and trade-offs listed below should be considered as "potential". Whether they materialise will depend on the design and management of the practice (including how well adapted it is to the local context, whether synergies between practices are realised, and whether and to what extent there is pro-active management and learning, to continue adapting practices when challenges are identified.) Management aspects include continuous monitoring of effectiveness and to identify potential negative side effects – which could be environmental, economic or social. They also include training and capacity development of farmers and other stakeholders.</td></tr>
<tr><td>Co-benefits and trade-offs for water quality and quantity:</td></tr>
<tr><td>Co-benefits and trade-offs for soil health:</td></tr>
<tr><td>Co-benefits and trade-offs for productivity:</td></tr>
<tr><td>Co-benefits and trade-offs for income:</td></tr>
<tr><td>Co-benefits and trade-offs for nutrition:</td></tr>
<tr><td>Co-benefits and trade-offs for gender equity:</td></tr>
<tr><td>Works well with/brings synergies with practice</td><td>Listing other practices from this guide that could be combined with the current practice, outlining the specific synergies that could potentially occur</td></tr>
<tr><td>Does not work well/competes with practice…</td><td>Listing other practices from this guide that might compete with the current practice</td></tr>
</table>

Because of the context specificity of resources and support required for different practices, no values for set-up costs have been included. However, the sections on land/natural resources, capital/financial resources and labour/human resources in the practice sheets can be used as checklists of cost items that could be used to estimate the implementation costs for practices in a specific context.

Table 3 to → Table 5 compare the resource requirements, expected biodiversity impacts and co-benefits of the different practice, using a crude three-point rating.

Table 3 Resources and support required for the adoption of biodiversity-friendly agricultural practices Source: Author's own

Agricultural practices with the potential to enhance biodiversity	**Resources and support required (as compared to conventional farm practices) for implementation** (3 = high, 2 = medium, 1 = low)				
	Labour	**Skills / knowledge**	**Land and other natural resources**	**Capital / finance**	**Collective action**
Crop rotation	1	2	1	1	3
Intercropping	1	2	1	1	3
Conservation and use of local crop varieties	1	3	1	1	3
Conservation and use of local livestock breeds	1	3	2	2	3
Bee keeping	2	3	2	3	2
Organic soil amendments	3	3	1	1	3
Minimum/zero tillage	2	2	2	2	3
Soil and water conservation	3	3	3	3	3
Integrated fish-crop-livestock system	2	3	2	3	3
Sustainable rangeland and herd management	2	3	3	1	3
Agroforestry	3	3	3	2	3
Community-managed / assisted natural regeneration	2	3	3	2	2
Integrated Pest Management (IPM)	2	3	1	2	3
Landscape features to create biodiverse habitats	3	3	3	3	2

Table 4 Biodiversity impacts from the adoption of biodiversity-friendly agricultural practicess Source: Author's own

Agricultural practices with the potential to enhance biodiversity	Biodiversity benefits (as compared to conventional farm practices) for implementation (3 = high, 2 = medium, 1 = low)		
	Genetic diversity	**Species diversity**	**Ecosystem diversity**
Crop rotation	1	2	2
Intercropping	1	2	2
Conservation and use of local crop varieties	3	2	2
Conservation and use of local livestock breeds	3	2	2
Bee keeping	3	2	2
Organic soil amendments	1	2	2
Minimum/zero tillage	1	2	2
Soil and water conservation	1	2	2
Integrated fish-crop-livestock system	2	3	3
Sustainable rangeland and herd management	2	2	3
Agroforestry	2	3	3
Community-managed/assisted natural regeneration	2	3	3
Integrated Pest Management (IPM)	3	3	2
Landscape features to create biodiverse habitats	2	3	3

Table 5 Potential co-benefits from the adoption of biodiversity-friendly agricultural practices Source: Author's own

Agricultural practices with the potential to enhance biodiversity	Potential co-benefits (as compared to conventional farm practices) (3 = high, 2 = medium, 1 = low)								
	Climate change mitigation	**Climate change adaptation**	**Water quality**	**Water quantity**	**Soil health**	**Productivity**	**Incomes**	**Food and nutrition security**	**Gender equality**
Crop rotation	1	2	2	2	2	2	2	2	1
Intercropping	1	2	2	2	2	2	2	3	2
Conservation and use of local crop varieties	2	3	2	2	2	2	2	3	3
Conservation and use of local livestock breeds	1	3	2	2	2	2	2	2	2
Bee keeping	1	2	1	1	2	3	3	3	2
Organic soil amendments	2	3	2	2	3	3	2	2	1
Minimum/zero tillage	3	3	2	2	3	3	2	2	1
Soil and water conservation	1	3	2	3	3	3	2	2	2
Integrated fish-crop-livestock system	1	2	2	1	2	3	3	3	2
Sustainable rangeland and herd management	3	3	2	2	2	2	2	2	2
Agroforestry	2	3	2	2	3	2	2	2	2
Community-managed/assisted natural regeneration	2	3	2	3	3	3	3	3	3
Integrated Pest Management (IPM)	2	3	2	2	2	3	2	2	2
Landscape features to create biodiverse habitats	1	3	2	2	2	2	2	2	2

3.3 Making use of synergies

(Agro)biodiversity is integral part of the food and agriculture system and is characterised by multiple and complex connections and feedback loops[13]. Agricultural practices impact on environmental parameters via a range of mechanisms, which can mutually reinforce each other. For example, the use of organic soil amendments is more effective and beneficial if areas have been treated with soil and water conservation measures to reduce surface runoff and erosion. Hence, these practices are synergetic – the combined effect of both is larger than the sum of their individual effects.

Similarly, the co-benefits of biodiversity-enhancing practices can be synergistic – e.g. the social capital developed through collective action for the establishment of landscape features can also strengthen the community-wide implementation of Integrated Pest Management (IPM). Or the economic benefits of crop rotation and the use of local crop varieties can reinforce each other. However, practices can also compete with each other for resources – in particular for labour. For example, a labour- and skill intensive IPM component might, in the short term, compete for time with other practices such as soil and water conservation or agroforestry. → Section 4.3 therefore emphasise the need for integrated planning that considers the combined effects of and requirements for all practices.

Farmers are aware of this and have been combining practices that are synergistic, whilst also managing constraints such as seasonal labour availability and access to natural resources. The identification, adaptation and promotion of biodiversity-enhancing practices need to strengthen and use synergies, whilst reducing wherever possible competition between practices.

3.4 The role of the enabling environment

For the (ongoing) adaptation (to local contexts), adoption and sustainable management of all biodiversity-enhancing practices, a supportive institutional and policy context is required that provides technical, organisational, financial and material support. Agricultural policies and strategies at national and local level should ideally ensure that this support is available to farmers and other food system actors in the long term, rather than relying on project funding only.

13 See for example ‣ Ortiz et al. 2021 for interactions between interactions between biodiversity, agriculture, climate change, and international trade.

At national policy level, National Biodiversity Strategies and Action Plans (NBSAPs) under the Convention on Biological Diversity offer entry points for the integration of biodiversity objectives into agricultural policies. The Global Biodiversity Framework includes → Target 10 which states that by 2030, Parties shall: *"Ensure that areas under agriculture, aquaculture, fisheries and forestry are managed sustainably, in particular through the sustainable use of biodiversity, including through a substantial increase of the application of biodiversity friendly practices, such as sustainable intensification, agroecological and other innovative approaches, contributing to the resilience and long-term efficiency and productivity of these production systems, and to food security, conserving and restoring biodiversity and maintaining nature's contributions to people, including ecosystem functions and services."*

Target 4 (halt human induced extinction of threatened species, maintain and restore genetic diversity of native, wild and domesticated species) and **Target 7** (reduce pollution risk and impact from pollution, including reducing excess nutrients lost to the environment by half; reducing overall risk from pesticides and highly hazardous chemicals by at least half, including through integrated pest management; reducing plastic pollution) of the Global Biodiversity Framework are furthermore of particular relevance and biodiversity-enhancing practices contribute to their achievement.

In addition, these efforts are closely aligned with the **United Nations Framework Convention on Climate Change (UNFCCC)** and the **United Nations Convention to Combat Desertification (UNCCD)**. The Paris Agreement under the UNFCCC explicitly recognizes the importance of conserving and enhancing sinks and reservoirs of greenhouse gases – including forests, soils, wetlands and oceans (Article 5) – as well as the role of intact ecosystems for both mitigation and adaptation. Ecosystem-based adaptation (EbA) approaches are increasingly promoted within UNFCCC processes as cost-effective strategies that use biodiversity and ecosystem services to help communities adapt to climate change while delivering co-benefits for mitigation and livelihoods. In parallel, the UNCCD advances Land Degradation Neutrality (LDN) and explicitly calls for avoiding, reducing and reversing land and soil degradation in agricultural lands through sustainable land management, biodiversity-friendly practices and ecosystem-based approaches. In most countries, **national Agricultural Development Plans** or other sectoral strategies (e.g.on soil health, plant and animal genetic resources) can support the integration of biodiversity enhancing practices. However, agricultural policies are not always coherent, sometimes promoting both agroecological practices and external input dependant practices simultaneously[14]. Government subsidies can be politically motivated rather than evidence

14 This could either be deliberate (supporting both an export-oriented agro-industrial sector and a peasant sector producing food – e.g. in Brazil and China, see ‣ Scoones et al. 2016) or due to a lack of coherent policy development, with different influences within and outside government pushing for different approaches to agriculture.

based (see e.g. → Mason et al. 2013 for the case of Zambia). There may be little that an individual agricultural or livelihood project can do to influence national policies – but there may be opportunities to work with local governments at county or district level to create a more inducive environment for biodiversity-enhancing practices. This could include aligning local by-laws to support the use of the practices, training of agricultural extension staff, and including biodiversity considerations into local development planning and budgeting.

Technical and organisational support is required for identification, testing, adaptation and scaling (see also → section 4.6) of biodiversity-enhancing practices. Key agencies providing this support are national agricultural research institutes and universities, agricultural advisory service providers (both public and private) and civil society organisations such as farmer organisations and NGOs. An analysis of the existing agricultural innovation system (see → Annex 2) can help identify opportunities and challenges with regards to these organisations, and any associated capacity needs that a project could support – e.g. via initial and ongoing training and capacity development support for farmers, agricultural extension staff and other actors. The specific capacity needs will also depend on the nature of the practice (and to what extent it builds on existing, locally known practices or is new to the area). It may also include organisational support to farmer groups or cooperatives, to develop their technical and social capacities, address conflicts of interest and ensure their long-term sustainability. The specific instruments for capacity development are similar to those for any other new practice and include farmer field schools, farmer-to-farmer peer learning, exchange visits, and increasingly the use of digital technologies (see e.g. → Choruma et al. 2024 for a recent overview of the digital technologies currently employed by smallholder farmers in Sub-Saharan Africa, and associated challenges and opportunities).

But knowledge alone may not be sufficient to bring about a shift in agricultural practices – in particular where biodiversity-enhancing practices require (substantive) upfront investments, without producing tangible co-benefits in the short or even medium term. **Financial support** may be required for the initial investment (provision of or loans for tools and materials, labour wages for the initial establishment of the practice etc.) and possibly for ongoing maintenance – for example, in the form of PES (Payments for Ecosystem Services). There have been many instances where development organisations have shouldered the initial costs of environmentally beneficial agricultural practices, with the assumptions that farmers would be able and willing to undertake any ongoing maintenance activities without further incentives. Some development organisations have experimented with subsidies to incentivise a transition to agroecological farming practices.[15] Soil and water conservation initiatives have often used food-for-work or cash-for-work, e.g. as part of humanitarian support in areas with high levels of environmental degradation. A recent review by the International Food Policy Research Institute (IFPRI) reflects on a range of different strategies used to support sustainable agricultural systems, including financial tools (→ Swinnen et al. 2025).

Most practices require **ongoing monitoring and adaptive management** to achieve their full potential. This is particularly important where there is limited or no pre-existing experience with a practice, and hence farmers and those supporting them need time to build up that experience, which may well include making mistakes and learning from them. As a rule of thumb, the more complex a practice, the more management support its promotion will require. This applies in particular to practices that require collective action/collaboration between different individuals or groups, such as soil and water management, ANR, IPM and rangeland management. The practice sheets provide many examples whereby practices may have unintended negative impacts – either by design (because the practice has certain weaknesses with regards to some of the objectives that it is meant to contribute to), or because of poor implementation and management.

→ Annex 2 provides a summary of **potential entry points for biodiversity conservation** that include awareness raising for all food system actors (producers, consumers, other value chain actors, policy makers, CSOs etc.), strengthening institutions that support biodiversity enhancement, identifying and removing harmful incentives and subsidies (and replacing them with positive incentives), integrating biodiversity considerations into planning and policies at all levels, promotion of 'green' business models, certification systems, and mobilisation of funds from all possible sources.

15 For example, DanChurchaid in Uganda and Zimbabwe (results not yet published)

4

Which practice for what context?

4 Which practice for what context?

4.1 From context analysis to the promotion of biodiversity-enhancing practices at scale – a step-by-step approach

There is a vast range of agricultural practices with the potential for Biodiversity for Food and Agriculture (BFA) enhancement – but identifying those that work well in a specific context is a real challenge. Questions to consider in the selection process might include:

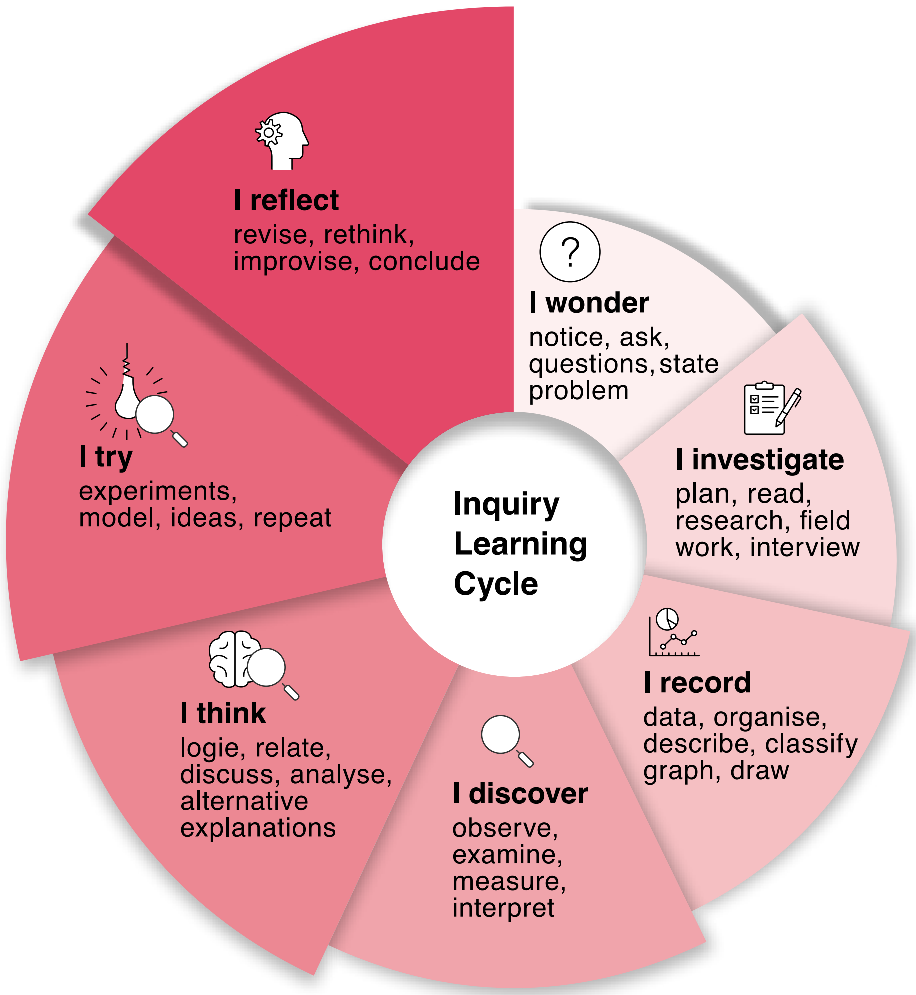
- What priority BFA challenges need to be addressed? Do different stakeholders have different priorities?
- Which practices can potentially address these BFA challenges? What is known about their effectiveness in the specific local context?
- How well do the practices fit with local farming system? Are the resources required for adoption of these practices locally available, or can they be made available in a sustainable way?
- Are there sufficiently strong co-benefits to incentivise the adoption of these practices, also in the long run?
- Are there any other barriers to adoption?

Answering these questions can be a time-consuming exercise. Fortunately, in most cases, there are existing sources of information, including local knowledge and previous studies, that can be built on. Local communities are key participants throughout the whole learning cycle – not only to contribute information and knowledge, but also to contribute to analysis and decision making.

The following sections provide a step-by-step guide to the identification, testing and promotion of biodiversity-enhancing agricultural practices. Starting with the process of understanding the existing farming system and any associated biodiversity challenges, it then moves to identifying and selecting suitable practices, testing and adapting them, before promotion at scale and monitoring of impacts. Rather than being a linear process with a clearly defined start and end point, it may be helpful to conceptualise the steps as a learning cycle

(→ Figure 1), where action ("I try") is followed by reflection, adaptation, monitoring and experimentation. There is no blueprint for this process and there is no substitute for local innovation and adaptation - this applies to all types of agricultural practices and technologies, not only those aiming to enhance Biodiversity for Food and Agriculture. It is well understood and documented that the promotion of "one size fits all" agricultural practices and technologies has rarely resulted in large scale adoption. *"Scaling is a continuous process in which innovations are contextualized, used, embedded into societal dynamics, aiming to create widespread positive impacts."* (→ Martinez-Baron et al. 2024) .

Figure 1 Inquiry learning cycle
Source: ‣ https://www.structural-learning.com/post/inquiry-cycle



4.2 Analysing the context and the need for action

The **selection of a specific approach or combination of practices needs to consider the respective local context** (in terms of environmental, social, economic and policy environment), and any known challenges in agriculture, environment and biodiversity. An assessment of these issues would have been made at least partly at the project design stage, which would normally include an analysis of the local context and the specific challenges to address by the project interventions. The steps below can draw on any pre-existing analysis, including data and information from other sources (such as any surveys, studies and assessments done by NGOs, research institutes or universities, or government departments). When using such secondary sources information, it is important to be aware of their limitations because of e.g. the methodology used, the sample size, the geographic scale or the time when the study was conducted. The use of such information sources is not a substitute for a participatory process that involves and empowers local stakeholders – rather, it complements such a process.

4.2.1 Analysing the agri-food systems

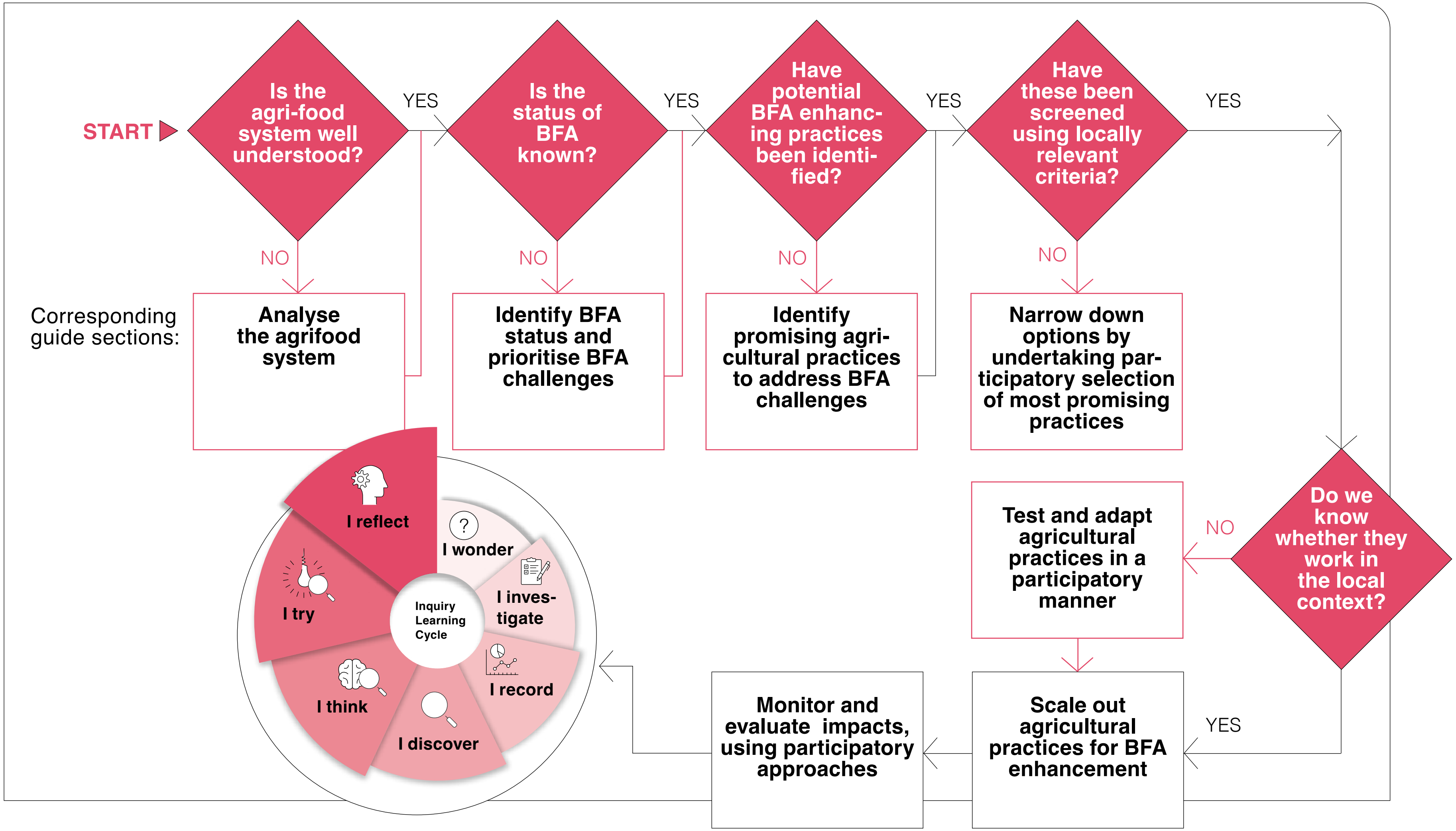
EXPECTED OUTPUT:
Knowledge/understanding of the agri-food system (components, linkages, challenges)

Understanding the existing agricultural system is the obvious starting point for any interventions aimed at introducing more biodiversity-friendly agricultural practices. It provides the information and knowledge required to adapt the system by integrating biodiversity considerations.

Analysing agricultural production systems requires a multi-faceted approach, often combining quantitative and qualitative methods to address their ecological, economic, and social complexity. It can be done in a very detailed way, collecting and using both quantitative and qualitative data on all aspects of the production system and the wider contexts, or in a less detailed way that relies mostly on existing data and knowledge of (selected) stakeholders.

The most prominent methods are **Systems Analysis, Farming Systems Research, and Agroecosystem Analysis**, with each offering a different lens for understanding and evaluating these complex systems. See → Annex 2 for a description of these methods. Existing data and information from various sources (previous studies, data sets and research reports from project partners in government, academia or civils society; census data) can be used where available and

Figure 2 Steps towards the widespread adoption of biodiversity-enhancing agricultural practices Source: Author's own



accessible. Some methods rely primarily on qualitative information gathered through Participatory Rural Appraisal (PRA) methods that use focus group discussions and visualisation to understand local perspectives on farming systems and the environment.

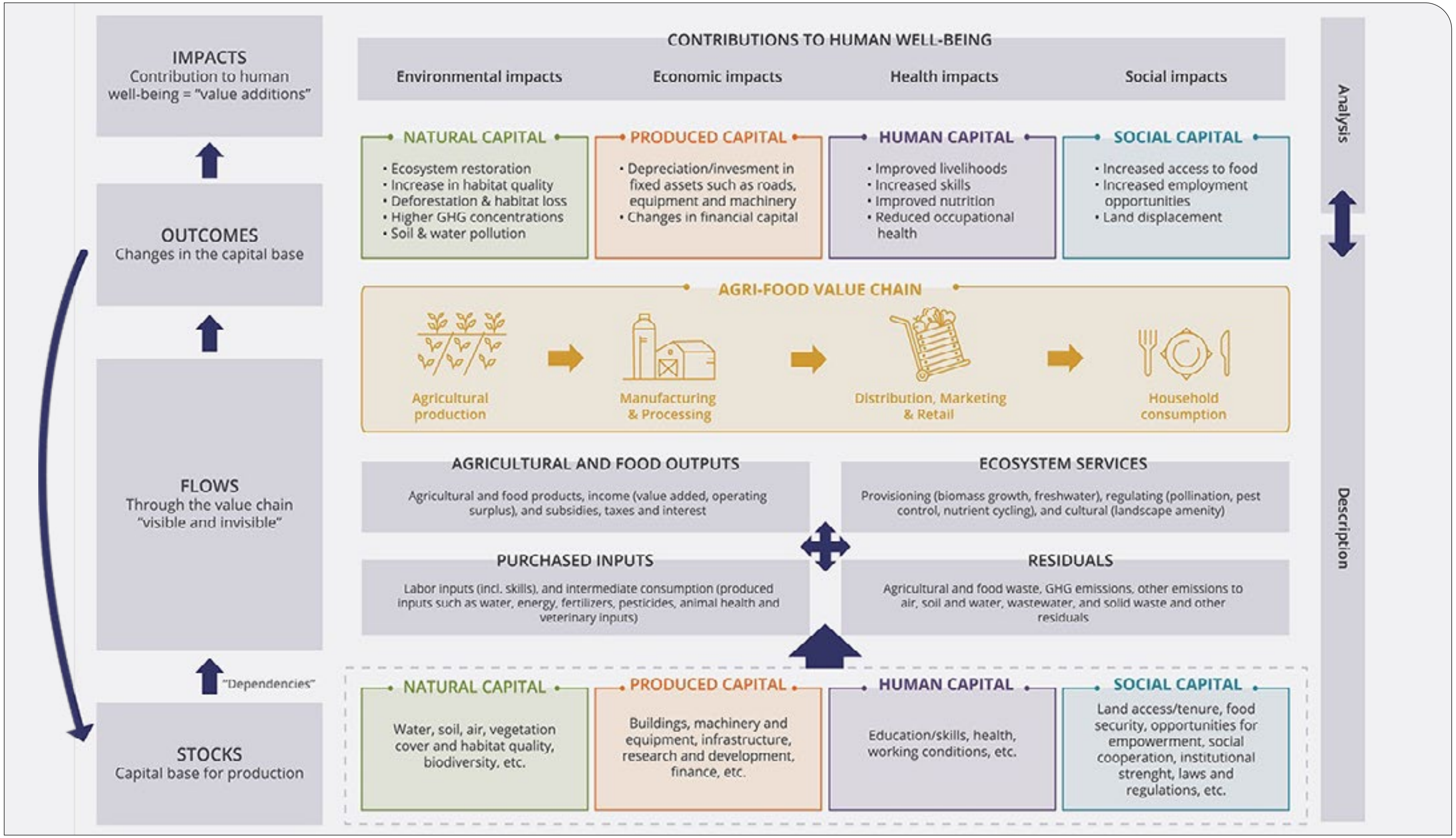
This guide is concerned with agricultural production practices and not practices that could enhance biodiversity within the wider food system (which includes processing, transport, marketing, consumption etc.). However, agricultural production is embedded in the food system overall, with multiple feedback loops between production and consumption. Therefore, considering only the production side of the system risks arriving at an incomplete understanding of opportunities and challenges to improve the production system. Several of the approaches outlined above consider not just the production system, but also the wider socio-economic and policy context in which it operates, helping to identify potential challenges and opportunities for the adaptation, adoption and scaling up of biodiversity enhancing practices.

Whilst these diagnostic and analytical methods and tools include environmental and biodiversity issues to some extent, their main focus is on social and economic parameters. More recently, other frameworks have been developed that use a systems perspective which includes environmental impacts. → Reyers et al. (2013) developed a framework for assessing ecosystem services, using a social-ecological approach that considers the interactions between farms and their environment. → Pogue et al. (2020) used it in analysing ecosystems services from beef production in Canada, but the framework can be used in any context to explore the linkages between ecosystem services, human wellbeing, social-ecological structures and processes, and governance and management – all dimensions explored in the practice sheets of this guide. Similarly, the TEEBAgriFood Evaluation Framework[16] (→ Eigenraam et al. 2020) considers the importance (and costs) of maintaining and enhancing natural capital in agri-food systems.

16 A link to a google drive with training materials is available on their website at
‣ https://www.unep.org/topics/teeb/teeb-agriculture-and-food-teebagrifood/teebagrifood-evaluation-framework

Figure 3 Components of the TEEBAgriFood Evaluation Framework

► https://www.unep.org/topics/teeb/teeb-agriculture-and-food-teebagrifood/teebagrifood-evaluation-framework



4.2.2 Identifying priority biodiversity issues that need addressing

EXPECTED OUTPUT:
Knowledge/understanding of the current status of Biodiversity for Food and Agriculture in the existing agri-food system and identification of priority challenges and opportunities.

An agri-food system analysis would provide some initial pointers with regards to the status of Biodiversity for Food and Agriculture, such as indications for soil erosion or land degradation, the type of crop varieties and livestock breeds used, any issues with pollination, pests or diseases, etc. However, loss or deterioration of Biodiversity for Food and Agriculture may not be immediately noticeable:

- Tangible impacts of biodiversity loss or degradation on food and agriculture may only emerge over time, and recognising them requires knowledge, skills and experience. There are complex feedback loops between agri-food systems, biodiversity loss, and agricultural productivity and resilience, which are often difficult to observe, let alone quantify.

- Similarly, attributing any observed challenges with the agricultural production system to changes in Biodiversity for Food and Agriculture requires a very good understanding of local agro-ecosystems – and this knowledge may not be present among professionals trained primarily in agronomy or other agricultural sciences.

Despite these shortcomings, it is important to assess the current status of Biodiversity for Food and Agriculture in the intervention area, and possible impacts of degradation on the agricultural systems. This can be done by using secondary data, by collecting and analysing data generated by the project, and/or through qualitative methods relying on perceived changes in the environment. A comprehensive list of methods and resources is included in → **Annex 3**.

Once a good understanding of the agriculture and food system and the biodiversity that it depends on has been achieved, key issues that require addressing need to be identified and prioritised in participatory way, involving the main stakeholders. Workshop can be effective ways for this, possibly combined with field visits to explore some challenges in practice and in more detail.

Because of the inevitable power differences[17] between organisational stakeholders (e.g. from government departments, research institutes or project staff) and

17 A useful tool to analyse stakeholders is the power-interest matrix, which maps stakeholders in a two-dimensional space in relation to the topic of concern: Power / influence, and Interest. See ‣ https://urbact.eu/sites/default/files/stakeholders_power_interest_matrix_0.pdf on how to use this tool.

members of local communities, it is advisable to prepare for a prioritisation exercise through community exercises that gather priority challenges and proposed solutions from different community members (including women and men, youths and elderly people; farmers and pastoralists from different wealth groups, and representatives from local institutions such as farmer groups, cooperatives etc.). These can then feed into "higher level" workshops involving other stakeholders, who have a supportive or facilitating role in addressing the challenges identified.

Some of the tools presented in → **Annex 3**, in particular PRA-type exercises that use focus group discussions and visualisation, are also suitable for identifying and prioritising biodiversity challenges and interventions at the local level. Skilful facilitation is required to ensure that such a process is genuinely community driven (rather than using community engagement to rubber-stamp decisions made elsewhere), and that local perspectives and understandings of the linkages between biodiversity and agricultural performance (productivity, resilience, diversity…) are identified and acted on.

Specifically, the following tools[18] may be useful for community-level workshops:

- **Problem trees:** This is a simple tool to identify causes for and effects of priority challenges or problems. It is often used in community-based planning, to come up with actions required to address challenges. The metaphor of a tree is often well understood by local people (roots as causes, stem as the main issue / challenge and branches and leaves as the effects) – see e.g. → **Mnkeni et al. (2010)**.[19] After the tree is done, it can be helpful to convert it into a solution tree (flip causes to opportunities/actions) and a **pathway map** (who, what, when). The strength of this method is that it aims to connect causes and effects, which is essential when trying to understand the impacts of biodiversity degradation on the agricultural production system, and in turn the effects of this degradation on key agricultural system performance parameters.

- **Visioning and back casting as a forward-looking, solution-oriented exercise:** Rather than starting with the identification of problems, it can be helpful to start on a positive note, identifying a community vision of Biodiversity for Food and Agriculture. Once a vision has been agreed, the steps required to get there can be identified through "back casting". The → **UNEP toolkit (2022)** could be used for the design of such a process,

18 For a comprehensive training guide on participatory learning and action, see Pretty et al. 1995.

19 See ‣ https://www.efdinitiative.org/news/digging-roots-problem-tree-helps-strengthen-climate-smart-agriculture-policies-0 for an example of using a problem tree in a community context.

but would need to be adapted for the local context, to take into account literacy levels, power relations between different groups of local stakeholders etc.:

- **Step 1:** Convene stakeholders (farmers, pastoralists, biodiversity/resource managers, local government) and facilitate a visioning workshop – what is our desired future for "biodiversity in food & agriculture" (e.g., resilient landscapes, diverse crop/livestock genetic resources, sustainable pastoral systems) in 10–15 years.
- **Step 2:** Working backwards from that vision, identify major milestones (e.g., by year 5, by year 0) needed to reach it.
- **Step 3:** For each milestone, identify required actions, responsibilities (which stakeholder group), resources, and links to biodiversity and the food and agriculture system.
- **Step 4:** Use this to build a "pathway-to-impact" – a roadmap of what needs to happen, when, and who does it.
- The UNDP toolkit explicitly links this to partnership/team design and stakeholder mapping, which is helpful when processes include diverse actor groups.

- **Ranking and scoring to prioritise biodiversity related challenges and actions:** A range of tools can be used to get a sense of priority, both for the challenges identified and the solutions proposed. PRA/PLA tools for this purpose include matrix ranking or scoring, which enable the assessment of an issue (challenge or solution) along a range of criteria identified by the stakeholders. In addition to some of the older PRA manuals such as → **Ellis-Jones (2005)**, the more recent → **Food Security and Livelihoods Cluster and iMMAP Inc. Ukraine (2024)** guide explains different ranking tools in an easy-to-understand manner.

As with all bottom-up approaches, there is a risk that local stakeholders will not be aware of some of the biodiversity challenges, because they are not immediately recognisable. Community members may also not be aware of some methods and approaches that could be used to address the challenges identified. Hence, whilst it is essential that development practitioners and government staff understand farmers' perspectives, and respect and learn from their local knowledge, it is also important that farmers are exposed to new insights about agriculture-biodiversity linkages, and new methods and approaches to reduce any negative impacts of agriculture on biodiversity.

Box 3
Farmers' understanding of virus borne plant diseases

Cassava mosaic disease (CMD) and cassava brown streak disease (CBSD) are virus diseases affecting cassava production in many parts of Sub-Saharan Africa. Yet, most farmers are not aware that these diseases are caused by viruses (→ **Yabeja et al. 2024**), which are spread by whiteflies (Bemisia tabaci). Some farmers in Uganda and Tanzania have observed whiteflies in diseased fields, and, assuming that they are directly responsible for causing the symptoms, have tried to control the diseases by spraying pesticides[20]. This is not only ineffective, but also costly – and may have negative impacts on Biodiversity for Food and Agriculture and human health.

Farmer fields schools (FFS) have been used in many parts of Africa to demonstrate the transmission pathways of CMD and CBSD to farmers – including posters or brochures showing how whiteflies spread the virus from plant to plant, and how cuttings from diseased plants will also be diseased. FFS have also been used to experiment with and demonstrate various control methods (in particular, phytosanitation and the use of resistant cassava varieties). Without this external knowledge input, it would be difficult for farmers to understand why pesticide use cannot control the disease.

4.3 Identifying promising agricultural practices to address biodiversity challenges

EXPECTED OUTPUT:
A validated list of practices that seem to have the potential to address the prioritised biodiversity challenges.

During the participatory processes of identifying priority BFA issues that need addressing, a range of potential solutions will probably already have emerged. These could include traditional or local agroecological farming practices that have been used and refined over time, or practices that have been introduced more recently via farmer-to-farmer exchange, government or project initiatives, or private sector actors.

20 Author's own observations while working with farmers, researchers and extension staff in Uganda, Tanzania and Nigeria on the control of virus diseases in cassava and sweet potato.

Farmers' own knowledge and experiences are invaluable, as they would have emerged through local experimentation and adaptation over time. But as the context changes, e.g. as a result of climate change impacts, local knowledge needs to be complemented with solutions from outside – e.g. other geographic areas, or other types of knowledge creation such as formal research. This process of incremental, participatory and equitable knowledge development is captured in the concept of "Participatory Innovation Development" (PID), which has been tested and promoted by some research and development organisations (see **Box 4**). There are also a number of international initiatives and communities of practice focusing on the specific aspects of biodiversity conservation – for example, the International Initiative for the Conservation and Sustainable Use of Soil Biodiversity's → **Plan of Action** (2020–2030) and the International Pollinators Initiative's → **Plan of Action** (2018–2030).

Box 4
The PROLINNOVA initiative

For example, the PROLINNOVA[21] initiative (PROmoting Local INNOVAtion in ecological agriculture and natural resource management) emerged when diverse organisations in several countries in Africa, Asia and Latin America joined forces to promote local innovation processes in agriculture and natural resource management. The core mandate of PROLINNOVA is the co-creation of innovations through bottom-up, farmer-led research (which may or may not include collaboration with formal research institutions).

To facilitate this process, Country Platforms have been developed that design their own programmes and agree on joint international activities for mutual learning and policy dialogue. This Global Partnership Programme is a community of practice that is built from the bottom up, in the spirit of the Global Forum on Agricultural Research (GFAR).

PROLINNOVA currently has regional platforms in Asia and Pacific, Eastern and Southern Africa, West and Central Africa, and in the Andes (this latter one was inactive, as of November 2025). There are also 18 country platforms, including 15 in BMZ partner countries. These country platforms can be a useful entry point to identify national and local level expertise on PID processes, which could be used to identify and adapt biodiversity supporting agricultural practices.

21 ‣ https://prolinnova.net/

Hence, the next step in the process is now to map out what sort of practices could potentially address the identified priority BFA issues, where these practices came from, any information about these practices and their potential impacts (and the reliability of this information), and the resources required to implement them. At this stage, it could be helpful to systematically list any available information about the practice, as a base for decision making, similar to the information available in the practice sheets in this guide (see → **Table 2**).

There may be existing agricultural practices that could be modified to provide BFA benefits – for example, the use of organic soil amendments may already be a well-established practice but could be improved and combined with other practices to maximise soil health benefits.

Some of this information may not be available in a scientific or quantitative way, and there will inevitably be gaps, which may need to be filled before an informed decision can be made. Sources of information can include documentation (such as the practice sheets in this guide or reports from agricultural research studies) and knowledge of local or national experts (including farmers, agricultural extension staff, project staff, agricultural researchers).

Not all characteristics (resource requirements and impacts) of the practice will be equally important in the local context. For example, where labour is a serious constraint because of seasonal or long-term outmigration of men and youths, information about labour requirements is particularly crucial. Similarly, if water scarcity had been identified as a key constraint, impacts of the practice on water availability, as well as water requirements to implement the practice, should be considered as a priority.

Once this process of compiling information about the practice is completed, a full list of the identified options can be shared with various stakeholders for validation. At the community level, visual aids such as photographs or drawings could be used to explain practices that local people are not familiar with and to get feedback on their suitability in the local context. Again, at this stage, some new suggestions may emerge, including innovations by individual or groups of farmers.

4.4 Narrowing down options

Probably, the number of options that will be tested needs to be narrowed down, applying locally relevant criteria. This could be done in a participatory workshop with stakeholders, using methods such as matrix ranking or scoring to evaluate practices and identify the most promising ones for testing (see → **Annex 4** for details). Similar to the identification of biodiversity challenges, separate events for farmers and other stakeholders might be appropriate, unless an effective representation of (different types of) farmers can be guaranteed in a wider stakeholder workshop.

A key challenge for effective scoring could be a lack of knowledge and information about a practice at the local level – whereby little information is available on their potential performance and resource requirements. It may be possible, as part of a study tour, to visit sites with similar agroecological conditions where practices have been tested and used for some time. However, it cannot be assumed that a practice fits with local farming and livelihoods systems only because it has worked well in a seemingly similar context.

4.5 Testing and adapting agricultural practices for biodiversity enhancement

EXPECTED OUTPUT:
A range of locally adapted practices that address priority biodiversity challenges.

Once practices have been identified that are promising (i.e., likely to address the biodiversity issue, possible to implement with locally available resources and support systems, and generating relevant co-benefits), a testing and adaptation process can be used to make sure it really works in the local context and delivers the expected benefits. This could be done both on-station and on-farm, using participatory processes that encourage experimentation. Such processes are different from demonstrations – which are for demonstrating tried and tested practices. The farmer field school (FFS) approach was developed by FAO and partners in around 2000 and has since been applied in a range of contexts in over 90 countries[22]. The main principle is experiential learning – with farmers testing both local and external practices. Whilst in practice, many FFS are run

22 ‣ FAO (2016) provides guidance on how to set up and run a successful FFS. → FAO's "Global Farmer Field School Platform" has a wide range of resources on FFS, including events and news stories.

like demonstrations and training centres, with farmers and other local people having little or no say in the design of the experiments, the original concept was very much about farmer-led experimentation.

The number of options that can be tested locally will depend on the resources and time available in the project but is likely to be limited. Completely new practices may be better tested first on a research station rather than on-farm, with farmers observing and providing feedback. For on-farm research (whether as part of a FFS or on farmers' own fields), feedback on the performance of the practice can again be collected via matrix scoring (see → **section 4.3**) – either done by individual farmers or by farmer groups. If done in groups, it is important to ensure that group members are similar with regards to their socio-economic characteristics – for example, men with lots of land, women-headed households, youths without land etc.

Facilitating many matrix scoring exercises can be quite time consuming – in particular where the project area is large. A new methodology, CIAT TRICOT[23] , has been developed by the Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT) (→ **Steinke and van Etten 2026**). This method is using a triadic comparison of technologies to allow farmers to rank agricultural technologies that they have tried on their own farm. Researchers can crowd source information from many farmers, using a mobile app and platform[24].

No matter what methodology is used for testing and evaluating practices, it is important that the results are used to adapt the practices to reduce disadvantages and increase benefits. Such modifications could involve steps to make the practice cheaper to implement and maintain or to increase synergies with other practices. In some cases, practices may need to be discarded as not suitable for the intended purpose. It may well happen that the practices that farmers like best are not the ones that maximise biodiversity benefits. But as a practice is only as good as its adoption, there is a strong point to be made for projects to compromise and be guided by farmers' preferences[25] – if there are at least some biodiversity benefits.

With a typical project cycle lasting only three to five years, testing and adaptation would normally need to be done within the first two to three agricultural seasons, whilst many biodiversity-enhancing practices (e.g. soil and water con-

23 A detailed description of the methodology, including videos, is available at ‣ https://alliancebioversityciat.org/tools-innovations/tricot-triadic-comparisons-technologies

24 ‣ https://climmob.net/

25 See also ‣ Adolph (1996) on an example of negotiating soil and water conservation practices that fit with farmers' preferences in India.

4

servation, landscape features, agroforestry) require several years to show their impact potential. To achieve sustainable outcomes, it is essential to achieve buy-in from those stakeholders (such as national and local government institutions, the private sector, farmer organisations or local NGOs) who can continue the testing, adaptation and promotion of practices.

4.6 Scaling agricultural practices for biodiversity enhancement

EXPECTED OUTPUT:
Wide scale use (with ongoing adaptation) of agricultural practices that address priority biodiversity challenges.

Scaling has three dimensions: **Scaling out** refers to the replication of an approach, strategy or intervention in more locations or impacting larger numbers (of people, organisations, countries…) – but with the required local adaptation. The emphasis here is the horizontal "on the ground" spreading of the innovation. **Scaling up** refers to embedding the concept in policies, laws and organisations, so that sustainable change can be facilitated "from the top" (see also → section 3.3 about the enabling environment). As shown in → Figure 4, scaling up supports scaling out. **Scaling deep** is about impacting on relationships, cultural values and beliefs by building networks and connecting people in various ways. It supports the other scaling dimensions by embedding the underlying principles in institutions ("the way things are done"), which should increase the sustainability of change in the long term.

Scaling out, i.e. increasing the rates of adoption of technologies or practices, has been for some time a key paradigm related to technological change in agriculture. Many project still assess their success by measuring adoption rates. However, the concept of adoption has been criticised for not reflecting real-life decisions taken by farmers and other food system actors, *"which are not simple, dichotomous yes/no, once-and-for-all and linear progressions by which inferior existing materials or methods become obsolete and are abandoned in favour of new, superior ones"* (→ Glover et al. 2016).

Promoting the adoption of packages of improved crop varieties and agricultural inputs during the Green Revolution (e.g. → Pingali 2012) was relatively straightforward and significantly increased yields of some staple food crops under favourable, homogenous conditions - albeit with some negative environmental and socio-economic impacts. The promotion and adoption of location specific biodiversity-enhancing agricultural practices is a much more complex process. The iterative, locally led learning approach described in → sections 4.2 to 4.5 can be scaled out, but not the specific solutions and practices that this approach produces. Hence, there is a trade-off between, on the one hand, a bottom-up process that is grounded in local experiences and contexts (and that is therefore sustainable – but takes time and resources), and adoption at scale that may be short lived (but cheaper and easier to replicate).

Most biodiversity-enhancing practices would require adoption at scale to make a significant impact – hence promoting the concept widely is an important step in the process. If projects can successfully identify and test biodiversity-enhancing agricultural practices that are well adapted to the local context and have co-benefits that respond to farmers' priorities, chances are that wide-scale adoption (with further local adaptation, if required) can be achieved through:

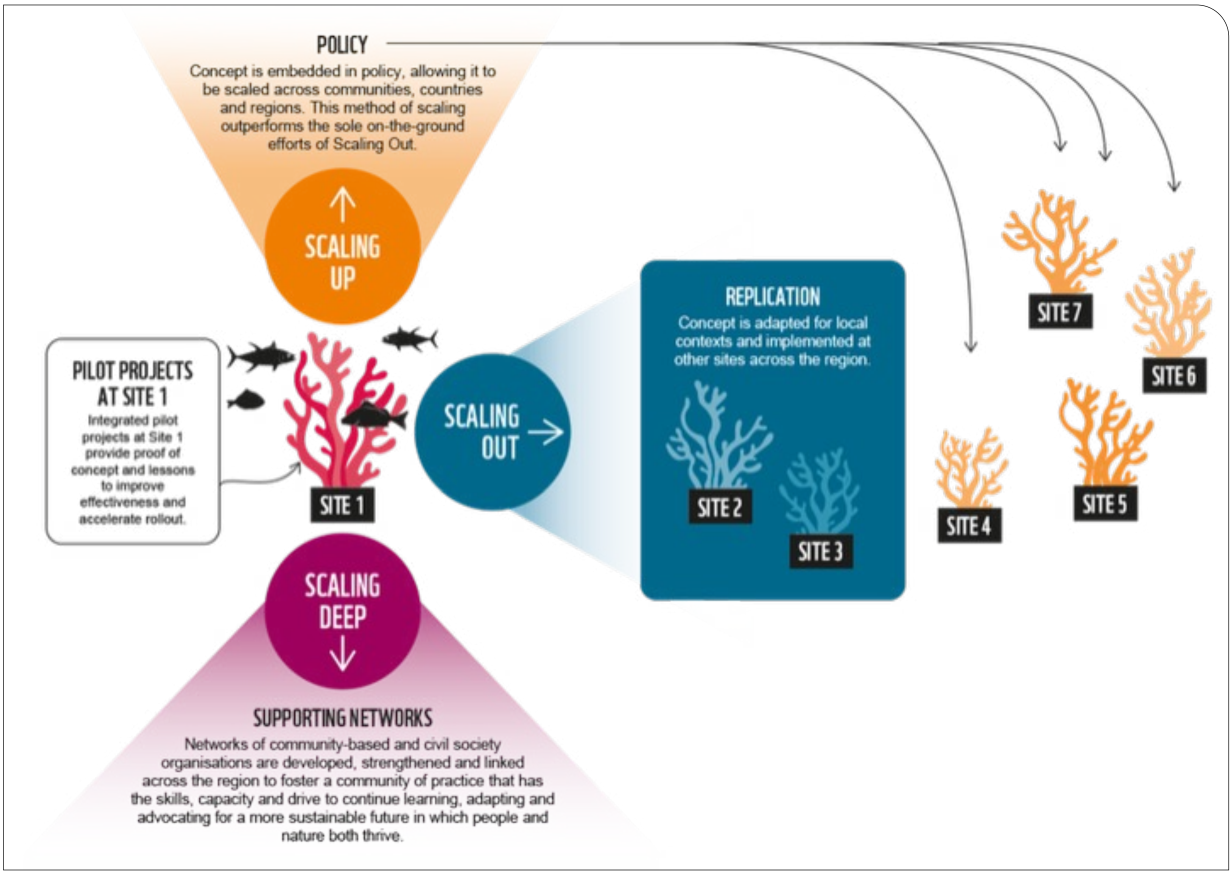
- Farmer-to-farmer learning mechanisms and platforms, e.g. via farmer organisations,
- Promotion by agricultural advisory services staff (who may have been trained by the project in the various biodiversity-enhancing agricultural practices), and
- FM radio, TV/video, mobile phone apps, social media channels etc.

Scaling up provides the necessary mechanism for scaling out by providing the institutional and policy framework required to bring about change at scale. In the context of biodiversity-enhancing agricultural practices, this means initiating and supporting the process of bringing together stakeholders for the process described in → sections 4.2 to 4.5 . Specific instruments to support scaling up include integrating biodiversity considerations into the work plans of local government departments, advocating for policy change at the national level to support key aspects of biodiversity-enhancing agriculture, and embedding Biodiversity for Food and Agriculture in the curricula of agricultural colleges and universities.

Scaling deep complements scaling up by connecting actors and bringing about changes in attitudes, behaviours and values. This includes effective communication of the benefits of biodiversity-enhancing agricultural practices (see also → section 2.2), and the development of a community of practice and critical mass of practitioners. To ensure that scaling happens in a way that is sustainable, it also helps to avoid interventions that are project dependent in the long term (e.g. requiring expensive and difficult to source inputs), unless there are mechanisms to ensure that these materials can be procured, maintained and replaced by farmers (e.g. via a revolving fund for equipment, or through government grants).

Figure 4 Scaling Up, Scaling Out and Scaling Deep model of WWF

Source: ▸ https://www.wwf-swio.org/about_us/our-scaling-model/



Many studies and guides have been developed on scaling agricultural practices and technologies. See for example → Neufeldt et al. (2015) with a focus on climate-smart agriculture, → Ncube et al. (2025) on using agricultural innovation platforms for scaling, and → Sseguya et al. (2022) for sustainable intensification. Scaling approaches are as context specific as the practices and technologies, depending on the enabling environment (policies, markets and other infrastructure, natural resources, knowledge and experiences, social networks etc.) and need to be tailored accordingly.

4

4.7 Monitoring and evaluating the impact of agricultural practices on biodiversity

EXPECTED OUTPUT:
Understanding of the impacts (on Biodiversity for Food and Agriculture and on rural livelihoods) of adopted agricultural practices (and any need for adaptation of practices)

Careful monitoring of impacts – both intended and unintended ones – is a key step in the learning cycle. Where feasible, the monitoring of biodiversity related indicators should be integrated into the project's overall monitoring, evaluation and learning (MEL) framework to ensure a coherent analysis and learning process across project objectives.

→ **Figure 5** shows the main activities, expected outcomes and impacts from the integration of biodiversity-enhancing agricultural practices. As with any other project interventions, monitoring can focus on

- Activities that have been completed (resulting in outputs),
- Outputs achieved (contributing to outcomes), and
- Outcomes realised (contributing to impact).

Assessing outputs and intermediate outcomes is relatively straightforward – project records will normally track project outputs such as the identification and prioritisation of biodiversity challenges, the identification and screening of potential biodiversity-enhancing agricultural practices, further screening for the identification of suitable practices, and the results of testing and adaptation.

At outcome level, the adoption of tested and validated practices can be a proxy indicator for changes in Biodiversity for Food and Agriculture, provided that there is strong evidence for the effect of the practices on Biodiversity for Food and Agriculture (e.g. from on-station research). Other key outcomes might include changes in knowledge and capacities of farmers and other stakeholders, which can be assessed through capacity assessment tools26 adapted for this purpose.

26 See for example
‣ https://worldagroforestry.org/sites/default/files/Capacity%20Needs%20Assessment.pdf and Ndah et al. 2025.

Socio-economic co-benefits from the adoption of biodiversity-enhancing practices (agricultural productivity, incomes, food security, or gender equality) can be monitored with the same tools used for agricultural projects overall, such as

- Qualitative inquiry via focus group discussions, key informant interviews, outcome harvesting, most significant change methodology etc., and
- Quantitative surveys using questionnaires or other standardised tools.

Box 5
Examples of BFA indicators and measurement frameworks

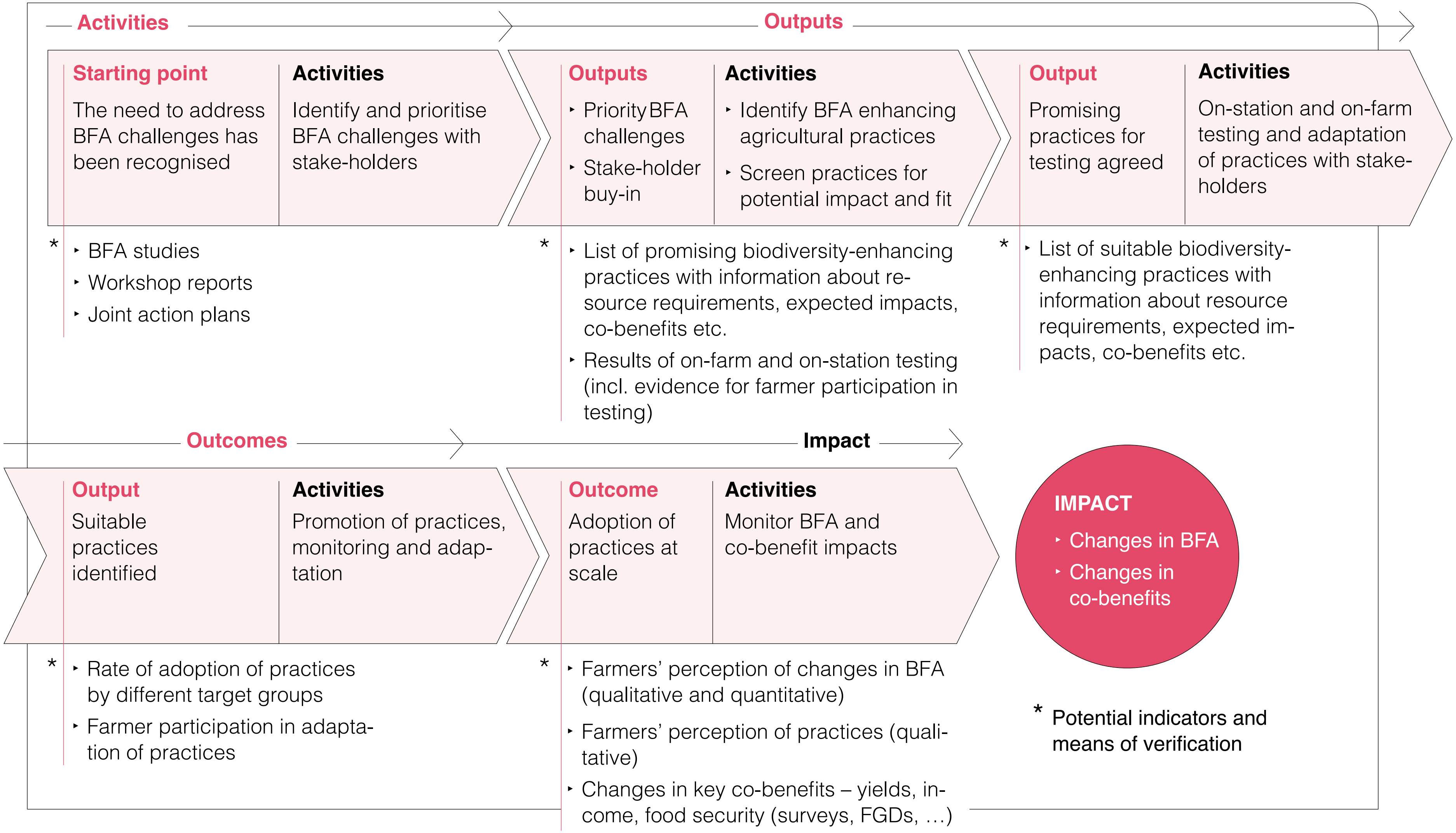
The Biodiversity Indicators Partnership (BIP) is a global initiative to promote the development, delivery, and use of biodiversity indicators. It currently includes almost → **90 indicator sets**, covering a broad range of biodiversity components.

The → **Group on Earth Observations Biodiversity Observation Network (GEO BON)** is a global network of researchers dedicated to improving the acquisition, coordination, and delivery of biodiversity information at the global, regional, and national levels. They developed two sets of biodiversity variables: EBVs (Essential Biodiversity Variables) and EESVs (Essential Ecosystem Service Variables), together with a range of resources on monitoring methods and procedures.

Specifically for land degradation, scientists from World Agroforestry (ICRAF) developed the Land Degradation Surveillance Framework (LDSF), which provides a science-based field protocol for measuring land and soil characteristics, as well as vegetation composition and land degradation status over time (→ **Vågen et al. 2023**).

The LDSF was developed by the "Regreening Africa" initiative, which aimed to pilot measures to address land degradation (→ **Regreening Africa 2022, 2023**). For its 2020 baseline report of seven countries, the initiative used a range of socioeconomic and biophysical indicators (→ **Hughes et al. 2020**) that were subsequently used to assess the programme's impact.

Figure 5 Simplified activities, outcomes and impacts for monitoring and evaluation



4

Measuring bio-physical co-benefits and impacts of agricultural practices on biodiversity is by far the most difficult and resource intensive part of MEL, because

- Measuring changes in Biodiversity for Food and Agriculture requires measuring a wide range of biophysical parameters, often requiring specialised equipment and technical skills, and

- It is difficult to attribute changes in Biodiversity for Food and Agriculture to changes in agricultural practices, as BFA are complex systems, with many feedback loops, and causal linkages cannot easily be established.

At global level, a number of indicator frameworks for biodiversity assessment have been developed that can be used or adapted for monitoring Biodiversity for Food and Agriculture (see → **Box 5**). These frameworks are not generally designed for project-level biodiversity assessments, but some of the indicators could be useful proxies for the biodiversity changes that a project aims to bring about.

As an alternative to scientific monitoring of biodiversity changes, participatory tools can be used that assess stakeholders' perception of changes. Such approaches can be particularly powerful where the main objective of the assessment is learning (to demonstrate benefits), and not accountability to funders or policy makers (→ **Napier et al. 2022**). Importantly, participatory M&E is not just about crowd sourcing data, but about joint analysis and reflection – something that is particularly important when working with complex systems such as Biodiversity for Food and Agriculture.

5 Conclusions

Conclusions

Biodiversity for Food and Agriculture is essential for agri-food systems worldwide. Reversing current trends of biodiversity loss requires a fundamental shift in the design and management of agri-food systems so that conservation, restoration and sustainable use of biodiversity become integral to food system development.

Biodiversity-enhancing practices are an emerging field of studies with new upcoming insights and experiences. This guide encourages the use of a flexible, participatory approach that combines scientific knowledge with farmers' experiences and priorities as well as learning and adaptation. Such an approach responds to diverse agro-ecological and socio-economic conditions and needs to be adapted to the very specific local context. It is suitable for scaling biodiversity-enhancing practices out, up and deep.

The identification and prioritisation of biodiversity-related challenges in agrifood systems and the selection, testing, adaptation, promotion and monitoring of promising biodiversity-enhancing practices are of crucial importance for integrating Biodiversity for Food and Agriculture into projects and programmes. Particular attention needs to be given to feedback loops between farming practices, landscape structures, ecosystem functions and socio-economic drivers, as well as the distribution of costs and benefits across different social groups. Adoption is unlikely to be sustained if practices generate clear biodiversity benefits but insufficient short- or medium-term co-benefits, e.g. in productivity, income, food security or risk reduction. Very often experiences and dedicated institutions or organisations exist in the countries or regions, to support and/or verify the project design.

The selected fourteen biodiversity-enhancing practices in the practice sheets can and shall be combined and adapted to specific production systems and landscapes. They need to be embedded in an enabling environment which consists of coherent policies and strategies – e.g. agricultural development strategies and National Biodiversity Strategies and Action Plans - supportive incentive structures and reduction of harmful subsidies, functional advisory and research systems, strong farmer organisations, and knowledge exchange. Cooperation between stakeholders, especially public institutions, research organisations, civil society, the private sector and local communities is essential to create the institutional and financial conditions for long-term impact. For monitoring, evaluation and learning, the guide outlines pragmatic approaches which include global and national biodiversity indicators, locally defined measures of ecosystem condition and services, and qualitative tools to capture farmers' perceptions and experiential knowledge. These are all well-established good practices that are required for any sustainable agrifood system development – so fostering them is not a new or additional task. Monitoring and evaluation should not only serve accountability but also support adaptive management by feeding evidence back into applied practices.

Biodiversity-enhancing agriculture is a core pillar of sustainable and resilient agri-food systems and is not in opposition to productivity and livelihood objectives, but rather a precondition for their long-term achievement, particularly in the face of climate change, land degradation and increasing resource scarcity. By providing a structured and flexible framework for analysis, participatory prioritisation, practice selection, scaling and monitoring, the guide can support development practitioners and their partners in translating global biodiversity commitments into context-specific, actionable and socially inclusive interventions at field, farm and landscape levels.

References

Association of Commonwealth Universities (ACU) (2023) Equitable Research Partnerships Toolkit. → https://www.acu.ac.uk/media/xbzlgrpg/acu-equitable-research-partnerships-toolkit_full-version.pdf

Adebo, S. (2000) Training Manual on Participatory Rural Appraisal. → https://www.fsnnetwork.org/sites/default/files/pra_guide.pdf

Adem Esmail B. and Geneletti D. (2018) Multi-criteria decision analysis for nature conservation: A review of 20 years of applications. Methods in Ecological Evolution 9: 42–53. → https://doi.org/10.1111/2041-210X.12899

Adolph, B. (1996) How should the bunds be built? Negotiating technologies for soil and water conservation in semi-arid South India. Paper presented at the International Seminar of the Euro-African Association for the Anthropology of Social Change and Development (APAD): “Negotiating Development: Brokers, Knowledge Systems, Technologies”, University of Hohenheim, Stuttgart, Germany, 5–8 June 1996. APAD Bulletin No. 11: 38–48. → https://journals.openedition.org/apad/661

Bastos Lima, M.G. and Palme, U. (2022) The Bioeconomy-Biodiversity Nexus: Enhancing or Undermining Nature’s Contributions to People? Conservation, 2: 7–25. → http://doi.org/10.3390/conservation2010002

Behera, U.K. and France, J. (2023) Chapter One - Farming systems research: Concepts, design and methodology, Editor(s): Donald L. Sparks, Advances in Agronomy, Academic Press, Volume 177, Pages 1–49. → https://doi.org/10.1016/bs.agron.2022.08.001

5

Benton, T., Bieg, C., Harwatt, H., Pudasaini, R. and Wellesley, L. (2021) Food system impacts on biodiversity loss: Three levers for food system transformation in support of nature. Research Paper, Energy, Environment and Resources Programme, Chatham House, UK. → https://www.chathamhouse.org/sites/default/files/2021-02/2021-02-03-food-system-biodiversity-loss-benton-et-al_0.pdf

Bioversity International (2017) Mainstreaming Agrobiodiversity in Sustainable Food Systems: Scientific Foundations for an Agrobiodiversity Index. Bioversity International, Rome, Italy.
→ https://cgspace.cgiar.org/items/6ad8c9de-132f-48e5-adf1-0c0ec93c31c2

Bioversity International (2018) The Agrobiodiversity Index: Methodology Report v.1.0. Rome, Italy: Bioversity International. → https://cgspace.cgiar.org/items/272dc054-1bce-4046-bcd6-a2087093f201

BMZ, KFW, GIZ (2016) Biologische Vielfalt in Vorhaben der Förderbereiche Landwirtschaft, Ernährungssicherung und Ländliche Entwicklung – Eine Orientierungshilfe für die Projektplanung. → https://d-nb.info/122003844X/34

Calub, M. (2003) Participatory Rural Appraisal guidebook. Los Baños: University of the Philippines. → https://africasocialwork.net/wp-content/uploads/2022/10/Participatory-Rural-Appraissal-PRA-Guidebook.pdf

Campanhola, C. and Pandey, S. (eds) (2019) Chapter 12 – The Term "Sustainable Intensification", Sustainable Food and Agriculture, Academic Press, 175–177.
→ https://www.sciencedirect.com/science/article/pii/B9780128121344000121

De Queiroz-Stein, G. and Siegel, K.M. (2023) Possibilities for mainstreaming biodiversity? Two perspectives on the concept of bioeconomy, Earth System Governance, Volume 17, 100181. → https://doi.org/10.1016/j.esg.2023.100181

Choruma, D.J., Dirwai, T.L., Mutenje, M.J. et al. (2024) Digitalisation in agriculture: A scoping review of technologies in practice, challenges, and opportunities for smallholder farmers in sub-saharan africa, Journal of Agriculture and Food Research, Volume 18, 101286. → https://doi.org/10.1016/j.jafr.2024.101286

DeClerck, F. A. J.; Koziell, I.; Sidhu, A. et al. (2021) Biodiversity and agriculture: rapid evidence review. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Research Program on Water, Land and Ecosystems (WLE).
→ https://doi.org/10.5337/2021.215

Department for International Development (DFID) (2001) Sustainable livelihoods guidance sheets. London: DFID. → https://www.livelihoodscentre.org/documents/114097690/114438878/Sustainable+livelihoods+guidance+sheets.pdf/594e5ea6-99a9-2a4e-f288-cbb4ae4bea8b?t=1569512091877

Eigenraam, M., McLeod, R., Sharma, K, and Obst, C. (2020) Applying the TEEBAgriFood evaluation Framework. Overarching Implementation Guidance. Global Alliance for the future of food. → https://futureoffood.org/wp-content/uploads/2025/07/GA_TEEBAgriFood_Guidance.pdf

Ellis-Jones, J., Schulz, S., Chikoye, D., de Haan, N., Kormawa, P. and Adedzwa, D. (2005) Participatory research and extension approaches. Ibadan: International Institute for Tropical Agriculture (IITA).
→ https://biblio.iita.org/documents/U05BkEllisjonesParticipatoryNothomNodev.pdf-1554b4f8b342fa41e8b3ff6c2828b088.pdf

Elouafi, I. (2024) Why biodiversity matters in agriculture and food systems. Science 386, eads8197(2024). → https://www.science.org/doi/10.1126/science.ads8197

European Commission (2025) A Strategic Framework for a Competitive and Sustainable EU Bioeconomy. Brussels: EC. → https://environment.ec.europa.eu/document/download/dbf8d2ba-9332-4f7a-b336-f356fa4b7236_en?filename=COM_2025_960_1_EN_ACT_part1_v10_0.pdf

FAO (2004) Building on Gender, Agrobiodiversity and Local Knowledge. A Training Manual. Rome: FAO. → https://openknowledge.fao.org/server/api/core/bitstreams/310c00b4-e3a4-46fd-89e8-bf40dc91ef1d/content

FAO (2013a) Climate-smart agriculture sourcebook. Rome: FAO.
→ https://www.fao.org/4/i3325e/i3325e.pdf

FAO (2013b) Guidelines for the preparation of the Country Reports for The State of the World's Biodiversity for Food and Agriculture. Rome: FAO.
→ http://www.fao.org/3/a-as644e.pdf

FAO (2016) Farmer field school guidance document. Planning for quality programmes. Rome: FAO. → https://openknowledge.fao.org/server/api/core/bitstreams/afcf7374-18b9-48df-abda-c0e9c13bc840/content

FAO (2019a) The State of the World's Biodiversity for Food and Agriculture, J. Bélanger & D. Pilling (eds.). FAO Commission on Genetic Resources for Food and Agriculture Assessments. Rome: FAO.
→ http://www.fao.org/3/CA3129EN/CA3129EN.pdf

FAO (2019b) TAPE Tool for Agroecology Performance Evaluation – Process of development and guidelines for application. Test version. Rome: FAO.
→ **https://openknowledge.fao.org/server/api/core/bitstreams/8ad4bb1b-c06d-4260-835e-564698493149/content**

FAO (2021a) Assessment of Agricultural Innovation Systems (AIS) A contribution to developing STI roadmaps for SDGs. Rome: FAO, Research and Extension Unit.
→ **https://openknowledge.fao.org/server/api/core/bitstreams/af2450a6-a183-4d48-b308-bdbf09f95893/content**

FAO (2021b) Biodiversity Integrated Assessment and Computation Tool | B-INTACT – Guidelines. Second edition. Rome: FAO.
→ **https://doi.org/10.4060/cb3393en**

FAO (2021c) Research and Extension - TECA Webinar Regenerative Agriculture: good practices for small scale agricultural producers, Rome: FAO.
→ **https://openknowledge.fao.org/server/api/core/bitstreams/15aa7c93-688c-4652-9a54-baa78cfb43d3/content**

FAO (2022a) Framework for Action on Biodiversity for Food and Agriculture. FAO Commission on Genetic Resources for Food and Agriculture. Rome: FAO.
→ **https://doi.org/10.4060/cb8338en**

FAO (2022b) Global Plan of Action for the Conservation, Sustainable Use and Development of Aquatic Genetic Resources for Food and Agriculture. Commission on Genetic Resources for Food and Agriculture. Rome: FAO.
→ **https://doi.org/10.4060/cb9905en**

FAO (2024) Action Plan for the implementation of the FAO Strategy on Mainstreaming Biodiversity Across Agricultural Sectors 2024 – 2027. Rome: FAO.
→ **https://openknowledge.fao.org/server/api/core/bitstreams/885a411c-2dc4-4966-8a44-0aa7f560d273/content**

Food Security and Livelihoods Cluster and iMMAP Inc. Ukraine (2024) Overview of participatory methods Participatory Rural Appraisal Manual.
→ **https://fscluster.org/sites/default/files/2024-10/2024%20FSLC%20%26%20iMMAP%20Inc.%20PRA%20Manual%20%5BENG%5D.pdf**

Geck, M., Adeyemi, C., Adoyo, B., Alpuerto, J., Arinloye, A.A.D.D., Ateku, D., Autfray, P., Barahona, C Chacha, R., Cluset, R., Karari, V., Mills, D., Ravonjiarison, N., Sörensen, L., Thomson, A., Weullow, E., Winowiecki, L., Woldemeskel, E., Zampela, P., Sinclair, F. (2024) Measuring Agroecology and its Performance (MAP): Key findings from applying the FAO Tool for Agroecology Performance Evaluation (TAPE) in Benin, Ethiopia, Kenya, and Madagascar in the context of the Global Programme Soil Protection and Rehabilitation for Food Security (ProSoil). Working Paper 8. Bogor, Indonesia and Nairobi, Kenya: CIFOR-ICRAF: The Transformative Partnership Platform on Agroecology.
→ https://cifor-icraf.org/publications/pdf_files/WPapers/TPP-WP-8.pdf

GIZ (2022) Synergies between adaptation, biodiversity and mitigation – How Ecosystem-based Adaptation can build bridges between Nationally Determined Contributions and the new Global Biodiversity Framework. Bonn: GIZ.
→ https://www.giz.de/expertise/downloads/giz2024-en-eba-synergies.pdf

GIZ (2023) Biodiversity in global agricultural supply chains Solutions for a biodiversity-sensitive design of global agricultural supply chains. Eschborn: GIZ.
→ https://www.adaptationcommunity.net/wp-content/uploads/2024/03/publication-giz-en-Biodiversity-in-global-agricultural-supply-chains.pdf

GIZ (2024a) Position Paper Agroecology. Eschborn: GIZ. → https://www.giz.de/expertise/downloads/giz2024-en-position-paper-agroecology.pdf

GIZ (2024b) Guiding framework for the transformation of Agriculture and Food Systems. Bonn: GIZ. → https://www.giz.de/epertise/downloads/giz2024-en-guiding-framework-transformation-of-agriculture-and-food-systems.pdf

Glover, D., Sumberg, J. and Andersson, J. A. (2016) The Adoption Problem; or Why We Still Understand so Little about Technological Change in African Agriculture. Outlook on Agriculture, 45(1), 3–6.
→ https://doi.org/10.5367/oa.2016.0235

Gomez San Juan, M., Harnett, S. and Albinelli, I. (2022) Sustainable and circular bioeconomy in the biodiversity agenda. Opportunities to conserve and restore biodiversity in agrifood systems through bioeconomy practices. Rome: FAO.
→ https://openknowledge.fao.org/server/api/core/bitstreams/5c24cce4-5cff-410d-bdf0-6061f3ad3887/content

Gómez, C.M., Sthapit, B. and Vernooy, R. (2016) Safeguarding local crop knowledge: the use of community biodiversity registers. Rome (Italy): Bioversity International; South Africa: Department of Agriculture, Forestry and Fisheries.
→ https://hdl.handle.net/10568/78415

HCV Network (2021) HCV Assesment manual. → **https://cdn.prod.website-files.com/624493bb51507d22cf218d50/628685903d12e717c7de80c2_NT_HCV_AssessmentManual_Final-WO-Public-summary-.pdf**

Hughes, K., Oduol, J., Kegode, H., Ouattara, I., Vagen, T., Winowiecki, L.A., Bourne, M., Neely, C., Ademonla, D.A., Carsan, S., Van Schoubroeck, F. and Chomba, S. (2020) Regreening Africa Consolidated Baseline Survey Report. Nairobi: World Agroforestry. → **https://regreeningafrica.org/wp-content/uploads/2020/09/Regreening-Africa_Baseline-Report_WEB.pdf**

IPBES (2019) Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. E. S. Brondizio, J. Settele, S. Díaz, and H. T. Ngo (editors). Bonn, Germany: IPBES secretariat. → **https://doi.org/10.5281/zenodo.3831673**

IPBES (2024) Summary for Policymakers of the Thematic Assessment Report on the Interlinkages among Biodiversity, Water, Food and Health of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. McElwee, P. D., Harrison, P. A., van Huysen, T. L., Alonso Roldán, V., Barrios, E., Dasgupta, P., DeClerck, F., Harmáčková, Z. V., Hayman, D. T. S., Herrero, M., Kumar, R., Ley, D., Mangalagiu, D., McFarlane, R. A., Paukert, C., Pengue, W. A., Prist, P. R., Ricketts, T. H., Rounsevell, M. D. A., Saito, O., Selomane, O., Seppelt, R., Singh, P. K., Sitas, N., Smith, P., Vause, J., Molua, E. L., Zambrana-Torrelio, C., and Obura, D. (eds.). IPBES secretariat, Bonn, Germany.
→ **https://doi.org/10.5281/zenodo.13850289**

IPES-Food (2022) Smoke and Mirrors: Examining competing framings of food system sustainability: agroecology, regenerative agriculture, and naturebased solutions.
→ **https://ipes-food.org/_img/upload/files/SmokeAndMirrors.pdf**

IUCN (2020) IUCN Global Standard for Nature-based Solutions A user-friendly framework for the verification, design and scaling up of NbS. First edition. Gland, Switzerland: IUCN. → **https://portals.iucn.org/library/sites/library/files/documents/2020-020-En.pdf**

IUCN (2024) Agriculture and conservation: Living nature in a globalised world. IUCN Flagship Report Series No. 2. Gland, Switzerland: IUCN.
→ **https://portals.iucn.org/library/sites/library/files/documents/FRS-002-En.pdf**

Janssen, S., Louhichi, K., Kanellopoulos, A. et al. (2010) A Generic Bio-Economic Farm Model for Environmental and Economic Assessment of Agricultural Systems. Environmental Management 46, 862 – 877.
→ **https://doi.org/10.1007/s00267-010-9588-x**

Jones, S.K., Estrada-Carmona, N., Juventia, S.D. et al. (2021) Agrobiodiversity Index scores show agrobiodiversity is underutilized in national food systems. Nature Food 2, 712–723. → https://doi.org/10.1038/s43016-021-00344-3

Kessler, J.J. and Moolhuijzen, M. (1994) Low external input agriculture: Expectations and reality. Netherlands journal of agricultural Science 42-3, 181–194. → https://library.wur.nl/ojs/index.php/njas/article/download/596/310/398

Kleijn,D., Bommarco, R., Fijen, T.P.M., Garibaldi, L.A., Potts, S.G., and van der Putten, W.H. (2019) Ecological Intensification: Bridging the Gap between Science and Practice. Trends in Ecology & Evolution, Volume 34, Issue 2, pages 154–166. → https://doi.org/10.1016/j.tree.2018.11.002

Land Management Component (2006) Agro-ecosystems analysis and agro-ecological zoning, a handbook. Lao-Swedish Upland Agriculture and Forestry Research Program. Vientiane, Lao PDR: National Agriculture and Forestry Research Institute. → https://data.opendevelopmentmekong.net/dataset/2d77a6e2-a078-427f-8a94-f45af14700b3/resource/4753288c-0265-485e-805b-9be146bbbf2f/download/baf0009.pdf

Laumonier, Y., Adzan, G., Baatuuwie, B.N., Borah, J.R., Ickowitz, A., Moombe, K.B., Reed, J., Sunderland, T.C.H., Syampungani, S. and Zida, M. (2025) Guidelines for Monitoring Biodiversity in Social-Ecological Landscapes. Bogor, Indonesia: CIFOR; Nairobi, Kenya: ICRAF. → https://www.cifor-icraf.org/publications/pdf/guide/9400-Landscape-Biodiversity-Monitoring-Guideline.pdf

Mahesh, V., Swathi Lekshmi, P.S., Pavar, D.A., Daliyamol, Kumar, A. and Prakash, P. (2017) Matrix Ranking – An important PRA tool to assess farmers preferences and priorities. Agricultural Science Digest – A Research Journal. → https://arccjournals.com/journal/agricultural-science-digest/D-4530

Martinez-Baron, D., Gravsholt Busck, A. and Prager, S.D. (2024) Unpacking scaling in agricultural research for development: The role of social capital. Journal of Rural Studies, Volume 108. → https://doi.org/10.1016/j.jrurstud.2024.103296

Mason, N.M., Jayne, T.S. and van de Walle, N. (2013) Fertilizer Subsidies and Voting Patterns: Political Economy Dimensions of Input Subsidy Programs, 2013 Annual Meeting, August 4–6, 2013, Washington, D.C. 149580, Agricultural and Applied Economics Association. → https://ideas.repec.org/p/ags/aaea13/149580.html

Matthews, R.B., Rivington, M., Muhammed, S. et al. (2013) Adapting crops and cropping systems to future climates to ensure food security: The role of crop modelling, Global Food Security, Volume 2, Issue 1, pages 24 – 28.
→ https://doi.org/10.1016/j.gfs.2012.11.009

Millennium Ecosystem Assessment (2005) Ecosystems and Human Well-being: Synthesis.
→ https://www.millenniumassessment.org/documents/document.356.aspx.pdf

Mirzabaev, A., J. Wu, J. Evans, et al. (2019) Desertification. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. → https://www.ipcc.ch/site/assets/uploads/sites/4/2022/11/SRCCL_Chapter_3.pdf

Mnkeni, P.N.S., Chiduza, C., Modi, A.T., Stevens, J.B., Monde, N., van der Stoep, I. and Dladla, R. (2010) Best Management Practices for Smallholder Farming on Two Irrigation Schemes in the Eastern Cape and Kwazulu-Natal Through Participatory Adaptive Research. Report to the Water Research Commission by University of Fort Hare, WRC Report No. TT 478/10.
→ https://wrc.org.za/wp-content/uploads/mdocs/TT%20478%20web.pdf

Napier, A., Simister, N. and Jain, N. (2022) Participatory M&E. Oxford: INTRAC.
→ https://www.intrac.org/app/uploads/2017/01/Participatory-ME.pdf

Narayanasamy, N. (2009) Participatory Rural Appraisal: Principles, Methods and Application. New Delhi: Sage Publications India.
→ https://doi.org/10.4135/9788132108382

Ncube, X., Pittock, J., Bjornlund, H., & van Rooyen, A. (2025) Agricultural innovation platforms for scaling innovations – insights from the Transforming Irrigation in Southern Africa project. International Journal of Water Resources Development, 41(2), 466 – 488. → https://doi.org/10.1080/07900627.2024.2345913

Ndah, H.T., Knierim, A., Audouin, S., Ngouambe, N., Crestin-Billet, S., Randrianarison, N., Toillier, A., Traoré, O., Fongang, G. and Mathé, S. (2025) An organizational capacity self-assessment for innovation support service providers (OCATI) – approach and results from application in Madagascar. The Journal of Agricultural Education and Extension. → https://doi.org/10.1080/1389224X.2025.2519069

Neufeldt, H., Negra, C., Hancock, J., Foster, K., Nayak, D. and Singh, P. (2015) Scaling up climate-smart agriculture: lessons learned from South Asia and pathways for success. ICRAF Working Paper No. 209. Nairobi, World Agroforestry Centre. → http://dx.doi.org/10.5716/WP15720.pdf

Ortiz, A.M.D., Outhwaite, C.L., Dalin, C. and Newbold, T. (2021) A review of the interactions between biodiversity, agriculture, climate change, and international trade: research and policy priorities. One Earth, Volume 4, Issue 1, pages 88 – 101, ISSN 2590 – 3322. → https://doi.org/10.1016/j.oneear.2020.12.008

Pankhurst, C., Dube, B.M. and Gupta, V.V.S.R. (1997) Biological indicators of soil health. Wallingford: CABI. → https://www.isprambiente.gov.it/files/biodiversita/Pankhurst_1997_Biological_indicators.pdf

Pascual, U., Balvanera, P., Díaz, S. et al. (2017) Valuing nature's contributions to people: the IPBES approach. Current Opinion in Environmental Sustainability, Volumes 26 – 27, pages 7 – 16. → https://doi.org/10.1016/j.cosust.2016.12.006

Pingali, P.L. (2012) Green Revolution: Impacts, limits, and the path ahead, PNAS 109 (31) 12302 – 12308.

Pogue, S.J., Kröbel, R., Janzen, H.H., Alemu, A.W., Beauchemin, K.A., Little, S., Iravani, M., de Souza, D.M., and McAllister, T.A. (2020) A social-ecological systems approach for the assessment of ecosystem services from beef production in the Canadian prairie. Ecosystem Services, Volume 45. → https://doi.org/10.1016/j.ecoser.2020.101172

Pretty, J., Guijt, I., Scoones, I. and Thompson, J. (1995) A trainer's guide for participatory learning and action. London: IIED. → https://www.iied.org/sites/default/files/pdfs/migrate/6021IIED.pdf

Regreening Africa (2022) Integrating land restoration monitoring: Combining the socio-economic and biophysical aspects. Insights series volume 1. World Agroforestry, Nairobi, Kenya. → https://regreeningafrica.org/wp-content/uploads/2023/04/Insights-series_NovelMonitoring_Final.pdf

Reyers, B., Biggs, R., Cumming, G.S., Elmqvist, T., Hejnowicz, A.P. and Polasky, S. (2013) Getting the measure of ecosystem services: A social–ecological approach. Front. Ecol. Environ., 11 (5) (2013), pp. 268 – 273. → https://esajournals.onlinelibrary.wiley.com/doi/10.1890/120144

Richardson, K., Steffen, W., Bendtsen, J. et al. (2023) Earth beyond six of nine planetary boundaries. Science Advances 9, 37. → https://www.science.org/doi/10.1126/sciadv.adh2458

Rockström, J., W. Steffen, K. Noone et al. (2009) Planetary boundaries: Exploring the safe operating space for humanity. Ecology and Society 14(2): 32.
→ http://www.ecologyandsociety.org/vol14/iss2/art32/

Scoones, I., Amanor, K., Favareto, A. and Qi, G. (2016) A New Politics of Development Cooperation? Chinese and Brazilian Engagements in African Agriculture, World Development, Volume 81, Pages 1–12.
→ https://doi.org/10.1016/j.worlddev.2015.11.020

Secretariat of the Convention on Biological Diversity (2011) NBSAP training modules version 2.1 – Module 8. Biodiversity planning for states, provinces, cities and other local authorities; how to develop a sub-national biodiversity strategy and action plan. Montreal: CBD secretariat. → https://www.cbd.int/doc/training/nbsap/b8-train-biodiversity-plan-subnational-en.pdf

Secretariat of the Convention on Biological Diversity (2018) Biodiversity and the Sustainable Development Goals. CBD Press Brief.
→ https://www.cbd.int/cop/cop-14/media/briefs/en/cop14-press-brief-sdgs.pdf

Secretariat of the Convention on Biological Diversity (2019) Biodiversity's Role in Empowering People and Ensuring Inclusiveness and Equality. Input to the 2019 High-level Political Forum on Sustainable Development (HLPF).
→ https://sustainabledevelopment.un.org/content/documents/21369CBD_input_to_2019_HLPF_Final.pdf

Sseguya, H., Chikowo, R., Chimonyo, V., Chipungu, F., Groot, J., Muthoni, F., Ngulu, F. and Thierfelder, C. (2022) Taking technologies to a greater scale. In: Sustainable Agricultural Intensification: A Handbook for Practitioners in East and Southern Africa. Bekunda, M., Odhong, J. and Hoeschle-Zeledon, I. (eds), p. 145–156. Wallingford: CABI.
→ https://www.cabidigitallibrary.org/doi/book/10.1079/9781800621602.0000

Steinke, J. and van Etten, J. (2016) Farmer experimentation for climate adaptation with triadic comparisons of technologies (tricot): A methodological guide.
→ https://hdl.handle.net/10568/78782

Swinnen, J. and Barrett, C.B. (Eds.) (2025) Global food policy report 2025: Food policy: Lessons and priorities for a changing world. Washington, DC: International Food Policy Research Institute. → https://hdl.handle.net/10568/174108

Te Wierik, S., DeClerck, F., Beusen, A. et al. (2025) Identifying the safe operating space for food systems. Nature Food 6, 1153–1163.
→ https://doi.org/10.1038/s43016-025-01252-6

Terton, A., Tsioumani, E., Förster, J. & Morchain, D. (2024) Synergies between biodiversity- and climate-relevant policy frameworks and their implementation. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), International Institute for Sustainable Development (IISD), Helmholtz Centre for Environmental Research (UFZ).
→ https://www.adaptationcommunity.net/publications/synergies-between-biodiversity-and-climate-policy-frameworks-a-series-of-thematic-papers/

UNEP (2022) Foresight for the Country Planning Document Toolkit. Nairobi: UNEP. → https://www.undp.org/future-development/foresight-cpd-toolkit

Vågen, T.-G. and Winowiecki, L.A. (2023) The LDSF Field Manual. Land and Soil Health Assessments using the Land Degradation Surveillance Framework (LDSF). Nairobi: World Agroforestry. → https://worldagroforestry.org/output/land-degradation-surveillance-framework-field-manual

Willett, W. et al. (2019) Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet, Volume 393, Issue 10170, pages 447 – 492. → https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(18)31788-4/abstract

World Agroforestry (2023) Regreening Africa. Final Programme Report. Nairobi: World Agroforestry. → https://regreeningafrica.org/wp-content/uploads/2023/08/RegreeningAfrica-Final-Report_29Aug-ONLINE.pdf

World Bank (2025) Agriculture rooted in biodiversity. Washington: World Bank. Conference edition

World Economic Forum (2025) The Global Risks Report 2025, 20th Edition. Insight Report. Geneva: WEF.
→ https://reports.weforum.org/docs/WEF_Global_Risks_Report_2025.pdf

Worldwide Fund for Nature (2021) Farming with Biodiversity. Towards nature-positive production at scale. Gland, Switzerland: WWF International.
→ https://wwfint.awsassets.panda.org/downloads/farming_with_biodiversity_towards_nature_positive_production_at_scale.pdf

Worldwide Fund for Nature (2024) Living Planet Report 2024 – A System in Peril. Gland, Switzerland: WWF International. → https://wwflpr.awsassets.panda.org/downloads/2024-living-planet-report-a-system-in-peril.pdf

Yabeja, J.W., Shirima, R.R., Manoko, M.L.K. and Legg, J. (2024) Farmer Knowledge of Cassava Brown Streak and Cassava Mosaic Diseases in Tanzania.
→ http://dx.doi.org/10.2139/ssrn.5019171

Annexes

Annex 1
Production system classification

Table 6 Production system classification according to FAO Source: after ‣ **FAO 2013b**

Name of production system	Description
Irrigated crops – rice	Irrigated rice refers to areas where rice is cultivated purposely provided with water, including land irrigated by controlled flooding.
Irrigated crops – other	Irrigated crops other than rice refers to agricultural areas purposely provided with water, including land irrigated by controlled flooding.
Rainfed crops	Agricultural practice relying exclusively on rainfall as its source of water.
Livestock grassland-based systems	Systems in which the animals obtain a large proportion of their forage intake by grazing natural or sown pastures, includes: ‣ Ranching: grassland-based systems in which livestock is kept on privately owned rangeland ‣ Pastoralist: grassland-based systems in which the livestock keepers move with their herds or flocks in an opportunistic way on communal land to find feed and water for their animals (either from or not from a fixed home base)
Livestock landless systems	Systems in which livestock production is separated from the land where the feed given to the animals is produced.
Naturally regenerated forests	‣ Primary: Forests of native species, where there are no clearly visible indications of human activities and the ecological processes are not directly disturbed by humans ‣ Modified natural: Forests of naturally regenerated native species where there are clearly visible indications of significant human activities ‣ Semi-natural (assisted natural regeneration): Silvicultural practices in natural forest by intensive management (weeding, fertilizing, thinning, selective logging)

Name of production system	Description
Planted forests (PF)	• Semi-natural (planted component) : Forests of native spcies, established through planting or seeding, intensively managed • Plantations (productive) : Forests of introduced and/or native species established through planting or seeding mainly for production of wood or non-wood goods • Plantations (protective) : Forests of introduced and/or native species, established through planting or seeding mainly for provision of services
Self-recruiting capture fisheries	Includes capture fisheries in marine, coastal and inland areas that can involve • Natural ecosystems • Modified ecosystems e.g. reservoirs and rice paddies;
Culture-based fisheries	Fisheries on resources, the recruitment of which originates or is supplemented from cultured stocks (i.e., populations chosen for culture and not stocks in the same sense as that term is used for capture fisheries) raising total production beyond the level sustainable through natural processes
Fed aquaculture	The farming of aquatic organisms including fish, molluscs, crustaceans, aquatic plants, crocodiles, alligators, turtles and amphibians. Farming implies some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators etc. Farming also implies individual or corporate ownership of the stock being cultivated; i.e., the population chosen for culture and not a stock in the same sense as that term is used for capture fisheries. Fed aquaculture production utilizes or has the potential to utilize aquafeeds of any type in contrast with the farming of filter-feeding invertebrates and aquatic plants that relies exclusively on natural productivity. Also defined as “farming of aquatic organisms utilizing aquafeeds in contrast to that deriving nutrition directly from nature”.
Non-Fed aquaculture	The farming of aquatic organisms including fish, molluscs, crustaceans, aquatic plants that do not need supplemental feeding. Farming implies some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators etc. Farming also implies individual or corporate ownership of the stock being cultivated; i.e., the population chosen for culture and not a stock in the same sense as that term is used for capture fisheries. In non-fed aquaculture systems culture is predominately dependent on the natural environment for food, e.g. aquatic plants and molluscs.

Name of production system	Description
Mixed systems	Production systems with multiple components. They include: ‣ Crop-livestock: mixed systems in which livestock production is integrated with crop production. ‣ Agro-pastoralist: livestock-oriented systems that involve some crop production in addition to keeping grazing livestock on rangelands; they may involve migration with the livestock away from the cropland for part of the year; in some areas, agropastoral systems emerged from pastoral systems ‣ Agroforestry-livestock: mixed system in which livestock production is integrated with the production of trees and shrubs. ‣ Integrated aquaculture: mixed systems in which aquaculture is integrated with crop and livestock production. May involve ponds on farms, flooded fields, enrichment of ponds with organic waste, etc. ‣ Other combinations

Annex 2
Approaches, tools and methods for agri-food system analysis

Systems analysis approaches

This umbrella approach treats agricultural production as a dynamic system with interacting components and feedback loops. It is often mathematically and technically oriented, using different modelling techniques. They generally require reliable data sets on a whole range of production parameters, which may not be available. However, project partners such as agricultural research organisations or universities may have used these approaches, and their findings may be available in the public domain or on request. Examples include:

- **Bio-economic whole-farm models (BEFM)**: These models simulate the interactions within the farm system, including the exchange of resources like manure and fodder between crop and livestock components, to assess long-term changes in soil fertility, productivity, and economic performance. (→ Janssen et al. 2010).

- **Crop simulation models (CSM)**: These are quantitative models that predict crop growth, development, and yield as a function of weather, soil,

and management practices. They are often used to analyse the trade-offs of management practices, breeding scenarios, and adaptation to climate change (→ Matthews et al. 2013).

- Linear programming (LP) and multi-criteria decision analysis (MCDA): These mathematical techniques can help identify the optimal combination of farm enterprises and resource allocation to achieve multiple goals, such as maximising profit while minimising environmental impact. (→ Adem et al. 2018)

- Farm performance simulation (FARMSIM): This tool[27] simulates a farm over multiple years to estimate the probability distributions of various outputs, such as net income and cash reserves. It helps analysts understand the financial risks and potential outcomes of management decisions.

Farming systems research (FSR)

FSR emphasises a holistic, on-farm, and participatory approach to problem-solving, with farmers at the centre of the research process. This approach is particularly suitable where there is a need for understanding the interconnectedness of various farming systems components, where local knowledge and perceptions are important, and where there is insufficient time and resources for the collection and analysis of quantitative data (→ Behera 2023). The FSR analysis can be combined with a more biodiversity-focused participatory assessment (see → Annex 3 below). FSR typically involves a four-stage process:

1. **Diagnostic stage:** Involves informal surveys and tools like Rapid Rural Appraisal (RRA) and Participatory Rural Appraisal (PRA) to understand the farming system, identify constraints, and form homogeneous farmer groups.

2. **Design stage:** Researchers and farmers collaborate to develop potential interventions to address the identified constraints. This stage evaluates potential solutions for technical, economic, and social viability.

3. **Testing stage:** Promising interventions are tested on-farm, with trials ranging from researcher-managed to farmer-managed, to evaluate their performance under real-world conditions.

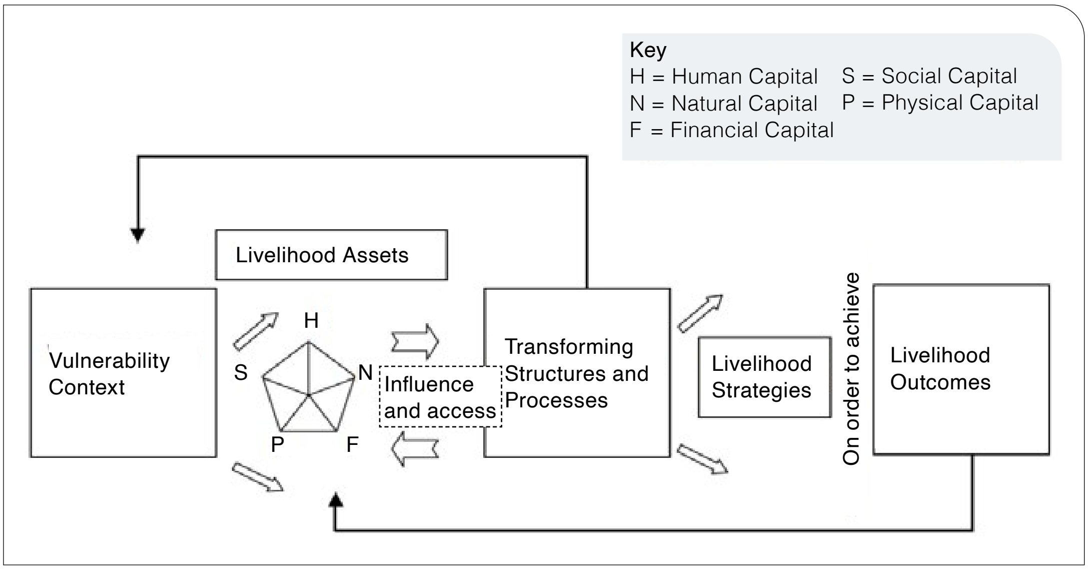
4. **Dissemination and feedback:** After testing, successful technologies are promoted, and feedback from farmers is used to refine the process and inform future research priorities.

27 → https://blackland.tamu.edu/models/farmsim/

The Sustainable Livelihoods framework (SL)

Whilst not developed specifically for the agricultural sector, this framework was developed to undertake a (relatively) quick analysis of the resources and strategies available to rural communities, and the institutional and policy environment in which they operate. The five "capital assets" (human, social, financial, physical and natural capital) at the disposal of a household or community will influence what livelihood strategies they can use, which will in turn determine the livelihoods outcomes. The "transforming structures and processes" (such as markets and policies), together with the "vulnerability context" (such as climate change and demography) will shape how successful livelihood strategies are in achieving the desired outcomes. This process of mapping out desired outcomes, resources and strategies to achieve these, and potential supporting and hindering factors can be helpful for the identification, adaptation and adoption of biodiversity-enhancing practices.

Figure 6 Sustainable Livelihoods Framework Source: after ‣**DFID (2001)**



Agroecosystem analysis (AEA)

AEA uses a systems perspective to analyse the interactions between the biophysical and socioeconomic components of an agricultural system. It often involves an interdisciplinary workshop setting to gather and interpret information (→ **Land Management Component 2006**). Key components analysed include:

- Spatiotemporal patterns: Analysing trends over different spatial scales (e.g., field, farm, landscape) and time scales (e.g., annual, seasonal, long-term).

- Flows and cycles: Mapping the movement of energy, nutrients, money, and information into, out of, and within the system.

- Decision-making: Investigating farmers' decision-making processes in response to system drivers and constraints.

- Resilience and vulnerability: Assessing the system's capacity to adapt and withstand shocks and stresses.

Integrated frameworks and tools

More recent approaches have combined elements of these traditional methods to offer more comprehensive analyses for specific purposes:

- **Tool for Agroecology Performance Evaluation (TAPE)**: A global effort led by the FAO to assess the performance of agroecosystems based on a set of ten elements of agroecological systems: Diversity, Synergies, Efficiency, Recycling, Resilience, Co-creation and sharing of knowledge, Human and social values, Circular and solidarity economy, and Responsible Governance (→ FAO 2019b). Experiences from using the TAPE tool to measure agroecological performance of a GIZ project is described in → Geck et al. 2024.

- **Agricultural Innovation Systems (AIS) analysis**: This approach focuses on the network of organisations, enterprises, and individuals involved in agricultural innovation. It is used to analyse how knowledge is generated and disseminated through these systems (→ FAO 2021a). It is hence a useful tool not just at the initial diagnostic stage, but also to identify potential champions and uptake pathways for biodiversity-enhancing practices.

Annex 3
Approaches, tools and methods to assess the status of Biodiversity for Food and Agriculture

Use of secondary data sources

At country level, there are several assessments on the state of biodiversity that may be of use. These include the following:

- **The ‣ National Ecosystem Assessments (NEAs)** initiative of UNEP-WCMC has supported 14 countries (as of 11/2025) in undertaking assessments of the status and drivers of change to biodiversity, whilst other countries have produced their own assessments with assistance from other partners. These assessments do not specifically focus on Biodiversity for

5

Food and Agriculture but may still be useful for a general overview. The details and reliability of the assessments vary significantly between countries, but they are still a good starting point for obtaining a general picture of the state of ecosystems in the country.

- **The High Conservation Values assessment** is a methodology that identifies and helps to protect High Conservation Values (HCVs) in areas targeted for land-use changes. It is globally applicable, works across a wide range of scales (large landscapes or jurisdictions, farms) and measures species diversity, landscape-level ecosystems, ecosystem mosaics and intact forest landscapes, ecosystems and habitats, ecosystem services, community needs and cultural values (→ HCV Network 2021).

- **The Agrobiodiversity Index**[28], developed by the Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT) collects data on biodiversity across the often-disconnected domains of Nutrition, Agriculture, and Genetic Resources. Besides measuring the status of agrobiodiversity, the Index identifies actions, risks, and opportunities to increase its use and conservation. → Country profiles exist (as of 11/2025) for the → BMZ partner countries Algeria, China, Egypt, Ethiopia, India, Kenya, Lebanon, Libya, Morocco, Nigeria, Peru, South Africa, Syria and Tunisia – however, some of them were developed as early as 2019, using data that may be more than 10 years old now, and hence not necessarily reflecting the current status of Biodiversity for Food and Agriculture. The country profiles may be useful for a general overview, but do not provide information at a finer spatial resolution (e.g. regional or district level).

- FAO publishes a range of **reports on different aspects of Biodiversity for Food and Agriculture at national level**[29]. National reports and assessments are prepared by countries and submitted to FAO, in the context of various agreed processes, on a range of topics related to biodiversity. Nominated National Focal Points are usually responsible for preparing country reports, with assistance from FAO, based on responses to a standardised questionnaire developed by FAO. These include:
  - Biodiversity for Food and Agriculture
  - Plant, Animal, Aquatic and Forest Genetic Resources for Food and Agriculture

28 See ‣ Bioversity International (2018) for details on the methodology used to develop the index.

29 Available at ‣ https://www.fao.org/biodiversity/knowledge-hub/country-reports/en

- Forest Resources Assessments
- Progress on the Implementation of the International Treaty on Plant Genetic Resources for Food and Agriculture.

Similar to the other national level reports mentioned above, these reports provide a (sometimes outdated) overall picture of the state of biodiversity, which is of limited use for the assessment of opportunities and challenges for Biodiversity for Food and Agriculture at the local level. The national reports are also used to compile global reports and action plans, e.g. for the implementation of the FAO Strategy on Mainstreaming Biodiversity Across Agricultural Sectors 2024–2027 (→ **FAO 2024**) or the Global Plan of Action for the Conservation, Sustainable Use and Development of Aquatic Genetic Resources for Food and Agriculture (→ **FAO 2022b**).

- Other data and resources from biodiversity focused surveys, studies or projects – country wide or for specific locations. There may also be plant genetic resources stored in regional, national or local gene banks, with information about the conservation status of these species. Such information may not always be available online, but could potentially be obtained on request by contacting individuals in national or local institutions (universities, research institutes, development projects and programmes etc.). As with secondary information on farming systems (→ **section 4.2.1**), it is important to critically assess the methods used for both data collection and analysis, which may vary in terms of reliability and representativeness.

Collection of biodiversity data and information

Because of the limitations of national-level biodiversity assessments, and the need for context-specific, local level information, it is normally necessary to collect data and information in the respective project or programme sites. As with assessments of the food and farming system, there are a range of tools that have been developed and tested for this purpose – but the resources required to implement varies significantly. For a project with a primarily focus on agriculture and rural livelihoods, it is not realistic to collect quantitative data on Biodiversity for Food and Agriculture that requires field level measurements in multiple locations. But in some cases, partnerships with research institutions in the partner country or elsewhere might enable the application of more elaborate methods – hence the overview below includes a range of approaches with different resource- and time requirements.

Assessing the state of biodiversity for food and agriculture (BFA) at a local level requires a mix of ecological, agricultural, and socio-economic tools and methods. These methods capture the diversity of crops, livestock, aquatic species, soil

biota, wild foods, pollinators, and ecosystem functions that support local food systems. The Center for International Forestry Research and World Agroforestry (CIFOR-ICRAF) recently published a comprehensive guide to monitoring biodiversity in social-ecological landscapes at sub-regional and local scale (→ Laumonier et al. 2025), which includes remote sensing, ground surveys, and the use of digital technology, but also participatory methods and citizen science approaches for use at a local level.

1. Participatory and community-based assessment tools

These tools are used to capture local and traditional knowledge about biodiversity, farming practices, and environmental change. They are particularly useful for engaging communities directly in the assessment process.

- **Participatory Rural Appraisal (PRA)/Participatory Learning and Action (PLA)**: This approach involves community workshops where participants use mapping, ranking, and time-trend analysis to describe agrobiodiversity and how it has changed. It helps identify locally important species, land uses, and shifts in crop or livestock diversity over time. This includes participatory mapping and transect walks, which are visual tools in which community members map or walk across their landscapes to locate biodiversity-rich zones, agroecosystems, and resource areas. These exercises help identify habitats for wild foods, pollinators, and other useful species, and they reveal spatial patterns of resource use and management. There is a wide range of training guides and case studies available on the use of PRA/PLA – see for example → Calub (2003) and the "PLA notes" series published by the International Institute for Environment and Development (IIED).[30]

- **Community Biodiversity Registers (CBRs)**: Locally maintained registers that record the crop varieties, livestock breeds, and wild species found within a community. They are valuable for tracking genetic resources, conserving traditional varieties, and documenting seed exchange or breeding practices (see → Gómez et al. 2016 for an example from South Africa).

- **Focus groups and key informant interviews**: Semi-structured discussions used to gather qualitative data on how biodiversity is used and valued, and what factors drive conservation or loss. They are useful for understanding cultural importance, management motivations, and perceived threats to local biodiversity.

30 For biodiversity-related methods and case studies, see → https://www.iied.org/search/type/publication?k=PLA%20notes%20biodiversity

2. Farm and field-level biodiversity inventories

These methods measure the actual biological diversity present in farms and fields. They provide quantitative data that can be compared across sites or tracked over time.

- **Field biodiversity inventories**: Systematic sampling of crops, trees, weeds, and associated species within plots or fields. Species richness and abundance data can be analysed using indices such as → Shannon, → Simpson, or → Margalef.
- **Soil biodiversity sampling**: Involves collecting soil cores and analysing them for macro- and micro-organisms through mor[31] phological or (e) DNA-based methods. This reveals information about soil health and functional diversity.
- **Environmental DNA** can also use used to analyse water of habitats of target species to estimate their existence.
- **Livestock breed inventories**: Household-level surveys and photographic documentation of livestock breeds help assess the number, distribution, and genetic uniqueness of local animal populations.
- **Genetic diversity analysis**: Laboratory techniques such as molecular markers or phenotyping can be used to assess within-species diversity in crops, livestock, or fish. This is a more technical and costly method but valuable for conservation planning.
- **Agrobiodiversity plots and transects**: Recording the number and type of crop and non-crop species along transects or within defined plots gives a snapshot of on-farm diversity at the landscape scale.

3. Ecosystem and landscape-level assessment tools

At broader scales, these methods examine habitats, ecosystem services, and landscape composition that underpin agricultural productivity and resilience.

- **Land cover and habitat mapping**: Satellite imagery, drone surveys, or Geographic Information Systems (GIS) tools are used to classify land use and vegetation types. These methods help detect habitat loss, fragmentation, or restoration areas. A wide range of free[32] (e.g. → Google Earth) or

31 See ‣ https://cearac.nowpap.org/activities/edna/ for details on eDNA sampling, including links to a sampling and experiment manual.

32 See ‣ https://eos.com/blog/free-satellite-imagery-sources/ for an overview of free satellite image sources.

fairly low cost satellite images are available for most parts of the world, including time series data that shows changes over time.

- **Ecosystem service modelling**: Spatial models (e.g. → InVEST or → ARIES) link biodiversity to services such as pollination, soil fertility, and water regulation. They estimate how changes in land use affect ecosystem service provision.

- **Landscape mosaics and agroecological zoning**: Analyses that classify landscapes according to land-use diversity and ecological connectivity. They reveal how heterogeneous landscapes can support biodiversity and reduce vulnerability.

- **Biodiversity intactness indices**: Metrics such as the Biodiversity Habitat Index (BHI) or Mean Species Abundance (MSA) quantify how land-use intensity affects biodiversity condition.

- **Participatory ecosystem mapping**: Combining remote-sensing data with local knowledge to identify key ecosystem components and hotspots of biodiversity within agricultural landscapes (see 1. above for participatory methods).

- **Methods for integrating ecosystem services into policy, planning and practice**: The ValuES project developed a number of tools to help decision-makers in recognizing and integrating ecosystem services into policy making, planning and implementation of specific projects. The tools are available on the project website.[33]

4. Indicators and monitoring frameworks

Indicators are used to measure and monitor the state of biodiversity and its changes over time. They allow data from local assessments to be linked to national or global reporting frameworks.

- **FAO agrobiodiversity indicators**: Cover crops, livestock, soil, and ecosystem diversity. Examples include the number of crop species per farm, proportion of local breeds maintained, and diversity of soil organisms.

- **CBD and SDG indicators**: Global frameworks such as the Convention on Biological Diversity[34] and the Sustainable Development Goals include relevant indicators (e.g. proportion of degraded land, protected area coverage).

33 ‣ https://www.aboutvalues.net/

34 CBD indicators are available at ‣ https://www.gbf-indicators.org/

- **Local Biodiversity Action Plan (LBAP) indicators**: Developed at district or municipal levels to monitor biodiversity status, trends, and conservation actions within local planning frameworks (→ Secretariat of the Convention on Biological Diversity 2011).

- **Composite biodiversity scores**: Combining ecological, social, and management indicators into a single index can help communicate results to policymakers[35].

5. Socio-economic and knowledge-based methods

These tools assess how people interact with biodiversity, manage it, and benefit from it. They provide insight into social drivers of biodiversity conservation or loss.

- **Household and farm management surveys**: Structured questionnaires that capture information on crops, breeds, input use, rotations, and conservation practices. They provide quantitative data on biodiversity-friendly management.

- **Value-chain analysis for agrobiodiversity products**: Examines the economic role of biodiversity-based goods (e.g. traditional varieties, honey, medicinal plants) and helps identify incentives for sustainable use.

- **Gender and equity assessment tools**: Collect disaggregated data to understand how men, women, and different social groups access and manage biodiversity. These are vital for designing equitable interventions.

- **Knowledge mapping and cultural valuation**: Documenting traditional ecological knowledge and cultural practices related to local species helps reveal non-economic values of biodiversity.

- **Participatory prioritisation of species**: Engaging communities in ranking locally important species or ecosystems for conservation or restoration planning.

35 See for example the Biodiversity Intactness Index of the Natural History Museum, https://www.nhm.ac.uk/our-science/services/data/biodiversity-intactness-index.html

6. Integrated and composite assessment frameworks

These frameworks combine ecological, social, and economic data into a single, coherent assessment suitable for decision-making and policy design. Some of the global assessments presented earlier in this section use such frameworks.

- **Biodiversity Integrated Assessment and Computation Tool**: This toolkit is used for the development of the national biodiversity assessments mentioned earlier, but it can be adapted for subnational and local use. It integrates participatory tools, ecological sampling, and indicator-based monitoring into one coherent process (→ FAO 2021b)

- **Agrobiodiversity Index (developed by Bioversity International and CIAT)**: A composite tool that measures how agricultural systems maintain biodiversity across diets, production systems, and genetic resources. This index is used to produced national level reports but can also be applied at a smaller scale (→ Jones et al. 2021).

- **Local Biodiversity Action Plans (LBAPs)**: Combine participatory and scientific data to guide conservation and sustainable management at district or landscape level.

- **Ecosystem-based monitoring systems**: Integrate field data, remote sensing, and local knowledge to produce continuous monitoring of biodiversity conditions and ecosystem services.

7. Potential combinations for local assessments

To conduct a robust local biodiversity assessment for food and agriculture, some of the tools above can be combined, to benefit from the different advantages of each method. For example:

- Combine participatory tools (e.g. PRA) with field inventories to document existing diversity.

- Use GIS mapping and ecosystem models (such as → InVEST) to assess spatial patterns and ecosystem services.

- Apply socio-economic surveys and gender assessments to understand management practices and equity aspects.

- Integrate all data within a composite framework such as the FAO Toolkit or Agrobiodiversity Index for coherent reporting and planning.

Annex 4
Matrix scoring for prioritisation of options

Ranking and scoring methods have been used for some time to compare different options (e.g. crop varieties, pest control methods, etc.) in a way that does not require literacy[36]. Ranking aims to put options into a priority order, from most preferred to least preferred, without necessarily considering specific attributes. For the purpose of systematically comparing different options along a range of agreed criteria, matrix scoring is more appropriate. It allows to quantitatively assess and compare different options, with each scored against numerous criteria agreed beforehand. The scores for each criterion are totalled up to provide a quantitative comparison of importance. This can be used as a basis for selecting and prioritising options.

Table 7 gives a simplified example of a matrix ranking exercise, with criteria in columns and options in rows. In the example, three methods are scored against five criteria, and the maximum score for each criterion is five (5). The maximum score achieved is 14 for farmyard manure, closely followed by vermicompost with a score of 13.

Table 7 Matrix scoring example

Soil amendment method	Criteria				TOTAL score
	Expected yield increase	Benefits for soil health	Availability of required resources	Ease of implementation	
Farmyard manure	3	3	4	4	14
Biochar	3	5	3	1	12
Vermicompost	5	4	1	3	13

Alternatively, different criteria can be given different weights to reflect their relative importance. In → Table 8, "expected yield increase" has been given a triple weight, whilst "benefits for soil health" and "availability of required resources" have been given a double weight. "Ease of implementation" has not been weighed. The resulting scores and ranks are now different, with vermicompost scoring highest.

The example shows that the most biodiversity-enhancing method may not be the most preferred option, if it does not meet other socio-economic criteria. It is

36 See for example ‣ Maxwell and Bart, ‣ ACU 2023, ‣ Mahesh et al. 2017, ‣ Narayamasami 2012, ‣ Adebo 2000.

counterproductive to "push" a technology that has significant adoption barriers – but these barriers can sometimes be overcome. Matrix ranking enables participants to reflect on priorities, feasibilities etc. For example, the result of → Table 7 could trigger a discussion on how to make biochar production and use easier – considering the significant benefits of this practice for yields and soil health.

Table 8 Matrix scoring example with weighed criteria

Soil amendment method	Criteria				TOTAL score
	Expected yield increase (weight x3)	Benefits for soil health (weight x2)	Availability of required resources (weight x2)	Ease of implementation (weight x1)	
Farmyard manure	3 x 3 = 9	3 x 2 = 6	4 x 2 = 8	4 x 1 = 4	27
Biochar	3 x 3 = 9	5 x 2 = 10	3 x 2 = 6	1 x 1 = 1	26
Vermicompost	5 x 3 = 15	4 x 2 = 8	1 x 2 = 2	3 x 1 = 3	28

Annex 5
Entry points for biodiversity conservation

These include both agricultural practices, as well as policies and business practices (BMZ, KfW, GIZ 2016):

- Raising awareness of the value of biodiversity and its conservation and sustainable use
  - Policy advice to promote sustainable agriculture
  - Information and training for producers
  - Raising awareness among consumers and other participants in the value chain
  - Establishing or strengthening relevant institutions or civil society organisations
- Remove negative incentives and create positive incentives for biodiversity conservation
  - Policy impact assessment
  - Reduce harmful subsidies
  - Take biodiversity into account in funding guidelines
  - Pay for the conservation of ecosystem services

- Reduce habitat loss and fragmentation of ecosystems
  - Establish protected areas on common land, participatory forest management, beekeeping, wildlife corridors, etc. with strong social safeguards (e.g. regarding access to and sustainable use of natural resources for Indigenous Peoples and local communities)
  - Reduce the expansion of agricultural land and fragmentation of natural habitats
- Prevent the spread of invasive species
  - e.g. through phytosanitary measures
  - through biological control measures in accordance with CBD guidelines
- Consider the diverse values of biodiversity and integrate them into planning
  - Analyse and evaluate ecosystem services and communicate them to decision-makers
  - Integrate biodiversity conservation objectives into the revision and implementation of national agricultural, rural development and food security policies (e.g. agricultural and land reform programmes, country and regional planning, agricultural research, food security strategies, agricultural trade, lending or strategic environmental assessments of national policies and programmes)
- Sustainable production and consumption within ecological limits
  - Production according to ecological standards, certification
  - Ecological sustainability as a condition, e.g. when granting loans or subsidies
  - Training and awareness-raising in relation to (agro)biodiversity among producers and consumers
  - Cooperation with the private sector and promotion of "green" business models
  - Corporate Ecosystem Services Review, Trade in biodiversity products and sustainable wild harvesting

- Sustainable land management
  - Promote sustainable production, taking into account biodiversity-conserving techniques, develop the necessary capacities and involve stakeholders in planning and implementation processes
  - Improve unsustainable land use practices (e.g. monocultures)
  - Dissemination of certification systems and approaches to integrated and biological crop protection and good agricultural practice,
  - Promotion of deforestation-free supply chains
- Support area-based conservation measures for ecosystems, species and genetic diversity
  - Integrate nature conservation measures into land use planning and regional development, establish ecological corridors, biosphere reserves
- Conserve genetic diversity in agriculture
  - Promote agrobiodiversity within agricultural production systems, for example through diversification (e.g. through mixed crops or agroforestry systems) and the conservation of traditional varieties and domestic animal breeds (in-situ conservation, e.g. through (e.g. through mixed crops or agroforestry systems) and the preservation of traditional varieties and domestic animal breeds (in-situ conservation, e.g. by e.g. by promoting traditional animal/plant breeding, and/or ex-situ conservation, e.g. through international/national gene banks or so-called community seed banks), in particular for adaptation to climate change
- Maintaining the resilience of ecosystems
  - e.g. through mixed cropping and genetic diversity
- Develop and implement NBSAPs
  - Involve the agricultural sector in the revision and implementation of National Biodiversity Strategies and Action Plans
- Improve, share and apply technologies and knowledge on biodiversity
  - Greater integration of biodiversity and ecological aspects, and indigenous knowledge and practices related to these, into agricultural research.
  - Conserve and restore ecosystem services

- Rehabilitate and restore damaged ecosystems (e.g. through forest landscape restoration and ecosystem-based climate adaptation measures)
  - Impacts of changes in ecosystem services on Indigenous Peoples and the local community, women and other marginalised population groups
  - Soil and water conservation measures
  - Promote and maintain soil fertility
- Access to genetic resources
  - Support the implementation of the Nagoya Protocol and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA)
- Integrate traditional knowledge and traditional use of biological resources
  - Promote biodiversity conservation in rural areas and preserve the associated traditional knowledge of local and indigenous communities, for example in the context of agricultural research
- Mobilise financial resources from all sources
  - Increase budget allocation for measures that contribute to biodiversity conservation

6

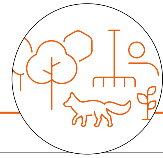
Practice sheets

Practice sheets

6.1 Agroforestry

Agroforestry is a land-use practice that combines the cultivation of trees, shrubs, and other perennial vegetation with agricultural crops or livestock on the same plot of land. It involves intentionally integrating woody plants into farming systems in a structured way, with arrangements that can vary from scattered trees within fields to more organised rows or multi-layered plantings. It is based on traditional practices that have been used by farmers in different parts of the world, with different objectives (including erosion control, shading (‣ Mensah et al. 2024), provision of different materials such as food, fodder and fuel from the same plot of land, etc.).

6.1 Agroforestry



Further short description	The species used in agroforestry systems can be sown directly at the location where they are mean to grow, or in nurseries (managed by farmers, development agencies or the private sector). There is a wide range of training manuals and guides available on agroforestry systems in different contexts, for example: ‣ General / not geography specific: ‣ Gassner and Dobie 2022. Agroforestry: A primer. Design and management principles for people and the environment. ‣ For Asia: ‣ RECTOFTC et al. 2020: Agroforestry for climate-resilient landscapes ‣ World Agroforestry's series ‣ "Agroforestry systems" includes agroforestry studies from Tanzania, Sumatra, Malawi, Cameroon, Vietnam, Côte d'Ivoire, Rwanda etc. ‣ Paparella et al. (2025): ‣ Multipurpose trees ‣ A bit dated, but still useful: ‣ Taylor and Beniest 2003: Training in agroforestry, and specifically for Kenya: ‣ Tengnas 1994: Agroforestry extension manual for Kenya

Context / suitability

Farm or landscape level	Farm / plot level, landscape level
Relevant production system (‣ FAO classification)	Rainfed crops, Irrigated crops, Livestock grassland-based systems, Mixed systems

6.1 Agroforestry

Resource requirements/cost implications

Land and other natural resources	Whilst the specific resources will vary between agroecological zones, the main natural resources required to practice agroforestry are: ‣ Land: space to integrate trees, crops, and/or livestock, whether on farms, homesteads, or communal areas. Secure land tenure is essential for the adoption of agroforestry practices due to the relatively high initial investment (saplings, labour etc.) and the time it takes to realise benefits. ‣ Soil: suitable soil types to support both woody and herbaceous species, with attention to fertility, drainage, and depth. ‣ Water: rainfall or irrigation sources to sustain diverse plantings, especially during the establishment phase. ‣ Sunlight: adequate solar radiation, as species are arranged to balance shade, canopy cover, and light requirements. ‣ Biodiversity base: locally adapted or native species that can be drawn upon for integration into the system.
(financial and physical) Capital/implements	The financial and capital resources needed for agroforestry usually include: ‣ Initial establishment costs: funds for land preparation, fencing, tools, and basic infrastructure (nursery facilities, irrigation if needed). ‣ Planting materials: purchase of tree seedlings, crop seeds, or vegetative propagules, if not locally available. ‣ Maintenance inputs: fertilisers, soil amendments, pest and disease management supplies, or protective materials (mulch, stakes, guards). ‣ Tools and equipment: hand tools (hoes, machetes, pruning tools), water containers, sprayers, etc. ‣ Transport and logistics for moving seedlings, materials, or harvested products to and from markets or storage. ‣ Longer-term capital: resources to sustain operations until trees reach maturity and begin producing, including bridging income gaps. ‣ Financial services: access to credit, savings schemes, or insurance to manage risks over the multi-year establishment phase. Development initiatives have often focused on low-cost technologies for agroforestry that use or adapt locally available resources in order to facilitate adoption.

6.1 Agroforestry

Labour (qualitative and quantitative/skills etc.)	Whilst labour requirements occur mostly at the farm/household level, knowledge and skills are required both by farmers and by agricultural advisory services supporting them: • Labour (possibly via labour sharing arrangements or by groups of (young) people as an income generating activity) ‣ Land preparation (clearing, contouring, digging pits, composting). ‣ Establishment and care of nurseries or transplanting seedlings ‣ Daily/seasonal tasks: weeding, mulching, pruning, watering, pest protection. ‣ Harvesting and basic processing of diverse outputs. • Skills and knowledge ‣ Nursery establishment (seed collection, seedling care, grafting, vegetative propagation). ‣ System design: spatial layouts, species compatibility, and long-term rotation planning. ‣ Soil and water management techniques ‣ Proper planting and spacing of trees and crops; seasonal timing of planting and harvesting. ‣ Pruning, coppicing, and thinning methods. ‣ Livestock management if integrated (grazing control, fodder harvesting). ‣ Local species selection (trees, crops, fodder plants) and their uses. ‣ Recognition of common pests/diseases and local remedies. ‣ Traditional land management and intercropping practices. ‣ Household-level planning: aligning agroforestry outputs with food, fuel, or fodder needs.

6.1 Agroforestry

Expected impacts on biodiversity

Detailed description of impacts on biodiversity:	Agroforestry can affect biodiversity at multiple levels, though the type and extent of impacts depend on system design, management, and landscape context. Agroforestry tends to enhance biodiversity compared to monocultures or degraded land, but its contribution is generally lower than that of intact natural forests, making system design and landscape placement critical.
continued Detailed description of impacts on biodiversity:	**Genetic diversity** ‣ Positive impacts: Maintaining and cultivating diverse tree varieties, traditional crops, and local landraces can help conserve genetic resources that might otherwise be lost under monocultures. On-farm seed saving and the use of indigenous tree species can preserve unique genetic pools. ‣ Potential risks: If only a narrow range of improved or exotic tree species is planted, local genetic diversity may decline, and wild populations may face genetic erosion through hybridisation or displacement. Locally not adapted tree species may not thrive in the local climatic and soil conditions. **Species diversity** ‣ Positive impacts: Multi-strata agroforestry systems provide habitats for a wide range of species, including plants, insects, birds, and soil organisms, by creating niches across vertical layers and successional stages. These systems can support higher species richness compared to conventional monocrops or open pasture. ‣ Potential risks: Simplified or commercial-oriented agroforestry (e.g., shade coffee or timber plantations with low species diversity) may not sustain as many species as more complex or natural forest systems. **Ecosystem diversity** ‣ Positive impacts: At a landscape scale, agroforestry creates a mosaic of land uses that link forests, farms, and grasslands, enhancing ecological connectivity and buffering forest edges. This can strengthen ecosystem functions like pollination, seed dispersal, and soil regeneration. ‣ Potential risks: If agroforestry replaces intact natural forest, ecosystem diversity can be reduced despite local gains, since natural habitats often harbour more specialised or rare ecosystems than managed systems.

6.1 Agroforestry

Complementarity and competition	
Co-benefits and trade-offs for climate change mitigation and adaptation:	Agroforestry can influence both climate mitigation and climate adaptation through several mechanisms: **Mitigation** ‣ Carbon sequestration: Trees in agroforestry systems absorb CO_2 from the atmosphere and store it in biomass (trunks, branches, leaves, roots) and soils. Tropical and sub-tropical regions, with rapid tree growth, can sequester significant amounts of carbon per hectare. ‣ Reduced deforestation pressure: By integrating trees into agricultural landscapes, agroforestry can reduce the need to clear natural forests for cropland or pasture, indirectly preventing carbon emissions. ‣ Improved soil carbon stocks: The addition of leaf litter and root biomass from trees increases soil organic matter, which stores carbon over the long term. **Adaptation** ‣ Microclimate regulation: Trees provide shade, reduce wind speeds, and moderate temperature fluctuations, protecting crops and livestock from heat stress. ‣ Soil and water conservation: Tree roots reduce soil erosion, enhance water infiltration, and maintain soil moisture, buffering crops against droughts or heavy rainfall. ‣ Diversified production: Combining crops, trees, and sometimes livestock provides multiple sources of food or income (e.g. by providing fodder, medicinal plants, honey, raw materials for cosmetics such as shea butter), reducing farmers' vulnerability to climate-related shocks (e.g., drought, floods, or pest outbreaks). ‣ Pest and disease control: Diverse plantings can reduce the spread of pests and diseases that may increase under climate change, enhancing ecosystem stability.
Co-benefits and trade-offs for water quality and quantity:	**Water quantity** ‣ Infiltration and groundwater recharge: Tree roots improve soil structure and water retention capacity, creating channels that increase water infiltration and reduce surface runoff. This can enhance groundwater recharge. ‣ Reduced runoff and flooding: Agroforestry systems slow down rainfall runoff due to canopy interception and root networks, reducing soil erosion and peak flood flows. ‣ Evapotranspiration effects: Trees can locally reduce soil moisture and streamflow if tree density is very high, but moderate integration often balances water use and conservation. ‣ Buffering against drought: By shading soils and reducing evaporation, trees help maintain soil moisture, which can improve crop resilience during dry spells.

6.1 Agroforestry

continued Co-benefits and trade-offs for water quality and quantity:	**Water quality** ‣ Nutrient retention: Tree roots absorb nutrients like nitrogen and phosphorus, reducing their leaching into waterways and mitigating eutrophication in downstream water bodies. ‣ Sediment control: The canopy and litter layer reduce soil erosion, minimising sediment runoff that can clog streams and degrade aquatic habitats. ‣ Pollutant filtration: Agroforestry systems can trap agrochemicals such as pesticides before they reach rivers or lakes, improving water quality. ‣ Temperature regulation: Shade from trees cools runoff water, benefiting aquatic ecosystems sensitive to temperature changes.
Co-benefits and trade-offs for soil health:	Agroforestry can have multiple effects on soil health by influencing soil physical, chemical, and biological properties: **Soil physical properties** ‣ Soil structure improvement: Tree roots create channels that improve soil porosity and aggregation, enhancing aeration and water infiltration. ‣ Erosion control: Canopy cover and root systems reduce surface runoff and protect soil from heavy rainfall, minimising erosion on sloped or exposed lands. ‣ Moisture retention: Leaf litter and root systems help maintain soil moisture by reducing evaporation and enhancing water-holding capacity. **Soil chemical properties** ‣ Nutrient cycling: Leaf litter and pruned biomass from trees decompose, returning nutrients such as nitrogen, phosphorus, and potassium to the soil. ‣ Soil fertility enhancement: Nitrogen-fixing trees (e.g., leguminous species) can increase available nitrogen, reducing the need for synthetic fertilisers. ‣ pH Buffering: Organic matter from trees can buffer soil pH, improving conditions for crops.

6.1 Agroforestry

continued Co-benefits and trade-offs for soil health:	**Soil biological properties** ‣ Microbial activity: Increased organic matter supports diverse soil microbial communities, which drive nutrient cycling and suppress soil-borne pathogens. ‣ Mycorrhizal networks: Tree roots often form symbiotic relationships with mycorrhizal fungi, improving nutrient uptake for both trees and crops. ‣ Biodiversity support: Agroforestry can enhance soil fauna diversity (earthworms, arthropods), which aids decomposition and soil structure maintenance. Overall, agroforestry can create a self-reinforcing cycle where trees improve soil structure, fertility, and biological activity, which in turn supports healthier crops and greater resilience in tropical and sub-tropical agricultural systems.
Co-benefits and trade-offs for productivity:	Agroforestry can influence productivity through interactions between trees, crops, and livestock. Impacts can be both direct and indirect, depending on species selection, system design, and management practices. Agroforestry can increase total farm productivity by producing a combination of crops, timber, fruits, medicinal and cosmetic products, and livestock outputs while stabilising yields over time. Productivity gains are highest when tree-crop-livestock interactions are carefully managed to minimise competition and maximize complementarities. **Crop and food productivity** ‣ Intercropping with trees: Shade-tolerant crops can thrive under tree canopies, allowing multiple harvests on the same land. ‣ Nutrient enhancement: Nitrogen-fixing trees improve soil fertility, potentially boosting crop yields without synthetic fertilisers. ‣ Microclimate regulation: Trees reduce heat stress and wind damage, stabilizing crop growth and improving productivity during extreme weather. **Timber, fruit, and non-timber products** ‣ Diversification of outputs: Trees provide timber, fruit, nuts, resins, or medicinal/cosmetic products alongside crops, enhancing overall farm productivity and income. ‣ Staggered harvests: Tree-based products often mature at different times than crops, providing year-round yields. **Livestock productivity** ‣ Fodder and shade: Trees supply fodder and shelter, improving livestock growth and health. ‣ Integrated agro-silvo-pastoral systems: Crop residues and leaf litter can be used as animal feed or compost, recycling nutrients and supporting farm productivity.

6.1 Agroforestry

Co-benefits and trade-offs for income:	Agroforestry can increase overall farm income and economic resilience by producing a variety of marketable goods, improving yields, reducing input costs, and providing long-term environmental stability. Income benefits are maximised when systems are well-designed, species are appropriately selected, and markets are accessible. **Diversification of income sources** ‣ Multiple outputs: Selling multiple products (crops, trees, fruits, nuts, timber, fodder…) reduces reliance on a single commodity and spreads financial risk. ‣ Staggered harvests: Tree-based products often mature at different times than crops, providing year-round income streams. **Productivity gains (see also previous entry)** ‣ Enhanced crop yields: Improved soil fertility, nutrient cycling, and microclimate regulation can increase crop yields, directly boosting income. ‣ Livestock benefits: Trees provide fodder and shelter, improving livestock productivity and associated income from milk, meat, or eggs. **Cost savings** ‣ Reduced input costs: Nitrogen-fixing trees and organic mulch reduce the need for synthetic fertilisers, lowering production costs. ‣ Erosion and soil maintenance: Tree cover reduces land degradation, decreasing the long-term cost of soil rehabilitation. **Market and non-market benefits** ‣ High-value products: Timber, fruits, nuts, honey, or medicinal/cosmetic plants may have higher market value than staple crops. ‣ Ecosystem services payment: In some regions, farmers can earn income through carbon credits, watershed protection schemes, or biodiversity incentives. **Risk mitigation** ‣ Buffer against climate shocks: Agroforestry systems are generally more resilient to droughts, floods, or pests, reducing crop failure risk and stabilising income over time.

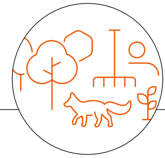
6.1 Agroforestry

continued Co-benefits and trade-offs for income:	**Trade-offs** ‣ Initial investment: Establishing agroforestry systems may require significant capital and labour upfront, delaying income realisation. ‣ Management complexity: Effective management of multiple species requires knowledge and skills, which may affect short-term profitability if poorly implemented.
Co-benefits and trade-offs for food and nutrition security:	Agroforestry can enhance both food availability and nutritional quality by providing diverse, micronutrient-rich foods, stabilising crop production, and increasing household income for food purchases. Well-managed systems can improve dietary diversity, resilience to climate stress, and long-term sustainability of food resources. **Diversification of food sources** ‣ Multiple crops and tree products: Agroforestry integrates fruits, vegetables, nuts, seeds, legumes, and staple crops, increasing dietary diversity and availability of micronutrient-rich foods. ‣ Animal products: Some systems incorporate livestock, poultry, or beekeeping, providing protein, fat, and essential micronutrients. **Increased and stabilised food production** ‣ Enhanced yields: Improved soil fertility, microclimate regulation, and pest management from tree-crop interactions can increase crop yields. ‣ Resilience to climate shocks: Tree cover buffers crops against droughts, floods, and extreme temperatures, stabilising production and reducing periods of food scarcity. **Improved nutritional quality** ‣ Micronutrient access: Tree fruits and leaves improve vitamin, mineral, and protein intake. ‣ Seasonal availability: Agroforestry systems often provide year-round harvests, reducing "lean season" nutrient deficiencies. **Income effects and market access** ‣ Additional income from timber, fruits, nuts, or medicinal/cosmetic plants allows households to buy complementary foods, improving overall nutrition. **Considerations and trade-offs** ‣ Land allocation: Balancing space between trees and crops is essential to ensure sufficient staple crop production for household consumption.

6.1 Agroforestry

Co-benefits and trade-offs for gender equity:	Agroforestry can promote gender equality by improving women's access to resources, income, knowledge, and decision-making authority. However, careful program design is essential to avoid increasing women's labour burden or reinforcing existing inequalities. **Access to land and other resources** ‣ Women's land rights: In many regions, women have limited access to land and trees. Agroforestry projects that explicitly allocate land use or tree ownership to women can improve their control over productive resources. ‣ Resource use: Women often manage food crops, fruits, and fuelwood. Agroforestry systems that incorporate these crops can enhance women's access to essential resources. **Income and economic empowerment** ‣ Diversified income sources: Agroforestry provides multiple products that women can manage and sell, generating independent income. ‣ Financial decision-making: Increased income from tree products can enhance women's bargaining power in household decisions. **Labour and workload distribution** ‣ Time and labour considerations: Some agroforestry practices may reduce labour for women - for example, nitrogen-fixing trees can improve soil fertility and reduce weeding or fertiliser needs. ‣ Potential labour burden: Conversely, introducing high-maintenance tree crops without appropriate planning can increase women's workload. **Knowledge and skills development** ‣ Extension and training: Agroforestry programs that provide training in tree management and post-harvest processing can empower women by improving technical knowledge and skills. ‣ Participation in decision-making: Ensuring women participate in training, planning, and cooperative management strengthens their role in local governance and agricultural decision-making. **Social and cultural impacts** ‣ Enhanced agency: Ownership or control over agroforestry products can enhance women's social status and agency in communities. ‣ Equity challenges: Cultural norms may limit women's access to markets, finance, or land, which needs to be addressed in program design to achieve gender-equitable benefits.

6.1 Agroforestry



Works well with/ brings synergies with practice…	Intercropping, Soil and water conservation, Conservation and use of local crop varieties, integrated systems, IPM
Does not work well/ competes with practice…	None

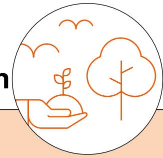
6.2 Assisted natural regeneration, community-managed natural regeneration, farmer-managed natural regeneration

All three practices – Assisted Natural Restoration (ANR), Community-Managed Natural Regeneration (CMNR) and Farmer-Managed Natural Regeneration (FMNR) – are ecosystem restoration and land rehabilitation approaches that focus on regenerating native vegetation in agro-silvo-pastoral systems by protecting and managing existing natural regeneration (stumps, roots, seeds, and seedlings) rather than planting new trees. They are generally low-cost, community-based alternatives to tree planting, especially effective in degraded tropical and subtropical landscapes.

6.2 Assisted natural regeneration, community-managed natural regeneration, farmer-managed natural regeneration

Further short description	Because of the key role of collective action at community level for natural regeneration, this practice sheet focuses particularly on CMNR – which applies ANR and FMNR principles at community level and under community leadership. ‣ **Assisted Natural Regeneration (ANR)**: ANR is the protection and facilitation of natural forest and rangeland regeneration by reducing human and animal disturbances and enhancing the survival of naturally occurring seedlings. Key practices include protecting regeneration from fire, grazing, and fuelwood collection, selectively thinning competing vegetation, enrichment planting where natural seed sources are limited, firebreak establishment and community monitoring. ‣ **Farmer Managed Natural Regeneration (FMNR)**: FMNR is a farmer-led form of ANR. Examples of large-scale success include Niger, where over 5 million hectares were restored via FMNR (‣ Garrity et al. 2019) ‣ **Community Managed Natural Regeneration (CMNR)**: CMNR extends ANR principles to community-owned or communal lands, emphasising collective management, local governance, and shared benefits. Participatory land-use planning is often used to demarcate CMNR zones, grazing areas, and agricultural fields. All three forms of the practice are particularly suited for semi-arid to humid regions with degraded lands, but existing natural seed sources. They provide a pathway to forest landscape restoration (FLR) and contribute to Nationally Determined Contributions (NDCs) under the UNFCCC and the Bonn Challenge. **Guidance and manuals:** ‣ With a focus on forest regeneration: FAO 2019: ‣ Restoring forest landscapes through assisted natural regeneration (ANR) – A practical manual. ‣ With a focus on community mobilisation and inclusion: Rinaudo et al 2019, ‣ Farmer Managed Natural Regeneration (FMNR) Manual.

6.2 Assisted natural regeneration, community-managed natural regeneration, farmer-managed natural regeneration



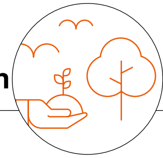
Context / suitability	
Farm or landscape level	Farm level, landscape level
Relevant production system (‣ FAO classification)	Livestock grassland-based systems, Livestock landless systems, Naturally regenerated forests, Rainfed crops, Mixed systems

Resource requirements/cost implications	
Land and other natural resources	In essence, CMNR does not require pristine land or heavy inputs, but it does need recoverable ecosystems: ‣ Land that is degraded but restorable - areas with some surviving rootstock, seed sources, or natural regeneration potential (e.g. overgrazed communal rangelands, fallow or abandoned cropland). CMNR can be implemented on small patches or landscapes covering thousands of hectares. ‣ Secure land tenure with clearly defined community or collective rights are essential. CMNR thrives where communities own, lease, or have customary rights over land and forest resources. Lack of tenure security discourages investment in long-term restoration. ‣ Gentle to moderate slopes can benefit from erosion control and improved infiltration. In drylands, moisture conservation practices (mulching, contour bunds, zai pits) can enhance regeneration success.
(financial and physical) Capital/implements	CMNR is generally low-cost compared with conventional reforestation, since it relies on protecting and managing existing natural regrowth rather than planting. However, it does require initial and ongoing investments in community organisation, protection measures, and livelihood support to make the regeneration process viable and equitable. **Physical and material capital** ‣ Basic tools and equipment, infrastructure (firebreaks, simple fencing or natural barriers to exclude livestock), nursery materials (optional), transport and communication tools ‣ Water harvesting and soil conservation structures: contour bunds, terraces, check dams, or small ponds to improve soil moisture retention and reduce erosion in semi-arid and sub-humid areas

6.2 Assisted natural regeneration, community-managed natural regeneration, farmer-managed natural regeneration

continued (financial and physical) Capital/implements	**Financial capital** ‣ Project start-up funds for community mobilisation, participatory land-use planning, mapping, and baseline assessments; training on CMNR techniques (often provided by NGOs, government agencies, or donor programs) ‣ Community organisation and governance to strengthen local management committees and draft bylaws – may cover meetings, facilitation, and conflict-resolution activities ‣ Stipends or in-kind incentives (e.g., food-for-work) for community members involved in protection and enabling finance for scaling and sustainability. ‣ Livelihood support and incentives: Support for alternative income sources that reduce pressure on regenerating land (e.g., small livestock or non-timber forest products (NTFP) enterprises)
Labour (qualitative and quantitative/skills etc.)	CMNR requires some amount of labour and skills to be successful, as well as strong governance mechanisms to ensure a fair distribution of benefits. **Community level labour inputs** ‣ Site preparation and protection: Clearing invasive species and competing vegetation, establishing and maintaining firebreaks, fences, or natural barriers, marking CMNR boundaries etc. ‣ Regeneration management: Selecting, pruning, and thinning naturally regenerated shoots or seedlings; maintaining soil moisture and erosion control structures (e.g., contour bunds, check dams); enrichment planting where natural regeneration is insufficient. ‣ Protection activities: Guarding regenerating areas from livestock grazing, illegal cutting, or fire; organising rotational patrols and community watch groups. ‣ Maintenance and monitoring: Recording survival and growth rates of regenerating vegetation; adjusting management practices seasonally or based on observed conditions. ‣ Community coordination: Participating in meetings, training, and collective decision-making; contributing labour to group tasks through community workdays or “food-for-work” programs.

6.2 Assisted natural regeneration, community-managed natural regeneration, farmer-managed natural regeneration



continued Labour (qualitative and quantitative/skills etc.)	**Knowledge, skills, and experience requirements** ‣ Ecological and technical knowledge: Understanding local plant and tree species; identifying resprouting or regenerating species suitable for protection, recognising indicator species that signal soil fertility, moisture, or degradation; knowledge of seasonal patterns that affect regeneration success; skills in selective pruning, coppicing, and thinning to enhance growth; awareness of soil and water conservation techniques relevant to local landscapes. ‣ Social and governance skills: Participatory planning and negotiation skills for land-use agreements; ability to formulate and enforce community bylaws for protection, grazing, and harvesting; conflict resolution and consensus-building skills; record keeping and transparent financial management for community funds.

Expected impacts on biodiversity

Detailed description of impacts on biodiversity:	CMNR can significantly enhance biodiversity - particularly where natural seed sources remain, and community protection is strong. However, biodiversity outcomes depend heavily on-site condition, management continuity, and community priorities. Without careful balance between livelihood use and conservation, regeneration can become ecologically simplified or biased towards income generation, at the expense of biodiversity impacts. **Genetic diversity** ‣ CMNR relies on natural regeneration from existing rootstocks, stumps, seeds, and seed banks, maintaining the original genetic pool of the site. It helps conserve locally adapted genotypes suited to specific microclimates, soils, and disturbance regimes. ‣ Natural regeneration allows ongoing natural selection, promoting genetic traits for drought tolerance, pest resistance, and local adaptability. This is especially valuable under climate change, where genetic diversity enhances resilience. Unlike tree-planting programs that often use non-native or few selected species, CMNR enhances in-situ conservation of diverse native genotypes. ‣ Risks / Disadvantages: Severely degraded lands may have few surviving individuals or mother trees/plants, leading to inbreeding or low genetic variability. Some hardy pioneer species may dominate regeneration, reducing genetic heterogeneity across species. Repeated cutting of preferred trees (for timber or fuelwood) can unintentionally remove genetically valuable individuals.

6.2 Assisted natural regeneration, community-managed natural regeneration, farmer-managed natural regeneration

continued Detailed description of impacts on biodiversity:	**Species diversity** ‣ Protection from grazing and fire allows natural succession and recovery of native shrubs, trees, and herbs. Over time, species diversity often matches or exceeds that of adjacent natural forests. ‣ Regeneration of diverse vegetation provides food, shelter, and nesting sites for birds, pollinators, and mammals. This supports the return of seed dispersers and pollinators, further enhancing species recovery. When CMNR sites are near remaining forest patches, seed dispersal (via wind, water, or wildlife) enhances diversity. Improved plant litter input and root systems restore soil microbial communities, fungi, and invertebrates, essential for nutrient cycling. ‣ Risks/disadvantages: If seed sources are distant or dispersal agents are missing, species richness may recover slowly. Most animal species will not recover if restored areas are not connected to (relatively) undisturbed habitats (e.g. via migration corridors). In disturbed sites, invasives can outcompete natives if not managed. Communities may preferentially protect economically valuable species, inadvertently reducing overall species diversity. **Ecosystem diversity** ‣ CMNR often restores mosaic landscapes of woodlands, agroforestry zones, grass-tree mixtures, and riparian vegetation. This supports heterogeneous habitats, increasing ecosystem-level diversity. ‣ Enhanced soil fertility, water infiltration and microclimate regulation re-establishes trophic networks (plants – herbivores – predators – decomposers) and nutrient cycling. ‣ Diverse, multi-layered regenerating systems are more resistant to droughts, fires, and pests than monocultures or bare land. ‣ Risks/disadvantages: If CMNR is implemented in scattered plots, ecosystem recovery may be spatially uneven, limiting broader landscape connectivity. Without sustained management, regrowth may be reversed by fire, overgrazing, or fuelwood harvesting, reducing ecosystem stability. Expansion of CMNR areas may limit grazing or crop land, creating land-use conflicts that affect ecosystem continuity.

6.2 Assisted natural regeneration, community-managed natural regeneration, farmer-managed natural regeneration

Complementarity and competition

Co-benefits and trade-offs for climate change mitigation and adaptation:	CMNR is a powerful nature-based climate solution that can deliver low-cost, community-driven carbon sequestration while enhancing ecosystem and livelihood resilience to climate variability. However, long-term success depends on continued protection, equitable benefit distribution, and adaptation to local climatic conditions. **Mitigation** ‣ Regeneration of trees, shrubs, and ground cover leads to substantial carbon uptake in both above-ground and below-ground biomass. Improved plant litter input, root turnover, and reduced erosion rebuild soil organic carbon pools – which is especially important in degraded tropical soils with high past carbon losses. Because CMNR relies on natural regeneration and community stewardship, restored ecosystems often persist longer than externally planted forests – leading to more stable carbon stocks. ‣ Reduced emissions from land degradation: Prevention of further deforestation by providing local fuelwood, timber, and fodder within community-managed areas. Lower implementation emissions compared with tree planting. Firebreak maintenance and vegetation cover reduce frequency and intensity of wildfires, a major emission source in dry tropics. ‣ Landscape-scale climate regulation: Restored vegetation improves microclimates by increasing shade, evapotranspiration, and humidity. Local cooling effects can lower land surface temperatures and moderate heat stress in agricultural zones. Enhanced vegetation cover contributes to regional rainfall recycling and hydrological stability. **Adaptation** ‣ Enhanced ecosystem resilience: Vegetation recovery stabilises soils, retains moisture, and buffers landscapes against drought, floods, and storms. Diverse native species increase functional redundancy, allowing ecosystems to recover more quickly after shocks. Tree cover reduces wind speed and surface evaporation, improving microclimatic conditions for crops and livestock. ‣ Strengthened livelihood and food security: Communities benefit from sustainable supplies of fuelwood, fodder, fruits, nuts, and NTFPs, reducing vulnerability during climate extremes. Mixed tree–crop systems diversify incomes, spreading risk across multiple production sources. ‣ Social and institutional adaptation: CMNR strengthens collective management institutions, promoting social cohesion and adaptive governance. Local communities gain knowledge and agency to manage resources under changing climatic conditions. This encourages low-cost, locally driven adaptation rather than dependence on external interventions.

6.2 Assisted natural regeneration, community-managed natural regeneration, farmer-managed natural regeneration

continued Co-benefits and trade-offs for climate change mitigation and adaptation:	**Risks and limitations** ‣ Extended droughts, extreme heat, or erratic rainfall can reduce natural regeneration success or increase mortality of organisms. Without continued protection, regenerated areas may be re-cleared or burned, releasing stored carbon. If carbon or Payments for Ecosystem Services (PES) benefits are unevenly shared, it may create social tensions or reduce motivation to maintain forests. Measuring and verifying carbon benefits in small, scattered CMNR sites can be technically and financially difficult.
Co-benefits and trade-offs for water quality and quantity:	CMNR can improve water regulation and quality by restoring vegetation cover and soil function. It enhances groundwater recharge, reduces erosion, and stabilises flows, delivering vital ecosystem services for both people and nature. However, success depends on long-term protection, balanced species selection, and fair distribution of water benefits among users. **Water quantity** ‣ Regenerated vegetation and carefully managed crop production increase soil organic matter, improving soil structure and porosity. Root systems create channels for rainwater infiltration, enhancing groundwater recharge and sustaining springs and wells. Reduced surface runoff slows the loss of rainfall from the landscape. This is particularly effective in dry sub-humid and semi-arid zones where infiltration and soil water storage are key for dry-season flows. ‣ With more infiltration and groundwater recharge, base flow in streams and rivers is maintained longer into the dry season. Reduces the frequency and severity of flash floods during intense rainfall events. Helps sustain domestic and agricultural water supplies downstream. ‣ Tree cover shades the ground, reducing evaporation and helping retain soil moisture for crops and vegetation. Enhanced transpiration contributes to localised humidity and dew formation, improving micro-hydrological balance. ‣ CMNR areas slow runoff across hillsides and floodplains. Improves the timing and distribution of water availability across the watershed rather than increasing total rainfall per se. **Water quality** ‣ Increased vegetation cover stabilises slopes and streambanks, reducing soil erosion. Lower sediment loads in rivers and reservoirs improve water clarity and storage capacity. ‣ Forest litter, root mats, and soil microorganisms act as natural filters, trapping nutrients, pesticides, and pathogens. Improved riparian vegetation buffers agricultural runoff, protecting downstream drinking water sources. ‣ CMNR promotes recovery of riparian vegetation zones, which regulate water temperature, provide habitat, and reduce bank erosion. This leads to healthier aquatic ecosystems and improved biodiversity of freshwater species.

6.2 Assisted natural regeneration, community-managed natural regeneration, farmer-managed natural regeneration

continued Co-benefits and trade-offs for water quality and quantity:	**Risks/potential disadvantages** ‣ As vegetation regrows and transpiration increases, less surface runoff may initially reach streams, slightly reducing short-term water yield - though this usually stabilises as ecosystems mature. In very dry regions, tree regrowth can compete with crops or shallow wells for limited soil moisture, particularly if high-water-demand species dominate. Downstream communities may benefit more than upstream managers unless fair water-use arrangements are in place.
Co-benefits and trade-offs for soil health:	CMNR has the potential to restore soil function holistically - rebuilding organic matter, stabilising structure, and re-activating nutrient and water cycles. Healthy soils, in turn, support vegetation recovery, agriculture, and resilience to climate stress. The main challenges lie in maintaining cover, balancing tree–crop interactions and managing fire or overuse to protect long-term gains. ‣ **Soil structure and stability**: Increased vegetation cover, from both crops and natural vegetation, protects the soil surface from raindrop impact and wind erosion. Tree and shrub roots bind soil particles, reducing landslides and gully formation on slopes. Leaf litter cushions the ground, limiting splash erosion and surface sealing. Regrowing vegetation enhances root turnover and organic matter inputs. Organic residues promote stable soil aggregates, improving infiltration and reducing crusting. This results in better aeration and root penetration for crops and regenerating plants. ‣ **Soil fertility**: Leaf fall, root decay, and decomposing litter increase soil organic carbon content. Organic matter acts as a slow-release nutrient source and improves cation-exchange capacity. This enhances moisture retention, particularly in sandy or degraded tropical soils. Natural regeneration often includes nitrogen-fixing species. These enrich the soil, benefiting both regenerating trees and adjacent crops. Greater vegetative cover reduces runoff and leaching, keeping nutrients within the root zone. This acts as a nutrient sink, capturing atmospheric dust and organic debris. ‣ **Soil moisture and temperature**: Shaded soil surfaces experience lower evaporation and more stable temperatures, reducing heat stress on roots. Improved infiltration and organic matter content lead to higher soil moisture storage capacity. Moist microclimates favour biological activity and decomposition, accelerating soil formation. ‣ **Risks / disadvantages**: Early plant litter layers may temporarily tie up nitrogen before full decomposition. Dense regrowth can compete with nearby crops for water and nutrients if boundaries are not managed. Uncontrolled burning or removal of leaf litter can quickly deplete soil organic matter. Dominance of certain pioneer or exotic species may alter soil chemistry or pH.

6.2 Assisted natural regeneration, community-managed natural regeneration, farmer-managed natural regeneration

Co-benefits and trade-offs for productivity:	CMNR can significantly influence the productivity of land, vegetation, and farming systems – often transforming degraded, low-yield landscapes into sustainable, multi-use systems. **Agricultural and land productivity** ‣ As vegetation regenerates, organic matter and nutrient cycling improve soil fertility (see previous section). This can lead to higher and more stable crop yields, particularly in rainfed systems. In the Sahel, East Africa, and South Asia, FMNR/CMNR has increased millet, sorghum, and maize yields by 30 –100 % compared to degraded control sites (Binam 2017). ‣ CMNR naturally evolves into parkland or agro-silvo-pastoral systems, where trees, crops and sometimes livestock coexist. Trees provide leaf litter (mulch), nitrogen fixation, and fodder, boosting overall system productivity. Farmers gain diverse products from the same land area, increasing total output per hectare. Where livestock is integrated, it provides additional benefits. ‣ Increased tree cover and soil moisture improve drought tolerance and reduce yield variability under climate stress. Regenerated areas can continue producing during dry spells when conventional croplands fail. **Forest and biomass productivity** ‣ CMNR accelerates natural regeneration compared to passive abandonment. Biomass accumulation rates in humid and sub-humid tropics are generally high. This also provides a renewable supply of wood and non-timber products, reducing the need for external inputs or replanting. ‣ Controlled community management allows periodic pruning, coppicing, and harvesting without degrading the resource base. This supports sustainable fuelwood, charcoal, and building material supply, which are key in rural economies. ‣ Regeneration increases grass and shrub diversity and improves dry-season fodder availability. This provides browse and shade for livestock, enhancing weight gain and animal health, and reduces the need for long-distance grazing, helping manage land pressure.

6.2 Assisted natural regeneration, community-managed natural regeneration, farmer-managed natural regeneration

Co-benefits and trade-offs for income:	CMNR can enhance household and community incomes by increasing agricultural and forest product yields, lowering production costs, diversifying income streams, and creating opportunities for collective enterprise and ecosystem service payments. However, the timing, equity, and sustainability of income gains depend on secure land tenure, good governance, fair market access, and ongoing protection of regenerating areas. • Direct income benefits include the sale of forest and tree products, enhanced crop and livestock productivity and reduced input costs. • Indirect or secondary income benefits result from a diversification of livelihoods (crops + trees + livestock + NTFPs), the development of local enterprises and potentially access to environmental incentives and payments (such as PES or carbon finance). • Risks / disadvantages and limitations include unequal benefit distribution (with landless or marginalised groups potentially excluded from resource use or benefit-sharing), delayed financial returns, as income from tree and NTFP products typically emerges after 2 – 5 years of protection, market volatility for NTFPs and dependence on external facilitation (e.g. for carbon credits).
Co-benefits and trade-offs for food and nutrition security:	CMNR often has powerful and multi-layered impacts on food and nutrition security, especially in contexts where rural livelihoods depend directly on land productivity and ecosystem health. • Food availability: Increased crop yields, diversified on-farm production and improved livestock feed supply all increase food availability. • Food access: Increased household incomes and reduced food expenditure (from NTFP use) result in savings that translate into more cash available for food purchases. CMNR may also enhance local availability of fresh food (e.g. fruit and nuts). • Food utilisation: Access to fruits, nuts, leaves, and animal products can improve dietary diversity. • Food stability from seasonal buffering, as many CMNR tree species produce during the dry or hungry season, filling food supply gaps. • Risks/disadvantages include short-term land-use restrictions (because of protection of regenerating areas), competition between trees and crops, and unequal access to food resources.

6.2 Assisted natural regeneration, community-managed natural regeneration, farmer-managed natural regeneration

Co-benefits and trade-offs for gender equity:	CMNR can have profound impacts on gender equity, because it reshapes access to land, resources, income, and decision-making - areas where gender relations are deeply embedded. • **Empowerment and participation**: CMNR is community-based, often involving collective decision-making on resource use and protection. Women's participation in village committees, patrol groups, and management planning can strengthen their voice and influence in local governance and build leadership and negotiation skills. CMNR activities also provide opportunities for training and skill development accessible to women, enhancing women's technical knowledge about trees, ecosystems, and climate adaptation. • **Livelihood opportunities**: Regenerated areas provide forest products that women traditionally collect and sell. CMNR improves availability and sustainability of these resources close to home, saving time and energy. This enables women to earn independent income, often used for food, schooling, and healthcare - directly improving household welfare. Restoration of nearby tree cover reduces time spent on fuelwood and water collection, tasks typically done by women and girls. This frees up time for education, childcare, or small enterprise development. It can also improve women's physical well-being by reducing heavy workloads and long-distance walking. • **Social status and agency**: CMNR validates and strengthens the traditional ecological knowledge of women – especially in identifying useful species, managing regrowth, and ensuring food and medicine supplies. Women's groups often emerge to manage specific CMNR activities or product value chains. Collective action fosters mutual support networks, strengthening women's bargaining power within households and communities. • **Risks / disadvantages and constraints**: Where women lack formal land tenure or user rights, they may not benefit fully from CMNR outcomes. Men may control income from regenerated resources, even when women contribute most of the labour. CMNR can unintentionally increase women's workload if protection, patrolling, or restoration tasks fall on them without compensation. In patriarchal settings, women may face limited mobility, time constraints, or exclusion from public meetings where CMNR decisions are made. Women may have less access to extension services, credit, or information, constraining their ability to benefit from CMNR-linked enterprises.
Works well with/ brings synergies with practice…	• Agroforestry: Fodder trees and other multi-purpose trees can be used for enrichment planting • Integrated crop-livestock systems and conservation and utilisation of local livestock breeds: CMNR can be integration with extensive livestock production • Soil and water conservation measures can assist regeneration.

6.2 Assisted natural regeneration, community-managed natural regeneration, farmer-managed natural regeneration

Does not work well/ competes with practice…	None
Any other disadvantages of the practice (not already mentioned above)	None

6.3 Bee keeping

Beekeeping, also known as apiculture, is the practice of managing and caring for honeybee colonies – usually in human-made hives – to produce honey, beeswax, and other bee products, as well as to support pollination of crops and plants. Beekeepers, or apiarists, provide bees with suitable shelter, monitor their health, manage hive populations, and protect them from pests, diseases, and harsh weather. The practice requires an understanding of bee behaviour, seasonal cycles, and sustainable hive management, ensuring both the well-being of the bees and the productivity of the colony.

6.3 Bee keeping

Further short description	Avoiding or managing competition between introduced honeybees (in particular the Western honeybee, Apis mellifera) and native bee species is essential to achieve biodiversity benefits. For more detailed guidance, see: ‣ FAO et al. 2021: ‣ Good beekeeping practices for sustainable apiculture ‣ Paparella et al. 20205: ‣ Farming with alternative pollinators ‣ Paterson 2021: ‣ Beekeeping in Tropical Africa ‣ Kugonza 2009: ‣ Beekeeping theory and practice ‣ Wojciket al. 2018: ‣ Floral Resource Competition Between Honey Bees and Wild Bees: Is There Clear Evidence and Can We Guide Management and Conservation?

Context / suitability

Farm or landscape level	Farm level, landscape level
Relevant production system (‣ FAO classification)	Rainfed crops, irrigated crops, Forests, mixed systems

Resource requirements/cost implications

Land and other natural resources	Beekeeping requires a mix of natural resources that support healthy colonies and consistent honey production: ‣ Floral resources (land with vegetation): Bees need access to diverse flowering plants for nectar (their carbohydrate source) and pollen (their protein source). This can come from wild meadows, forests, gardens, or cultivated crops and flower strips. ‣ Clean water sources: Bees use water to regulate hive temperature and to dilute honey for feeding larvae. This can be from ponds, streams, or shallow containers provided by the beekeeper.

6.3 Bee keeping

continued Land and other natural resources	‣ Suitable climate and shelter: While bees can adapt to many climates, they need areas with seasonal blooms and protection from extreme weather. The land should allow space for hives, ideally in sunny, dry, and sheltered spots. ‣ Natural forage diversity: A mix of plants that flower at different times of the year ensures a steady food supply and reduces the need for supplemental feeding.
(financial and physical) Capital/implements	Some initial capital investments are required to start with bee keeping ‣ Beehives and hive components: Wooden or modern hives, frames, and foundation sheets for the bees to build comb. ‣ Bee colonies: Initial purchase of healthy bee colonies or nucleus colonies ("nucs"). ‣ Protective gear, tools and equipment: Bee suits, gloves, and veils to protect the beekeeper during inspections and honey harvesting. Smokers (to calm bees), hive tools (for prying open hives and handling frames), and feeders (for supplemental feeding if needed). ‣ Honey extraction and storage equipment: Manual or motorised extractors, strainers, settling tanks, and food-grade storage containers. ‣ Transport and ongoing working capital: Costs for moving hives to better forage locations or markets (if migratory beekeeping is practiced). Small reserves to cover seasonal expenses such as supplemental feed, pest and disease treatments, and replacement of damaged equipment.
Labour (qualitative and quantitative/skills etc.)	‣ Labour requirements are typically modest compared to most agricultural activities, but they vary depending on scale (number of hives), management style (stationary vs. migratory) and harvest frequency (often 2–4 times per year in the tropics). ‣ In tropical and subtropical contexts, beekeeping tends to require more frequent hive inspections than in temperate zones, because bees are active year-round and threats like pests, diseases, and hive absconding can occur in any season. An estimate of labour requirements for small-scale beekeeping (20–30 hives) is 30–40 person days per year, which includes time for hive inspections (checking brood, food stores, pests) every 2–3 weeks, honey harvesting and processing 2–4 times/year, feeding (if needed during dearth periods) – as needed, hive maintenance and equipment repairs – ongoing, and record keeping, marketing. ‣ https://hiveology.org/blogs/news/how-much-time-is-needed-for-beekeeping, ‣ https://www.ctc-n.org/sites/default/files/resources/kno-100009_beekeeping.pdf ‣ In addition, for a start-up enterprise, training and knowledge resources are required (through workshops, manuals, or mentorship to build beekeeping skills and disease management practices). See for example ‣ Attfield 2001, and ‣ Paterson 2021 (for the African context).

6.3 Bee keeping

Expected impacts on biodiversity

Detailed description of impacts on biodiversity:	Beekeeping can have both positive and negative impacts on biodiversity, and these effects depend greatly on how it is practiced, the local environment, and whether native or non-native bee species are used. **Genetic diversity** ‣ Sustainable beekeeping with locally adapted honeybee strains can help conserve their genetic diversity, making bee populations more resilient to pests, diseases, and climate change. ‣ Community-based breeding programs can maintain and propagate traits suited to local conditions. ‣ Importing non-native bee subspecies can lead to genetic dilution of native honeybee populations through interbreeding, reducing local adaptations (‣ Qui et al. 2023). Commercial queen breeding often narrows genetic diversity if a small number of breeding lines are overused. Studies show that native honey bees such as the Asian honeybee (Apis cerana) are in decline in many parts of the world (‣ Theisen-Jones and Bienefeld 2016).
continued Detailed description of impacts on biodiversity:	**Species diversity** ‣ By providing pollination services, managed honeybees can increase seed set and reproduction in a wide variety of wild and cultivated plants, indirectly supporting diverse plant and animal communities. ‣ Overly dense honeybee populations can compete with wild pollinators (such as solitary bees, butterflies, and birds) for nectar and pollen, especially in resource-scarce environments (‣ Lindström et al. 2016, ‣ Badano and Vergara 2011). Invasive honeybee strains can sometimes displace native bee species through aggressive foraging or nesting behaviour. **Ecosystem diversity** ‣ Healthy pollinator populations contribute to the regeneration of forests, grasslands, and agricultural landscapes by enhancing plant reproduction, which in turn supports broader food webs. Beekeeping can provide economic incentives for conserving habitats instead of converting them to intensive agriculture or development. ‣ Large-scale, industrial beekeeping in monoculture areas can reduce the variety of floral resources available, indirectly affecting other species and ecosystem balance. If not carefully managed, bees can spread pathogens (e.g., Nosema, viruses) to wild pollinators, disrupting ecosystem health. Where local trees are used to build bee hives, a large demand for hives can contribute to a reduction in the number of these trees (FGD Africa – Malawi)

6.3 Bee keeping

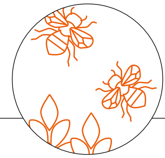
Complementarity and competition

Co-benefits and trade-offs for climate change mitigation and adaptation:	**Mitigation** ‣ Indirect enhancement of carbon sequestration: By pollinating wild plants, trees, and crops, honeybees help sustain vegetation growth and regeneration, which in turn stores carbon in biomass and soils. Well-pollinated forests, agro-forestry systems, and pastures can sequester more carbon.Example: Restoration projects that integrate beekeeping with native tree planting have shown better plant survival and faster canopy recovery, indirectly increasing carbon storage. ‣ Conservation incentive for habitats: Beekeeping can make forested or semi-natural areas economically valuable without clearing them, reducing pressures for land-use change—a major source of emissions in many developing countries. ‣ Low-emission livelihood: Compared to livestock or mechanised farming, beekeeping produces negligible direct greenhouse gas emissions, requiring no fertiliser application, heavy machinery, or large water withdrawals.
	Adaptation ‣ Diversified income and livelihood resilience: Beekeeping can provide a year-round or seasonal income stream that is less dependent on rainfall or soil fertility than many crops, helping rural households buffer against climate-related agricultural losses. ‣ Pollination support under shifting climates: Healthy bee populations can help maintain crop yields even when plant flowering times shift or other pollinators decline, aiding food system stability. ‣ Agroecosystem resilience: Pollination by managed bees can sustain biodiversity in agricultural landscapes, which helps make ecosystems more resilient to pests, diseases, and climate extremes. ‣ Climate-resilient land management practices: Beekeeping is often paired with agroforestry, reforestation, or range-land restoration – all practices that improve soil moisture retention, reduce erosion, and buffer microclimates.

6.3 Bee keeping

continued Co-benefits and trade-offs for climate change mitigation and adaptation:	**Potential limitations or risks** ‣ Climate vulnerability of bees themselves: Heatwaves, droughts, and altered flowering patterns can reduce nectar availability, stress colonies, and increase disease susceptibility meaning beekeeping is not immune to climate change shocks. ‣ Overreliance on one pollinator species: If beekeeping displaces wild pollinators, ecosystems may become more vulnerable, since honeybee populations can suffer from climate-related collapse. ‣ Maladaptation risk: If beekeeping leads to overstocking of hives in fragile ecosystems, it may degrade floral resources and reduce ecosystem resilience.
Co-benefits and trade-offs for water quality and quantity:	Beekeeping has a relatively small direct footprint on water quantity and quality, especially compared to most forms of agriculture, but it still creates some important indirect impacts - both positive and negative. **Water quantity** ‣ Low direct water use: Bees need water for cooling the hive, diluting honey for feeding larvae, and sometimes for mineral intake. A colony might consume a few litres per week during hot, dry periods, which is negligible compared to irrigation for crops or livestock water needs. ‣ Dependence on local water availability: In the dry season, especially in tropical climates, bees may compete with other water users (livestock, wildlife, humans) if natural water sources are scarce, requiring beekeepers to provide supplemental water. ‣ Indirect effect via vegetation: By supporting pollination of plants and trees, beekeeping can help maintain vegetation cover, which reduces runoff and improves local water retention in soils – especially in agroforestry or reforestation systems. **Water quality** ‣ Pollination services help sustain plant cover along riparian zones, wetlands, and watersheds. This can reduce erosion and sedimentation, keeping waterways clearer. ‣ Reduced agrochemical runoff (in low-input systems): In small-scale, low-chemical-use tropical farms, beekeeping doesn't require fertilisers or pesticides, lowering risk of water pollution compared to intensive farming.

6.3 Bee keeping



continued Co-benefits and trade-offs for water quality and quantity:	**Potential negative impacts** ‣ Agrochemical contamination risk: In regions where beekeeping is integrated into farms using pesticides, herbicides, or fungicides, these chemicals can be carried by runoff into water bodies. While bees themselves do not pollute water, their forage patterns can link them to contaminated landscapes, and honey or wax can be contaminated. ‣ Potential concentration of bees near water sources: If many hives are clustered near a limited water source (e.g., a pond or small stream), trampling of vegetation and localised nutrient loading from bee droppings could slightly affect water quality – though this is usually minimal compared to livestock.
Co-benefits and trade-offs for soil health:	Beekeeping has no direct mechanical impact on soil, but it can influence soil health indirectly through its role in plant–pollinator relationships and land-use choices. ‣ A beekeeping site's physical footprint is small - just the hive stands and access paths – so direct soil alteration is minimal. ‣ Enhanced plant reproduction and ground cover: Pollination by managed bees supports flowering plant reproduction, leading to denser and more diverse vegetation. This ground cover protects soils from erosion and dehydration from wind and heavy rainfalls. ‣ Improved organic matter inputs: Better pollination increases seed set and fruit/seed drop, which in turn contributes organic matter to the soil as plant litter decomposes. ‣ Support for soil microbial diversity: Healthy, diverse vegetation fosters a more complex root network and rhizosphere, promoting beneficial fungi and bacteria that improve nutrient cycling. ‣ Integration with agroforestry or restoration projects: In many tropical/subtropical livelihood projects, beekeeping is paired with tree planting or mixed-crop systems, which improve soil structure, increase infiltration, and enhance carbon storage in soils. ‣ Potential negative impacts: Floral resource overuse (if there are too many hives)

6.3 Bee keeping

Co-benefits and trade-offs for productivity:	Beekeeping can have substantial positive impacts on crop productivity, mainly through pollination but the scale of the benefit depends on crop type, landscape diversity, and management practices: **Agricultural and land productivity** ‣ Improved yields for pollinator-dependent crops: Many tropical and subtropical crops, such as coffee, mango, avocado, passionfruit, watermelon, coconut, cashew, and various vegetables, depend partly or fully on insect pollination. Managed honeybees can increase fruit set, seed development, and uniformity. ‣ Better crop quality: Pollination often improves size, shape, and shelf life of fruits and vegetables, leading to higher market value. ‣ Pollination insurance: In regions where wild pollinator numbers have declined due to habitat loss or pesticides, managed bees can help ensure consistent pollination services. ‣ Multi-crop benefit: Because bees forage widely, they can pollinate multiple crops and wild plants in the same landscape, benefiting both farm and surrounding vegetation. ‣ Crops that are self-pollinating (e.g., many legumes, tomatoes under certain conditions, some bananas), wind-pollinated (e.g., rice, maize, sorghum, sugarcane) or vegetatively propagated (tubers, bulbs, bananas) will see little to no direct benefit from beekeeping, though they may gain indirect benefits from ecosystem health. **Potential negative impacts** ‣ Competition with wild pollinators: If hive densities are too high, honeybees may outcompete native pollinators that specialise in certain crops (e.g., buzz-pollinated plants like tomatoes and eggplants, which honeybees can't pollinate effectively). This could reduce yields for those crops in the long term. ‣ Pollination mismatch risk: Climate change can shift flowering times, so if beekeeping is not managed to match crop bloom periods, pollination benefits may be reduced. ‣ Pesticide exposure: In tropical farming systems with heavy pesticide use, bees can be harmed during foraging, reducing their effectiveness and potentially causing colony losses. (‣ Tosi et al. 2022)

6.3 Bee keeping

Co-benefits and trade-offs for income:	Beekeeping can have significant positive impacts on household and community incomes, particularly for smallholder farmers and rural livelihoods. These effects arise from both direct and indirect sources of revenue. **Direct income sources** ‣ Honey production: The main income-generating product, which can be sold locally, regionally, or internationally. Honey prices in tropical regions can be high due to quality and organic/natural production premiums, and because it is often used for medicinal rather than culinary purposes (with a higher "willingness to pay" by consumers). ‣ Other hive products: Beeswax, propolis, royal jelly, pollen, and bee venom are valuable products for cosmetics, pharmaceuticals, and food industries. Beeswax, for instance, can be more valuable than honey per kilogram in some markets. ‣ Seasonal income smoothing: Beekeeping often provides revenue during periods when crop production is low, helping households maintain cash flow and reduce vulnerability to food insecurity. **Indirect income benefits** ‣ Enhanced crop yields through pollination: Improved productivity of pollinator-dependent crops (e.g., coffee, mango, avocado, watermelon) can increase farm income without additional land or input costs. ‣ Diversification of livelihoods: Income from beekeeping reduces reliance on a single crop or livestock, increasing resilience to market shocks or climatic variability. ‣ Value-added opportunities: Processing honey into comb honey, flavoured honey, or packaged consumer products can increase profit margins. **Factors influencing income impact** ‣ Hive numbers and management: Higher numbers of healthy colonies generally lead to greater honey production, but overstocking can reduce forage availability and harm yields. ‣ Market access: Income gains are higher where farmers have access to local cooperatives, urban markets, or export channels. ‣ Technical capacity: Training in colony management, pest/disease control, and harvesting techniques affects both quantity and quality of products, impacting revenue. ‣ Integration with crops: Farms that integrate beekeeping with pollinator-dependent crops benefit from synergistic effects on income.

6.3 Bee keeping

continued Co-benefits and trade-offs for income:	**Potential challenges / limitations** ‣ Colony losses: Disease, pests, or climate events can reduce hive numbers and income. ‣ Market volatility: Honey prices fluctuate seasonally and regionally, potentially affecting household revenue. ‣ Initial investment and labour: Start-up costs for hives, protective gear, and training can be a barrier in some tropical contexts (see section above about capital /financial resources needed)
Co-benefits and trade-offs for food and nutrition security:	Beekeeping can have positive impacts on food and nutrition security through multiple pathways, both directly via bee products and indirectly through pollination services that enhance crop productivity. **Direct contributions to nutrition** ‣ Honey: Provides a natural source of calories and simple sugars, useful for energy, particularly in areas with limited food access. Honey also contains trace vitamins, minerals, and antioxidants. ‣ Other hive products: Pollen: Rich in protein, vitamins, and minerals. Royal jelly: Contains proteins, amino acids, and bioactive compounds. Propolis and beeswax: While not directly consumed in large amounts, they can be processed into food supplements or medicinal products. ‣ Dietary diversity: Incorporating bee products into the diet can enhance nutrient intake and improve overall dietary quality. **Indirect contributions via pollination** ‣ Increased crop yields: Many tropical crops – including fruits (mango, papaya, avocado, guava), vegetables (tomato, cucumber, eggplant), legumes, and nuts – depend on insect pollination. Beekeeping can significantly improve fruit and seed set, directly increasing food availability. ‣ Improved food quality: Better pollination often results in larger, more nutritious fruits and vegetables, increasing both caloric and micronutrient supply. ‣ Support for smallholder farmers: Higher productivity can reduce the need to purchase food, improving household food security.

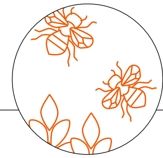
6.3 Bee keeping

continued Co-benefits and trade-offs for food and nutrition security:	**Resilience and year-round food access** ‣ Income for food purchase: Honey and hive products provide cash income, which households can use to buy staple foods during lean seasons. ‣ Risk diversification: Beekeeping income is somewhat less sensitive to drought or soil fertility than some crops, providing a buffer against climate-related food shortages. Unlike crops, hives can survive through low-output years, and colonies can recover when rains return. Some drought-tolerant flora (e.g. acacias, certain shrubs) continues to flower in dry periods, softening the impact depending on vegetation type. ‣ Agroecosystem stability: Pollination maintains wild plant diversity that can serve as supplemental food sources in rural communities. **Potential limitations** ‣ Dependence on floral resources: In degraded or monoculture landscapes, limited forage can reduce honey production and pollination benefits, affecting both direct and indirect food contributions. ‣ Pesticide exposure: If hives are located near pesticide-treated crops, contamination of bee products could reduce food safety. ‣ Limited local knowledge or technology: Poor colony management or insufficient knowledge about hive maintenance may reduce productivity, limiting impacts on food security. ‣ Risk of vandalism and theft: With bee hives being valuable assets in resource-poor rural areas, there is a risk of them getting damaged or stolen (‣ Ricketts and Shackleton 2019).
Co-benefits and trade-offs for gender equity:	Beekeeping can have notable impacts on gender equality, primarily by providing women with opportunities for income generation, skill development, and participation in decision-making. These impacts are often context-specific and depend on cultural norms, access to resources, and project design. **Income and economic empowerment** ‣ Access to independent income: Beekeeping can provide women with a relatively low-capital, manageable enterprise that generates cash from honey, beeswax, and other hive products. ‣ Control over earnings: In many smallholder systems, women who manage hives can retain income for household needs, education, or nutrition, enhancing their financial autonomy. ‣ Entrepreneurship opportunities: Women can engage in value addition (processing honey, making candles or cosmetics), strengthening economic roles beyond farm labour.

6.3 Bee keeping

continued Co-benefits and trade-offs for gender equity:	**Skill development and knowledge** ‣ Training and capacity building: Beekeeping projects often provide training in hive management, pest control, product processing, and marketing. Women's participation can increase their technical knowledge and confidence. ‣ Leadership and networking: Women involved in cooperatives or beekeeper groups can gain leadership roles and access to social networks, improving decision-making power within households and communities. **Time and labour considerations** ‣ Manageable labour demands: In many tropical systems, hives require relatively limited daily attention, making bee-keeping compatible with women's other domestic and agricultural responsibilities (see also the section on labour requirements) ‣ Potential challenges: If hive numbers or distances increase, women may face constraints due to mobility, cultural norms, or competing labour demands. **Social and cultural impacts** ‣ Enhanced status and recognition: Successful women beekeepers can gain respect and visibility in the community. ‣ Gender-sensitive project design matters: Projects that explicitly include women in training, credit, and cooperative membership tend to have stronger gender equality outcomes than those that do not. **Possible tensions:** ‣ In some contexts, male household members may dominate high-value aspects of beekeeping (e.g., marketing or hive placement), limiting women's control over benefits unless programs address these dynamics.
Works well with/ brings synergies with practice…	‣ Agroforestry: Fodder trees and other multi-purpose trees can be used for enrichment planting ‣ Integrated crop-livestock systems and conservation and utilisation of local livestock breeds: CMNR can be integration with extensive livestock production ‣ Soil and water conservation measures can assist regeneration.
Other co-benefits	Beehive fencing has been shown to be effective in deterring wild herbivores (elephants) . See ‣ https://www.conservationevidence.com/actions/2489 for details.
Works well with/ brings synergies with practice…	None

6.3 Bee keeping



Does not work well/ competes with practice…	None
Any other disadvantages of the practice (not already mentioned above)	Bees could potentially cause harm to humans or livestock, if not managed properly.
Possible mitigation measures to manage trade-offs/ address disadvantages	Bee keeping requires a lot of skills, knowledge and experience. Careful monitoring of impacts is essential in order to identify potential trade-offs/tensions early on and address them.

6.4 Conservation and use of local crop varieties

Local crop varieties – often called landraces or traditional varieties - can be conserved and used in different ways, with multiple objectives. The preservation can be managed by individual farmers, community institutions or organisations working in agricultural research or advisory services. Preservation can be in situ (i.e. in the local agroecosystem – by growing these varieties and possibly using methods to avoid cross-pollination) or ex situ in specific seed banks. The use of these varieties can involve participatory variety selection (to assess suitability for the given or changing local context – which may include pest and disease resistance, drought tolerance, nutritional and cultural value, etc.), propagation, and dissemination and use.

6.4 Conservation and use of local crop varieties

Further short description	Seed fairs have been used to enable farmers and community groups to share crop varieties, in order to make them more widely available (as many local crop varieties have been lost). Local crop varieties are also the bedrock of plant breeding, with international agreements[37] regulating the use of plant genetic resources and the rights to seeds and associated traditional knowledge (‣ Marden et al. 2023). There are controversies over the fair ownership of and control over genetic material from local crop varieties (‣ Oberthür 2011, ‣ Haugen 2020).

Context / suitability

Farm or landscape level	Farm level, plot level, landscape or community level
Relevant production system (‣ FAO classification)	Rainfed crops, irrigated crops

Resource requirements/cost implications

Land and other natural resources	Land, water (for irrigated crops) – the natural resources requirements are similar to those of improved crop varieties.
(financial and physical) Capital/implements	Financial requirements are likely to be lower than for improved crop varieties, which may have to be purchased in the market (e.g. from certified agrodealers). Informal seed exchanges are usually not involving cash payments (but may require exchanges in kind, e.g. during seed fairs).

37 International Treaty on Plant Genetic Resources for Food and Agriculture and Nagoya Protocol under the CBD, ‣ https://www.cbd.int/abs/default.shtml

6.4 Conservation and use of local crop varieties

Labour (qualitative and quantitative/skills etc.)	Labour requirements vary between local and improved crop varieties throughout the cropping cycle: ‣ Planting and establishment: Local varieties are often sown using traditional methods (broadcasting, hand planting, mixed cropping), which may require more labour during planting if intercropped with other species or planted in diverse patterns. Seed preparation (cleaning, sorting, pre-soaking) is often done by the farmer, which adds labour. In contrast, improved varieties are usually designed for mechanised or uniform planting (row planting, spacing), and seeds often come pre-treated (e.g. with hormones for fast germination) and ready to plant, reducing pre-sowing labour. ‣ Crop Management: Local varieties tend to be more weed-competitive (taller plants, broader canopy) so may require less frequent weeding. They are also often pest- and disease-tolerant under local conditions, reducing labour for pest control. They may require more skill and observation to manage in diverse polycultures, which may add labour but is often family-based. The higher yield potential of improved varieties often comes with greater susceptibility to pests, diseases, or nutrient deficiencies, meaning more labour for spraying, fertiliser application, and irrigation. Improved varieties are usually grown in monocultures, which can mean more intense weeding in early growth stages. ‣ Harvesting: The harvest time of local varieties may be staggered (due to uneven maturation), requiring multiple rounds of harvesting – more labour spread over time. Traditional post-harvest processing (e.g., threshing, winnowing) is often manual and labour-intensive. Improved varieties are usually bred for uniform maturity, allowing one-time harvesting (easier to mechanise, less labour overall). Grain size and uniformity can make post-harvest cleaning faster. ‣ Seed Management: Farmers saving their own seed from local crop varieties requires labour and skills for selection, drying, and storage. There is no need to buy seed annually (less cash outlay, but ongoing labour investment). In comparison, improved varieties often require farmers to buy fresh seed each season – which saves labour in seed saving but adds dependency on markets. Supporting local seed systems through training, seed exchanges (e.g. via seed fairs) and seed storage can significantly enhance the use of local crop varieties. For details, see for example ‣ El Khoury and Delve 2018 and ‣ CRS et al. 2002.

6.4 Conservation and use of local crop varieties

Expected impacts on biodiversity

Detailed description of impacts on biodiversity:	**Genetic diversity** ‣ Local varieties (landraces) are genetically diverse within themselves because they have evolved under open pollination, farmer selection, and variable environmental conditions. They maintain intra-varietal variation (plants within the same variety are not genetically identical), which provides adaptation to local microclimates, offers resistance to multiple pests and diseases, and serves as a gene reservoir for future breeding programs. (‣ Tokatlidis et al. 2016) ‣ Impact: Maintains a broad genetic base in agricultural systems, reducing the risk of widespread crop failure. **Species diversity** ‣ In tropical/subtropical smallholder systems, local varieties are often grown in polycultures or crop rotations alongside other species. Farmers may maintain multiple varieties of the same crop and different crops in the same field. Benefits include habitat variety for insects, pollinators, soil microbes, and birds; reduced pest/disease spread because different species and varieties act as barriers; continuous food supply for humans and wildlife due to staggered flowering and fruiting times. ‣ Impact: Supports higher on-farm species richness compared to monocultures of improved varieties. (‣ Alliance for Mediterranean Nature and Culture) **Ecosystem diversity** ‣ In tropical/subtropical regions, farms using local varieties often have mosaic landscapes: Mixed fields of cereals, legumes, tubers, vegetables, and tree crops; agroforestry systems where annuals grow under or between perennials; variations in planting and harvesting times across the community. Local varieties are adapted to different niches – some suited for uplands, others for floodplains, shaded valleys, or marginal soils. (‣ Priyadarshana et al. 2024) ‣ Impact: Creates heterogeneous agricultural landscapes that mimic natural ecosystems, increasing habitat variety and ecological resilience.

6.4 Conservation and use of local crop varieties

Complementarity and competition

Co-benefits and trade-offs for climate change mitigation and adaptation:	**Adaptation** Local crop varieties (landraces) are the result of long-term co-evolution between plants, farmers, and local environments. This can give them several adaptive advantages: ‣ Stress tolerance: Many have traits for drought, flooding, salinity, heat, or poor soils – these can also be used in conventional breeding or genetic modification to develop new varieties (for example, flood tolerance in rice, ‣ Emerick 2019) ‣ Genetic diversity within populations: Mixed genotypes mean some plants survive even in extreme years, buffering yield loss. ‣ Pest and disease resilience: Co-evolved resistance to local pests/diseases reduces vulnerability to outbreaks intensified by climate change. ‣ Cultural and knowledge integration: Farmers know how to manage them under variable weather, e.g., adjusting planting dates, mixing varieties. ‣ Diverse cropping systems: Local varieties are often grown in polycultures or rotations that spread risk and stabilise yields. **Mitigation** The use of local varieties can contribute to reducing greenhouse gas emissions and enhancing carbon sinks: ‣ Lower input requirements (synthetic fertiliser/pesticide inputs), reducing nitrous oxide (N_2O) and CO_2 emissions from production and transport of inputs. ‣ Local varieties are often grown in mixed systems with trees, increasing carbon sequestration in biomass and soils. ‣ Local varieties are often suited to low-till or traditional cultivation that preserves soil carbon. ‣ On-farm seed production avoids emissions from seed transport and industrial processing.

6.4 Conservation and use of local crop varieties

Co-benefits and trade-offs for water quality and quantity:	• Local varieties often require fewer synthetic inputs and are grown in less chemically intensive systems, which reduces water pollution risk. Taller, deep-rooted landraces and intercropping can lead to better soil cover and structure, which helps prevent soil erosion, reducing siltation in water bodies. • Local crop varieties are often adapted to local rainfall patterns, reducing irrigation water demand. Variable maturation times can lead to more efficient water use across the season. Local varieties often perform better on marginal land, resulting in less competition for prime irrigated land. • However, some local varieties have longer growth cycles, which may require sustained soil moisture over a longer period. Also, under very intensive traditional systems (e.g., flooded rice paddies), methane emissions and water use may still be high (unless water-saving practices are applied).
Co-benefits and trade-offs for soil health:	Growing local crop varieties can have positive effects on soil health because they are often embedded in low-input, diverse, and ecologically attuned farming systems. Specifically: • Deeper or more extensive root systems in many local varieties increase below-ground biomass, which contributes organic matter to the soil. Traditional cropping patterns with local varieties (e.g., intercropping, crop rotations, fallows) promote continuous organic matter inputs from crop residues and associated plants. • Taller plants and dense canopies in some landraces reduce raindrop impact and surface runoff. Also, many local varieties are grown in polycultures or under agroforestry systems, where multiple canopy layers protect soil from erosion. • Diverse root exudates from genetically variable plants feed a wider range of soil microbes. Traditional farming with local varieties often incorporates organic manures, crop residues, and mulches that stimulate earthworms and beneficial fungi. • Many local varieties are nutrient-efficient, able to yield under low fertility without heavy synthetic fertiliser inputs. For example, legume landraces (e.g., cowpea, pigeon pea) have strong nitrogen-fixing ability, replenishing soil nitrogen naturally. • However, in very poor soils, yields may remain low without some fertility enhancement, which could limit residue returns over time.

6.4 Conservation and use of local crop varieties

Co-benefits and trade-offs for productivity:	‣ In the short term, yield per hectare is often lower than improved varieties under high-input conditions, as modern improved varieties are bred for maximum yield under optimal irrigation, fertilisation, and pest control. Local varieties usually yield less per hectare in such controlled, high-input settings. ‣ However, under low-input, stress-prone environments (such as rainfed, marginal, or degraded soils), local varieties can perform as well or better because of stress tolerance. ‣ In terms of inter-annual yield stability, local varieties typically offer greater yield stability across seasons with variable weather. Genetic diversity within a landrace population buffers against total crop failure. ‣ Because of co-evolution with local pests and pathogens, local varieties tend to be more resilient to pests, diseases and climate extremes, which can reduce yield losses in outbreak years. ‣ Local varieties are often grown in intercropping, agroforestry, or rotation systems, which may produce lower yield of a single crop, but higher total productivity per unit area when all outputs (grain, fodder, fuelwood, fruit) are considered.
Co-benefits and trade-offs for income:	Income effects depend heavily on the production environment, market access, and household livelihood strategies: ‣ Local varieties tend to require less irrigation, fertiliser and pesticides, resulting in higher net margins through cost savings, even if gross revenue per hectare is lower. ‣ Genetic diversity within landraces increases resilience to climate shocks, reducing the likelihood of total crop loss. This stability in production means households can avoid sharp income drops in bad years. ‣ Where local varieties are grown in mixed or intercropping systems, they can contribute to diversified income streams from the same land area. ‣ Local varieties may have higher nutritional value, taste, or processing qualities, which can in higher economic returns per unit yield (for example aromatic rice landraces in Southeast Asia command higher market prices than improved varieties – ‣ Agustin et al. 2023). ‣ They may also be important in cultural ceremonies, gifts, and barter, which reduce household expenditure and maintain social capital. This could result in savings and indirect economic benefits that do not appear as cash income. ‣ However, if markets demand uniform, high-yielding produce, local varieties may lack markets, fetch lower prices or face adoption barriers. Also, for large-scale mechanised farming, variable plant height and maturity in local varieties can increase harvesting costs and reduce incomes.

6.4 Conservation and use of local crop varieties

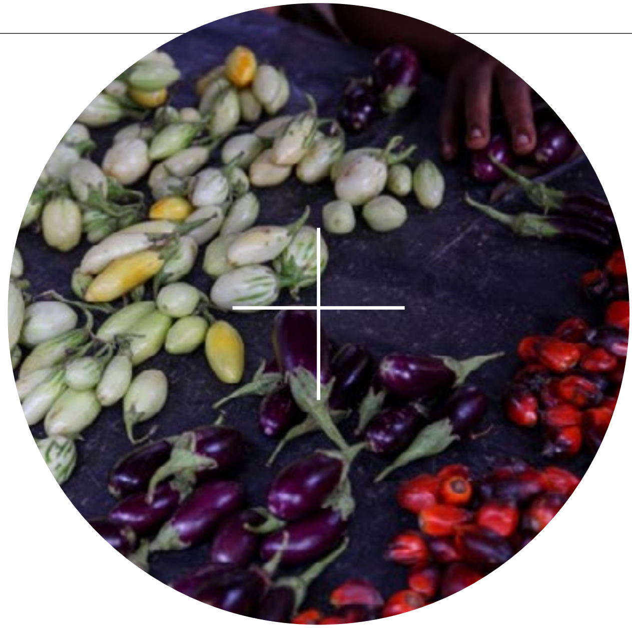
Co-benefits and trade-offs for food and nutrition security:	Growing local crop varieties can have significant effects on food and nutrition security – not just by producing calories, but by influencing diet diversity, resilience, and cultural food systems: • Food availability: Adaptation to local conditions means local varieties may still be able to produce some food under drought, poor soils, pests, or floods, ensuring supply even when improved varieties fail. Many local varieties are grown in diverse cropping systems (intercropping, rotations, agroforestry), which produce multiple foods from the same land. • Access to food: Farmers can save and replant seeds, avoiding yearly purchases and making crops more accessible. Surplus or specialty varieties can be sold at premium prices, increasing household purchasing power for other foods. • Utilisation (food quality): Many local varieties have higher micronutrient content compared to modern varieties (e.g. banana varieties with high vitamin content, or local millet and sorghum varieties with a higher iron and zinc content). Traditional varieties often have better cooking qualities (taste, storability), encouraging their inclusion in diets. • Stability (across time): Because local varieties are more resilient to climate variability, they ensure food is available across years. Genetic diversity within local varieties reduces the risk of total crop failure, which directly protects household food reserves. • Cultural and social dimensions: Many local varieties are used in traditional dishes, festivals, and rituals; preserving them maintains cultural diets. Cultural food traditions often support nutritious preparation methods (e.g., fermentation, sprouting) that improve nutrient availability. As with productivity and income effects, if local varieties have lower yields and premium markets are absent, total calorie availability may be less than from high-yielding modern varieties.
Co-benefits and trade-offs for gender equity:	Growing local crop varieties can influence gender equality in several interconnected ways - mostly through control over resources, decision-making, labour division, and cultural knowledge systems: • In many traditional farming systems, women are custodians of seed, selecting, storing, and exchanging local varieties. Maintaining local varieties, e.g. in community seed banks, keeps seed systems in the hands of women, rather than shifting control to external seed companies. This strengthens women's bargaining power in households and communities. • Local varieties are often linked to niche or local markets for specialty foods, herbal products, or processed goods - areas where women dominate production and sales. Women can retain a higher share of income when markets are local and informal, as opposed to large-scale commercial supply chains.

6.4 Conservation and use of local crop varieties

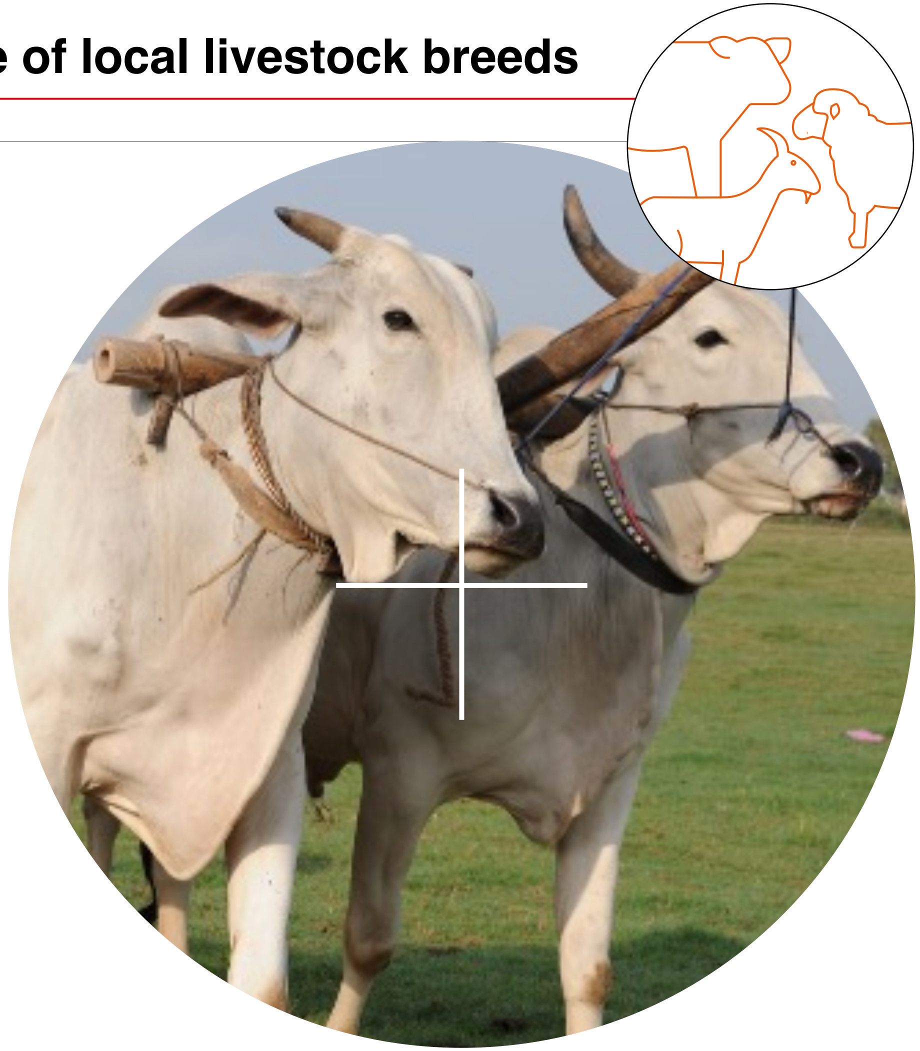
continued Co-benefits and trade-offs for gender equity:	• The skills required to cultivate local varieties - such as identifying pest-resistant plants or managing inter-cropping - are often based on indigenous knowledge held by women. Recognition of these skills in community seed banks and participatory plant breeding can elevate women's status. • Women often prioritise food and nutrition security in household decision-making. Since many local varieties are nutrient-rich and suited for diverse cropping systems, they help women improve family diets, indirectly strengthening their role as providers of household health. • Local varieties are tied to cultural dishes, rituals, and heritage - areas where women are primary custodians. By preserving local varieties, women maintain their influence in cultural and social spheres, which can support broader recognition of their contributions. However, some local varieties require more manual labour (weeding, harvesting, processing), which can increase women's workload if labour-sharing is unequal. Also, if markets for local varieties expand rapidly, men may take over control of profitable crops, reducing women's benefits unless safeguards are in place.
Works well with/ brings synergies with practice…	• Crop rotation and intercropping • Soil and water conservation and use of organic soil amendments • IPM • Bee keeping • Agroforestry
Works well with/ brings synergies with practice…	None
Does not work well/ competes with practice…	None
Any other disadvantages of the practice	Not suitable for larger scale, mechanised farming and where markets demand larger quantities of uniform, high-yielding produce.

6.4 Conservation and use of local crop varieties

Possible mitigation measures to manage trade-offs/ address disadvantages	‣ Farmers often grow both local and improved crop varieties on their farms, to benefit from the advantages of each. This is a practice that could be encouraged (provided there are sufficient land and other resources available). ‣ Projects may also consider addressing issues of post-harvest management/processing (product development) as well as consumer behaviour for local crop varieties as part of their activities. See for example ‣ activities of the Indian NGO DDS (Deccan Development Society) on promoting local millet varieties. ‣ In some countries, the commercialization of seeds of un-certified varieties is not allowed or even penalised. Interventions need to take into account these legal constraints and/or support an enabling legal framework for the conservation and use of landraces.

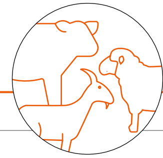


6.5 Conservation and sustainable use of local livestock breeds



This practice focuses on maintaining, improving, and sustainably utilising indigenous livestock breeds that are well adapted to local environments. These breeds have evolved under natural and traditional management conditions, giving them resilience to heat, diseases, parasites, and poor-quality feed – traits often lacking in exotic or improved breeds.

6.5 Conservation and sustainable use of local livestock breeds



Furthershort description	The practice involves: ‣ In-situ conservation: Keeping local breeds within their natural production environments and encouraging continued use by local farmers, e.g. through community-based breeding programs and support for traditional management systems. ‣ Ex-situ conservation: Preserving genetic material (semen, embryos, DNA) in gene banks (cryo-conservation – see ‣ Boes et al. 2023) or ex situ in vivo conservation (e.g. zoos – see ‣ FAO 2013). This is useful as a backup against breed loss due to crossbreeding or changing farming systems. ‣ Sustainable utilisation: Promoting market opportunities for products (e.g. milk, meat, hides) from indigenous breeds, often valued for quality or cultural identity; integrating local breeds into climate-smart agriculture programs due to their adaptive traits.

Context / suitability

Farm or landscape level	Farm level, landscape level
Relevant production system (‣ FAO classification)	Livestock grassland-based systems, mixed systems

6.5 Conservation and sustainable use of local livestock breeds

Resource requirements/cost implications

Land and other natural resources	This practice requires moderate to extensive land areas with access to natural pastures, water sources, and shade, but overall relies less on external inputs and is well suited to marginal or variable environments where exotic breeds would struggle. Requirements include: **Land resources** ‣ (Secure access to) grazing land / rangelands: Local breeds are usually reared in extensive or semi-extensive systems that rely on natural pastures, fallows, and communal rangelands. ‣ Moderate to large areas of land may be needed, depending on livestock density and vegetation productivity, as indigenous breeds efficiently use native grasses, shrubs, and crop residues, which are often of low nutritional quality. ‣ Integration with crop farming allows use of stover, husks, and bran, minimising waste. Fodder trees and legumes can be planted to improve feed supply and soil fertility. **Water resources** ‣ Access to surface water (rivers, ponds, watering points) or shallow wells is essential for livestock, particularly during the dry season. Local breeds generally have lower water requirements and higher drought tolerance than exotic breeds. **Shelter and shade areas** ‣ Livestock may need trees or constructed shelters for protection from heat and heavy rains.
(financial and physical) Capital/implements	The financial and capital resources needed for keeping local livestock breeds can be quite substantial, in particular as start-up costs are high: **Initial investment needs** ‣ Breeding stock acquisition: Purchasing or maintaining high-quality local breed animals for breeding herds or community breeding centres. Costs are usually lower than for exotic breeds but may still require investment to access animals with the desired traits. ‣ Infrastructure: Basic housing and shade structures, watering facilities, fencing or enclosures for controlled grazing, storage facilities for feed and veterinary supplies (if applicable). ‣ Equipment: Tools for animal handling, weighing, identification, and record-keeping.

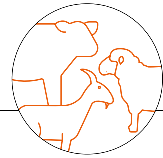
6.5 Conservation and sustainable use of local livestock breeds

continued (financial and physical) Capital/implements	**Operational costs** • Feed and grazing management: Usually low, since local breeds depend largely on natural forage and crop residues. Some supplementary feeding during dry seasons may require purchase of fodder or concentrates. • Veterinary care and disease control: Local breeds have lower disease incidence, but periodic vaccinations, de-worming, and basic health services are necessary. Community-based animal health workers can help reduce costs. • Maintenance of traditional transhumance routes where pastoral systems are practiced is important and requires adequate policy and management support. Smallholders may need microcredit or grants to start or expand breeding herds. Policy incentives (e.g., payments for ecosystem services or biodiversity conservation) can enhance financial sustainability.
Labour (qualitative and quantitative/skills etc.)	• Family or hired labour is needed for herding, watering, feeding, and health checks, but labour needs vary, depending on system intensity (extensive vs. semi-intensive). In some cases, herding livestock is done by young boys, which may impact on their school attendance. • Sustainable grazing management (e.g., rotational grazing, controlled stocking rates, rangeland restoration) helps prevent land degradation but requires skills and experience. • Water harvesting and conservation for dry periods requires additional skills and investments, as well as labour.

Expected impacts on biodiversity

Detailed description of impacts on biodiversity	Some of these impacts are similar to those outlined in the practice sheet "Conservation and use of local crop varieties". **Genetic diversity** • Conservation of local breeds maintains adaptations to heat, drought, low-quality feed, and endemic diseases – traits often lost in commercial or exotic breeds. Promoting local breeds counters the widespread trend of genetic dilution from uncontrolled crossbreeding with high-yielding exotics. The broad genetic base of indigenous livestock provides valuable genes for developing climate-resilient, low-input, and disease-tolerant breeds in the future. Community-based breeding programs encourage selection within local populations, keeping variability high while improving performance. • Potential negative or neutral aspects: If conservation focuses only on a few "popular" local breeds, less-known varieties may still face decline or extinction.

6.5 Conservation and sustainable use of local livestock breeds

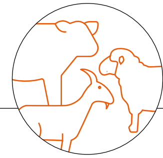


continued Detailed description of impacts on biodiversity	**Species and ecosystem diversity** • Sustainable grazing by local breeds supports habitat heterogeneity, which benefits native grasses, shrubs, birds, and soil fauna and helps maintain diverse landscapes. Local breeds often underpin traditional ecological knowledge and land management practices that conserve entire ecosystems (e.g., Maasai rangelands, Sahelian transhumance routes). • Livestock integrate with crops and trees, sustaining multi-species agricultural landscapes rather than monocultures. Grazing, manure deposition, and movement patterns of local breeds contribute to nutrient cycling, seed dispersal, and soil fertility. Productive and resilient livestock reduce reliance on hunting or harvesting of wild species for protein or draught power. • Potential risks: Overgrazing (if poorly managed) can reduce plant species richness and favour invasive species. In particular in high-density areas or during drought, livestock may contribute to rangeland degradation, soil compaction, or reduced vegetation cover – though typically less so than exotic breeds due to lower feed demand.

Complementarity and competition

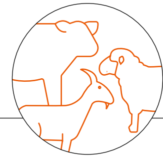
Co-benefits and trade-offs for climate change mitigation and adaptation	**Adaptation** Local livestock breeds are powerful assets for adaptation because they have evolved under harsh and variable tropical and sub-tropical environments. Their traits and management systems strengthen the resilience of farming and pastoral livelihoods in several ways: • Many indigenous breeds are physiologically adapted to high temperatures, limited water, and fluctuating forage availability. Their natural resistance to local diseases (e.g., trypanosomiasis, ticks) reduces mortality and dependency on veterinary drugs. Local breeds thrive on coarse forage, crop residues, and browse – resources that are abundant even when pastures dry up. Many pastoral breeds are suited to transhumance systems that track seasonal vegetation and water availability. • Local breeds may produce less per animal but maintain production during droughts or heat waves when exotics fail. Reduced need for feed, medicines, and housing lowers vulnerability to supply disruptions and price shocks. Traditional herding knowledge and management strategies - often linked to local breeds – enhance adaptive capacity at community level. • By preventing land abandonment or degradation, local livestock support vegetation recovery and soil stabilisation. Mixed crop-livestock systems recycle nutrients and reduce climate risks across both components.

6.5 Conservation and sustainable use of local livestock breeds



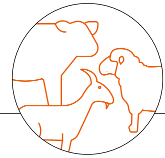
continued Co-benefits and trade-offs for climate change mitigation and adaptation	**Mitigation** While livestock are often associated with greenhouse gas (GHG) emissions, local breeds and their management systems can reduce emissions intensity and support ecosystem carbon functions. ‣ Local breeds often produce more output per unit of input (especially under stress) compared to exotic breeds that require high-quality feed and infrastructure. Lower use fertilisers, feed concentrates, and transport results in smaller carbon footprints. Local animals tend to live longer and reproduce reliably, reducing replacement rates and cumulative emissions. ‣ Moderate grazing pressure by local breeds maintains ground cover and promotes soil carbon storage. Continued use of traditional grazing lands (e.g., savannas, wetlands) discourages conversion to cropland or degraded wasteland. Systems based on local breeds are less likely to collapse during climate shocks, preventing livestock losses that would otherwise waste embodied emissions and resources. **Potential risks or limitations** ‣ Low productivity per animal may lead to higher absolute emissions if herd sizes increase without improved management. ‣ Without sustainable grazing practices, carbon benefits can be offset by rangeland degradation. ‣ In some regions, policy and market neglect of local breeds can limit investment in improved husbandry and reduce climate benefits.
Co-benefits and trade-offs for water quality and quantity:	**Water quantity** ‣ Local livestock breeds are physiologically adapted to heat, drought, and intermittent water availability, often requiring less frequent watering than exotic breeds. ‣ Traditional pastoral systems utilise seasonal water points, wells, and ephemeral streams without heavy infrastructure demands, spreading use over space and time. ‣ Since local breeds thrive on natural pastures and crop residues, they indirectly reduce agricultural water demand (no need for irrigated fodder). ‣ Even resilient breeds can contribute to competition for scarce water if herd sizes exceed local carrying capacity.

6.5 Conservation and sustainable use of local livestock breeds



continued Co-benefits and trade-offs for water quality and quantity:	**Water quality** ‣ Local breed systems are generally extensive or semi-extensive, with dispersed manure deposition that enhances nutrient cycling and soil fertility, rather than concentrated waste discharges. Limited dependence on synthetic feed, fertilisers, or veterinary drugs minimises runoff into waterways. ‣ Well-managed grazing maintains ground cover, reducing soil erosion and sedimentation in nearby water bodies. In some regions, traditional livestock management helps maintain floodplains, riparian vegetation, and seasonal wetlands, which act as natural water filters.
Co-benefits and trade-offs for soil health:	Local livestock breeds are typically raised in extensive or mixed crop-livestock systems that rely heavily on natural pastures and traditional management. These systems - when well managed - tend to enhance soil fertility, structure, and biological activity, making them an important part of sustainable land management in tropical and sub-tropical regions. ‣ **Soil fertility and nutrient cycling**: Indigenous livestock deposit manure directly on rangelands or provide dung for use in croplands, improving soil organic matter, nitrogen, phosphorus, and micronutrient levels. Integration of local livestock into crop-livestock systems enable nutrient transfer – animals feed on crop residues and return nutrients to the soil through manure and urine. The organic manure enhances soil microbial activity and nutrient availability, supporting long-term soil productivity and reducing chemical inputs. ‣ **Soil structure and organic matter**: Moderate trampling and manure deposition by grazing animals increase soil carbon content, water infiltration, and aggregate stability. Regular dung and residue deposition increases soil organic carbon (SOC), critical for soil fertility and moisture retention. Indigenous breeds are often smaller and lighter, causing less soil compaction and structural damage. ‣ **Erosion control and ground cover**: Local breeds are generally grazed under rotational, mobile, or low-density systems, helping maintain continuous plant cover and root biomass. Movement of animals spreads seeds through dung and fur, aiding natural pasture regeneration and stabilising soils. Well-managed grazing with adapted breeds prevents bare soil exposure and wind/water erosion. ‣ **Soil biodiversity**: Manure inputs support soil micro-organisms, earthworms, and insects, all vital for decomposition and nutrient cycling. Diverse grazing systems maintain biologically active soils capable of withstanding drought and temperature stress. ‣ **Potential negative impacts (if mismanaged)**: High stocking rates or continuous grazing can reduce vegetative cover, compact soil, and impair infiltration. If animals frequently rest or water in one area, nutrients can accumulate unevenly, causing soil imbalances or contamination. Without adaptive management, drought-stressed pastures may become degraded, increasing erosion risks.

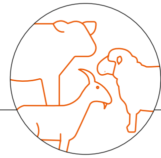
6.5 Conservation and sustainable use of local livestock breeds



Co-benefits and trade-offs for productivity:	Local livestock breeds are often perceived as “low yielding” compared to exotic or improved breeds. However, when productivity is assessed holistically[38] – considering environmental constraints, input costs, system resilience, and long-term sustainability – these breeds can be highly productive and efficient within their local contexts: ‣ **Stable and sustainable output**: Local breeds maintain steady milk, meat, or draft output even during droughts, heat waves, or feed scarcity, when exotic breeds’ productivity collapses. Indigenous animals have better fertility, calving/kidding rates, and lower mortality, ensuring sustainable herd growth and reliable returns. They often remain productive for many years, reducing replacement costs and improving lifetime productivity. ‣ **Efficiency under low-input conditions**: Local breeds efficiently convert low-quality forage, crop residues, and browse into animal products. Limited need for feed concentrates, veterinary drugs, and housing means lower production costs and higher net returns per unit of input. They make optimal use of resources unsuitable for crop production, turning non-edible biomass into protein and income. ‣ **Multifunctional productivity**: Local breeds contribute draft power, manure for soil fertility, hides, fibre, and cultural services (social value). In mixed crop-livestock systems, animals enhance overall farm productivity by providing manure and traction, reducing fertiliser and fuel costs. ‣ **Genetic resource for future productivity gains**: Conserving local breeds preserves genetic traits (e.g., disease resistance, heat tolerance) that can be used in crossbreeding or selection programs to improve productivity sustainably. Their resilience ensures that production systems remain viable as conditions change, safeguarding long-term productivity. ‣ **System-level productivity**: Local breeds often yield higher productivity per hectare in marginal or low-input areas, because they can utilise poor-quality land and feed that improved breeds cannot. Their resilience minimises losses during climatic shocks, giving more stable long-term yields and income. ‣ **Limitations and challenges**: Per-animal production of milk, meat, or eggs is usually lower than that of improved exotic breeds. Slow growth rates and later maturity can limit market competitiveness if systems are not managed efficiently. Many local breeds lack structured selection schemes, performance recording, or support services to enhance productivity. Products from local breeds (e.g., hardy meat or milk with high fat content) may be undervalued unless specific markets or branding (e.g.,“indigenous breed products”) are developed.

38 A holistic assessment of productivity would not only include per-animal output (milk, meat, eggs, wool), but also reproductive performance (calving/kidding interval, survival rates); labour use efficiency; feed efficiency under local conditions; survival, longevity, and disease resistance; costs of inputs (feed, vet care, housing, labour); by-products (manure for crops, draft power, hides, cultural value); and risk of production failure. See e.g. ‣ Smith et al. 2017.

6.5 Conservation and sustainable use of local livestock breeds

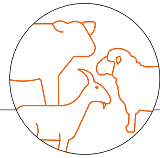


Co-benefits and trade-offs for income:	Income benefits and trade-offs overlap to some extent with productivity impacts. Local livestock breeds are the economic backbone of millions of smallholders and pastoralists in tropical and sub-tropical regions. While individual animals may yield less than improved breeds, their low costs, high resilience, and multifunctional outputs make them key contributors to stable and diversified incomes, especially in low-input and climate-stressed environments. • **Stable and reliable livelihoods**: Local breeds sustain production and reproduction under drought, heat, or feed scarcity, ensuring continuous income flows when exotic breeds or crops fail. Their adaptation to local conditions means fewer losses from disease or feed shortages - resulting in more predictable earnings over time. Livestock serve as living savings and insurance, providing cash in times of emergency (e.g., selling an animal to cover school or medical expenses). • **Low production costs and high net returns**: Local breeds thrive on natural grazing and crop residues, requiring little to no purchased feed, housing, or intensive veterinary care. Lower dependence on external inputs means less exposure to input price volatility and debt risks. Although yields may be smaller, the profit margin per unit of cost can be higher than for high-input exotic systems. • **Diverse income streams**: Local breeds provide milk, meat, manure, hides, fibre, and draft power, spreading income sources throughout the year. Their manure reduces fertiliser costs, and their traction saves on machinery or fuel expenses - effectively increasing net farm income. Livestock often have ceremonial, dowry, or prestige value, which can be monetised or exchanged within communities. • **Niche market and value addition opportunities**: Products from indigenous breeds can attract higher prices for their distinctive quality, taste, or cultural authenticity (e.g., indigenous beef, milk, cheese, or heritage breeds). Linking local breeds to biodiversity conservation, organic production, or climate-friendly systems can create new market niches. In some areas, traditional livestock breeds support eco-tourism, agri-tourism, and cultural heritage enterprises. • **Potential limitations and risks**: Per-animal productivity and total revenue may be lower if markets value only volume rather than quality or sustainability. Remote pastoral communities often face poor infrastructure, limited value chains, and price volatility. Without clear labelling or marketing, indigenous products may sell at the same price as generic goods despite their unique qualities. Few credit, insurance, or breeding programs specifically target local breed keepers, constraining income growth potential.

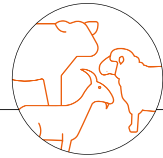
6.5 Conservation and sustainable use of local livestock breeds

Co-benefits and trade-offs for food and nutrition security:	In tropical and sub-tropical regions, local livestock breeds play a vital role in household and community food systems, especially among smallholders and pastoralists. Their adaptability, reliability, and multiple uses contribute to all four pillars of food security – availability, access, utilisation, and stability – while supporting diverse and nutritious diets. ‣ **Food availability**: Local breeds continue to produce milk, meat, eggs, and other animal products even during droughts, feed scarcity, or disease outbreaks when exotic breeds fail. Indigenous animals convert natural vegetation, crop residues, and browse into edible protein, expanding food production in areas unsuitable for crops. Mixed herds (goats, cattle, sheep, poultry) ensure year-round availability of animal-source foods and other products. ‣ **Food access**: Households owning local breeds have direct access to milk, meat, and eggs, reducing dependence on purchased food. Sale of animals or products provides cash income that families use to buy staple foods or diversify diets. The reliability of local livestock as assets ensures economic access to food even during climatic or market shocks. ‣ **Food utilisation (nutrition quality)**: Local breeds provide high-quality proteins, essential fatty acids, iron, zinc, and vitamins, improving household nutrition, particularly for children and women. Products from indigenous animals often have higher fat, micronutrient, and flavour content due to natural grazing and diverse diets. Traditional foods derived from local breeds enrich cultural food heritage and diet diversity. ‣ **Food stability**: Because local breeds are resilient to drought, disease, and heat, they ensure stable food supplies under changing environmental conditions. Owning local livestock provides a safety net during poor crop harvests, helping households maintain food availability and dietary quality. Indigenous breeds, often passed down as family assets, maintain long-term household food security. ‣ **Potential limitations and risks**: Total food quantities (milk or meat) may be smaller than those from improved breeds, especially where populations are large or growing. Weak dairy or meat value chains in remote areas may restrict surplus sales, reducing local breed contributions to broader food systems. Indigenous animal products are sometimes undervalued in formal markets and nutrition programs. Extreme events may still reduce productivity if traditional grazing reserves or water points are degraded.

6.5 Conservation and sustainable use of local livestock breeds



Co-benefits and trade-offs for gender equity:	In many countries, women play a central role in managing local livestock breeds, especially small ruminants (goats, sheep), poultry, rabbits, guinea pigs, and sometimes pigs or dairy cattle. Because these breeds are typically low-cost, locally adapted, and managed close to home, they provide women – and sometimes youth –with accessible entry points to livestock ownership, decision-making, and income generation. Thus, conserving and using local breeds can significantly enhance gender equity and empowerment within rural communities. Specifically: ‣ **Increased access to productive assets**: Local livestock breeds are more affordable and manageable than exotic or large commercial animals, enabling women to own and control assets directly. For example, women frequently keep indigenous chickens, goats, or dairy cattle, which are vital sources of household food and income. In many traditional systems, women can inherit or receive small livestock as gifts or dowry, strengthening their asset base and social status. ‣ **Enhanced income and financial autonomy**: Sale of milk, eggs, offspring, or small animals from local breeds provides regular, small-scale income that women can manage independently. Local breeds require minimal inputs, reducing financial barriers and dependence on male household members for investment or technical inputs. Control over livestock-derived income strengthens women's role in household budgeting, education, and nutrition decisions. ‣ **Empowerment in knowledge and skills**: Women often possess deep knowledge of animal husbandry, health care, and feed resources, especially for indigenous species. Conservation programs that recognise and formalize this knowledge enhance women's visibility and influence in agricultural innovation. Involving women in community-based breeding and conservation initiatives fosters leadership, technical skills, and collective empowerment. By managing and selectively breeding indigenous livestock, women act as guardians of animal genetic resources, contributing directly to biodiversity conservation. Supporting local breeds therefore aligns conservation goals with women's empowerment, reinforcing both gender equity and sustainability. ‣ **Improved household nutrition and well-being**: Women's ownership of local livestock increases household access to milk, eggs, and meat, improving family nutrition and food security. Women's livestock serve as a social safety net, providing quick cash or food in emergencies, enhancing household resilience. ‣ **Potential challenges and risks**: Women may face barriers to extension services, veterinary care, credit, and markets, which constrain their ability to benefit fully from livestock enterprises. In some areas, social norms may limit women's participation in breeding associations or decision-making about larger livestock. Women's livestock responsibilities can add to unpaid labour if men do not share household or production tasks. If indigenous breed products become lucrative, men may take over control of animals or income streams, reducing women's benefits.



6.5 Conservation and sustainable use of local livestock breeds

Works well with/ brings synergies with practice…	• Agroforestry: Fodder trees and legumes can be planted to improve feed supply and soil fertility. • Integrated crop-livestock systems: Integration with crop farming allows use of stover, husks, and bran, minimising waste. Integration with agroforestry and mixed crop-livestock systems increases land use efficiency. • Soil organic amendments: Healthy soils support productive pastures; local livestock also contribute organic manure, enhancing soil fertility. • Sustainable rangeland and herd management: Local livestock breeds thrive when managing rangelands and herds in a sustainable way.
Does not work well/ competes with practice…	None
Any other disadvantages of the practice	None
Possible mitigation measures to manage trade-offs/ address disadvantages	See details under each impact area.

6.6 Crop rotation

Crop rotation is the practice of growing different types of crops or soil improving plants in the same area in a planned, recurring sequence over several seasons or years, instead of planting the same crop repeatedly (monocropping). This is a traditional practice that has been used for centuries by farmers worldwide to preserve and/or improve soil fertility, break pest and disease cycles, enhance yields and meet the needs for different food and cash crops from the same plot of land.

6.6 Crop rotation

Further short description	The specific crops or crop types vary between farming systems and agroecological zones, but common sequences include legume-cereal rotations (whereby legumes enrich the soil with nitrogen, which is then used by the following season's cereal crop) and root-leaf-fruit sequences in vegetable cultivation. Crops can also be rotated with soil improving plants (legumes, grasses, etc.) as green manure or cover crops, or with plants used for livestock feed. Green manure plants are normally cut and worked into the soil before flowering or left as a mulch on the soil surface. Because of the context specificity of crop rotations, there is limited generic guidance available. Some useful publications include: ‣ Paparella et al. 2025: ‣ Crop rotation ‣ Mohler and Johnson 2009: ‣ Crop rotation on organic farms : a planning manual ‣ A ‣ tropical annual vegetable planting guide ‣ Florentín et al. 2011: ‣ Green manure/cover crops and crop rotation in Conservation Agriculture on small farms ‣ For the Indian and South Asican context: Gupta et al. 2021: ‣ Sustainable Agriculture in India (with chapters on crop rotation and green manure) ‣ Soya-maize rotations: Acevedo-Siaca et al. 2020: ‣ Soy-maize crop rotations in sub-Saharan Africa: a literature review

Context / suitability

Farm or landscape level	Farm level, plot level
Relevant production system (‣ FAO classification)	Rainfed crops, irrigated crops, mixed systems

6.6 Crop rotation

Resource requirements/cost implications	
Land and other natural resources	• Basically, the same natural resources are required as for monocropping: Arable land, water (if growing irrigated crops), suitable climatic conditions, • Soil should have the capacity to regenerate nutrients and maintain structure under different crops. The land area needs to be sufficiently large to be subdivided for rotation, ensuring not all plots are planted with the same crop at once. Land with different micro-ecologies (upland vs. lowland) can diversify rotations.
(financial and physical) capital/implements	• Depends on the specific crops to be grown, whether seed is purchased or kept from own harvests, and what other types of inputs are being used. • Rotating crops is not normally more capital intensive than growing the same crops every season. However, where new crops are being introduced into the system, seed and implements may need to be purchased. If the rotation includes green manure or cover crops, implements may be required for cutting the plants and incorporating them into the soil.
Labour (qualitative and quantitative/skills etc.)	Labour is one of the most important resources in crop rotation. Compared to monocropping, crop rotation usually requires more skills (to select suitable rotations that optimise soil fertility, whilst also meeting the different needs of the farming household). Where a system is transitioning from mono-cropping to crop rotation, knowledge and skills of the newly introduced crop are required.

Expected impacts on biodiversity	
Detailed description of impacts on biodiversity	**Species diversity** • Increases plant species diversity over time: By growing different crops in sequence, more plant species occupy the land across seasons or years. • Supports diverse soil microbial communities: Different root exudates and residues from varied crops promote diverse microbial populations (‣ Zander et al. 2016) • Enhances above-ground biodiversity: A changing crop environment supports a wider range of insects (pollinators, predators), birds, and small mammals (‣ Priyadarshana et al. 2024)

6.6 Crop rotation

continued Detailed description of impacts on biodiversity	**Ecosystem diversity** ‣ Temporal landscape diversity: The same field changes appearance and function over seasons, unlike monocropping. Increasing crop heterogeneity can be an effective way to mitigate the impacts of farming on biodiversity without taking land out of production. (‣ Sirama et al. 2019) ‣ Spatial planning: On a regional scale, if many farmers rotate crops differently, the landscape becomes a mosaic of species and growth stages. ‣ Ecological corridors and buffers: Certain rotational crops (e.g., cover crops, legumes) can act as refuges or buffers for wildlife

Complementarity and competition

Co-benefits and trade-offs for climate change mitigation and adaptation	**Adaptation** ‣ Where crops and crop varieties are selected based on their suitability for a particular season, taking into accounts the likelihood of droughts, floods etc., crop rotations can contribute to climate change adaptation. **Mitigation** ‣ Crop rotations reduce the need for fertiliser application, thus contributing to climate change mitigation. Adding legumes, deep-rooted perennials, or cover crops boosts carbon input to soils. Better rotation improves soil organic carbon accumulation and reduces CO_2 release from tillage.
Co-benefits and trade-offs for water quality and quantity:	‣ Compared to monocropping, crop rotations can be expected to benefit water quality and quantity, as soil quality is enhanced through careful selection of crop rotations that avoid soil being exposed / bare and that replenish soil organic matter (for example, via leaf litter fall). Healthy, diverse soils with improved infiltration capacity, as fostered by crop rotation, can better absorb rainfall, reducing surface runoff and the associated nutrient pollution (especially nitrogen and phosphorus) into waterways. ‣ Because crop rotation can break pest and disease cycles, it reduces the need for agrochemical applications, thus mitigating the risk of water contamination from these chemicals.
Co-benefits and trade-offs for soil health:	‣ Crop rotations such as legume-cereal rotations increase soil fertility and soil organic matter, which is beneficial for soil health (see also above).

6.6 Crop rotation

Co-benefits and trade-offs for productivity:	‣ Crop rotations generally increase productivity by using nutrients more efficiently. There are many studies that document the yield benefits of growing in particular cereal-legume rotations: ‣ For South Africa: ‣ Lengwati et al. 2020 ‣ For Ghana: ‣ Adjei-Nsiah et al. 2008 ‣ For China: ‣ Wei Yao et al. 2025 ‣ For SSA overall (systematic review): ‣ Franke et al. 2018 ‣ However, the specific impact on productivity depends on the metrics used. For example, in terms of caloric output, crop rotations that replace a staple cereal with less energy-rich crop could decrease the overall caloric output per unit area. Also, some soils may also not be suitable for legume rotations (e.g. due to phosphorus deficiency – see ‣ Mhango et al. 2013)
Co-benefits and trade-offs for income:	‣ The specific income effect depends on several factors, including the initial investments required for the introduction of an additional crop, and the market situation. ‣ A positive impact on incomes has been demonstrated in many contexts, but there are also examples where crop rotations led to decreased incomes, in particular in the short term. Reasons for this include inadequate advisory support to farmers, a lack of markets for the introduced / additional crops, low soil fertility and high initial costs for the switch (e.g. for Brazil: ‣ Volsi et al. 2020).
Co-benefits and trade-offs for food and nutrition security:	‣ Crop rotation is a form of diversification that can improve food and nutrition security, provided that crops are grown at least partly for home consumption. The introduction of legumes into a cereal-based system can increase the availability of protein and micro-nutrients in farmers' diets. ‣ However, where food crops are replaced by cash crops in the rotation, and the income from these cash crops is not spent on food purchases, food security impacts could be negative.
Co-benefits and trade-offs for gender equity:	‣ The specific gender impacts depend on the crops grown and the respective roles of men and women in their cultivation. Where a crop traditionally grown by men (such as a cereal in West Africa) is rotated with a crop cared for by women, the workload for women could increase (but also their stake in the crop and possibly their influence on how it is used). Hence, gendered labour and household dynamics need to be considered when assessing impacts on gender equity. may take over control of animals or income streams, reducing women's benefits.

6.6 Crop rotation

Works well with/ brings synergies with practice…	• Intercropping and Agroforestry: Crop rotations reenforce the beneficial impacts of intercropping and agroforestry in terms of diversity and soil health. • Use of indigenous crop varieties/landraces for crop rotations. • Minimum/no tillage benefits on cover crops to reduce the emergence of weeds. • Soil and water conservation.
Does not work well/ competes with practice…	None

6.7 Integrated fish-crop-livestock production systems

An integrated fish–crop–livestock production system (IFS) is a diversified and synergistic farming approach where fish, crops, and livestock are produced together on the same farm. Each component supports the others– optimising resource use, reducing waste, and increasing overall farm productivity and sustainability.

Key features are integration and recycling, the use of animal manure and crop residues to fertilise fishponds and fields, re-use of nutrient-rich pond water for irrigation and crop fertilisation, use of crop by-products and aquatic vegetation to feed livestock or fish.

6.7 Integrated fish-crop-livestock production systems

Further short description	Typical examples include fish-rice and fish-duck-rice systems (ducks forage in rice paddies and fishponds, controlling pests and fertilising water with droppings), pig-fish systems (pig manure fertilises pond algae and plankton, which serve as fish feed) and fish-vegetable-livestock systems: pond water used to irrigate vegetables, vegetable residues feed livestock, manure enriches ponds). The benefits, trade-offs, and potential impacts depend strongly on production intensity. Extensive systems with low stocking density and feed use generally have little or no negative environmental impacts, whereas semi-intensive systems that rely on feed can have significantly higher impacts. An example for low intensity systems are Community Fish Refuges (CFR), developed by GIZ in Cambodia, which work well in floodplain areas. Studies show that restoring habitats and connectivity significantly increases rice-field fisheries productivity and biodiversity. Examples of guidance documents and reviews of IFS: ‣ ‣ IFAD 2021 training manual on IFS (for Kiribati, but with many generic recommendations) ‣ Magada (2025) ‣ Integrated Farming Systems ‣ FAO (2024) ‣ Integrated farming systems: improving land-use efficiency while ensuring food safety ‣ Bhagat et al (2024) ‣ The integrated farming system is an environmentally friendly and cost-effective approach to the sustainability of agri-food systems in the modern era of the changing climate: A comprehensive review ‣ GIZ (2022) ‣ La production d'alevins de carpe en rizières (French training manual on carp fry production in rice fields in Madagascar) ‣ Freed et al. (2020) ‣ Rice field fisheries: Wild aquatic species diversity, food provision services and contribution to inland fisheries

Context / suitability

Farm or landscape level	Plot level, farm level
Relevant production system (‣ FAO classification)	Irrigated crops, mixed systems

6.7 Integrated fish-crop-livestock production systems

Resource requirements/cost implications

Land and other natural resources	The land and natural resources requirements vary significantly, depending on the specific types of system and its scale. The following is a general overview of the main components required **Land requirements** ‣ The total land area required depends on the scale of production but typically ranges from 0.5 to 5 hectares for smallholder systems. Low-lying areas are suited to ponds, while slightly higher ground suits crops and livestock sheds. Ideally, the land should have a gentle slope (1–3%) to facilitate gravity-based water flow from livestock units to ponds, and from ponds to crop fields for irrigation. ‣ The land should allow for fishponds, crop fields or vegetable plots on slightly elevated ground, livestock housing and grazing areas on well-drained land nearby. A compact layout with short distances between components enhances nutrient recycling and reduces transport costs. ‣ Soils should have good water retention for pond construction (clay or loamy soils), fertile and well-drained soils for crop cultivation, and firm ground for livestock housing. **Water** ‣ Adequate and reliable freshwater supply is essential year-round. Rainfall may support part of the water demand, but supplementary irrigation or water storage may be necessary during dry seasons. ‣ Water must be unpolluted, with low salinity and chemical contamination. ‣ Common sources are rainwater harvesting, boreholes, streams, canals, or reservoirs. Water recycling between ponds and crop fields is a defining feature of IFS. Pond effluent rich in nutrients is used to irrigate crops and runoff from crop fields may be channelled back to ponds after filtration. **Other natural resources** ‣ Availability of crop residues and animal manure is crucial for nutrient cycling. ‣ Encouraging native flora and fauna around ponds and fields supports ecological balance.

6.7 Integrated fish-crop-livestock production systems

(financial and physical) capital/implements	Developing an IFS requires moderate initial capital for ponds, housing, and water systems, ongoing operational inputs for feed, seed, and labour, and strategic use of recycled nutrients to minimise costs. The exact costs vary with scale, level of technology, and local resource availability. **Capital (fixed) inputs (= one-off investments made during the establishment phase)** Land and infrastructure ‣ Land preparation (levelling, constructing bunds and drainage channels). ‣ Pond construction: excavation, dyke building, pond lining, installation of inlet/outlet structures. ‣ Water supply system and drainage: wells, boreholes, pumps and pipelines for distributing water. Channels to drain ponds and irrigate crops using nutrient-rich pond effluent. ‣ Livestock housing: pens, sheds, or poultry houses on well-drained ground, preferably roofed for protection from heat and rain. ‣ Crop infrastructure: nursery beds, trellises, composting units, and fencing for crop plots. ‣ Storage and processing: feed stores, cold rooms, drying racks, space for post-harvest handling. Tools, equipment, machinery and energy ‣ For aquaculture: Nets, aerators (if needed), harvesting gear, weighing scales, water quality test kits. ‣ For crops: Hand tools, sprayers, irrigation pipes, or low-cost drip systems. ‣ For livestock: Feeders, drinkers, veterinary equipment, manure-handling tools. ‣ Transport: Small carts, wheelbarrows, or motorcycles for moving feed and produce. ‣ Investment in mechanisation is usually modest; smallholder systems rely mainly on manual labour. ‣ Power supply for pumps, lighting, and possibly aeration. Renewable sources such as solar pumps or biogas digesters (from animal waste) reduce long-term costs and carbon footprint.

6.7 Integrated fish-crop-livestock production systems

continued (financial and physical) Capital/implements	**Operating (recurrent) financial inputs** (= regular expenditures required to run the system efficiently) Inputs for production ‣ Fish seed or fingerlings: purchase of healthy fry or fingerlings for stocking fishponds. ‣ Feed and fertilisers in more intensive production systems: fish feed (commercial or farm-made), crop fertilisers, and other nutrient inputs. At lower stocking density, it is possible to rely on the natural productivity of the pond, using fertiliser and lime (without additional feed) ‣ Livestock stock: initial animals such as piglets, ducklings, chicks, goats, or breeding pairs. ‣ Veterinary supplies: vaccines, medicines, and other animal health products. ‣ Crop inputs: quality seeds, fertilisers, and pest- or disease-control materials. ‣ Water management: energy costs for pumping and water exchange (diesel, electric, or solar). ‣ Maintenance: regular repairs to ponds, housing, fencing, tools, and replacement of worn equipment. Labour and management costs ‣ Family labour or wage labour for feeding, harvesting, and pond/crop management may be required. ‣ Technical support or training costs may be incurred for managing integrated nutrient flows and disease prevention. Marketing and transport ‣ Costs for packaging, local transport to markets, and basic value addition (e.g. fish smoking, vegetable drying, milk processing). ‣ Establishing market linkages or cooperatives can reduce these costs over time. **Working capital** ‣ Adequate working capital is needed for the first production cycle (6–12 months) before revenues begin. That includes cash for input purchases, emergency repairs, and feed supply continuity.

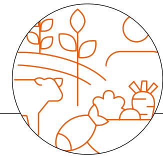
6.7 Integrated fish-crop-livestock production systems

Labour (qualitative and quantitative/skills etc.)	IFS is labour-intensive and success requires multi-disciplinary knowledge: aquaculture, crop production, livestock management, and integration skills. Hands-on experience, supported by formal or informal training, is crucial for productivity, sustainability, and profitability. Effective labour planning and skills development are key to reducing risks and optimising returns. **Labour requirements** ‣ IFS is generally labour-intensive, especially for smallholder systems where manual work predominates. Labour is needed for feeding, pond management, crop cultivation, livestock care, and waste/nutrient recycling. Family labour is commonly used in smallholder farms and reduces cash outlay. Waged labour may be needed for larger operations or during peak periods. **Knowledge, skills, and experience requirements** ‣ Aquaculture skills: Pond construction and management; stocking density calculations and fish health monitoring; water quality management: monitoring pH and nutrient levels; disease prevention and treatment, and biosecurity measures. ‣ Crop management skills: Soil fertility and irrigation management; pest, weed, and disease control using IPM; crop rotation and intercropping techniques compatible with fish and livestock integration. ‣ Livestock management skills: Animal nutrition and feeding strategies; breeding and reproductive management; health management; manure handling and utilisation for fertilising ponds or crops. ‣ Integration and system management skills: Planning and coordinating the flows of nutrients, water, and energy between fish, crops, and livestock; scheduling production cycles for crops, fish, and livestock to maximise resource use; balancing stocking rates, feed inputs, and crop area. ‣ Business and financial skills: Basic record-keeping for inputs, outputs, and costs; marketing and sales of fish, crops, and livestock products; accessing credit or grants.

6.7 Integrated fish-crop-livestock production systems

Expected impacts on biodiversity	
Detailed description of impacts on biodiversity	IFS can strengthen biodiversity by creating multifunctional landscapes and promoting ecological integration. The overall impact depends on species selection, intensity of production, and environmental management practices. Maintaining native species, controlling nutrient flows, and avoiding exotic introductions are crucial to ensuring positive biodiversity outcomes. Specifically: **Genetic diversity** ‣ Promotes the use and conservation of local breeds and strains of fish, crops, and livestock and reduces dependence on imported, uniform breeds or hybrids. ‣ Encourages on-farm genetic diversity through multiple species and varieties cultivated or reared together and enhances genetic resilience to climate variability, pests, and diseases due to mixed species and strains. ‣ Potential challenges and trade-offs: Over-reliance on commercial or fast-growing breeds and strains (e.g., hybrid tilapia) can reduce local genetic diversity; potential genetic pollution, if exotic fish species escape into natural water bodies and interbreed with wild populations; limited breeding management may lead to inbreeding depression or genetic uniformity and related health problems within on-farm populations. **Species diversity** ‣ Encourages multi-species farming, combining fish, livestock, and various crop species in one system. This increases functional biodiversity, as each component contributes different ecological roles (e.g., nutrient cycling, pest control, pollination). ‣ Creates a heterogeneous farm habitat supporting associated species such as insects, birds, amphibians, and beneficial microorganisms. Integrating aquatic and terrestrial species encourages cross-habitat biodiversity, linking pond and field ecosystems. ‣ Potential challenges and trade-offs: Poorly designed systems may lead to species dominance (e.g., weedy plants) that outcompete others; high nutrient inputs from livestock waste or feed residues can cause eutrophication, reducing aquatic biodiversity; disease transmission between integrated species (fish-livestock or livestock-crop) may reduce diversity within and across species.

6.7 Integrated fish-crop-livestock production systems



continued Detailed description of impacts on biodiversity	**Ecosystem diversity** ‣ Promotes landscape diversification - combining ponds, croplands, pastures, and vegetated buffer zones enhances habitat variety – and enhances connectivity between aquatic and terrestrial ecosystems, fostering ecological interactions and resilience. ‣ Improves ecosystem services, such as nutrient recycling, soil fertility, water retention, and carbon sequestration. It reduces environmental degradation by recycling organic waste (e.g., manure and crop residues) rather than discharging it into the environment. ‣ Encourages sustainable land use by integrating production with ecological conservation. ‣ Potential challenges and trade-offs: Unsustainable water use or pond expansion in sensitive areas can lead to loss of wetlands or natural habitats; poor waste management may degrade water and soil quality; conversion of natural habitats into integrated farms may fragment ecosystems. Fish of exotic species might escape in the natural environment, posing risks to the ecosystem overall.

Complementarity and competition

Co-benefits and trade-offs for climate change mitigation and adaptation	Well-managed IFS can act as climate-smart agricultural models, combining adaptation and mitigation benefits. The balance between adaptation and mitigation benefits depends on system design, management skill, and local environmental conditions. **Adaptation** ‣ Reduces vulnerability to climate-induced losses by spreading risk across fish, crop, and livestock enterprises; provides economic and nutritional security throughout the year even when one component fails due to droughts, floods, or disease outbreaks. ‣ Integrated ponds act as on-farm water storage systems, supporting irrigation during dry spells; enhances water-use efficiency through reuse of nutrient-rich pond effluent for crop irrigation. ‣ Application of organic manure and pond sludge increases soil organic matter and water-holding capacity, improving drought resilience; continuous organic inputs improve soil structure and reduce erosion from heavy rainfall. ‣ Potential challenges and trade-offs: Ponds and livestock housing may be damaged by floods or storms if not properly designed; droughts can reduce water availability, affecting fish and crop productivity simultaneously; warmer, wetter climates can increase the incidence of diseases and pests across all components of the system.

6.7 Integrated fish-crop-livestock production systems

continued Co-benefits and trade-offs for climate change mitigation and adaptation	**Mitigation** ‣ Reuse of manure and crop residues reduces the need for synthetic fertilisers, thereby lowering emissions from fertiliser manufacture and application. Integration of crops, trees (in agroforestry components), and organic waste management increases soil carbon storage. Ponds and vegetated areas act as small carbon sinks through organic matter accumulation. ‣ Livestock manure can be used in biogas systems, reducing dependence on fossil fuels. ‣ Produces more food (fish, crops, meat, eggs, milk) per hectare with less overall carbon footprint compared to separate specialised systems. On-farm nutrient cycling minimises external input transport and associated emissions. ‣ Potential challenges and trade-offs: Fishponds can emit methane (CH_2) from anaerobic decomposition. Livestock manure and enteric fermentation also contribute to methane emissions if not properly managed. Over-application of manure or pond effluent on crop fields can lead to nitrous oxide (N_2O) release, a potent greenhouse gas. Dependence on diesel or electric pumps for irrigation and aeration can increase fossil fuel emissions if renewable energy is not used.
Co-benefits and trade-offs for water quality and quantity:	When properly designed and managed, IFS can significantly improve water-use efficiency and reduce pollution by closing nutrient and water loops and improving resilience to drought, leading to net positive outcomes for water quality and availability. When poorly managed or overly intensified, nutrient overloads and inefficient water use can degrade both surface and groundwater resources. The outcome depends on management practices, pond design, species combinations, and local rainfall patterns. **Water quality** ‣ As livestock manure and crop residues are reused as pond fertilisers or compost, nutrient discharge into natural water bodies is reduced. Integration also lowers dependence on synthetic fertilisers and pesticides, leading to cleaner runoff and reduced chemical contamination. ‣ Vegetation around ponds and fields acts as a biofilter, trapping sediments and nutrients before they reach open water. Recycling and reuse of water within the system decrease the need for frequent water discharge, helping maintain local water quality. ‣ Potential challenges or trade-offs: Excessive use of manure or feed can lead to nutrient accumulation (nitrogen and phosphorus) in ponds, causing algal blooms and oxygen depletion. Discharge of nutrient-rich water into natural water bodies can degrade downstream ecosystems. If livestock waste enters ponds directly, it may introduce pathogenic bacteria, parasites, or antibiotics, compromising water quality and fish health. Misuse of pesticides or veterinary drugs may contaminate pond and irrigation water, or lead to harmful residues in produce (crops, fish). High organic loads from manure or uneaten feed may cause oxygen depletion.

6.7 Integrated fish-crop-livestock production systems

continued Co-benefits and trade-offs for water quality and quantity:	**Water quantity** ‣ Pond water serves multiple purposes - aquaculture, crop irrigation, and livestock watering – maximising productivity per unit of water. Fishponds function as on-farm reservoirs, storing rainwater for use during dry periods. This provides a local source of water for crops and livestock during droughts, improving resilience to rainfall variability. ‣ Ponds collect and store rainwater, reducing surface runoff and increasing groundwater recharge. Integration minimises reliance on rivers, wells, or irrigation canals through internal water cycling. ‣ Potential challenges or trade-offs: Evaporation losses from ponds can be significant and water requirements for fish culture, crops, and livestock combined can strain limited water resources in dry seasons. Poorly designed ponds and irrigation systems may lead to seepage or wastage. Overuse of groundwater for refilling ponds or irrigation can deplete local aquifers.
Co-benefits and trade-offs for soil health:	IFS have strong potential to restore and maintain soil health in tropical and sub-tropical regions. The system's impact on soil health depends on input quality, application rate, and balance among fish, crop, and livestock components. **Benefits** ‣ Application of livestock manure, pond sludge, and crop residues increases organic matter and nutrient content and improves soil microbial activity. Regular addition of organic inputs enhances soil porosity, aeration, and root penetration, and promote beneficial soil organisms. ‣ Continuous incorporation of manure and crop residues builds up soil carbon and improves water-holding capacity, helping crops withstand dry spells. Crop cover, contour bunds, and vegetative buffer zones around ponds and livestock units minimise runoff and topsoil loss. ‣ Fishpond effluent provides balanced nutrients for crops. Crop residues feed livestock, and manure from livestock returns nutrients to soil – forming a closed nutrient loop. **Potential challenge or trade-offs** ‣ Over-application of pond effluent or manure can lead to nutrient accumulation (particularly nitrogen and phosphorus). In poorly drained tropical soils, excess nutrients may cause salinity build-up and reduced crop productivity. Continuous use of organic residues with high nitrogen content, or certain manures, can gradually acidify soils if not balanced with lime or buffering materials. ‣ If livestock feed or pond inputs contain contaminants (e.g., copper, zinc, antibiotics), residues can accumulate in soils over time. Similarly, direct application of untreated livestock manure may introduce harmful microbes (e.g., E. coli, salmonella) into soil and crops.

6.7 Integrated fish-crop-livestock production systems

Co-benefits and trade-offs for productivity:	IFS can boost overall productivity and profitability in tropical and sub-tropical regions through efficient resource use and diversification. The productivity advantage lies in synergy and recycling, not in maximising yield of any single component. **Benefits** • IFS produces multiple outputs (fish, crops, and livestock products) from the same land and water resources (resulting in higher total productivity per unit area). The system converts waste into productive resources and thus maximises resource use efficiency. Livestock manure fertilises ponds and crops, improving nutrient availability. Fishpond effluent provides irrigation and nutrients to crops, reducing fertiliser requirements. Crop residues feed livestock, lowering feed costs. • Organic inputs and efficient irrigation sustain soil fertility and water availability, enhancing long-term productivity. This reduces yield decline caused by soil degradation or nutrient depletion. • To make best use of available resources and space, breeding and stocking fingerlings can be done in a pond, connected to rice fields when fish are large enough to survive in rice fields. **Potential challenge or trade-offs** • The system requires high skill and coordination. Water, feed, and labour demand from different components may conflict, particularly during dry seasons. Over-allocation of resources to one enterprise (e.g., fishponds) can reduce performance of others (e.g., crops). • Close interaction among components can facilitate the spread of pathogens (e.g., manure-borne diseases affecting fish or crops). Disease outbreaks can lower productivity system-wide. • Initial investment for pond construction, housing, and water systems may limit adoption or expansion, particularly for smallholders.
Co-benefits and trade-offs for income:	IFC can enhance rural incomes and reduce vulnerability when properly designed and supported. Profitability depends on management skill, market access, and risk management capacity. **Benefits** • Sequential harvesting can be done, using a fish trap to capture small fish and control fish population in the pond (avoiding overpopulation). Those fish can be consumed or sold throughout the year. Integration also allows staggered harvests - crops and fish provide seasonal returns, while livestock offer continuous output (milk, eggs, manure). Diversification also buffers against crop failure, market fluctuations or disease outbreaks in one component.

6.7 Integrated fish-crop-livestock production systems

continued Co-benefits and trade-offs for income:	‣ Lower production costs through resource recycling increases profit margins. The system generates employment and adds value through diversified production and processing opportunities. Greater self-sufficiency in feed and fertiliser improves profit margins. ‣ The system can create year-round on-farm and off-farm employment for family members and local workers. Processing fish, meat, or crops into higher-value products (e.g., smoked fish, compost, vegetables) increases profitability and may enable participation in local and niche markets. **Potential challenge or trade-offs** ‣ Construction of ponds, animal housing, and irrigation systems requires substantial upfront expenditure. This may lead to debt or cash-flow pressure in the early years, before returns stabilise. ‣ Inadequate management skills can reduce lower profitability. High labour intensity may raise operational costs or reduce household labour availability for other income-earning activities. ‣ Saturation of local markets with perishable products (fish, vegetables) can lower prices. Price volatility for livestock feed, seed, or energy may affect overall margins. ‣ Over-intensification may cause nutrient or water imbalances that reduce yields and profitability. Poorly balanced systems can have lower returns than specialised enterprises. ‣ Limited access to credit, inputs, or markets can constrain income benefits for poorer farmers. Inequality may widen if only better-resourced farmers adopt the system effectively.
Co-benefits and trade-offs for food and nutrition security:	IFS can greatly improve nutrition and food security by linking ecological efficiency with dietary diversity. Success depends on management skills, hygiene practices, gender equity, and access to markets and extension services. Nutrient dense fish such as Mola in Bangladesh can be promoted for "Nutrition sensitive aquaculture", in polyculture with carps (‣ Dubey et al., 2024). However, cultural norms need to be considered – e.g. fish raised with pig manure as fertiliser may not be acceptable in some contexts. **Benefits** ‣ Increased food availability from diversified food production, continuous food supply and improved land and water productivity. ‣ Improved food access from stable and diversified income, lower production and food costs and employment generation. ‣ Improved food utilisation and nutrition from enhanced dietary diversity, better child and maternal nutrition (animal-source foods) and fresh and safe food from own production. ‣ Strengthened food stability due to resilience to climate and market shocks.

6.7 Integrated fish-crop-livestock production systems

continued Co-benefits and trade-offs for food and nutrition security:	**Potential challenge or trade-offs** ‣ Food safety and quality risks from microbial or chemical contamination, or waterborne diseases. ‣ Cash crop or commercial fish sales might prioritise market income over household consumption. ‣ Environmental and systemic risks from over-intensification.
Co-benefits and trade-offs for gender equity:	Well-designed integrated systems can promote greater gender equity by increasing women's economic participation, income control, and decision-making power. Gender equity outcomes depend on cultural context, resource access, and inclusiveness of institutional support. **Benefits** ‣ Expanded economic opportunities for women from diversified income-generating activities, increased control over resources and income (if e.g. poultry, vegetables, fish marketing remains under women's management), and employment creation. Fishponds are often located in the homestead, with women in charge of fish feeding, management and harvesting. ‣ Knowledge and skill empowerment from training in production, processing, and marketing. ‣ Strengthened social status (individually and collectively) and decision-making through increased visibility and leadership resulting from women's participation in IFS activities. ‣ Time and resource synergies due to proximity of enterprises to the home. **Potential challenge or trade-offs** ‣ Increased workload and labour burden (added responsibilities, invisible and unpaid labour). ‣ Unequal access to resources and services (land, water, finance, technology). ‣ Gendered control over benefits due to male dominance in high-value enterprises and unequal decision-making. ‣ Cultural and institutional barriers (social norms and taboos) and the risk of exclusion from innovation (if e.g. cooperatives or market chains are male-dominated).
Works well with/ brings synergies with practice…	‣ IPM, soil and water conservation, conservation of local crop varieties and livestock breeds, agronomic practices (crop rotation, intercropping, organic soil amendment)
Does not work well/ competes with practice…	No direct competition.

6.8 Intercropping

Intercropping is an agricultural practice where two or more crops are grown together on the same field at the same time. The goal is to make better use of resources like sunlight, water, and nutrients, while also improving yields, controlling pests and weeds naturally, and reducing the risk of crop failure.

Crops can be grown together in different patterns, the most common ones being alternating rows or strips, or as mixed intercropping without a specific pattern, either on flat land or on mounds (a traditional practice in parts of sub-Saharan Africa). Common intercropping combinations include cereals and legumes.

6.8 Intercropping

Further short description	Depending on their growth habit, different crops can be planted either at the same time, or at different times (in a relay pattern, whereby a second crop is planted before the first crop is harvested). Like crop rotation, intercropping is a traditional agricultural practice used in most parts of the world, and therefore the specific agronomic practices (what crops to plant / sow when and at what spacing) vary significantly. A specific type of intercropping is "Push–pull", which was developed to manage pests and improve soil fertility. It involves "pushing" insect pests away from the main crop (such as maize) by interplanting repellent species like des-modium between crop rows, and "pulling" pests towards trap plants such as Napier or Brachiaria grass grown around the field's edges. Examples for agronomic guidance on intercropping include: ‣ Paparella et al. (2025): Intercropping ‣ Baijukya et al. (2016): Maize-legume cropping guide. Africa Soil Health Consortium, Nairobi. ‣ Specifically on push-pull: ICIPE 2015, The 'Push–Pull' Farming System: Climate-smart, sustainable agriculture for Africa. ‣ A useful generic guide, explaining in detail the principles of intercropping, is Sullivan 2003, Intercropping principles and production practices.

Context / suitability	
Farm or landscape level	Plot level, farm level
Relevant production system (FAO classification)	Rainfed crops, irrigated crops, mixed systems

6.8 Intercropping

Resource requirements/cost implications

Land and other natural resources	The requirements are similar to those needed for growing the same crops separately. Natural resources need to cater for the needs of the different types of plants grown together: ‣ Soil fertility: Soils must support the nutrient needs of multiple crop species simultaneously, often requiring a broader nutrient base. ‣ Moisture availability: Greater or more evenly distributed soil moisture may be needed to sustain multiple crops with differing water demands. ‣ Light distribution: Sufficient sunlight must reach all crop layers, particularly in mixed-height systems (e.g. maize and beans). ‣ Rooting space: More extensive or deeper soil profiles may be needed to avoid root competition between species. ‣ Pollinator and beneficial insect habitats: A more diverse ecological environment encourages pollination and natural pest control, essential for mixed cropping. ‣ Microbial and soil biota diversity: Richer biological activity helps manage nutrient cycling between different plant types.
(financial and physical) capital/implements	Depends on the specific crops to be grown, whether seed is purchased or kept from own harvests, and what other types of inputs are being used. Intercropping can be more capital intensive than growing only one crop, if additional inputs or implements need to be purchased for the additional crop.
Labour (qualitative and quantitative/skills etc.)	‣ Knowledge of suitable intercropping patterns (to avoid competition and maximise synergies) is required, e.g. to plan for beneficial companion plants that can optimise pest and disease control, and nutrient management. ‣ Intercropping can increase labour requirements, particularly for weeding, and make the introduction of mechanisation more challenging. However, the overall impact on labour needs is complex and varies, depending on factors such as the specific crops, agronomic practices used, and the availability of machinery. ‣ Relay cropping can potentially reduce labour peaks, spreading labour requirements over a longer period of time.

6.8 Intercropping

Expected impacts on biodiversity	
Detailed description of impacts on biodiversity	**Species diversity** ‣ Intercropping tends to increase species richness (number of species) and species evenness (relative abundance). It also supports higher invertebrate, bird, and microbial diversity by creating complex habitats and varied food sources. Intercropping systems can enhance resource availability through niche complementarity (‣ Brooker et al. 2015). ‣ Intercropping supports synergies, such as nitrogen fixation (e.g., legumes), pest suppression (via trap or repellent crops), and pollinator support. **Ecosystem diversity** ‣ Widespread adoption of intercropping contributes to heterogeneous agricultural landscapes by creating a mosaic of different species and cropping arrangements. It reduces the spatial dominance of monocultures, supporting habitat connectivity and ecological corridors for wildlife and beneficial organisms (‣ Sirami et al. 2019). ‣ Intercropping is often used in agroforestry systems, home gardens, or mixed farming systems that contribute to landscape complexity.

Complementarity and competition	
Co-benefits and trade-offs for climate change mitigation and adaptation	**Adaptation** ‣ Mixing crops with different growth cycles, root depths, and water use spread risk and can stabilise yields in the face of erratic rainfall or temperature shocks (e.g. maize-legume systems can buffer maize yield losses during dry spells thanks to legumes' shorter growing period and better drought tolerance). ‣ Crop combinations allow for more complete use of water, light, and nutrients, which becomes crucial under climate-induced stress (e.g. sorghum-pigeon pea systems exploit different rooting depths and canopy structures, reducing competition and improving resilience). ‣ Increased plant diversity disrupts pest cycles and reduces reliance on pesticides, which are less effective under rising temperatures and evolving pest pressures. ‣ Intercropping can contribute to climate change adaptation by increasing diversity and reducing risk for smallholder farmers.

6.8 Intercropping

continued Co-benefits and trade-offs for climate change mitigation and adaptation	**Mitigation** ‣ Legume intercrops fix nitrogen, reducing dependence on synthetic fertilisers, and their ground cover protects soils from erosion and moisture loss. Intercropping can reduce the need for fertiliser application, thus contributing to climate change mitigation.
Co-benefits and trade-offs for water quality and quantity:	Intercropping can enhance water quality and improve water-use efficiency, provided crop combinations are carefully selected and managed to minimise competition. Systems that pair legumes with cereals or deep- and shallow-rooted crops tend to perform best under variable rainfall conditions. **Benefits** Water quality ‣ Reduced soil erosion and runoff: Continuous vegetative cover minimises the loss of topsoil and associated nutrients or agrochemicals into waterways. ‣ Lower nutrient leaching: Diverse root systems capture residual nutrients at different depths, reducing nitrate and phosphate leaching into groundwater. ‣ Improved filtration and water retention: Enhanced soil structure and organic matter increase infiltration and natural filtration of rainwater, improving groundwater quality. ‣ Reduced pesticide reliance: Crop diversity often decreases pest pressure, potentially reducing the use of chemical inputs that could contaminate water sources. Water quantity and efficiency ‣ Better water-use efficiency: Complementary crops (e.g. deep- and shallow-rooted species) utilise soil moisture more completely, improving overall water productivity. ‣ Enhanced soil moisture conservation: Canopy cover reduces evaporation and maintains cooler soil temperatures, especially valuable in sub-tropical dry seasons. ‣ Improved infiltration: Varied root structures create channels that increase water percolation and reduce surface water loss.

6.8 Intercropping

continued Co-benefits and trade-offs for water quality and quantity:	**Potential challenges or trade-offs** ‣ Competition for water: In dry or semi-arid zones, crops with overlapping water needs can compete, leading to moisture stress if irrigation or rainfall is insufficient. ‣ Complex irrigation management: Different water requirements among intercrops may complicate scheduling or distribution of irrigation. ‣ Risk of localised water depletion: If dense intercrops are used without adequate spacing or mulching, they may increase total evapotranspiration.
Co-benefits and trade-offs for soil health:	Intercropping generally enhances soil health through improved fertility, structure, and biological activity – provided crops are well chosen and managed to balance competition and resource sharing. **Benefits** ‣ Improved soil fertility: Leguminous intercrops (e.g. cowpea, groundnut) fix atmospheric nitrogen, enriching the soil for subsequent crops. ‣ Enhanced nutrient cycling: Different root systems exploit various soil layers, reducing nutrient depletion and improving nutrient use efficiency. ‣ Reduced soil erosion: Continuous ground cover from multiple crops protects the soil from heavy rainfall and surface runoff, common in tropical climates. ‣ Better soil structure: Varied root systems promote aggregation and porosity, improving water infiltration and root aeration. ‣ Increased organic matter: Greater biomass input from roots and crop residues adds carbon to the soil, enhancing microbial activity. ‣ Suppression of soil-borne pests and diseases: Crop diversity interrupts pest life cycles and reduces the build-up of soil pathogens. ‣ Greater microbial and faunal diversity: A mix of crops supports a wider range of beneficial soil organisms, vital for nutrient transformation and decomposition.

6.8 Intercropping

continued Co-benefits and trade-offs for soil health:	**Potential challenge or trade-offs** ‣ Competition for soil nutrients and moisture: Poorly matched crop combinations can lead to nutrient imbalances or reduced yields if one species dominates. ‣ Complex nutrient management: The presence of multiple crops may complicate fertiliser planning and make it harder to meet each crop's specific needs. ‣ Possible depletion of certain micronutrients: Continuous intercropping without rotation or replenishment can selectively exhaust trace elements.
Co-benefits and trade-offs for productivity:	Intercropping generally increases overall system productivity, making it a valuable practice for smallholder and sustainable farming systems. However, the magnitude of benefit depends strongly on crop compatibility, management skill, and local environmental conditions. **Benefits** ‣ Higher overall yield per unit area: Intercropping often produces a greater total output (combined yield of all crops) than monocropping, due to more efficient use of land, light, water, and nutrients. A Land Equivalent Ration (LER) greater than 1 indicates a yield advantage over monoculture, showcasing the spatial and temporal complementarity effects that intercropping systems can offer. For example, a study on maize-pigeonpea intercropping showed an average LER greater than 1, meaning it required less land to produce the same amount of food compared to monocultures (‣ Toker et al. 2024). ‣ Improved resource-use efficiency: Complementary crop combinations (e.g. deep- and shallow-rooted species) make better use of available soil nutrients and moisture. ‣ Yield stability and risk reduction: If one crop fails because of drought, pests, or disease, the other may still produce a harvest, providing resilience against climatic variability common in tropical zones. ‣ Enhanced biological nitrogen fixation: Leguminous intercrops (e.g. cowpea, groundnut) contribute nitrogen to the system, boosting the productivity of non-leguminous companions like maize or sorghum. Studies have shown productivity increases of cereal-legume intercropping systems as compared to monocultures, e.g. for sub-Saharan Africa (a systematic review of cowpea-cereal systems (‣ Namatsheve, et al. 2020). ‣ Improved pest and disease management: Crop diversity can reduce pest outbreaks, indirectly supporting higher and more stable yields. "Push-pull" is particularly suitable for this, as it not only reduces pest damage (e.g. from stem borers and fall armyworm) but also enhances soil nitrogen, suppresses weeds like Striga, and improves overall productivity – making it a highly effective and sustainable form of intercropping tailored to tropical conditions.

6.8 Intercropping

continued Co-benefits and trade-offs for productivity:	**Potential challenge or trade-offs** ‣ Competition between crops: Poorly matched species may compete for light, nutrients, or water, leading to lower yields for one or more components. ‣ Complex management requirements: Intercropping systems require greater knowledge and careful planning of planting density, timing, and nutrient application. ‣ Harvesting difficulties: Mixed cropping can complicate harvesting and post-harvest handling, particularly when crop maturity differs. ‣ Possible reduction in individual crop yield: While total system yield is often higher, the yield of each single crop may be lower compared with monocropping.
Co-benefits and trade-offs for in-come:	Intercropping generally enhances household income and financial resilience, particularly for smallholder farmers who rely on diverse, risk-reducing production systems. The economic advantage is strongest when crops are well matched agronomically and commercially, and when markets for all intercrop components are accessible. **Benefits** ‣ Higher overall returns per unit area: Intercropping often produces more total output (combined yield value) than monocropping, leading to greater gross income from the same land area. This is particularly important for smallholder farmers with small plots. For an inspiring example from India, see ‣ THIS video[39] about the ATM approach (Any Time Money) from Andhra Pradesh, India. ‣ Income stability and risk reduction: The diversity of crops buffers farmers against total crop failure due to pests, disease, or erratic rainfall, providing a more consistent income over time. ‣ Diversified market opportunities: Multiple crops can be sold at different times or to different markets, improving cash flow and reducing dependence on a single commodity. By diversifying the range of crops that can be sold, farmers reduce the risk of total crop failure and associated income losses. ‣ Reduced input costs: Improved nutrient cycling (e.g. through legume nitrogen fixation) and pest suppression can lower fertiliser and pesticide expenses. ‣ Extended employment and food supply: Staggered planting and harvesting create more consistent labour demand and household food availability throughout the year. ‣ Potential for value addition: Intercropped produce can support diversified processing or local sales (e.g. cereals and legumes sold together or in rotation-linked markets).

39 Scroll down the page to the video entitled “From Dryland to Year-Round Harvests with Natural Farming – The Incredible Journey of Narayanappa”.

6.8 Intercropping

continued Co-benefits and trade-offs for income:	**Potential challenge or trade-offs** ‣ Lower yield of main cash crop: If not properly managed, competition between crops can reduce the marketable yield of the dominant species, affecting short-term income. ‣ Higher labour requirements: Intercropping systems are often more labour-intensive, increasing production costs where labour is scarce or expensive. ‣ Complexity in marketing: Managing and selling multiple crops can be challenging, especially where market infrastructure is weak or price information is limited. ‣ Delayed returns: Some intercrops mature later, which may postpone income compared with fast-harvesting monocultures.
Co-benefits and trade-offs for food and nutrition security:	Intercropping increases crop diversity, which generally enhances household and community nutrition by promoting dietary diversity, a more balanced nutrient intake, and food security. But this benefit only occurs if at least some of the diversified crops are consumed by the farming household, or crops are sold, and the income is used to purchase nutritious foods. The strongest nutritional gains occur when systems combine cereals or tubers with legumes, fruits, or vegetables, and when households consume part of the produce rather than selling it all. The potential of intercropping non-food cash crops (e.g. cotton) with nutritious food and fiber crops (e.g. legumes) could be specifically highlighted regarding nutrition co-benefits (e.g. potential to enhance workforce nutrition). Recent studies suggest that intercropping could be a feasible, eco-friendly, low-cost, and short-term approach for improving the nutritional quality and yield of crops sustainable way through nature-based biofortification (‣ Ebbisa 2022). **Benefits** ‣ Improved dietary diversity: Intercropping produces a range of food types (e.g. cereals, legumes, vegetables), increasing the availability of carbohydrates, proteins, vitamins, and minerals for farm households. ‣ Enhanced protein intake: Including legumes (such as cowpea, pigeon pea, or groundnut) improves the protein quality of diets dominated by starchy staples like maize, cassava, or millet. ‣ Greater micronutrient availability: Diverse crop combinations provide essential micronutrients such as iron, zinc, and vitamin A, which are often limited in monoculture-based diets. ‣ Year-round food supply: Staggered planting and harvesting across intercrops extend the period of food availability, reducing seasonal hunger common in tropical regions.

6.8 Intercropping

continued Co-benefits and trade-offs for food and nutrition security:	‣ Improved household food security: By reducing the risk of total crop failure, intercropping ensures more reliable access to food for both consumption and sale. ‣ Enhanced soil fertility and crop nutrient content: Legume-based systems improve soil nitrogen and organic matter, which can increase the nutrient density of subsequent crops. **Potential challenge or trade-offs** ‣ Reduced focus on high-value or nutrient-dense crops: If intercropping prioritises staple yields over vegetables or pulses, nutritional benefits may be limited. ‣ Possible nutrient dilution: When one crop dominates the system, the relative contribution of nutrient-rich intercrops may decline. ‣ Post-harvest and storage challenges: Managing multiple crops can complicate processing and preservation, potentially leading to nutrient losses.
Co-benefits and trade-offs for gender equity:	Intercropping can promote gender equity by broadening women's economic and decision-making roles and enhancing household nutrition and resilience. However, the extent of benefit depends on social structures and access to resources – equitable land rights, training, and market access are essential for intercropping to deliver lasting gender-equitable outcomes. **Benefits** ‣ Greater inclusion of women in decision-making: Intercropping systems often involve multiple crops, some of which (e.g. legumes, vegetables) are traditionally managed by women, increasing their participation in farm planning and management. ‣ Enhanced income opportunities for women: Women frequently control the sale of secondary or intercrops such as pulses, leafy greens, or spices, improving their access to and control over income. ‣ Improved household nutrition: Since women are often responsible for food preparation and child nutrition, the dietary diversity resulting from intercropping directly supports their caregiving role and family health. See ‣ Owoputi et al. 2022 for an example from Nigeria. ‣ Year-round labour and income balance: Staggered planting and harvesting schedules can distribute labour and income more evenly, helping women manage workloads and cash flow throughout the year. ‣ Capacity-building and knowledge sharing: Intercropping promotes skill development in crop management, seed selection, and soil care, which can strengthen women's technical expertise and status in farming communities. ‣ Strengthened resilience and autonomy: By diversifying production and reducing risk, intercropping can give women greater security and flexibility in managing small plots or home gardens.

6.8 Intercropping

continued Co-benefits and trade-offs for gender equity:	**Potential challenge or trade-offs** ‣ Increased workload and labour burden (added responsibilities, invisible and unpaid labour). ‣ Unequal access to resources and services (land, water, finance, technology). ‣ Gendered control over benefits due to male dominance in high-value enterprises and unequal decision-making. ‣ Cultural and institutional barriers (social norms and taboos) and the risk of exclusion from innovation (if e.g. cooperatives or market chains are male-dominated).
Works well with/ brings synergies with practice…	‣ Crop rotation is complementary to intercropping, benefiting soil health and productivity. ‣ Agroforestry systems often involve rows of trees, with arable crops in between – a specific type of intercropping. ‣ IPM is applicable to all cropping systems – intercropping can work synergistically with IPM by using push-pull technologies. ‣ Use of indigenous crop varieties / landraces can enhance the benefits from intercropping, provided the selected varieties are well suited for the selected intercropping pattern.
Does not work well/ competes with practice…	None

6.9 Integrated Pest Management

Integrated Pest Management (IPM) is an ecologically based approach to controlling pests that combines multiple strategies to keep pest populations below economically damaging levels, while minimising risks to people, crops, livestock, and the environment. In tropical and sub-tropical regions, where pest pressure is often high due to warm, humid conditions and year-round crop growth, IPM aims to create a balanced agroecosystem that naturally suppresses pests.

6.9 Integrated Pest Management

Further short description	**Key components:** ‣ The "hierarchy of IPM" describes the guiding principles from prevention (sanitation, resistant varieties, exclusion), followed by monitoring and identification, then cultural/physical controls (traps, barriers), biological controls (natural enemies), and finally, chemical controls (pesticides) as a last resort, ensuring effective management with minimal environmental impact. ‣ **Prevention and cultural practices**: Crop rotation to break pest and disease cycles, intercropping and polycultures to reduce pest spread, use of resistant or tolerant varieties suited to local climates, adjusting planting dates to avoid peak pest periods, soil and water management to maintain plant health, use of bio-stimulants to strengthen plants, use of push-pull strategies to repel pests from crops and attract them to other plants (‣ Cook et al. 2007). ‣ **Monitoring and identification**: Regular field scouting and trapping to identify pest species and natural enemies, use of economic threshold levels (ETLs) to decide when intervention is necessary, climatic monitoring (temperature, humidity, rainfall) to predict pest outbreaks. ‣ **Biological control**: Conservation and release of natural enemies; use of entomopathogenic fungi, bacteria, or viruses; use of allelopathy (biopesticides released by an organism that have an inhibitory or stimulatory effect on neighbouring organisms – ‣ Kiely et al. 2023); promotion of habitat diversity to sustain beneficial organisms. ‣ **Mechanical and physical controls**: Hand-picking, trapping, and barriers (e.g. insect-proof nets); tillage, flooding, or solarisation to reduce pest stages in the soil. ‣ **Chemical control (as last resort)**: Targeted, selective pesticides used only when pest populations exceed ETLs; preference for biopesticides or botanical extracts (e.g. neem, pyrethrum); rotation of chemical classes to prevent resistance.

6.9 Integrated Pest Management

	Guides and resources: ‣ Vaagt et al. 2018: ‣ Integrated Pest Management in international cooperation projects with partner countries A Guideline ‣ FAO 2025: ‣ Guidance on integrated pest management for the world's major crop pests and diseases. ‣ ‣ FAO IPM site with links to a range of publications ‣ ‣ Pesticide Action IPM site – also with links to resources ‣ Paparella et al. 2025: ‣ Integrated Pest Management ‣ Paparella et al. 2025: ‣ Biocontrol

Context / suitability	
Farm or landscape level	Plot level, farm level, landscape level
Relevant production system (‣ FAO classification)	Irrigated crops, rainfed crops, mixed systems

Resource requirements/cost implications	
Land and other natural resources	Successful IPM requires healthy, biodiverse land with good soil and water management, natural habitats for beneficial species, and locally available biological and botanical resources. These natural assets form the ecological foundation that allows IPM to function sustainably, reducing reliance on synthetic pesticides while maintaining productive farming systems. **Land requirements** ‣ Healthy, fertile soils promote vigorous crop growth, making plants more resistant to pest and disease attack. IPM benefits from heterogeneous landscapes – including field margins, hedgerows, buffer strips, and uncultivated patches – that serve as refuges for natural enemies. Land must allow crop rotation and intercropping, which break pest life cycles and enhance biodiversity. ‣ Water management is crucial, since standing water or excessive moisture can trigger pest and disease outbreaks. Good drainage and irrigation systems help maintain crop health.

6.9 Integrated Pest Management

continued Land and other natural resources	**Other natural resources** ‣ The foundation of IPM is the conservation and use of biodiversity. Beneficial insects, soil organisms, birds, and microbial life all help regulate pest populations naturally. Non-crop vegetation provides food and shelter for predators. Maintaining forest patches, windbreaks, or live fences supports this balance. Reliable information about temperature, humidity, and rainfall is vital for pest forecasting and timing interventions. Clean water is required for preparing biopesticides, irrigation, and maintaining crop health. Many IPM practices use natural materials – such as neem extracts, compost, or biological control agents – which depend on locally available plants or organisms.
(financial and physical) capital/implements	IPM requires moderate capital investment in monitoring, biological inputs, and irrigation infrastructure, along with steady financial resources for training, coordination, and maintenance. While the upfront costs can be higher than conventional pest control, IPM delivers long-term savings, environmental protection, and stable yields through reduced chemical dependence and improved ecosystem balance. **Capital resources (physical and material inputs)** IPM is knowledge- and management-intensive, rather than purely input-intensive, but it still requires some basic capital investments to implement effectively: ‣ **Infrastructure and equipment**: Field monitoring tools (insect traps, hand lenses, sweep nets); storage and handling facilities (safe storage for biological agents, botanical pesticides, and tools; equipment for composting or preparing biopesticides); irrigation and drainage systems (essential for managing moisture-related pests and diseases in humid climates); protective and application equipment / sprayers), transportation equipment (for monitoring). ‣ **Biological and technical inputs**: Biocontrol agents (purchase or rearing of beneficial insects, microbial inoculants, or biopesticides), botanical pesticide preparation equipment (simple processing units for neem, chilli, or other plant-based extracts), seeds of pest-resistant crop varieties (often locally available but may require initial purchase). ‣ **Financial resources**: Initial investment for programme setup (e.g. setting up monitoring and diagnostic systems, building nurseries or bio-labs for rearing beneficial organisms; training programs for farmers, extension officers, and local technicians) may be required. Operating costs include regular field monitoring, record-keeping, and pest scouting labour and purchase of biocontrol agents, botanical extracts, or selective pesticides.

6.9 Integrated Pest Management

Labour (qualitative and quantitative/skills etc.)	IPM tends to be labour- and knowledge-intensive rather than input-intensive, especially during the early adoption stages. Regular, skilled labour for monitoring and cultural management, supported by strong ecological knowledge, technical skills, and experience in adaptive decision-making is needed. Farmers need to understand pest ecology, apply control measures safely, and coordinate with their communities. Over time, this builds self-reliant, knowledge-driven farming systems that reduce dependence on chemicals and enhance resilience. **Type and intensity of labour** ‣ Frequent inspection of crops to identify pest and natural enemy populations - often weekly or bi-weekly during the growing season. Labour demands peak during planting and early crop growth, when pest monitoring and preventive actions are most critical. ‣ Labour for hand-picking pests, installing traps, pruning infested plants, and maintaining field hygiene. Labour needed for crop rotation, intercropping, mulching, cover cropping, and timely planting/harvesting. Labour for collecting and analysing pest monitoring data to guide decisions. **Labour source** ‣ Typically, labour would be family-based on small farms, but larger or cooperative farms may need trained extension agents, or community pest scouts. Gender roles often influence labour division – for example, women frequently engage in monitoring and botanical pesticide preparation. **Knowledge, skills, and experience requirements** IPM depends heavily on knowledge-based decision-making: ‣ Ecological and agronomic knowledge (understanding of crop–pest–natural enemy relationships; recognition of beneficial insects vs. harmful pests; knowledge of pest life cycles, disease vectors, and climatic influences on pest outbreaks). ‣ Technical and analytical skills (ability to monitor and identify pests and natural enemies accurately in the field; threshold-based decision-making, skill in preparing and applying biological or botanical controls correctly; understanding safe pesticide handling and resistance management principles when chemical control is necessary). ‣ Planning and management skills (seasonal planning for crop rotation, planting dates, and pest prevention; ability to integrate multiple pest control strategies in a coordinated way; record-keeping and data interpretation for continuous improvement). ‣ Communication and community skills (collaboration with neighbours or farmer groups for area-wide pest control; sharing observations and learning through farmer field schools or extension networks).

6.9 Integrated Pest Management

Expected impacts on biodiversity

Detailed description of impacts on biodiversity	In biologically rich regions, IPM generally enhances biodiversity across genetic, species, and ecosystem levels – provided it is implemented ecologically and locally adapted. It helps maintain functional biodiversity, essential for natural pest regulation and long-term sustainability. However, if implemented superficially or with poor ecological oversight (e.g., focusing only on biocontrol or resistant varieties), IPM can inadvertently reduce genetic and species diversity. **Genetic diversity** ‣ IPM encourages the use of locally adapted and pest-resistant varieties, which helps maintain traditional landraces and intra-species variation in tropical regions. Less frequent chemical use decreases the risk of pest resistance evolution and preserves genetic variability within pest populations and natural enemies. By integrating resistant varieties, biological control, and cultural methods, IPM supports diverse genetic pools useful for future breeding programmes. ‣ Potential negative impacts: Over-reliance on specific resistant varieties can lead to genetic uniformity, increasing vulnerability to new pest strains or diseases. Biocontrol introductions may affect the genetic integrity of native populations of related species. **Species diversity** ‣ IPM results in reduced pesticide mortality among non-target organisms (pollinators, decomposers, natural enemies) and promotes the conservation and augmentation of predators, parasitoids, and beneficial microbes, restoring species balance in agroecosystems. ‣ Through intercropping, mixed cropping, hedgerows, and cover crops, IPM increases plant and insect species richness. Reduced chemical inputs and use of organic amendments foster soil microbial diversity, which enhances nutrient cycling and pest suppression. ‣ Potential negative impacts: Poorly managed biological control introductions can sometimes displace native species, become invasive or cause unintended predation. Intensive monocultures using IPM principles may still limit species diversity compared to natural habitats, especially when landscape heterogeneity is low. Occasional selective pesticide use, even in IPM, can still harm sensitive non-target species if misapplied.

6.9 Integrated Pest Management

continued Detailed description of impacts on biodiversity	**Ecosystem diversity** ‣ Diverse agroecosystems under IPM maintain natural pest regulation, pollination, and nutrient cycling services. Maintaining buffer zones, wild refuges, and non-crop vegetation supports multiple interconnected habitats. Reduced pesticide runoff and residues protect aquatic and terrestrial ecosystems, which is particularly valuable in humid tropical environments. IPM encourages land-use mosaics - combining crops, trees, and natural vegetation, which strengthen ecosystem connectivity. ‣ Potential negative impacts: Conversion of natural habitats for IPM-compatible agriculture can still fragment ecosystems. If external biological control agents or exotic plants are used indiscriminately, they may disrupt native ecosystem dynamics. In poorly regulated systems, overexploitation of natural pest predators can reduce local ecological integrity.

Complementarity and competition

Co-benefits and trade-offs for climate change mitigation and adaptation	IPM contributes to climate-resilient agriculture by building healthy, diverse, and adaptive farming systems. Its principles – ecological balance, reduced chemical dependence, and improved soil and water management – help farmers adapt to and mitigate the effects of a changing climate. To maximise its climate benefits, IPM must be integrated with broader agroecological and climate-smart practices, such as precision nutrient management, water conservation, and landscape-level biodiversity planning. **Adaptation** ‣ IPM diversifies cropping systems, which increases resilience to climate shocks such as droughts, floods, and pest outbreaks. Climate change alters pest ranges, life cycles, and severity – IPM's monitoring, forecasting, and threshold-based decisions help anticipate and manage emerging pests. The use of biological control instead of chemicals supports adaptive, self-regulating pest control systems that function under diverse climatic conditions. ‣ Agronomic practices for IPM like mulching, reduced tillage, and cover cropping improve soil moisture and fertility, helping crops withstand heat and water stress. IPM promotes the use of resistant/tolerant crop varieties, maintaining yield stability even as pests and climate change. ‣ Farmers trained in IPM learn to observe, analyse, and adjust, fostering adaptive capacity at the farm and community level – a key element of climate resilience. ‣ Potential negative impacts: Increased labour or knowledge demands can limit adoption among resource-poor farmers facing multiple climate stresses. Changing pest patterns due to warming may outpace local IPM knowledge, requiring ongoing research and training. Some biological control agents or crop varieties may become less effective under altered climatic conditions.

6.9 Integrated Pest Management

continued Co-benefits and trade-offs for climate change mitigation and adaptation	**Mitigation** ‣ IPM reduces reliance on synthetic pesticides and fertilisers, whose manufacturing and transport contribute significant CO_2 and N_2O emissions. Fewer chemical applications also reduce fuel use for spraying operations. ‣ IPM's emphasis on organic matter management, composting, and cover cropping enhances soil carbon storage, particularly valuable in degraded tropical soils. Healthy soils act as carbon sinks, mitigating CO_2 levels. By promoting efficient nutrient cycling and organic inputs, IPM helps minimise excess nitrogen that would otherwise volatilise as N_2O (a potent greenhouse gas). ‣ Many IPM systems integrate trees or perennial vegetation for habitat management, contributing to carbon sequestration and microclimate regulation. By maintaining biodiversity and reducing pollution, IPM sustains ecosystem functions that underpin long-term carbon and nutrient cycles. ‣ Potential challenges and trade-offs: Improper handling of compost or manure can release methane (CH_4) or nitrous oxide (N_2O) if decomposition occurs anaerobically in humid tropical climates.
Co-benefits and trade-offs for water quality and quantity:	IPM influences water systems both directly (through reduced agrochemical use and improved field management) and indirectly (through changes in cropping systems, soil health, and vegetation cover). IPM supports cleaner surface and groundwater systems and enhances soil – water interactions that sustain agricultural productivity. As always, some risks exist if practices are mismanaged. **Water quality** ‣ A core principle of IPM is to minimise pesticide use and rely on biological or cultural methods. This significantly reduces pesticide runoff, leaching, and residues in surface and groundwater. Biodegradable biopesticides (e.g., neem) break down quickly and have minimal aquatic toxicity. ‣ IPM encourages balanced fertilisation and organic soil amendments, reducing nutrient leaching in water bodies. Practices such as mulching, cover cropping, and organic matter addition improve infiltration and reduce sedimentation in nearby streams. ‣ Potential challenges and trade-offs: Overuse or poor formulation of botanical or microbial products can introduce organic pollutants or pathogens into water systems. IPM does not completely eliminate chemical pesticides – misapplication can still cause acute contamination events. If organic inputs are over-applied, nitrogen and phosphorus leaching may increase.

6.9 Integrated Pest Management

continued Co-benefits and trade-offs for water quality and quantity:	**Water quantity** ‣ Healthier soils under IPM resulting from practices such as mulching, retain more moisture, reducing irrigation needs and helping to maintain local water tables. IPM often integrates drought-tolerant and pest-resistant varieties, which require less water to maintain productivity under pest stress. ‣ **Potential challenges and trade-offs**: Water used for biopesticide preparation or cleaning equipment can increase total on-farm water use slightly. Some IPM strategies involve extra vegetation or trap crops that may compete for water, especially in dry tropical regions.
Co-benefits and trade-offs for soil health:	IPM, being ecologically oriented, generally improves soil health by reducing chemical inputs, promoting biological activity, and enhancing organic matter management. However, outcomes depend on how IPM practices are implemented. Benefits include: ‣ Improved biological activity and diversity: Reduced pesticide use lessens harm to soil biota (microbes, fungi, earthworms, arthropods), allowing natural soil food webs to recover. IPM favours organic amendments and biological control agents, which increase microbial biomass and enzymatic activity, vital for nutrient cycling. Enhanced soil biodiversity improves pest suppression, as beneficial microbes compete with soil-borne pathogens. ‣ Enhanced organic matter and nutrient cycling: Agronomic practices commonly used in IPM such as composting, mulching, and green manuring increase soil organic carbon and long-term fertility. ‣ Improved soil structure and moisture retention: With less reliance on heavy chemical treatments and more on organic matter, IPM promotes aggregate stability and water infiltration. ‣ Reduced soil contamination: Fewer synthetic pesticides and herbicides mean lower residues and less accumulation of toxic compounds in soil. Reduced runoff and leaching protect both topsoil fertility and subsurface microbial activity. **Potential challenge or trade-offs** ‣ Excessive application of manure or compost may lead to nutrient imbalances or anaerobic soil conditions in humid climates. Inappropriate release of exotic soil microbes or predators may disrupt native soil microbial communities. Even when used sparingly, broad-spectrum or residual pesticides can temporarily reduce beneficial soil fauna and microbial activity. ‣ Some IPM methods (e.g. soil solarisation, flooding) can suppress pests but may also disrupt beneficial soil organisms or alter pH temporarily. If farmers adopt only the pest control components (e.g., biopesticides) but neglect soil-building practices, soil health benefits are minimal.

6.9 Integrated Pest Management

Co-benefits and trade-offs for productivity:	IPM aims to maintain crop yields by keeping pest populations below economic thresholds, while preserving ecological balance. IPM sustains - and often improves - productivity in tropical and sub-tropical agriculture by reducing pest losses, protecting ecosystem functions, and improving resource efficiency. Its effects on productivity are mostly positive - especially over the medium and long term - but they can vary depending on farmer capacity, climate, and implementation quality. The practice requires time, knowledge, and ecosystem integrity to reach full potential. • More stable yields: IPM reduces yield losses by keeping pest populations in check through continuous monitoring and early intervention and helps stabilise production across seasons. • Improved crop health and vigour: Reduced pesticide exposure protects beneficial soil and pollinator species, leading to better pollination, nutrient uptake, and growth. Healthier soils under IPM support stronger root systems and improved nutrient efficiency, translating to higher yield potential. • Long-term productivity through soil and ecosystem health: Practices like composting and reduced tillage improve soil structure, fertility, and water retention, sustaining productivity over time. • Cost-effective and input-efficient production: Although initial yields may match conventional systems, IPM often leads to higher net productivity when accounting for lower input costs (chemicals, fuel) and reduced pest resistance. **Potential challenge or trade-offs** • When shifting from conventional pesticide-based systems to IPM, farmers may experience temporary yield dips as natural enemies and ecological balances re-establish. Without sufficient training, farmers may miss pest thresholds, leading to occasional yield losses. In areas with low literacy or limited extension support, adoption barriers can reduce productivity gains. • Under extreme pest infestations (e.g., locusts, armyworms, fruit flies), biological and cultural methods alone may not control damage fast enough. Reliance on selective pesticides is sometimes necessary, but improper timing can still lead to partial losses. • IPM relies on healthy natural enemy populations and soil biodiversity. If surrounding landscapes are degraded (e.g., monocropping), IPM effectiveness – and thus productivity – may decline.

6.9 Integrated Pest Management

Co-benefits and trade-offs for income:	IPM influences income through multiple channels by changing production costs, yield stability, market opportunities, and risk exposure. Overall, it tends to increase net income over time by reducing pesticide expenses and yield losses, though initial transition costs and knowledge barriers can temporarily reduce short-term profits. ‣ Reduced production costs (by producing inputs such as botanical extracts on-farm instead of purchasing pesticides) lead over time to higher profit margins even when yields remain constant. ‣ By preventing pest outbreaks and improving soil and plant health, IPM supports steady harvests, which translate into more consistent income and lower financial risk. ‣ IPM aligns with the principles of sustainable and eco-friendly agriculture, improving farmers' chances to access organic, fair-trade, or residue-free markets (with premium prices). ‣ Lower pesticide exposure leads to better farmer and worker health, reducing medical expenses and labour losses due to illness or poisoning. This indirect saving increases net household income. ‣ Diversified IPM systems (intercropping, agroforestry, crop rotation) generate multiple income streams and reduce vulnerability to market or pest-related losses. **Potential challenge or trade-offs** ‣ Higher short-term labour and knowledge costs for field monitoring, record-keeping, and informed decision-making. Farmers may also need to invest in training, extension services, or monitoring equipment, which adds short-term financial pressure. ‣ Transitional yield or income fluctuations leading to temporary lower income. Farmers may not benefit from subsidies on conventional inputs. Obtaining certification or quality assurance can be costly or bureaucratic, especially for smallholders without cooperative support.
Co-benefits and trade-offs for food and nutrition security:	IPM strengthens food and nutrition security primarily through reducing pest losses, improving food safety, enhancing dietary diversity, and stabilising production and incomes. These gains are especially significant for smallholder and subsistence farmers, who depend directly on their crops for food. However, full benefits require knowledge support, inclusive training, and gender-sensitive approaches to ensure that all household members benefit. ‣ Improved food availability: IPM reduces pest-induced yield losses, ensuring that more of what is grown is harvested and available for consumption or sale. Enhanced soil fertility and crop health under IPM also support sustained productivity over time, improving long-term food availability. ‣ Enhanced food safety by reducing the use of synthetic pesticides and improved nutritional quality and dietary diversity from crop diversification (e.g. inclusion of legumes and vegetables in rotation).

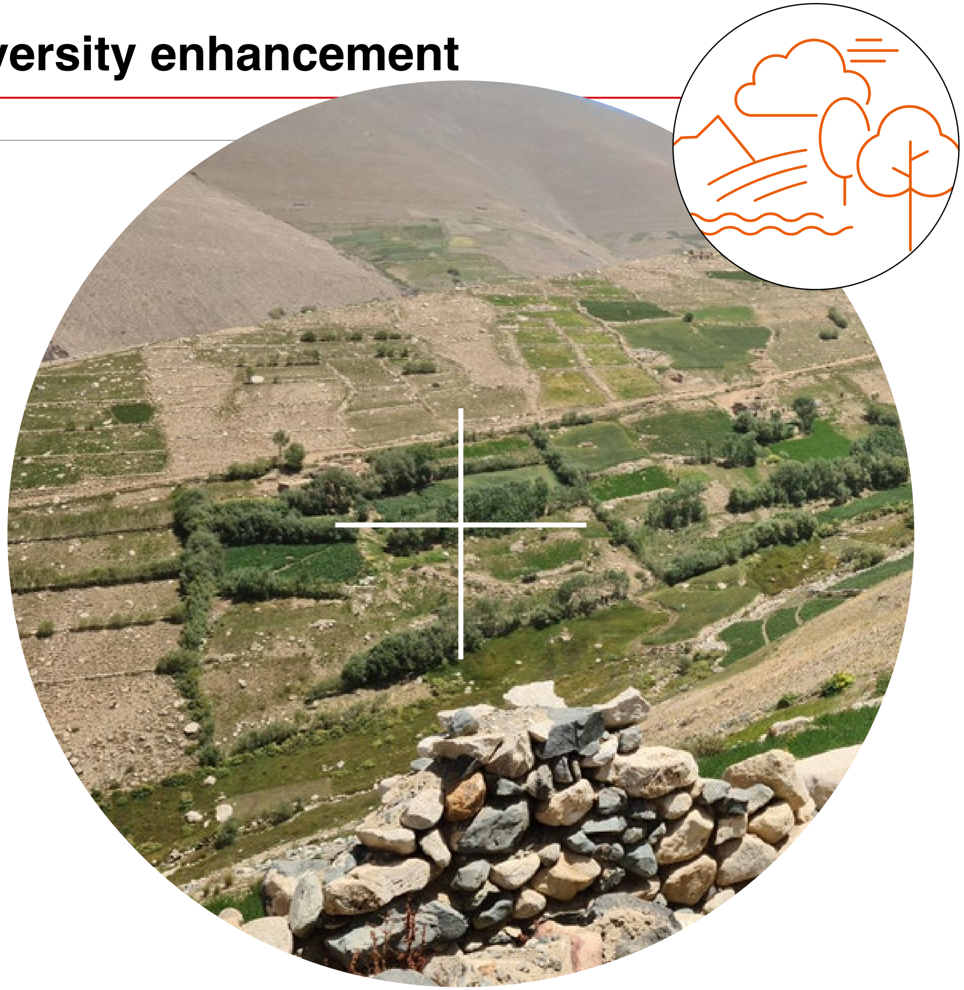
6.9 Integrated Pest Management

continued Co-benefits and trade-offs for food and nutrition security:	‣ Increased economic access to food through higher net incomes reduced need for medical treatment Greater food system stability and resilience. ‣ **Potential challenges and trade-offs** include the already mentioned transitional yield fluctuations, high labour and knowledge demands, limited short-term reach among poor households who may lack access to training and inputs, and market and policy constraints. Some IPM practices (e.g., trap crops, buffer zones) may reduce the area directly planted with staple crops.
Co-benefits and trade-offs for gender equity:	IPM changes who has knowledge, decision-making power, control of resources, and exposure to risks within farming households and communities. Because women and men often perform different agricultural roles, IPM can have both empowering and challenging effects depending on how it is introduced and supported. ‣ Reduction in health risks: By reducing pesticide use, IPM lowers women's and children's exposure to toxic chemicals – a major equity benefit since women often handle post-harvest processing, washing, or weeding near sprayed fields. ‣ Empowerment through knowledge, skills and increased control over productive resources and decisions: IPM relies on farmer education, observation, and participatory learning. These formats create opportunities for women to gain technical knowledge. As women gain knowledge, they often become more active decision-makers in production planning. In diversified IPM systems, women frequently manage and benefit from non-cash, subsistence, or value-added activities, strengthening their economic roles. ‣ Strengthened social capital and voice: Participatory learning approaches within IPM (especially through group training) foster collective action, peer learning, and leadership skills among women. These strengthen women's voice in local agricultural governance and community decision-making. ‣ Enhanced income and entrepreneurship opportunities: IPM encourages value-added and diversified enterprises – sectors where women can participate effectively. ‣ **Potential challenges and trade-offs** (if gender dimensions are ignored) include increased labour burden for women (for monitoring, hand weeding, or preparation of organic controls); exclusion from training and decision-making; unequal control over economic benefits, reduced access to productive inputs and the risk of marginalisation in commercialised IPM systems.
Works well with/ brings synergies with practice…	‣ Agroforestry, Crop rotation, Intercropping, organic soil amendment, bee keeping, integrated crop-livestock systems, conservation of local crop varieties, landscape features

6.9 Integrated Pest Management

Does not work well/ competes with practice…	None

6.10 Landscape features for biodiversity enhancement



Landscape features in this context are small- to medium-scale, semi-natural or human-made features embedded within agricultural or mixed-use landscapes that support biodiversity, ecological connectivity, and ecosystem functioning. They often serve as habitat patches, movement corridors, refugia, or buffers that maintain ecological processes within fragmented or intensively managed land.

6.10 Landscape features for biodiversity enhancement

Further short description	Whilst such features have been recognised and promoted in more developed contexts, with e.g. the European Union providing subsidies to farmers for establishing them, they have not received much attention in the agricultural development literature from the Global South. However, over the past decade, in the context of climate change adaptation, the concept of "nature-based solutions" has gained traction worldwide, with many of these solutions being applicable to agricultural landscapes. ‣ A slightly dated, but comprehensive guide to different landscape features in the tropics is ‣ Schroth et al. 2004. ‣ For guidance specifically related to ecological corridors (a particular type of landscape features) see ‣ Hilty et al. 2020. ‣ An excellent guide on the design and use of ponds, albeit in a temperate and sub-tropical context, is ‣ Biggs et al. 2024.

Context / suitability

Farm or landscape level	Plot level, farm level, landscape level
Relevant production system (‣ FAO classification)	Rainfed systems, mixed systems, livestock grassland-based systems

6.10 Landscape features for biodiversity enhancement

Resource requirements/cost implications

Land and other natural resources	Overall, successful implementation of these features relies on strategically using marginal or multifunctional land, carefully managing water and soil resources, and ensuring that ecological, social, and hydrological systems are well integrated. ‣ **Land resources**: A small proportion of the total farm area (e.g. 2–10 %) is typically sufficient, with these features best located on marginal or less productive land, such as field edges, drainage lines, slopes, corners, or riparian zones. Hedgerows and live fences usually occupy narrow strips (1–3 m wide) along boundaries or paths, while grass or buffer strips are somewhat broader, commonly three to ten metres wide, to intercept runoff and provide habitat. Riparian buffers tend to require more space, generally 10–30 metres along each side of a watercourse, to stabilise banks and maintain ecological connectivity. Ponds and small wetlands can range from a few square metres up to about one hectare, depending on topography and available water, while woodlots or tree patches may extend over several tenths of a hectare or more. Terraces, stone bunds, and earth walls occupy slender, linear zones on sloping ground, often representing two to five per cent of the total cultivated area. ‣ **Water**: Adequate water resources are essential for wetland and pond features, which depend on rainfall, surface runoff, shallow groundwater, or controlled inflows from irrigation channels or drainage ditches. Hydrological connectivity – allowing water to move naturally between fields, ditches, and wetlands – is vital, as it sustains aquatic habitats and facilitates species dispersal. ‣ **Vegetation, soil and biological resources**: Native plant species are critical for establishing resilient habitats. Soil depth, texture, and fertility determine which features are viable. Functionally diverse features also depend on biological resources, such as nearby source populations of pollinators, amphibians, and birds, which can recolonise newly established habitats.
(financial and physical) capital/implements	As this practice includes a range of different physical features, the specific financial and physical resources vary greatly, depending on the type and scale of the feature. Below is an overview of the main categories of resources that may be required. ‣ **Initial capital investment**: Required for planning, site preparation, materials, and establishment of features such as hedgerows, ponds, terraces, and buffer strips. ‣ **Land preparation and construction costs**: Small-scale earthworks for ponds, ditches, or bunds, fencing materials or posts for hedgerows and live fences, tools and equipment for planting, pruning, and maintenance, excavation, lining, or spillway materials for small ponds or wetlands.

6.10 Landscape features for biodiversity enhancement

continued (financial and physical) capital/implements	‣ **Planting and biological establishment costs**: Purchase or propagation of native seedlings, seeds, or aquatic plants; development of local nurseries for indigenous species; soil amendments, compost, or mulch to aid establishment. ‣ **Maintenance and management costs** (generally modest, but recurring): periodic pruning, mowing, or selective cutting of vegetation; control of invasive species or weeds; dredging or desilting ponds and repairing embankments or ditches; protecting features from livestock or farm machinery damage. ‣ **Opportunity costs** arise from taking land out of production – these can exceed physical establishment costs in productive zones. Financial incentives and support mechanisms can offset opportunity costs and encourage adoption, for example agri-environment schemes or biodiversity stewardship payments, payments for ecosystem services (PES) related to water, soil, or carbon benefits, access to carbon or biodiversity credit markets, grants or subsidies from government, NGOs, or private sustainability programmes. Overall, successful implementation depends on combining modest start-up capital for establishment, steady maintenance funding, and incentives or compensation for lost production.
Labour (qualitative and quantitative/skills etc.)	‣ **Local labour inputs** are central to planning, establishing, and maintaining most landscape features. Activities include site clearing, planting, staking or fencing, constructing bunds, ponds, or terraces, and subsequent maintenance. In smallholder systems, this is often family or community labour, sometimes organised through local cooperatives or collective action days. For labour-intensive features, short-term hired labour, community work groups or cash-for-work schemes are common. ‣ **Skilled labour and technical expertise** may be needed for surveying land gradients, drainage lines, and water flow for pond or buffer-strip placement; designing pond depth profiles, spillways, and embankments; selecting appropriate plant species and establishing nursery stock; and integrating features into farm layouts to avoid interference with cultivation or irrigation. ‣ **Traditional and local ecological knowledge** provides critical insight into seasonal water patterns, soil behaviour, and local species performance; traditional land-management features such as live fences, contour bunds, or small earth dams; and locally adapted management practices that can reduce establishment risk and maintenance costs.

6.10 Landscape features for biodiversity enhancement

continued Labour (qualitative and quantitative/skills etc.)	‣ **Scientific and technical knowledge** complements local expertise through understanding biodiversity functions (pollination, pest regulation, soil health, connectivity); knowledge of native species composition and habitat requirements; monitoring methods for ecological outcomes; and guidance on invasive species control, nutrient management, and hydrological balance. ‣ **Institutional and organisational knowledge** is also required to coordinate action at the landscape scale, including mapping and planning connectivity between multiple farms or watercourses; managing communal lands, drainage lines, or riparian zones across ownership boundaries; and setting local rules for grazing exclusion, fire management, or harvesting of vegetation.Communication and community skills (collaboration with neighbours or farmer groups for area-wide pest control; sharing observations and learning through farmer field schools or extension networks).

Expected impacts on biodiversity

Detailed description of impacts on biodiversity	When locally adapted species and context-specific designs are used, landscape features overwhelmingly have positive long-term impacts on biodiversity. However, achieving these outcomes requires ecologically informed planning, ongoing maintenance, and avoidance of simplified, exotic, or over-engineered designs. The greatest biodiversity gains occur where features connect existing natural habitats, restore ecological processes, and respect local hydrology and species composition. **Genetic diversity** ‣ Landscape features such as hedgerows, riparian buffers, and scattered trees act as corridors or stepping stones, facilitating gene flow between fragmented populations of plants and animals. Retention of native vegetation preserves local genetic lineages of trees, shrubs, and wild relatives of crops. Living fences can maintain a diverse mix of genetic material when they use locally adapted species rather than uniform exotics. Small wetlands and ponds support genetically distinct populations of amphibians, fish, and aquatic plants that can serve as reservoirs of local genetic variation. **Species diversity** ‣ Increased habitat heterogeneity within farmland supports a greater number of species by providing a mosaic of microhabitats (dry, wet, shaded, open). Hedgerows, buffer strips, and ponds create niches for pollinators, seed dispersers, natural pest predators, amphibians, and waterfowl. Features connecting fields to nearby forests or riparian zones enable the movement of wildlife and reduce the isolation of small populations. Enhanced species diversity can improve ecosystem resilience, pest control, and pollination, benefiting both natural and agricultural systems.

6.10 Landscape features for biodiversity enhancement

continued Detailed description of impacts on biodiversity	**Ecosystem diversity** ‣ Integration of multiple feature types - such as ponds, tree lines, grass strips, and wetlands – creates a mosaic of interconnected ecosystems within predominantly agricultural matrices. Restored hydrological elements (e.g., ponds, wetlands) enhance aquatic–terrestrial linkages, nutrient cycling, and water regulation. By reconnecting habitats and maintaining semi-natural areas, these features help sustain ecological processes such as decomposition, carbon sequestration, and soil formation. Even small-scale interventions can support ecosystem-level integrity across modified landscapes. ‣ **Potential disadvantages or trade-offs**: Although the overall effect is positive when features are well designed, several risks may arise if they are poorly planned or managed. This includes risks from introducing non-native or invasive species; edge and disturbance effects (whereby some features inadvertently increase predation or parasitism if they attract generalist predators or invasive species near sensitive habitats, and increased edge habitats may favour disturbance-tolerant species over forest specialists), and hydrological and nutrient impacts (from poorly designed ponds or buffer strips). There are also risks of displacement of local biodiversity through land-use change, in addition to short-term disturbance during establishment.

Complementarity and competition	
Co-benefits and trade-offs for climate change mitigation and adaptation	When designed with native species, balanced hydrology, and adaptive management, landscape features provide strong co-benefits for both climate adaptation and mitigation. **Adaptation** ‣ Trees, hedgerows, and other windbreaks reduce wind speed, buffer temperature extremes, and provide shade for crops and livestock. Vegetation cover moderates soil surface temperatures and reduces evapotranspiration losses, improving water-use efficiency. Terraces, bunds, and vegetated buffer strips reduce soil erosion and runoff, enhancing infiltration and soil moisture retention. Ponds and wetlands help store water for dry seasons, recharge groundwater, and reduce flood peaks. Improved soil structure enhances resilience to droughts and intense rainfall events. Integration of trees, ponds, and multi-layered vegetation provides diverse income and resource sources, reducing vulnerability to climate shocks. Corridors and semi-natural patches allow species migration and adaptation to changing climatic conditions. Restored riparian and wetland habitats act as ecological refuges during extreme events such as floods or droughts.

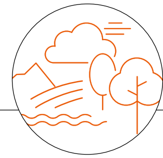
6.10 Landscape features for biodiversity enhancement

continued Co-benefits and trade-offs for climate change mitigation and adaptation	**Mitigation** • Trees, hedgerows, and agroforestry systems sequester carbon in above- and below-ground biomass. Grassy strips, cover vegetation, and wetlands increase soil organic carbon through root inputs and reduced disturbance. Wetlands and riparian buffers can store significant carbon in sediments and peaty soils when waterlogged conditions are maintained. Vegetative cover limits soil erosion and oxidation of organic matter, lowering CO_2 emissions. Improved nutrient retention in buffer strips and wetlands reduces nitrous oxide (N_2O) losses from fertiliser runoff. Rehabilitated hydrology in degraded wetlands may reduce methane (CH_4) variability through better water management. Hedgerows and woodlots can supply renewable fuelwood or construction material, reducing pressure on natural forests. Integration of nitrogen-fixing species reduces reliance on synthetic fertilisers, indirectly cutting fossil fuel-related emissions. • **Potential challenges and trade-offs**. While generally beneficial, certain climate-related risks or trade-offs can arise if features are poorly designed or managed. This could include methane emissions from wetlands and ponds, water competition and resource trade-offs, carbon loss from disturbance or mismanagement, high maintenance and input demands, and unintended climatic side effects.
Co-benefits and trade-offs for water quality and quantity:	When designed with appropriate hydrology, vegetation, and maintenance, biodiversity-friendly landscape features are a powerful tool for improving water quality, regulating flows, and increasing landscape water security in tropical and subtropical farming areas. • **Water quality**: Grass buffer strips, riparian vegetation, and contour hedgerows trap sediment, reducing soil particles entering streams and ponds. Root systems and plant litter layers filter nutrients, pesticides, and agrochemicals from surface runoff before they reach water bodies. Vegetated channels and wetlands promote biological uptake and microbial breakdown of pollutants, improving downstream water quality. Wetlands and ponds act as biogeochemical sinks, retaining or transforming nitrogen and phosphorus through plant uptake and denitrification. Vegetation slows runoff, allowing sediment-bound nutrients to settle rather than flow into rivers or reservoirs. Lower nutrient inputs mean reduced risk of eutrophication, algal blooms, and aquatic oxygen depletion. Tree cover along streams and ponds provides shade, moderating water temperature and improving habitat for aquatic species. Leaf litter and organic input support diverse microbial and invertebrate communities essential for healthy aquatic ecosystems.

6.10 Landscape features for biodiversity enhancement

continued Co-benefits and trade-offs for water quality and quantity:	• **Water quantity**: Vegetation and root systems increase soil porosity, slowing runoff and encouraging infiltration into groundwater. Terraces, bunds, and vegetated drains reduce overland flow, enhancing soil water retention and maintaining baseflows during dry periods. Wetlands, buffer zones, and farm ponds act as temporary water storage areas, absorbing heavy rainfall and reducing flood peaks. Stabilised riparian zones and vegetated ditches prevent gully formation and bank erosion, protecting watercourses from sediment surges. Retention ponds and restored wetlands provide local water sources for livestock, irrigation, or wildlife during dry spells. Improved soil moisture helps sustain crops through short droughts, enhancing landscape resilience to climate variability. • **Potential challenges and trade-offs**: Although generally positive, landscape features can cause localised water management issues if implemented without careful planning. This includes reduced water availability for downstream users, the risks of waterlogging and salinisation, accumulation of pollutants in sediments, increased methane emissions and oxygen depletion, and some vector and health risks from stagnant water.
Co-benefits and trade-offs for soil health:	Biodiversity-enhancing features typically strengthen soil structure, fertility, and resilience while reducing nutrient and sediment losses. These improvements support long-term productivity and ecosystem stability, making soils more resistant to erosion, drought, and degradation. However, to avoid negative outcomes such as nutrient competition, imbalance, or contamination, features must be properly designed for slope, soil type, and rainfall; managed through periodic pruning, sediment removal, or crop–tree spacing adjustment; and integrated within broader soil and water conservation strategies rather than treated as isolated elements. • **Reduced soil erosion and sediment loss**: Vegetative strips, contour hedgerows, terraces, and bunds slow surface runoff, protecting soil from erosion by rain and overland flow. Root systems stabilise soil structure and enhance infiltration, preventing gullying and slumping, particularly on slopes and in high-rainfall tropical areas. Retained topsoil maintains productivity, soil biodiversity, and organic matter content. • **Enhanced organic matter and carbon storage**: Leaf litter, root turnover, and decaying plant material from hedgerows, woodlots, and buffer strips add organic carbon to the soil. Over time, this builds soil organic matter (SOM), improving nutrient-holding capacity, moisture retention, and microbial activity. • **Increased soil biodiversity**: Semi-natural vegetation supports diverse soil micro- and macro-organisms, including decomposers, nitrogen fixers, and mycorrhizal fungi. Improved soil biodiversity enhances nutrient cycling, pest suppression, and resilience against degradation.

6.10 Landscape features for biodiversity enhancement



continued Co-benefits and trade-offs for soil health:	‣ **Nutrient retention and recycling**: Vegetation traps nutrient-rich sediment and runoff, reducing nutrient losses from cropland. Decomposing plant litter and deep-rooted species recycle nutrients from subsoil layers to surface horizons. In leguminous hedgerows or agroforestry systems, biological nitrogen fixation supplements soil nitrogen inputs naturally. ‣ **Potential challenges and trade-offs**: Despite clear benefits, poorly designed or mismanaged features can produce localised soil and nutrient challenges, including nutrient accumulation or imbalance, changes in soil moisture regime, and soil disturbance during establishment.
Co-benefits and trade-offs for productivity:	Implementing landscape features for biodiversity enhancement (such as hedgerows, ponds, buffer strips, terraces, and agroforestry elements) can influence agricultural productivity in both direct and indirect ways. The effects depend strongly on landscape design, spatial scale, and management intensity – and in tropical and subtropical settings, these interactions can be particularly dynamic due to high rainfall variability, pest pressures, and soil constraints. ‣ Reduced erosion and degradation, and improved soil fertility and structure (see above) can be expected to increase productive capacity over the long term. Similarly, enhanced pollination and pest control services from the provision of habitats for pollinators and natural pest predators can lead to higher pollination rates and reduced pest outbreaks, improving crop productivity and stability. ‣ Vegetation reduces wind speed and radiation stress, protecting crops from heat, wind, and evapotranspiration losses. Shade and humidity moderation can enhance productivity of shade-tolerant or moisture-sensitive crops (e.g., coffee, cocoa, vegetables). An increase in water retention and availability can support sustained crop growth in variable climates. ‣ Potential challenges and trade-offs include loss of cultivable area, competition for resources, shading and reduced light interception, pest or disease spillover from natural vegetation, delayed productivity gains, and a high maintenance and management burden.

6.10 Landscape features for biodiversity enhancement

Co-benefits and trade-offs for income:	In the short term, biodiversity-enhancing landscape features can slightly reduce income due to establishment and opportunity costs. In the medium to long term, they tend to increase or stabilise farm income by diversifying production and reducing input costs, enhancing ecological resilience and yield reliability, and providing access to incentive schemes and new markets. The net income effect depends strongly on the scale of land set-aside, the availability of financial or technical support and the capacity of farmers to manage multi-output systems. • The main income benefits include diversification of income sources (fruit, fuelwood, fodder, honey, fish, timber, medicinal plants, or crafts), reduced input costs and improved efficiency, potential access to environmental incentive payments, enhanced land and asset value, risk reduction and livelihood resilience, and community and employment benefits. • Potential challenges and trade-offs include short-term income reduction due to land set-aside, delayed economic returns, upfront establishment costs, maintenance and transaction costs, the risk of unequal benefit distribution, and market and price uncertainties for the additional products produced.
Co-benefits and trade-offs for food and nutrition security:	The introduction of landscape features for biodiversity enhancement can significantly affect food and nutrition security, both directly (through food production and access) and indirectly (through ecosystem stability, diet diversity, and resilience). • The main benefits include diversified food sources and diets (from fruits, nuts, wild greens, mushrooms, honey, fish, small game, and livestock fodder), improved stability and reliability of food supply as a result of above-mentioned adaptation benefits, improved livestock nutrition and productivity, enhanced household resilience and adaptive capacity, and benefits from cultural and traditional food security (where traditional or wild food species are reintroduced). • Potential challenges and trade-offs include a reduced short-term staple food production (due to loss of crop land), competition for household labour and resources, access and equity issues and potential contamination risks. • To maximise food security benefits, successful implementation requires inclusive planning that ensures equitable access to shared resources, selection of multifunctional, locally valued species and integration with nutrition-sensitive agriculture and community food programmes.

6.10 Landscape features for biodiversity enhancement

Co-benefits and trade-offs for gender equity:	Gender is a critical dimension of landscape management, particularly where women and men have distinct roles, access rights, and knowledge systems related to natural resources. Biodiversity-enhancing landscape features have strong potential to advance gender equity when designed with inclusive participation, equitable benefit-sharing, and attention to women's roles and constraints. • Recognition and use of women's ecological knowledge: Women often hold detailed knowledge about wild food species, medicinal plants, soil fertility indicators, and water management practices. Landscape restoration and biodiversity enhancement initiatives can validate and elevate women's knowledge, strengthening their voice in local decision-making. Inclusion in design and management of features (e.g., home gardens, buffer strips, ponds) recognises women as environmental stewards, not just labourers. • Expanded livelihood and income opportunities: Features such as multi-purpose trees, kitchen gardens, or ponds provide women with new or enhanced sources of food and income from fruits, vegetables, herbs, fodder, honey, or fish. These activities often align with women's existing responsibilities and time constraints, offering low-entry, home-based livelihood options. Increased control over the sale or use of products can improve women's financial autonomy and household bargaining power. • Improved household food and nutrition security: Since women are typically responsible for food preparation and family nutrition, enhanced availability and diversity of foods from landscape features can strengthen their role as providers of household wellbeing. • Greater participation in natural resource governance: Participatory or community-based landscape projects often encourage inclusive management committees or user groups, opening leadership and decision-making spaces for women. When supported by gender-sensitive facilitation, such involvement can shift social norms and promote equitable governance. • Reduced vulnerability and enhanced resilience: Access to diverse on-farm resources (e.g., fuelwood, water, fodder) reduces time and effort spent collecting materials, particularly for women and girls. This can free time for education, rest, or other income-generating activities, contributing to overall empowerment. **Potential challenges and trade-offs** Despite strong potential for positive outcomes, biodiversity-oriented landscape interventions can exacerbate existing gender inequities if poorly planned or implemented: • Women are often expected to contribute unpaid labour to tree planting, weeding, mulching, and watering, adding to their existing workload. Without explicit labour-sharing arrangements, such projects may unintentionally reinforce gendered divisions of labour.

6.10 Landscape features for biodiversity enhancement

continued Co-benefits and trade-offs for gender equity:	‣ Where women have limited land ownership or decision-making rights, they may contribute labour without gaining access to benefits (e.g., harvests, payments, or incentives). Men may control income from saleable products or compensation schemes, perpetuating economic disparities. ‣ If land is converted to ponds, buffer zones, or woodlots, women's access to small plots or gathering areas (for vegetables, herbs, or firewood) may be reduced. Elite capture of restored or "protected" areas can exclude poorer women and female-headed households from resource use. ‣ In projects offering training or incentives, benefits may accrue disproportionately to women with higher education or social status, widening intra-gender inequalities.
Works well with/ brings synergies with practice…	This practice can be combined with any of the other practices, depending on the specific context (production system, agroecological zone etc).
Does not work well/ competes with practice…	No direct competition with any practice.
Any other dis-advantages of the practice (not already mentioned above)	None

6.11 Organic soil amendments

The use of organic soil amendments – such as compost, manure, green manure, crop residues, and biochar – can improve soil fertility, soil structure, and water-holding capacity, while supporting beneficial soil microbes. In particular in tropical and sub-tropical climates, rapid organic matter decomposition, nutrient leaching from heavy rains, and soil degradation can be serious challenges. Organic amendments help replenish nutrients, increase cation exchange capacity, enrich soil biodiversity and enhance resilience against erosion and drought.

6.11 Organic soil amendments

Further short description	There are a wide range of materials and management practices that can be used, depending on the local context and farming system. These include: ‣ Compost is made from decomposed organic materials such as food waste, plant residues (including agro-industrial waste, i.e. residues from agricultural and food processing industries, such as coconut husks, sugarcane bagasse, and fruit peel and pulp waste, cashew apples). Vermicompost is a sub-category of compost that is produced with the help of earth worms. ‣ Manure: Animal manure from cattle, poultry or rabbits/guinea pigs is a rich source of nutrients and organic matter. Manure is often added to other organic material in compost. ‣ Green manures and cover crops: Plants grown specifically to improve soil health and fertility, which are incorporated into the soil (green manure) or left on the surface as mulch (cover crops). They can fix atmospheric nitrogen (legumes), increase soil organic matter, prevent erosion, suppress weeds, and provide a habitat for beneficial organisms (for example cowpeas, groundnuts, clover, rye, mustard). See also the practice sheet on crop rotation for more information on green manures. ‣ Biochar: A charcoal-like material produced by heating biomass in the absence of oxygen (pyrolysis), biochar is rich in carbon and enhances soil health and water retention capacity. ‣ Biofertilisers: These are preparations containing beneficial microorganisms that enhance nutrient cycling and plant growth in the soil. They include nitrogen-fixing bacteria (Rhizobium, Azotobacter), phosphorus-solubilising bacteria (Bacillus megaterium), and mycorrhizal fungi. ‣ There are training manuals on organic fertilisers for different geographical zones: ‣ The IFOAM training manuals for organic agriculture: ‣ Weidman et al. 2007 (for arid and semi-arid contexts) and ‣ Eyhorn et al. 2004 (for tropical contexts) ‣ ‣ FAO and ITPS 2021: Recarbonising global soils – A technical manual of recommended management practices. ‣ A training manual on vermicomposting: ‣ Munroe 2007 ‣ A training manual on manure management: ‣ Teensta et al. 2015 ‣ A range of training manuals and videos on biochar: ‣ https://www.warmheartworldwide.org/resources.html ‣ Paparella et al. 2025: ‣ Organic fertilizers ‣ Paparella et al. 2025: ‣ Sustainable manure management

6.11 Organic soil amendments

Context / suitability	
Farm or landscape level	Farm level, plot level (but with landscape level impacts)
Relevant production system (‣ FAO classification)	Rainfed crops, irrigated crops, forests, mixed systems

Resource requirements/cost implications	
Land and other natural resources	‣ The main natural resource required is the organic matter itself, which can be challenging in a context where there is a shortage of organic matter in the system and therefore competition for its use. For example, crop residues would ideally be left on the field to enrich the soil, but they are also required for fencing, as fuel and for livestock feed. Sometimes, by-products or food waste can be used (e.g. pulp, green waste). ‣ Some methods (composting, in particular vermicomposting) require water. Whilst grey water (from household use) can be used, this can still be a challenge in dry areas or during periods of drought.
(financial and physical) capital/implements	‣ Transportation of organic materials is required – first from the point of origin to the point of processing, and then to the point of use. Transport can be manual (e.g. head loading of manure in India) or using livestock (with or without carts). A lack of transport facilities can be a main obstacle for smallholder farmers. ‣ Tools for cutting, mixing and applying the organic materials. ‣ Some practices require buying in specific materials such as earth worms for vermicomposting, agro-industrial waste, or animal manure (if not produced on-farm/locally) ‣ Space for composting (e.g. windrows). ‣ Compost can be blended with rock phosphate or other elements, which must be purchased. ‣ Compost starter is expensive but not always needed.

6.11 Organic soil amendments

Labour (qualitative and quantitative/skills etc.)	‣ The labour requirements for the production and application of organic soil amendments vary significantly, depending on the specific practice and the local context. There is broad agreement that the labour involved is higher than for the application and use of inorganic fertilisers.
	  ‣ Dalzell et al. (1987) discuss labour requirements for compost production in some detail, pointing out that the amount of labour required in composting depends on the degree of mechanisation employed. For preparation and spread of 1 ton of compost, between 1 and 3 days were required – but this did not include the collection of the organic material.
	  ‣ Gebretsadkan (2018) cites in his study an estimate of 20 workdays per hectare for collection and application of farmyard manure in Ethiopia.
	‣ There is scope for reducing labour requirements through mechanisation (to transport, mix and spread organic matter), but experience with this is still limited in a smallholder farming setup.

Expected impacts on biodiversity

Detailed description of impacts on biodiversity	**Genetic diversity** ‣ Soil microbial gene pools: Organic inputs can increase functional gene diversity in soil microbial communities. This includes genes for nutrient cycling (N-fixation, P-solubilisation) and disease suppression – for example in trials in paddy fields in South Korea, see Walitang et al. 2023. ‣ Crop genetic diversity: Improved soil fertility and structure from organic amendments can make marginal land more productive, encouraging the use (and conservation) of local landraces that might be abandoned under low-yield conditions. **Species diversity** ‣ Soil biota: Compost and manure add diverse organic substrates, supporting richer communities of earthworms, nematodes, arthropods, and fungi. In tropical agroecosystems, manure-amended plots often show 20 – 40 % higher soil macrofauna abundance than mineral-fertilised plots (from trials in Zimbabwe, Tauro et al. 2021) ‣ Above-ground biodiversity: By improving soil moisture and nutrient balance, organic amendments can support non-crop plant species in field margins and understorey. They can also reduce herbicide dependence (e.g., with green manures), allowing more diverse field flora. ‣ Pest-predator balance: Diverse soil and plant communities help stabilise predator–prey dynamics, reducing outbreaks of certain insect pests.

6.11 Organic soil amendments

continued Detailed description of impacts on biodiversity	**Landscape diversity** ‣ Land-use mosaics: Organic amendment strategies (especially green manures and crop–livestock integration) promote mixed farming systems, where crops, fodder, and pasture coexist. This creates structurally and functionally diverse landscapes. ‣ Agroforestry links: In many tropical systems, manure and compost come from livestock integrated into tree-crop systems, strengthening the tree cover component of agricultural landscapes, which benefits birds, bats, and pollinators.

Complementarity and competition

Co-benefits and trade-offs for climate change mitigation and adaptation	**Mitigation:** ‣ The impacts are mainly about reducing greenhouse gas (GHG) emissions or increasing carbon storage (‣ FAO 2005): ‣ Soil carbon sequestration: Compost, manure, green manures, crop residues, biochar add organic carbon directly to soils and promote conditions that slow its loss. ‣ Reduced synthetic fertiliser dependence: Organic amendments can supply a significant share of N, P, and K to crops, lowering synthetic fertiliser use and the associated CO_2 emissions from manufacture. ‣ Biochar as a stable carbon pool: Biochar contains highly recalcitrant carbon that can persist for centuries, effectively locking away atmospheric CO_2 captured by plants. ‣ Influence on non-CO_2 GHGs: Methane (CH_4): In flooded paddy fields, certain organic inputs can increase CH_4 if not managed carefully; however, composted materials generally emit less CH_4 than fresh manure. Nitrous oxide (N_2O): Can be reduced if organic amendments improve synchrony between N release and plant uptake, but poorly timed applications may raise N_2O emissions. **Adaptation:** These benefits help farming systems withstand and recover from climate stresses: ‣ Improved soil water holding capacity: Organic matter increases porosity and water retention, buffering crops against drought and erratic rainfall. In sandy tropical soils, compost or manure can increase available water capacity by 15–30 % within a few seasons. ‣ Enhanced soil structure and erosion control: Stable soil aggregates from organic matter reduce runoff and erosion during intense tropical rains, protecting topsoil and nutrients.

6.11 Organic soil amendments

continued Co-benefits and trade-offs for climate change mitigation and adaptation	• Temperature regulation: Mulches and organic-rich soils moderate soil surface temperatures, reducing heat stress on roots in hot climates. • Nutrient buffering: Organic matter increases cation exchange capacity (CEC), helping retain nutrients during heavy rainfall events common in tropical/subtropical regions. • Biodiversity and resilience: Increased microbial and macrofaunal diversity under organic amendment use improves soil's capacity to recover after disturbances like floods, pests, or droughts. **Key trade-offs:** • Decomposition rates: In warm, moist climates, organic matter breaks down faster, which means that benefits for soil organic carbon and water retention require regular re-application. • GHG balance: Some fresh organic inputs (especially high-moisture manures) can produce more CH_4 and N_2O if poorly managed.
Co-benefits and trade-offs for water quality and quantity:	There are both benefits and trade-offs to consider. **Water quality:** • Increased soil organic matter (SOM) improves cation exchange capacity (CEC) and binds nutrients, slowing leaching into groundwater. • Organic matter binds phosphate, reducing solubility. Better aggregation reduces erosion and sediment-bound nutrient transport to waterways. • Higher SOM adsorbs some hydrophobic pesticides, contributing to reduced pesticide leaching (indirect benefit). • Fresh, high-moisture manure or excessive application can cause spikes in nitrate and phosphate runoff – so there is a risk of short-term increases in nutrient loss if poorly managed. **Water quantity (availability to crops)** • SOM and biochar improve pore size distribution and retention of plant-available water, increasing water-holding capacity. • Stable aggregates and macro-pores allow faster infiltration, reducing runoff losses. • Higher plant-available water delays onset of drought stress. • Increased infiltration and retention mean more rainfall/irrigation water benefits crops. • Enhanced water storage means longer intervals between irrigations.

6.11 Organic soil amendments

Co-benefits and trade-offs for soil health:	The soil health benefits overlap to some extent with the benefits for climate change adaptation. **Physical properties:** ‣ Stable aggregates form as organic matter binds particles. This improves aeration, infiltration, and root penetration. ‣ Bulk density generally decreases, especially in degraded sandy soils. Low bulk density supports root growth and drainage. ‣ Water-holding capacity increases, providing a buffer against droughts common in tropical dry seasons. **Chemical properties:** ‣ Soil organic carbon (SOC) increases under regular manure/compost inputs. SOC underpins nutrient cycling, structure, and water retention. ‣ Organic amendment supply N, P, K and micronutrients in slow-release form, which reduces dependency on synthetic fertilisers. ‣ Cation exchange capacity (CEC) increased via humus and biochar surface charges, which enhances nutrient retention in leaching-prone tropical soils. ‣ pH buffering: Many organic inputs moderate acidity, which reduces aluminium toxicity in highly weathered tropical soils. **Biological properties:** ‣ Organic soil amendments can boost bacteria, fungi, and beneficial microbes. Higher diversity supports nutrient cycling and disease suppression. ‣ Earthworms, termites, and arthropods increase with organic matter. This in turn improves aeration, mixing, and decomposition. ‣ Higher dehydrogenase, phosphatase, and urease activities are indicators of active nutrient cycling and soil vitality. However, high decomposition rates in warm, moist climates mean that benefits can decline quickly without repeated applications.

6.11 Organic soil amendments

Co-benefits and trade-offs for productivity:	Productivity impacts depend on a range of contextual and management factors and can be both positive and negative. Development initiatives aim to select practices and management approaches that maximise the positive impacts (through careful adaptation of practices to the local context) and minimise the negative ones. The main impacts are as follows: **Positive/benefits:** ‣ Improved nutrient supply: Slow-release N, P, K from manures, compost, and green manures prolongs nutrient availability across the season. For example, in sub-tropical China, combined pig manure and mineral fertiliser increased rice grain yield by 15–20% over mineral-only plots in red soils (10-year trial). ‣ Xie et al. 2022 ‣ Enhanced soil structure: Better aggregation improves root penetration and water/nutrient uptake. ‣ Greater water availability: Organic matter improves water retention, buffering crops against dry spells. For example, in semi-arid Kenya, green manure (Mucuna) increased maize yield by 0.5–1.2 t ha^{-1} in dry years vs. control. ‣ Ajebesone 2011 ‣ Improved soil biology: Higher microbial biomass and mycorrhizal activity improve nutrient cycling. ‣ Residual effects: Benefits often persist into following seasons, reducing input needs. **Challenges/trade-offs:** ‣ Nutrient mineralisation mismatch: In warm, wet climates, rapid decomposition can release nutrients before peak crop demand, limiting yield benefits unless timed well. ‣ Low nutrient content materials: High-carbon, low-nutrient inputs (e.g., rice husk biochar) may improve soil health but have minimal immediate yield impact unless supplemented with other, more nutrient rich amendments (e.g. mixture with high-nutrient inputs or blending, e.g. with rock phosphate). ‣ Initial immobilisation: Very fresh residues with high C:N ratio can temporarily immobilise N, causing short-term yield dips. ‣ Pathogen carry-over: Poorly composted manure in tropical vegetable systems can increase disease incidences. However, there are methods to reduce the contamination of organic amendments (these may only be economically viable in high value crops – see ‣ Jabnoun-Khiareddine et al. (2020) for an example of soil solarisation in Tunisian vegetable production).

6.11 Organic soil amendments

Co-benefits and trade-offs for in-come:	The use of organic soil amendments can affect farmer incomes through a mix of direct and indirect pathways: ‣ Increased yields and marketable quality: By improving soil fertility, structure, and water-holding capacity, organic amendments often boost crop yields and quality. Better quality produce can fetch premium prices in local and ex-port markets, especially when marketed as “organic” or “chemical-free.” ‣ Reduced input costs: On-farm materials like manure, crop residues, and compost reduce reliance on purchased synthetic fertilisers. Lower cash outlay for fertiliser can improve net margins, especially in smallholder systems where fertiliser prices are volatile. ‣ Long-term soil productivity and risk reduction: Soil organic matter build-up reduces vulnerability to drought and nutrient loss, stabilising yields over time – this income stability is important in variable climates. Fewer crop failures translate to lower income variability and more predictable cash flows. ‣ Access to organic and niche markets: Farmers who adopt organic soil amendments as part of certified organic sys-tems can access price premiums, although certification costs and compliance must be managed. ‣ Labour costs and opportunity costs: Preparing and applying organic amendments is labour-intensive – collecting, composting, transporting, and spreading may require more workdays than using synthetic fertiliser. This can raise costs if labour is hired, but in households with under-employed labour, it may be an economically neutral or even beneficial use of time.
Co-benefits and trade-offs for food and nutrition security:	The use of organic soil amendments affects food and nutrition security through a set of interlinked pathways: **Food availability – increased and stabilised crop production (see also above section on co-benefits for productivity)**: ‣ Higher yields: Organic amendments improve soil fertility, structure, and moisture retention, which can boost yields, especially over the long term. ‣ Stability under climate stress: Improved soil organic matter reduces drought and flood impacts, stabilising food production year-to-year. **Food access - improved household incomes (see also above section on co-benefits for income):** ‣ Increased yields and reduced input costs improve economic access to food by raising farm incomes (cash to buy diverse foods).

6.11 Organic soil amendments

continued Co-benefits and trade-offs for food and nutrition security:	**Food utilisation – enhanced nutritional quality of food** • Organic amendments can increase micronutrient content of crops (e.g. Zn, Fe, Mg), enhancing the nutritional value of staples and vegetables. • Higher soil biological activity can also enhance secondary metabolites (flavour compounds, antioxidants) in vegetables, improving diet quality. **Stability – reduced risk of food insecurity** • By improving soil health, organic amendments reduce dependence on costly external fertilisers, buffering farmers from price shocks. • Stronger soils mean fewer total crop failures, which stabilises local food availability. **Potential challenges:** • Labour requirements for producing and applying organic amendments can limit adoption for time-poor households. • Short-term nutrient release is sometimes slower than from synthetic fertilisers, which can delay yield benefits if soils are already degraded.
Co-benefits and trade-offs for gender equity:	The use of organic soil amendments can have both positive and negative gender equity implications, depending on context, access to resources, and division of labour. It can enhance gender equity by giving women greater control over productive resources, boosting their incomes, and strengthening decision-making roles. However, without deliberate planning, the added labour demands and structural inequalities in resource access may reinforce gender gaps rather than close them. Opportunities for women’s empowerment: • Income and decision-making: Where women manage home gardens or smallholder plots, the use of compost, kitchen waste, and manure - inputs often under their control - can increase yields of vegetables and other nutrient-rich crops. This can enhance women’s bargaining power in the household by providing them with produce for sale or home consumption. • Skills development: Composting and vermiculture projects often include training sessions where women gain technical knowledge, which can increase their participation in community decision-making.

6.11 Organic soil amendments

continued Co-benefits and trade-offs for gender equity:	Risks and workload considerations: ‣ Labour intensity: Producing, transporting, and applying organic amendments can be labour-heavy. In many contexts, these tasks fall disproportionately to women, adding to their existing workload. ‣ Access to inputs: Women may have less access to livestock (for manure) or land (for green manures), which can limit their ability to adopt and benefit from organic amendments. Equity through market participation: ‣ If organic produce fetches a premium price in niche or certified markets, women farmers—especially those in co-operatives—can gain improved market access and higher returns. Social and Cultural Dynamics: ‣ In some settings, composting and organic amendment preparation is viewed as “low-status” work; recognising and valuing these tasks can shift social perceptions and support gender equity. ‣ Participatory extension approaches that involve women equally in training and decision-making have been shown to improve adoption rates and equitable benefits.
Works well with/ brings synergies with practice…	Soil and water conservation, use of local crop varieties, agroforestry, ANR (assisted natural regeneration)
Does not work well/ competes with practice…	None
Any other dis-advantages of the practice (not already mentioned above)	None
Possible mitigation measures to man-age trade-offs/ address disadvan-tages	‣ Development and promotion of labour-saving technologies (transport, appropriate mechanisation) ‣ Because of the complexity of factors influencing the impacts of organic soil amendments, these practices have inherent risks if not managed carefully. Therefore, training and capacity development are required to avoid negative environmental impacts (e.g. leaching of nutrients, high GHG emissions from poor management etc.).

6.12 Soil and water conservation

Physical SWC measures include a wide range of practices that aim to reduce soil erosion and increase water infiltration. They include the construction of different types of bunds (either along the contour or along the field boundary), terracing, ridges, half-moon shaped plant basins and many others. These structures slow down water runoff, thus reducing soil erosion, and increasing water infiltration into the soil. The specific dimensions and materials of the structures are context specific, depending on slope, soil characteristics, rainfall, etc.

6.12 Soil and water conservation

Further short description	Many research and development organisations have developed guidance for SWC measures in specific contexts – see e.g.: ‣ Paparella et al. 2025: ‣ Mechanical soil and water conservation ‣ Paparella et al. 2025: ‣ Green manure ‣ For Nepal: ‣ https://lib.icimod.org/records/84h9w-4ac65 ‣ For Burkina Faso and Mali: ‣ https://www.accessagriculture.org/contour-bunds ‣ For West Africa in general: ‣ https://cgspace.cgiar.org/server/api/core/bitstreams/cff83285-cc7f-4513-b561-a0457e847724/content ‣ For Kenya: ‣ https://kenyarapid.acaciadata.com/media/cluster0/3R_Flyer_-_contour_bunds_and_terraces_-_KenyaRAPID_AW_19092019_vcDcAzW.pdf ‣ For various contexts: ‣ https://www.fao.org/4/x4799e/x4799e.pdf

Context / suitability	
Farm or landscape level	Both. SWC measures can be used on cultivated land and uncultivated land, and as part of a watershed-based / landscape level land management approach.
Relevant production system (‣ FAO classification)	Rainfed crops, livestock grassland-based systems, naturally regenerated forests, planted forests

Resource requirements/cost implications	
Land and other natural resources	The very aim of SWC measures is to improve land and other natural resources. Context specific measures can be implemented on all sorts of land, under a wide range of agroecological conditions.

6.12 Soil and water conservation

(financial and physical) capital/implements	The main financial and physical resources required relate to equipment and tools, transport, and maintenance costs – these can be substantial, depending on the specific measures implemented. ‣ Equipment and tools: Purchase or rental of basic tools (hoes, picks, shovels, wheelbarrows, crowbars). Costs for more advanced tools such as line levels, water levels, A-frames, or GPS devices for accurate contour layout. ‣ Transport costs: Moving stones, earth, mulch, compost or seedlings from external sources can be expensive in areas with poor road infrastructure. ‣ Maintenance costs: Regular upkeep of bunds, terraces, grass strips, and drainage channels requires periodic labour and sometimes replacement materials. Specifically, structural measures such as check dams, may require: ‣ Earth-moving capacity: Machinery (e.g., tractors, ox-drawn ploughs, small excavators) can be capital-intensive but significantly reduces labour time. Hiring machinery often requires upfront cash or access to credit. ‣ Construction materials: Stone for stone bunds, check-dams, and retaining walls. Wood, bamboo or treated poles for small diversion structures. Geotextiles or plastic liners (in some projects) to stabilise slopes or line infiltration pits. For vegetative measures, capital requirements include: ‣ Planting material: Seeds or seedlings for cover crops, hedgerow species, agroforestry trees, and grass strips. Some species (e.g., vetiver) may need to be purchased from nurseries. ‣ Organic inputs: Compost, manure, biochar, mulches or green manure seed sometimes need to be purchased, especially where local availability is limited. ‣ Nursery infrastructure: Farmers or cooperatives may need basic nursery equipment: seedbeds, polythene bags, watering cans, shading nets, and potting mixtures.
Labour (qualitative and quantitative/skills etc.)	Labour requirements for SWC measures tend to be high, which is a major reason why development organisations or government programmes tend to provide funding for the initial establishment of the measures (e.g. through cash-for-work or food-for-work, as part of social protection programmes that provide employment to the local population – both landowners and landless). Collective action is normally required to plan and implement SWC measures on a watershed or community basis, to ensure that downstream areas are not adversely affected.

6.12 Soil and water conservation

continued Labour (qualitative and quantitative/skills etc.)	The work to move or stabilise earth, stones or other materials generally represents the largest cost of SWC structures. There are a number of sources on approximate requirements (of labour and other resources) available online, e.g. ‣ ProPAS (managed by IITA, the International Institute for Tropical Agriculture) and the ‣ WOCAT database on sustainable land management. In locations where there is little or no local experience with SWC, significant investment in training and capacity development may be required.

Expected impacts on biodiversity

Detailed description of impacts on biodiversity	**Species diversity:** ‣ Soil conservation methods reduce surface run-off and associated soil erosion and increase water infiltration. Combined with the application of organic soil amendments (crop residues, compost, manures) or cover crops, this can increase soil organic matter and the number and diversity of soil micro-organisms over time (‣ FAO and ITPS 2015). ‣ SWC structures like terraces, contour bunds, zaï pits, and mulching reduce erosion, maintain soil moisture, and regulate temperature – conditions that support microbial, fungal, and invertebrate diversity. (‣ Qiu et al. 2024) ‣ However, introducing non-native trees or grasses (e.g. for bund stabilisation) can reduce local biodiversity and outcompete native species. **Ecosystem diversity:** ‣ When implemented at scale, SWC measures can reduce or even reverse land degradation, whilst providing a more stable soil ecosystem that is more resilient to pressures such as pest outbreaks (‣ Hawker et al. 2020). ‣ However, poorly planned physical structures such as large-scale embankments or check dams may disrupt local hydrology and affect aquatic species or wetland biodiversity, especially if they block natural water flow or fish movement.

6.12 Soil and water conservation

Complementarity and competition

Co-benefits and trade-offs for climate change mitigation and adaptation	‣ Reduced runoff in favour of water retention in the soil is a very effective adaptation measure to prolonged dry periods, as well as to flash floods / high rainfall events (provided SWC structures are dimensioned accordingly). ‣ Increasing the amount of organic matter that a soil receives and retains can help prevent soil desiccation through drought (‣ Hawker et al. 2020).
Co-benefits and trade-offs for water quality and quantity:	‣ Reduced runoff in favour of water retention in the soil, and increased water infiltration, can recharge groundwater and filter water, thus improving water quality. ‣ Groundwater recharge may benefit downstream users, if they have the capacity to dig wells.
Co-benefits and trade-offs for soil health:	‣ Reduced soil erosion contributes to better retention of organic matter, increasing soil health.
Co-benefits and trade-offs for productivity:	‣ The impacts on productivity are very context specific. Over time, yield increases can be expected as a combined result of reduced soil erosion and increased water retention of soils. Where degraded land is restored through SWC, additional benefits occur from an expansion of the area under cultivation – an important impact in particular in areas with land shortage. ‣ Some examples: ‣ Ethiopia: Integrated SWC measures improved grain yield by 13–19%, and up to 34% for stone-faced bunds compared to untreated land (Alemayehu et al. 2020). ‣ India: Contour bunding and compartmental bunding delivered 35–43% yield increases in grain crops (soy-bean, pigeon pea, sorghum), compared to flat-bed systems.

6.12 Soil and water conservation

Co-benefits and trade-offs for income:	• If the cost of establishing the SWC structures is born by a development agency, the practices are likely to result in medium to long-term income increases as a result of yield increases (due to water retention, organic matter accumulation etc.) – assuming that any increased production can be sold, or would reduce the amount of food a household has to purchase in the market.
	• The specific cost-benefit ratio of the practice is highly context specific. Examples include:
	  ‣ Kenya: An analysis of contour farming (incl. bunds/ridging) practices among 433 smallholder farms over a 15-year horizon showed positive Benefit–Cost Ratios (>1), signalling profitability. When high-value fodder grasses were used to stabilize structures (e.g., grass strips), the payback period shortened to 1–2 years, improving returns significantly (‣ Onduru et al. 2011).
	  ‣ India: An evaluation of the performance of conservation structures in the black soil area at Bijapur found a cost-benefit ratio for contour bunding of 3.66 and a pay-back period of 3 years.

Co-benefits and trade-offs for food and nutrition security:	• Land degradation has been linked to reduced food and nutrition security, e.g. in India, China and Indonesia (‣ Yaseen et al. 2025). However, soil conservation measures on their own will not normally directly impact on nutrition in the short term.
	• In the longer term, increases in agricultural productivity as a result of SWC can increase food production and income, both of which may improve food and nutrition security. Improving soil quality may also enable crop diversification (inclusion of crops that require better soil quality and higher soil moisture). Examples:
	  ‣ Tanzania: A study of 500 households showed that the adoption and duration of adopting SWC technologies had a significant and positive impact on household dietary diversity (‣ Manda et al. 2023).
	  ‣ There are however no studies that specifically linked the adoption of SWC measures with nutrition outcomes – generally such impact studies focus only on agricultural productivity.

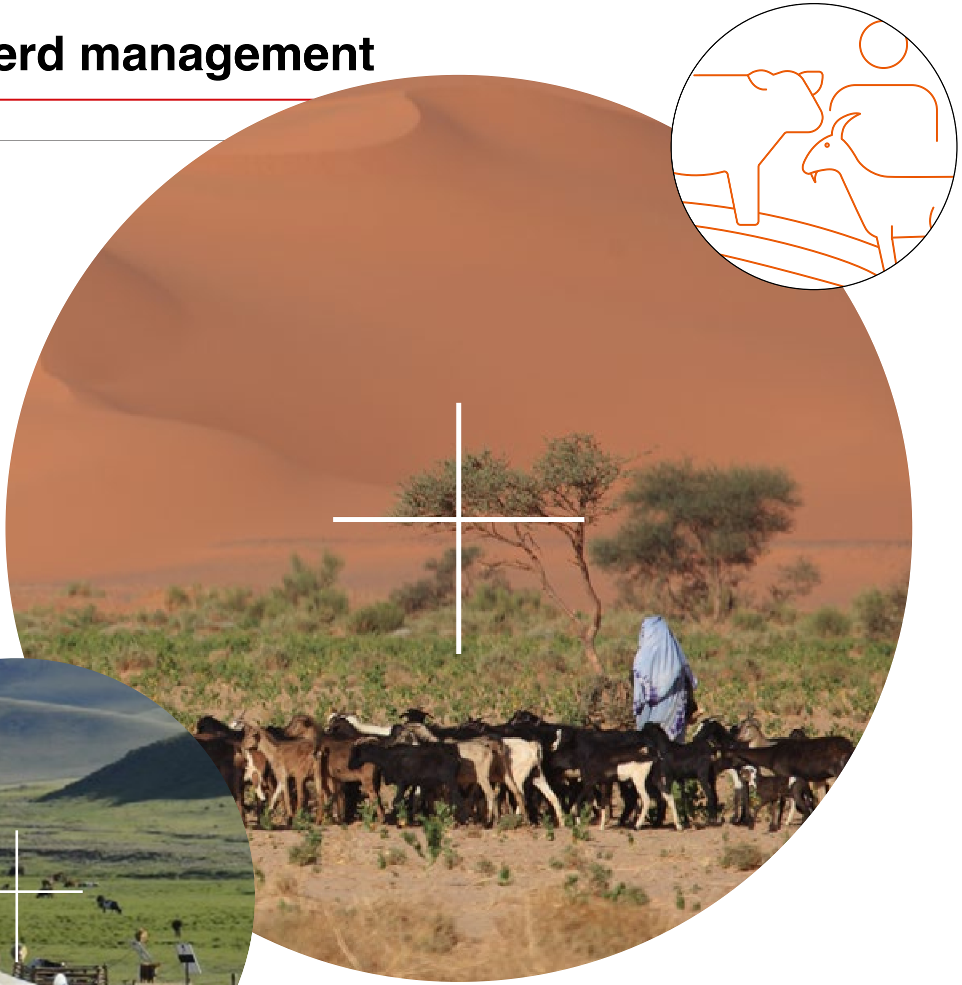
Co-benefits and trade-offs for gender equity:	• Women have played an important role in many soil conservation initiatives, implemented by national governments, development agencies or NGOs. However, the extent to which women are involved in the process (from design of the measures through implementation to monitoring and maintenance) varies significantly between programmes. • There is scope to work with existing women's groups to implement the soil conservation activities, or to initiate new groups for this purpose. Women's inclusion, active participation and decision-making power in local management committees can be strengthened by development initiatives.

6.12 Soil and water conservation

Works well with / brings synergies with practice…	‣ Agroforestry: In some contexts, trees and other permanent vegetation can be planted on the bunds, providing additional benefits (shading, fruit, fodder, erosion control…). ‣ Application of organic soil amendments: The adoption of SWC measures brings synergies with the use of organic soil amendments, as organic matter is preserved in-situ (rather than washed away).
Does not work well / competes with practice…	‣ No obvious competition with other practices. ‣ Some SWC projects encourage intensification of staple crops (e.g. maize, wheat) on newly stabilised land, which may lead to reduced plant diversity (mono-cropping replacing traditional mixed cropping systems).
Any other disadvantages of the practice	‣ Some SWC measures, such as bunds, reduce the area under cultivation. This is particularly unpopular with farmers in areas where plots are small. The reduced production resulting from reduced area under cultivation is not always compensated by increases in crop yields (‣ Adimassu et al. 2014). ‣ Where contours diverge from farm boundaries, contour-based soil conservation measures can result in land fragmentation or even conflicts over land – in such cases, boundary bunds could be considered as an alternative (‣ Adolph 1996). ‣ SWC practices reduce surface runoff, which may have a negative effect on downstream water users (if they rely on harvesting surface water).
Possible mitigation measures to manage trade-offs / address disadvantages	‣ Use participatory land management approaches to fully involve different sections of the local community (women, men, youth; different wealth categories) in all stages (design, implementation and monitoring of SWC measures). ‣ Make sure that off-site effects of SWC measures (e.g. reduced run-off affecting downstream users) are taken into account. Design compensation mechanisms (e.g. digging of wells downstream). ‣ Plant high-value vegetation (trees / fodder grasses) on bunds and along other SWC measures to compensate for the reduction in land. ‣ Adapt SWC structures to farmers' preferences (e.g. boundary bunds rather than contour bunds). ‣ Pay farmers for initial investments in SWC measures. ‣ Use PES (payments for ecosystem services) to make downstream beneficiaries pay for (parts of) the initial investment costs.

6.13 Sustainable rangeland and herd management

Sustainable rangeland and herd management (SRHM) refers to the use of pastures and rangeland (African savannas, South Asian drylands, and Latin American grasslands) for livestock (e.g. cattle, sheep, goats, camels, camelids, donkeys, mules) and ways of managing these in ways that maintain or enhance the long-term productivity, biodiversity, and ecological health of rangeland ecosystems while supporting the livelihoods of pastoralists and farmers.



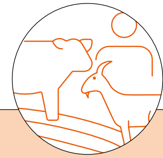
6.13 Sustainable rangeland and herd management

Short description	Core practices include: ‣ Rotational or planned grazing, ensuring mobility: Alternating livestock across rangelands to allow vegetation recovery and reduce soil erosion. ‣ Controlled stocking rates: Matching herd size or grazing intensity to the land's carrying capacity to prevent overgrazing. ‣ Species and breed selection: Using locally adapted, drought- and disease-resistant animal breeds and forage species. Managing mixed species herds (e.g., cattle, goats, sheep) and allowing seasonal mobility to follow forage and water availability. ‣ Integrated land and water management: Conserving water through soil bunds, check dams, or rotational watering points; protecting riparian zones. ‣ Pasture improvement: Reseeding degraded lands with native grasses and legumes; promoting agroforestry and silvo-pastoral systems where suitable; assisted natural regeneration (ANR) – see separate practice sheet. ‣ Community-based governance: Involving local pastoral associations or cooperatives in land-use planning and grazing agreements, paying respect to customary law on land use. ‣ Paparella et al. 2025: ‣ Agro-silvo pastoralism

Context / suitability

Farm or landscape level	Farm level, landscape level
Relevant production system (‣ FAO classification)	Livestock grassland-based systems, livestock landless systems, naturally regenerated forests, mixed systems

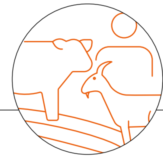
6.13 Sustainable rangeland and herd management



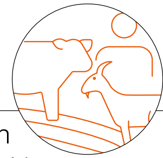
Resource requirements/cost implications	
Land and other natural resources	SRHM requires adequate land and water resources, managed through rotational use, biodiversity conservation, and community-based governance. **Land** ‣ Type and extent of land: Extensive rangelands including open grasslands, savannas, shrublands, dry forests, and semi-arid plains. The area required per livestock unit[40] depends on rainfall, vegetation productivity, and soil type. Contiguous or connected landscapes are needed to allow mobility and rotational grazing -crucial for regeneration and resilience. ‣ Land quality: Areas with a mix of native grasses, forbs, shrubs, and trees, without severe erosion or compaction under planned grazing pressure. ‣ Land tenure and access: Secured access rights (individual or communal) are essential to encourage long-term stewardship. Customary tenure systems often underpin pastoral management. Zoning and land-use planning help separate grazing areas, water points, and conservation zones. **Water resources** ‣ Reliable water points are critical - surface (rivers, ponds, pans, wetlands) and groundwater (boreholes, wells) at spacing that avoids overgrazing around them (see below re water investments) **Vegetation and forage resources** ‣ Native and drought-tolerant grasses, and leguminous shrubs and trees for nitrogen fixation and protein-rich browse. Forage biodiversity supports year-round grazing, reduces vulnerability to climate shocks, and improves soil health.

40 Tropical livestock units (TLU) are used to provide an equivalent estimate of livestock biomass. One TLU is equivalent to 250 kg, where one bovine is equivalent to 1 TLU, and a sheep or a goat to 0.1 TLU.“ Global livestock production systems

6.13 Sustainable rangeland and herd management



(financial and physical) capital/implements	SRHM requires relatively high medium to long-term investment in infrastructure, livestock assets, land rehabilitation, and institutional capacity. Costs and capital needs vary depending on scale (individual farm vs. communal rangeland), ecosystem condition, and degree of management intensification. Long-term sustainability depends on community governance, access to finance and public services, and integration with value chains. **Physical / infrastructure investments** ‣ Watering points to ensure year-round livestock watering and reduce overuse of single water points ‣ Adequate infrastructure to manage periodical grazing and protect herds from predators or theft ‣ Pasture rehabilitation to restore degraded rangelands and improve productivity ‣ Facilities to support animal health management, disease control, and breeding ‣ Possibly feed and fodder storage to ensure feed availability during dry seasons or droughts ‣ Transport and equipment to improve mobility, logistics, and access to distant grazing or water points ‣ Renewable energy systems to enhance energy efficiency and reduce dependence on fossil fuels ‣ Market and processing facilities to strengthen value chains, support marketing, and increase incomes (could include facilities for collection, storage and use of manure) **Financial capital and working funds** ‣ Livestock assets: Breeding stock, preferably for indigenous and/or climate-resilient breeds. ‣ Veterinary drugs, mineral supplements, vaccines; herder wages; transport and communication costs ‣ Rehabilitation and conservation funds for rangeland restoration, reseeding, tree planting. ‣ Index-based livestock insurance (IBLI) to cushion losses from drought or disease and/or drought contingency funds managed by cooperatives or pastoral unions.
Socio-economic and institutional conditions	‣ Community institutions for managing grazing schedules, resource access, and conflict resolution. ‣ Extension and veterinary services for herd health and pasture management. ‣ Market and infrastructure access for sustainable herd off-take and economic viability. ‣ Resilience planning: Requires drought contingency plans, early warning systems, and fodder banks.

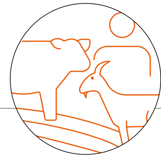


6.13 Sustainable rangeland and herd management

Labour (qualitative and quantitative/skills etc.)	Sustainable rangeland and herd management (SRHM) depends heavily on human capacity – people with the right mix of traditional, technical, and organisational skills. It blends indigenous pastoral knowledge with modern ecological, veterinary, and business management techniques to ensure productive, climate-resilient, and ecologically sound systems. Labour must be flexible, skilled, and community-coordinated, supported by ongoing training, participatory learning, and inclusive governance **Labour requirements** ‣ Moderate to high labour intensity - depending on herd size, grazing mobility, infrastructure, and management system. Both family labour and hired labour can be used. Veterinary support and skilled technicians (e.g. community animal health workers, are needed in more organised systems. ‣ Labour demand fluctuates with rainfall and forage availability (e.g. peak work during wet season movements or dry-season water management). **Knowledge and skills requirements** ‣ Traditional and indigenous knowledge: Deep understanding of seasonal forage patterns and mobility routes; drought signals and adaptive herd management; water source management and grazing rotation based on ecological cues; livestock behaviour, local breeds, and plant-animal interactions ‣ Technical and ecological skills: Rangeland ecology: grass and shrub identification; carrying capacity estimation; soil and vegetation monitoring; rotational grazing management: planning rest periods, mapping grazing units, adjusting stocking rates. ‣ SWC, pasture management: Building bunds, terraces, check dams, and maintaining vegetative cover; reseeding with native grasses and legumes; managing invasive species. ‣ Herd health management: Disease diagnosis, vaccination, parasite control, nutrition management. ‣ Business and organisational skills: financial literacy, market knowledge, record keeping, governance.

Expected impacts on biodiversity

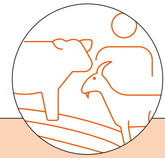
Detailed description of impacts on biodiversity	Rangelands are some of the most biologically diverse ecosystems on Earth. SRHM seeks to balance livestock production with ecosystem integrity, often producing positive biodiversity outcomes compared to intensive grazing or land conversion to crops.



6.13 Sustainable rangeland and herd management

continued Detailed description of impacts on biodiversity	**Genetic diversity** ‣ Conservation of indigenous livestock breeds adapted to local climates, diseases, and forage conditions (see also sheet on "conservation and utilisation of local livestock breeds"). ‣ Sustainable management encourages maintenance of herd genetic variability by avoiding excessive crossbreeding and preserving traditional breeding lines. It also promotes diversified forage species, maintaining plant genetic resources resilient to drought and pests. ‣ Potential risks (if poorly managed): Introduction of exotic, high-yield breeds can erode local genetic diversity and higher losses due to lacking adaptiveness to regional conditions. Overgrazing may reduce genetic diversity of native forage species by favouring only grazing-tolerant plants. **Species diversity** ‣ Rotational or adaptive grazing maintains a mosaic of grassland conditions – patches of short, medium, and tall grasses – supporting a wider range of plant, insect, bird, and mammal species. It also supports the maintenance of keystone species (grasses, nitrogen-fixing legumes, dung beetles, pollinators) that support ecosystem productivity. ‣ Moderate grazing pressure often enhances species richness compared to both overgrazing and total exclusion (the "intermediate disturbance hypothesis"). It encourages coexistence of wildlife and livestock, for example in African savannas (community conservancies in Kenya and Namibia). ‣ Potential risks (if mismanaged): Excessive grazing intensity can lead to loss of palatable species and dominance of unpalatable or woody plants ("bush encroachment"). Complete livestock exclusion (e.g. total protection) can also reduce plant diversity by allowing dominance of few tall species, restrict nutrient cycling and increase risk of wildfires. **Ecosystem diversity** ‣ SRHM sustains heterogeneous landscapes – mosaics of grasslands, shrubs, wetlands, and woodlands. It maintains key ecological processes: nutrient cycling (via dung and urine), seed dispersal (via hooves and fur), and soil aeration. It thereby reduces land degradation, soil erosion, and desertification – preserving ecosystem functions and services (carbon storage, water infiltration, pollination). ‣ It promotes connectivity between habitats, allowing wildlife migration and gene flow across the landscape. ‣ Potential risks (if mismanaged): Poorly designed water points or fencing can fragment habitats and concentrate grazing, leading to local ecosystem degradation.

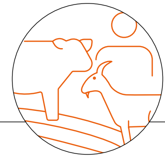
6.13 Sustainable rangeland and herd management



Complementarity and competition

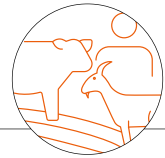
Co-benefits and trade-offs for climate change mitigation and adaptation	SRHM is a climate-smart approach that strengthens resilience to climate variability (adaptation) while contributing to carbon storage and reduced emissions (mitigation), supporting both sustainable livelihoods and ecosystem health. **Adaptation** ‣ Rotational access to water points, rainwater harvesting, and check dams ensure livestock survival and forage availability during dry spells. Rotational grazing and reseeding of drought-resistant grasses and legumes maintain consistent forage supply and prevent overgrazing. Practices like soil bunds, controlled burning, and maintaining vegetation cover enhance soil moisture retention, reduce erosion, bush encroachment, and stabilise microclimates. ‣ Indigenous and/or climate-resilient breeds are better adapted to heat stress, drought, and context-specific diseases. Seasonal movement of herds and maintaining mixed livestock species spreads climate risk and reduces vulnerability to localised droughts or diseases. ‣ Grazing committees and early-warning systems improve coordinated responses to climate shocks and reduce social vulnerability. **Mitigation** ‣ Maintaining vegetation cover, rotational grazing, and reseeding legumes increases soil organic carbon and offsets some livestock emissions. Integration of trees, shrubs, and perennials stores carbon above- and below-ground while improving forage resilience and microclimates. ‣ Controlled stocking rates preserve carbon-rich soils and prevent desertification. Optimised stocking rates and improved feed quality reduce methane emissions per unit of livestock product. ‣ Maintaining mixed-use landscapes and wildlife corridors supports natural carbon cycles through nutrient cycling, soil fertility, and habitat heterogeneity.
Co-benefits and trade-offs for water quality and quantity:	SRHM can enhance both water quantity and quality by improving infiltration, protecting riparian zones, controlling overgrazing, and preventing erosion and pollution. This supports resilient pastoral systems, healthy ecosystems, and reliable water supply in tropical and sub-tropical landscapes.

6.13 Sustainable rangeland and herd management



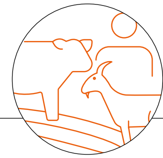
continued Co-benefits and trade-offs for water quality and quantity:	**Water quantity** ‣ Practices like maintaining vegetative cover and reseeding grasses increase infiltration and reduce runoff, helping recharge groundwater and surface water. Rotational grazing reduces over-concentration of livestock around water points, preventing overuse. Construction of small dams, ponds, and tanks captures seasonal rainfall, increasing water availability during dry periods. ‣ Silvo-pastoral systems (trees and shrubs in pastures) provide shade, reduce soil temperature, and lower water loss from evaporation. By improving soil and vegetation cover, SRHM buffers water sources against seasonal droughts and prolonged dry spells. **Water quality** ‣ Maintaining vegetation cover and controlling overgrazing prevents soil erosion, which reduces sediments in streams, rivers, and ponds. Controlled stocking rates and rotational grazing reduce the concentration of animal waste in one area, reducing nutrient and pathogen runoff into water bodies. ‣ Regulating access routes near rivers and wetlands prevents trampling and degradation, maintaining natural filtration and water purification functions. Healthy vegetation buffers along streams and ponds preserve aquatic ecosystems and help regulate water chemistry. Potential risks (if poorly managed): Contamination of water, possible overuse of water resources, competition between water for agricultural use and livestock needs. Management options are already reflected in the bullets above.
Co-benefits and trade-offs for soil health:	SRHM can enhance soil health by maintaining vegetation cover, improving organic matter and nutrient cycling, supporting soil microbial activity, preventing erosion, and increasing water retention. Healthy soils, in turn, support forage productivity, livestock resilience, and climate adaptation. ‣ **Soil structure and erosion control**: Rotational grazing and controlled stocking prevent overgrazing, maintaining vegetation cover that stabilises soil. Livestock movement distributes organic matter (dung, urine) which enhances soil structure and aggregation. Rotational grazing reduces continuous trampling in the same area, protecting soil porosity and root growth. ‣ Soil fertility and nutrient cycling: Livestock manure, urine, and plant residues increase soil organic carbon and over-all fertility. Controlled grazing ensures more uniform distribution of nutrients across the landscape rather than nutrient concentration near watering points. Integration of legumes in pastures contributes nitrogen to the soil, improving fertility without synthetic fertilisers.

6.13 Sustainable rangeland and herd management



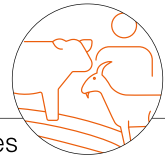
continued Co-benefits and trade-offs for soil health:	• Soil moisture and water retention: Maintaining vegetative cover and minimising bare patches increases water penetration into the soil. Mulching from plant litter and soil organic matter helps the soil hold water longer, supporting forage growth during dry periods. Soil protection and pasture cover slow water flow, decreasing erosion and improving groundwater recharge. • Soil biological activity: Organic matter inputs from livestock manure support soil bacteria, fungi, and decomposers, which drive nutrient cycling and soil health. Earthworms and dung beetles are encouraged by moderate grazing, improving aeration, organic matter incorporation, and nutrient recycling. Sustainable grazing prevents excessive nutrient hotspots and degradation, maintaining a stable soil microbial community. • **Potential risks (if poorly managed)**: overgrazing (see above under “co-benefits for water”
Co-benefits and trade-offs for productivity:	SRHM enhances productivity at multiple levels - livestock growth, milk and meat yield, forage quantity and quality, and overall ecosystem output. • **Livestock productivity**: Rotational grazing prevents overgrazing, ensures balanced forage availability, and reduces stress from poor nutrition. Adequate feed and reduced disease pressure from proper herd management support better fertility and calf survival. Consistent and high-quality forage improves milk production and weight gain in cattle, goats, and sheep. Proper water management, shelter, and disease control decrease losses during droughts and disease outbreaks. Using indigenous, climate-adapted breeds maintains productivity. • **Forage and pasture productivity**: Rotational grazing allows plants to recover, increasing biomass and forage quality. Integrating legumes, shrubs, and deep-rooted grasses increases protein content, seasonal availability, and drought resilience. Organic matter from dung and urine enriches soil nutrients, improving forage yields. Maintaining vegetation cover protects soil, sustaining long-term productivity of the rangeland. • **Potential Risks (if poorly managed)**: overgrazing and neglect of water and soil management can reduce pasture growth and livestock productivity.

6.13 Sustainable rangeland and herd management



Co-benefits and trade-offs for income:	SRHM can increase incomes by boosting livestock productivity, reducing losses, diversifying products, and creating opportunities from ecosystem services. It also stabilises income over time by reducing vulnerability to climate shocks and resource degradation. ‣ **Direct livestock-related income**: Increased milk yield, meat production, and liveweight gain improve household cash income. Reduced losses from disease and drought ensure more animals survive to be sold or used for household consumption. Use of indigenous and/or climate-adapted breeds and improved herd management increases market value of animals. Opportunities for milk, meat, hides, wool, and manure sales broaden income streams. ‣ **Forage and pasture-related income**: Reseeded pastures, fodder banks, and silvo-pastoral systems can produce surplus hay or fodder for sale. Improved pasture management reduces reliance on purchased feed, increasing net income. ‣ **Ecosystem service and land-based income**: Trees and shrubs in pastures provide fruits, timber, firewood, and non-timber products for sale. Carbon credits or biodiversity incentives can provide additional revenue to communities practicing SRHM. Well-managed landscapes with healthy wildlife populations can support eco-tourism or conservancy payments (e.g., in East Africa). ‣ **Risk reduction and income stability**: SRHM reduces losses during dry periods, maintaining more stable and predictable incomes. Healthier animals and better forage management reduce expenses, increasing net profitability. Participatory grazing plans reduce conflicts and associated losses, supporting more reliable livelihoods. ‣ **Potential risks / considerations**: High initial investments are required, before income benefits are realised. Improved productivity may not translate into higher income if markets are distant or underdeveloped or not adapted to local conditions.
Co-benefits and trade-offs for food and nutrition security:	SRHM can enhance food and nutrition security by ensuring consistent livestock productivity, maintaining high-quality forage, stabilising household income, and providing nutrient-rich animal-source foods. It is particularly important in tropical and sub-tropical rangelands, where climate variability and limited crop options make livestock a central component of food security. ‣ **Direct livestock contributions**: Animals grazing on diverse, well-managed pastures produce more nutritious milk and meat. Rotational grazing, fodder banks, and silvo-pastoral systems ensure livestock products are available even during dry seasons and regions unsuitable for crop farming. Better livestock productivity and access to nutritious foods enhance child and maternal nutrition in pastoral communities. Milk, meat, eggs, and other livestock products provide essential proteins, fats, and micronutrients (iron, zinc, vitamin B12, etc). Proper herd management, clean water, and rotational grazing reduce disease risk in livestock products, improving safe consumption.

6.13 Sustainable rangeland and herd management



continued Co-benefits and trade-offs for food and nutrition security:	• **Forage and pasture security**: SRHM maintains consistent pasture productivity, reducing feed shortages and ensuring livestock survival (and hence food from livestock) during droughts. • **Household and community resilience**: Healthy herds act as a buffer against drought or crop failure, providing food directly or through sales to purchase other foods. Increased and stabilised income from livestock enables households to buy diverse foods and improve diet quality. Integration of trees, shrubs, and multi-species pastures provides edible fruits, seeds, and fodder for small livestock. • **Potential risks/considerations**: If livestock products are sold rather than consumed, households may gain income but not direct nutritional benefits. Even with SRHM, extreme droughts or forage shortages can temporarily reduce availability of livestock products.
Co-benefits and trade-offs for gender equity:	SRHM can promote gender equity by improving women's access to resources, income opportunities, technical knowledge, and decision-making roles. When implemented with inclusive governance and gender-sensitive training, SRHM strengthens both economic and social empowerment of women in tropical and sub-tropical pastoral and agropastoral systems. • **Increased participation of women in decision-making**: Community-based management structures (e.g., grazing committees, conservancies) provide platforms for women to participate in resource governance. Inclusive planning allows women to contribute to decisions about herd management, pasture rotation, water access, and community investments. Strengthened voice of women in local institutions can influence livestock marketing and income allocation decisions. • **Access to resources**: SRHM encourages diversification of herd ownership, giving women access to small ruminants, poultry, and dairy animals. Rotational grazing and planned water systems can improve equitable access, reducing conflicts over resources. • **Economic empowerment**: Women can generate income from milk, small ruminants, eggs, and value-added products such as cheese or yogurt. Access to silvo-pastoral products (fruits, firewood, fodder) creates additional income streams for women. Increased control over income strengthens household bargaining power and economic security. • **Improved nutrition and household food security**: Women's involvement in livestock and pasture management ensures availability of nutritious foods (milk, meat, eggs) for children and families. Control over small livestock and agroforestry products allows women to improve family nutrition and health outcomes.

6.13 Sustainable rangeland and herd management

continued Co-benefits and trade-offs for gender equity:	• **Knowledge, skills, and capacity building**. SRHM programs can provide women with knowledge in herd management, pasture improvement, soil and water conservation, and climate adaptation. Participation in communal rangeland management develops negotiation, record-keeping, and conflict-resolution skills. Women can pass skills to younger generations, promoting long-term sustainability and equity. • **Potential challenges**: In some regions, women may still face restrictions on accessing certain animals, communal lands or livestock markets or in getting tenure rights or being involved in resource governance decisions. Without careful planning, women may bear additional labour responsibilities from both household duties and SRHM activities. Men may dominate financial decisions, reducing the potential impact of SRHM on gender equity.
Works well with/ brings synergies with practice…	• Agroforestry and Assisted Natural Regeneration: In some contexts, the sowing or planting of fodder trees and legumes can improve feed supply and soil fertility. ANR can improve rangeland quality. • Integrated crop-livestock systems: Integration with crop farming allows use of stover, husks, and bran, minimising waste. • Conservation and utilisation of local livestock breeds: managing rangelands and herds sustainably is a prerequisite for a successful use of local livestock breeds • Soil organic amendments: Healthy soils support productive pastures; local livestock also contribute organic manure, enhancing soil fertility.
Does not work well/ competes with practice…	In many parts of the world, and in particular in Africa, there are conflicts between pastoralists and crop farmers. Introducing pastoralism in areas dominated by farmers or the other way brings the risk of generating conflicts.
Any other disadvantages of the practice	None
Possible mitigation measures to manage trade-offs/ address disadvantages	See details under each impact area.

6.14 Zero or minimum tillage

Minimum or tillage is a conservation farming practice where the soil is disturbed as little as possible, often by planting crops directly into untilled fields using specialised seed drills (direct seeding). Instead of ploughing, farmers leave crop residues on the surface to protect the soil, retain moisture, and suppress weeds, while biological activity (earthworms, microbes) naturally improves soil structure.

6.14 Zero or minimum tillage

Further short description	The method is part of the "conservation agriculture" approach, which is based on traditional farming systems in the tropics. It has also been classified as a climate smart technology, as it contributes to both climate change mitigation and adaptation. For more detailed descriptions and guidance in specific contexts, see: ‣ Paparella et al. 2025: ‣ Minimum tillage ‣ For mechanised no till systems: ‣ Classen 1996 ‣ For conservation agriculture overall, including minimum/no tillage: ‣ African Conservation Tillage Network (undated), Corsi and Muminjanov 2019. ‣ The Centre for No Till agriculture has a number of videos and training modules at ‣ https://centrefornotill.org/training-center

Context / suitability

Farm or landscape level	Farm level, plot level
Relevant production system (‣ FAO classification)	Rainfed crops, mixed systems

6.14 Zero or minimum tillage

Resource requirements/cost implications	
Land and other natural resources	• Minimum/zero tillage can work on many soil types, but it performs best on soils with moderate to good structure and drainage. Extremely compacted or poorly drained soils may need some initial remediation before switching. • Adequate water supply is essential, whether from rainfall or irrigation. One of the benefits of no-till is that it improves water infiltration and retention but crops still need a dependable source of moisture to establish well in untilled soil. • Surface residues from previous crops are key to reducing evaporation, moderating soil temperature, and protecting against erosion. • Healthy populations of soil organisms (earthworms, microbes, fungi) help decompose residues, cycle nutrients, and maintain soil structure in the absence of mechanical tillage.
(financial and physical) capital/implements	For smallholder farmers, adopting zero or no tillage usually requires some initial capital investment and ongoing financial resources, though these can be relatively modest compared to fully mechanised systems. Typical needs include: **Capital resources (one-time or infrequent investments):** • Direct-seeding equipment – hand-operated jab planters, animal-drawn planters, or small mechanical no-till seed drills; sometimes available through cooperatives or local hire services to reduce cost. • Residue management tools – machetes, sickles, or light slashers for managing cover crops and weeds before planting. • Weed control equipment – hoes, backpack sprayers (if herbicides are used), or mulch applicators. • Cover crop seeds – for building residue cover and improving soil health in the first seasons. **Financial resources (recurring or seasonal expenses):** • Seed and inputs – crop seed, cover crop seed, and possibly small amounts of fertiliser or soil amendments (organic or mineral) to accelerate soil fertility improvement. • Weed and pest control costs – could include herbicides (if used) or labour for manual weeding; costs often shift from fuel for tillage to weed management. • Equipment maintenance – repairs or replacement of planting tools, sprayers, and hand implements. • Training and extension services – fees for farmer field schools, demonstration plots, or cooperative membership that provides access to equipment and know-how.

6.14 Zero or minimum tillage

continued (financial and physical) capital/implements	While zero tillage can reduce long-term operational costs (fuel, labour for ploughing), the initial investment in appropriate tools, weed control strategies, and farmer training is often the main financial hurdle for small-holders. There are lower cost alternatives (e.g. modifying existing tools, not using herbicides, sharing tools via cooperatives etc.) that could facilitate adoption.
Labour (qualitative and quantitative/skills etc.)	Labour requirements for zero or no tillage in tropical or subtropical regions tend to shift rather than simply decrease – some tasks become less labour-intensive, while others can demand more attention. In addition, there is a time dimension to it: An initial transition period of 1–3 years, where labour may stay the same or slightly increase due to new practices and weed pressure, is followed in the long term (after the system stabilises) by declining labour for land preparation and weeding, where the workload becomes more evenly spread throughout the season rather than concentrated before planting. On-farm testing, with monitoring of labour requirements, is required before scaling out the technology. Once it has been thoroughly tested and adapted to local context, demonstrations can help with promotion. **Reduced labour for land preparation** ‣ No ploughing or harrowing means fewer days of heavy draft-animal or tractor work, and less manual digging or hoeing to prepare seedbeds. ‣ Planting can be quicker if using jab planters or direct-seeding tools, especially when soil moisture is good and residue cover is manageable. **Increased or reallocated labour for weed control** ‣ Without soil turning to bury weed seeds, more effort is often needed for early-season weeding. ‣ Labour may go into manual weeding, mulching, or cover crop management rather than pre-plant cultivation. ‣ In some cases, herbicide application replaces part of the weeding labour, but this introduces cash costs and may have negative biodiversity impacts. **Labour for residue and cover crop management** ‣ Time is needed to slash or cut down previous crop residues and/or terminate cover crops before planting and applying compost or other soil amendments. ‣ Mulch spreading may require extra days, though this is seasonal and often lighter work than tillage. **Ongoing soil health management** ‣ Farmers may need to invest time in observing soil conditions, pest presence, and crop performance, as changes can be more gradual in no-till systems. Learning and adapting to new planting and weed control methods can initially demand more labour in the first 1–3 years.

6.14 Zero or minimum tillage

Expected impacts on biodiversity

Detailed description of impacts on biodiversity	**Genetic diversity:** • Positive potential: Zero tillage often encourages farmers to integrate cover crops, intercropping, and crop rotations, which can increase the genetic diversity of cultivated plants on a farm. • By maintaining more crop residue and perennial vegetation, the system can also support wild relatives of crops and locally adapted landraces. • In the soil seed bank, reduced disturbance allows natural regeneration of some native or semi-wild plant species. • Risks: If zero till is implemented as a monoculture with heavy herbicide use, genetic diversity can decline due to reduced variety in crop and non-crop species. **Species diversity** • Soil organisms: No till greatly benefits soil biodiversity (earthworms, mycorrhizal fungi, beneficial bacteria, arthropods) by maintaining a stable habitat with consistent organic matter inputs. • Above-ground fauna: Crop residues and cover crops provide food and shelter for beneficial insects, birds, and small mammals. • Plant species: Less disturbance allows a more diverse range of weed and non-crop plants to establish; this can be positive for pollinators but may require active weed management to avoid yield loss. • Risks: Over-reliance on chemical weed control can harm non-target species and reduce floral resources for beneficial insects. **Ecosystem diversity** • At the landscape scale, adopting zero tillage as part of conservation agriculture can enhance habitat connectivity by maintaining ground cover and reducing erosion, supporting watershed health. • On-farm, the practice can create a mosaic of microhabitats (mulched areas, cover crop patches, permanent vegetative strips) that support different species assemblages. • Over time, improved soil structure and moisture retention can revive degraded ecosystems, allowing re-establishment of more complex food webs. • Risks: If implemented uniformly over large areas without integrating diverse species or landscape features, benefits to ecosystem diversity may be limited.

6.14 Zero or minimum tillage

Complementarity and competition	
Co-benefits and trade-offs for climate change mitigation and adaptation	Minimum or zero tillage influences climate change mitigation and adaptation in distinct but interconnected ways: **Mitigation** ‣ Carbon sequestration in soils: By leaving residues on the surface and minimising disturbance, more organic matter is retained and gradually incorporated by soil biota, increasing soil carbon stocks over time. ‣ Reduced fuel use: Avoiding repeated ploughing and harrowing cuts fuel consumption for tractors or animal-drawn equipment, lowering CO_2 emissions from fossil fuels or livestock emissions. ‣ Lower soil carbon losses: Conventional tillage exposes organic matter to rapid decomposition; zero till helps slow this process, reducing CO_2 release. ‣ Potential trade-off: If herbicide use increases significantly, associated production and application emissions can offset some of the climate benefits. **Adaptation** ‣ Improved water retention and infiltration: Residue cover and stable soil structure reduce runoff and improve infiltration, helping crops withstand dry spells. ‣ Reduced erosion: Surface cover protects against heavy-rain events, preserving topsoil and nutrients crucial for productivity under more variable rainfall patterns. ‣ Temperature buffering: Mulch moderates soil temperatures, protecting seedlings from extreme heat and reducing evaporation losses. ‣ Enhanced soil biological activity: Diverse soil organisms help cycle nutrients and maintain soil health, improving resilience to shocks like drought or pest outbreaks. ‣ Diversification potential: When combined with cover crops and rotations, zero till supports more diverse and climate-resilient cropping systems.
Co-benefits and trade-offs for water quality and quantity:	Minimum or zero tillage affects both water quality and water quantity, mostly through its influence on soil structure, residue cover, and runoff dynamics:

6.14 Zero or minimum tillage

continued Co-benefits and trade-offs for water quality and quantity:	**Water quantity** ‣ Reduced sediment runoff: With less soil disturbance and more surface cover, erosion is greatly reduced, meaning fewer sediments (and the nutrients or agrochemicals they carry) reach rivers, lakes, or coastal waters. ‣ Lower nutrient leaching risk: Improved soil organic matter and infiltration allow nutrients to bind in the soil matrix, reducing leaching of nitrogen and phosphorus into groundwater. ‣ Fewer pesticide/herbicide losses via erosion: Soil cover traps agrochemicals, though if herbicide use increases, soluble chemicals can still leach or run off, requiring careful management. ‣ Improved biological filtration: Healthy, biologically active soils under zero till act like a filter, breaking down some pollutants before they reach water bodies. **Water quality** ‣ Improved infiltration: Stable soil aggregates and pore spaces from biological activity allow rainfall to soak in rather than run off, increasing effective water capture. ‣ Higher water retention: Mulch reduces evaporation losses, and increased soil organic matter boosts the soil's water-holding capacity, which is crucial during dry spells. ‣ More consistent base flow in streams: Reduced runoff and better infiltration can help maintain groundwater recharge and dry-season flow in local waterways (which can also be beneficial for aquatic biodiversity). ‣ Potential trade-off: In some cases, heavier mulch or cover crops can use some soil moisture early in the season, so planting time and species choice matter for water availability to the main crop.
Co-benefits and trade-offs for soil health:	Minimum or zero tillage has multiple effects on soil health, most of them positive if the practice is paired with good residue and crop management. **Soil structure and stability** ‣ Improved aggregate stability: Reduced disturbance allows natural binding agents (organic matter, fungal hyphae, root exudates) to strengthen soil aggregates. ‣ Better porosity and infiltration: Earthworms and other soil fauna create stable channels that improve aeration and water movement. ‣ Less compaction at the surface: Avoiding repeated ploughing prevents crust formation, though occasional subsoil compaction from machinery or animal traffic may still occur.

6.14 Zero or minimum tillage

continued Co-benefits and trade-offs for soil health:	**Organic matter and nutrient cycling** ‣ Higher soil organic matter (SOM): Crop residues decompose gradually on the surface, adding carbon and nutrients to the topsoil. ‣ Enhanced nutrient retention: SOM binds nutrients, reducing losses and making them available to plants over a longer period. ‣ More active nutrient cycling: Healthy soil biota breaks down residues and mineralise nutrients efficiently. **Biological activity and biodiversity** ‣ More abundant soil fauna: Especially earthworms, termites, and other beneficial arthropods thrive under stable, mulched conditions. ‣ Richer microbial communities: Fungi, bacteria, and other soil fauna flourish without mechanical disturbance, often shifting toward fungal-dominated communities that improve aggregate stability. ‣ Improved symbioses: Mycorrhizal fungi networks are preserved, enhancing nutrient and water uptake by plants. **Erosion control and topsoil preservation** ‣ Reduced erosion risk: Permanent soil cover prevents raindrop impact and surface sealing, preserving fertile topsoil. ‣ Slower loss of nutrients and carbon: Less physical removal of soil means more long-term fertility retention. **Potential risks if poorly managed** ‣ Weed pressure: Without tillage, weeds can build up if residue cover and rotations are not managed well. ‣ Pest and disease carry-over: Some pests may persist in crop residues if rotations are not diverse. ‣ Nutrient stratification: Over time, nutrients may accumulate near the surface, which can be an issue in very dry environments where deep roots struggle to access them.
Co-benefits and trade-offs for productivity:	The impact of minimum or zero tillage on crop productivity usually follows a time-dependent pattern: yields can be variable or slightly lower in the short term but often improve and stabilise in the long term if the system is well managed. **Short-term impacts (first 1 – 3 years)** ‣ Possible yield dip or variability: Residues on the surface can slow soil warming and germination in cooler or early rainy seasons. Higher weed pressure in the absence of tillage can compete with crops. Soil biological processes and organic matter buildup take time to deliver benefits. ‣ Exceptions: In degraded soils prone to erosion or crusting, yields can increase even in the first year due to improved moisture conservation and reduced compaction.

6.14 Zero or minimum tillage

continued Co-benefits and trade-offs for productivity:	**Long-term impacts (after 3 – 5+ years)** ‣ Yield recovery and improvement: Better soil structure, organic matter, and nutrient cycling improve water and nutrient availability to crops. More stable yields across seasons, particularly in drought years, due to higher water-holding capacity and deeper rooting. ‣ Higher system productivity: When combined with crop rotation, cover crops, and integrated fertility management, zero till can increase total biomass and grain yields over time. ‣ Resilience to climate extremes: Reduced yield losses in years with erratic rainfall or intense heat events. **Factors affecting productivity trends** ‣ Positive drivers: Good residue cover, diverse crop rotations, balanced fertility inputs, effective weed control, and adapted crop varieties. ‣ Negative drivers: Over-reliance on monoculture, poor residue management, nutrient depletion, persistent weeds, or pest carry-over.
Co-benefits and trade-offs for income:	Income impacts follow a similar pattern as productivity impacts but are dependent on additional factors such as markets. **Short-term impacts (transition phase, 1 – 3 years)** ‣ Potential income dip or stagnation due to slightly lower or more variable yields while soil biology and structure slowly improve; upfront costs for new tools (jab planters, direct seeding implements) or renting specialised equipment; and higher early-season weed control costs (labour or herbicides). ‣ Partial offset by savings from reduced ploughing and land-preparation costs (fuel, tractor hire, or animal power) and lower labour costs for land preparation, freeing time for other income-generating activities. **Long-term impacts (after 3 – 5+ years)** ‣ Higher and more stable incomes due to improved yields and yield stability in drought years or under erratic rainfall; higher value (in terms of cash and nutrition) legumes can be integrated once soil quality has improved; continued savings on land preparation costs; potential for diversified income streams from integrating cover crops, intercropping, or rotations with cash crops; reduced fertiliser costs if soil organic matter and nutrient cycling improve significantly. ‣ Lower risk profile: Greater resilience to climate shocks reduces the probability of catastrophic crop losses, which is financially stabilising even if average yields only modestly increase.

6.14 Zero or minimum tillage

continued Co-benefits and trade-offs for income:	**Influencing factors** ‣ Positive: Access to affordable seeding equipment, strong residue and weed management, diversified cropping, extension support. ‣ Negative: Over-reliance on purchased herbicides without adequate crop income, poorly managed monocultures, lack of markets for rotation crops.
Co-benefits and trade-offs for food and nutrition security:	Minimum or zero tillage affects food and nutrition security mainly through its influence on crop productivity, system diversity, and resilience to climate shocks. **Food availability** ‣ Short term: Production may remain stable or dip slightly during the transition period, especially if weed control or planting techniques are not yet optimised. ‣ Long term: Improved soil health, water retention, and climate resilience can lead to more stable or increased yields, especially in drought-prone years. ‣ Year-to-year stability: Zero tillage tends to reduce yield fluctuations, helping ensure a more consistent household food supply. **Food access** ‣ Income effects: Cost savings on land preparation and potentially more reliable yields can improve household purchasing power over time. ‣ Labour savings: Reduced tillage frees time for off-farm work or other income-generating activities, indirectly improving access to diverse foods. **Food utilisation and nutrition quality** ‣ Diet diversity potential: When combined with crop rotations, intercropping, or cover crops (e.g., legumes, vegetables), zero tillage can increase the variety of nutrient-rich foods available for home consumption. ‣ Soil fertility and crop nutrient content: Improved organic matter and soil biology may enhance micronutrient availability in crops, though this depends on crop and soil type. ‣ Livestock feed availability: Residues left on the field for soil cover may compete with use as fodder; this trade-off can affect protein availability in mixed crop–livestock households.

6.14 Zero or minimum tillage

continued Co-benefits and trade-offs for food and nutrition security:	**Stability of food systems (resilience over time)** ‣ Better soil structure and moisture retention make farms more resilient to erratic rainfall, heatwaves, and erosion, reducing the risk of food shortages in bad years. ‣ Diversified rotations and cover crops also reduce pest and disease outbreaks, which helps protect food supply stability.
Co-benefits and trade-offs for gender equity:	The impacts of minimum or zero tillage on gender equity depend on how labour, decision-making, and access to re-sources are structured within households and communities. The effects can be positive, neutral, or even negative if not implemented with gender-sensitive approaches. **Labour burden and division of work** ‣ Potential positives: Reduced need for heavy land preparation (ploughing, harrowing) can benefit women if those tasks were physically demanding or costly to hire out. However, in most farming systems, this work is done by men. Labour savings may free women's time for other productive, income-generating, or caregiving activities. ‣ Potential negatives: In some systems, zero tillage increases manual weeding requirements, which often falls dispro-portionately on women, potentially increasing their workload. If herbicide use replaces manual weeding, men may take over spraying tasks, shifting rather than sharing labour. **Access to equipment and inputs** ‣ Potential positives: Low-cost hand tools for direct seeding (jab planters) are more accessible to women than hiring tractors or oxen. Shared equipment through cooperatives can increase women's access if designed to be inclusive. ‣ Potential negatives: If adoption requires costly machinery or herbicides, men - who more often control household fi-nances - may have greater access, reinforcing existing inequalities. Health risks may result from herbicide exposure. **Decision-making and control over benefits** ‣ Potential positives: If zero tillage boosts yields or incomes from crops under women's management (e.g., vegetables, legumes), women's economic influence can increase. Group-based learning (e.g., farmer field schools) can improve women's participation in agricultural decision-making. ‣ Potential negatives: In male-dominated cash-cropping systems, productivity gains may not translate into improved control over income for women.

6.14 Zero or minimum tillage

continued Co-benefits and trade-offs for gender equity:	**Skills, training, and empowerment** ‣ Gender-sensitive extension programs that include women can strengthen their technical skills, enabling them to lead in conservation agriculture practices. ‣ If training sessions are scheduled or structured without considering women's time constraints or cultural barriers, women may be excluded from learning opportunities. Forming women's groups for training and demonstration sessions could address this challenge.
Works well with/ brings synergies with practice…	Crop rotation, intercropping, soil and water conservation, conservation and use of local crop varieties, agroforestry, use of organic soil amendments
Does not work well/ competes with practice…	None
Any other disadvantages of the practice	None
Possible mitigation measures to manage trade-offs/ address disadvantages	As the initial investments required may hinder adoption by resource-poor households, mechanisms to ease the burden of these costs can be considered, including subsidising inputs (implements/equipment), or making them available via cooperative arrangements at a reduced cost.

6.15 References for practice sheets

Acevedo-Siaca, L. and Goldsmith, P. D. (2020) Soy-Maize Crop Rotations in Sub-Saharan Africa: A Literature Review, International Journal of Agronomy, 2020, 8833872, 14 pages, 2020. → https://doi.org/10.1155/2020/8833872

Adimassu, Z., Mekonnen, K., Yirga, C. and Kessler, A. (2014) Effect of soil bunds on runoff, soil and nutrient losses, and crop yield in the central highlands of Ethiopia. Land Degradation and Development 25(6): 554–564.
→ https://cgspace.cgiar.org/items/4958b603-a2d4-4025-a27f-bf9f2686016b

Adjei-Nsiah, S., Kuyper, T.W., Leeuwis, C. et al. (2008) Farmers' agronomic and social evaluation of productivity, yield and N2-fixation in different cowpea varieties and their subsequent residual N effects on a succeeding maize crop. Nutr Cycl Agroecosyst 80, 199–209 (2008). → https://doi.org/10.1007/s10705-007-9133-3

African Conservation Tillage Network (undated) Conservation Agriculture Facilitator's Guidebook.
→ https://www.echocommunity.org/en/resources/7bbb0c8b-bb68-4dde-a47f-d438730b16e0

Agustin, A. M. L., Ordonio, J. L., Natividad, M. B. S., Lucob-Agustin, N. B., Suralta, R. R., Ehara, H., Mitsuya, S., & Kano-Nakata, M. (2023) Specialty Rice (Oryza sativa L.) with High and Stable Grain Yield under Rainfed Lowland Conditions. Agriculture, 13(10), 1985.
→ https://doi.org/10.3390/agriculture13101985

Ajebesone, N., Becker, F.E., Mtei, M. and Mark, K. (2011) Leguminous cover crops differentially affect maize yields in three contrasting soil types of Kakamega, Western Kenya. Journal of Agriculture and Rural Development in the Tropics and Subtropics, Vol. 112 No. 1 (2011) 1–10. → https://urn.fi/urn:nbn:de:hebis:34-2011101139312

Alemayehu, A. A., Getu, L. A., & Addis, H. K. (2020) Impacts of stone bunds on selected soil properties and crop yield in Gumara-Maksegnit watershed Northern Ethiopia. Cogent Food & Agriculture, 6(1). → https://doi.org/10.1080/23311932.2020.1785777

6.15 References for practice sheets

Alliance for Mediterranean Nature and Culture et al. (not dated) Use of local crop varieties.
→ https://iucn.org/sites/default/files/2023-05/practice_d.local-crops_final.pdf

Attfield, H.H.D. (2001) A bee keeping guide for the tropics and sub-tropics. Harlan H.D. Attfield and volunteers in technical assistance.
→ https://www.uog.edu/_resources/files/wptrc/BeekeepingGuide.pdf

Baijukya, F., Wairegi, L., Giller, K., Zingore, S., Chikowo, R. and P. Mapfumo (2016) Maize-legume cropping guide. Africa Soil Health Consortium, Nairobi. → https://cgspace.cgiar.org/server/api/core/bitstreams/f5d02302-5b5e-4b0c-9497-0330f0077b50/content

Badano, E.I. and Vergara, C.H. (2011) Potential negative effects of exotic honey bees on the diversity of native pollinators and yield of highland coffee plantations. Agricultural and Forest Entomology, 13: 365–372. → https://doi.org/10.1111/j.1461-9563.2011.00527.x

Bhagat, R., Walia, S. S., Sharma, K., Singh, R., Singh, G., & Hossain, A. (2024) The integrated farming system is an environmentally friendly and cost-effective approach to the sustainability of agri-food systems in the modern era of the changing climate: A comprehensive review. Food and Energy Security, 13, e534.

Bhattacharyya, R.; Ghosh, B.N.; Dogra, P.; Mishra, P.K.; Santra, P.; Kumar, S.; Fullen, M.A.; Mandal, U.K.; Anil, K.S.; Lalitha, M.; et al. Soil Conservation Issues in India. Sustainability 2016, 8, 565. → https://doi.org/10.3390/su806056

Biggs, J., Hoyle, S., Matos, I., McDonald, H., Nicolet, P., Oertli, B., & Teixeira, J. (2024) Ponds and Pondscapes: A technical guide to the use of ponds and pondscapes as nature-based solutions for climate change mitigation and adaptation.
→ https://doi.org/10.5281/zenodo.13844498

Binam, J.N., Place, F., Djalal, A.A. et al. (2017) Effects of local institutions on the adoption of agroforestry innovations: evidence of farmer managed natural regeneration and its implications for rural livelihoods in the Sahel. Agric Econ 5, 2.
→ https://doi.org/10.1186/s40100-017-0072-2

6.15 References for practice sheets

Blum, W.E., Zechmeister-Boltenstern, S., and Keiblinger, K.M. (2019) Does soil contribute to the human gut microbiome? Microorganisms, 7(9): 287. → https://pubmed.ncbi.nlm.nih.gov/31450753/

Boes, J., Boettcher, P. and Honkatukia, M., eds. (2023) Innovations in cryoconservation of animal genetic resources – Practical guide. FAO Animal Production and Health Guidelines, No. 33. Rome. → https://doi.org/10.4060/cc3078en

Brooker RW, Bennett AE, Cong WF, Daniell TJ, George TS, Hallett PD, Hawes C, Iannetta PP, Jones HG, Karley AJ, Li L, McKenzie BM, Pakeman RJ, Paterson E, Schöb C, Shen J, Squire G, Watson CA, Zhang C, Zhang F, Zhang J, White PJ (2015) Improving intercropping: a synthesis of research in agronomy, plant physiology and ecology. New Phytol. 2015 Apr;206(1):107–117. → https://pubmed.ncbi.nlm.nih.gov/25866856/

Cook, S.M., Khan, Z.R. and Pickett, J.A. (2007) The use of push-pull strategies in integrated pest management. Annual Review of Entomology, 52:375–400. → https://pubmed.ncbi.nlm.nih.gov/16968206/

Corsi, S. and Muminjanov, H. (2019) Conservation Agriculture: Training guide for extension agents and farmers in Eastern Europe and Central Asia. Rome: FAO. → https://openknowledge.fao.org/server/api/core/bitstreams/c2ef4bba-a15d-4df2-9326-ed557ab67c92/content

CRS, ICRISAT, and ODI (2002) Seed vouchers and fairs: a manual for seed-based agricultural recovery after disaster in Africa. PO Box 49675, Nairobi, Kenya: Catholic Relief Services; PO Box 39063, Nairobi, Kenya: International Crops Research Institute for the Semi-Arid Tropics; and Westminster Bridge Road, London, UK: Overseas Development Institute. 72 pp. → https://oar.icrisat.org/3338/1/Seed_Vouchers_and_Fairs.pdf

Dalzell, H.W., Riddlestone, A.J., Gray, K.R., Thurairajan, K. (1987) Soil management: compost production and use in tropical and subtropical environments. FAO Soils Bulletin No. 56, FAO Land and Water Division. → https://openknowledge.fao.org/items/1a5cac8f-d158-418c-9b65-5fa3c62a299c

6.15 References for practice sheets

Dubey, S.K., Gogoi, K., Islam, J. et al. (2024) Nutrition-sensitive carp–mola polyculture in ponds: Management and economics. Penang, Malaysia: WorldFish. Program report: 2024-36.
→ **https://worldfishcenter.org/publication/nutrition-sensitive-carp-mola-polyculture-ponds-management-and-economics**

Ebbisa, A. (2022) Mechanisms underlying cereal/legume intercropping as nature-based biofortification: A review. Food Prod Process and Nutr 4, 19 → **https://doi.org/10.1186/s43014-022-00096-y**

El Khoury, W. and Delve, R. (2018) How to do. Supporting smallholder seed systems. Rome: IFAD.
→ **https://www.ifad.org/documents/d/new-ifad.org/seeds_htdn-pdf**

Emerick K, Ronald PC. (2019) Sub1 Rice: Engineering Rice for Climate Change. Cold Spring Harb Perspect Biol. 2019 Dec 2;11(12):a034637. → **https://pmc.ncbi.nlm.nih.gov/articles/PMC6886445/**

Eyhorn, F., Heeb. M. and Weidmann, G. (undated) IFOAM training manual for organic agriculture in the tropics. FIBL, IFOAM and SIPPO. → **https://www.fibl.org/fileadmin/documents/shop/1299-manual-tropics-basic.pdf**

FAO (2005) Management of Tropical Sandy Soils for Sustainable Agriculture. A holistic approach for sustainable development of problem soils in the tropics. Proceedings of a conference, 27th November to 2nd December 2005, Khon Kaen, Thailand.
→ **https://www.fao.org/4/ag125e/AG125E00.htm**

FAO (2013) In vivo conservation of animal genetic resources. FAO Animal Production and Health Guidelines. No. 14. Rome.
→ **https://www.fao.org/4/i3327e/i3327e.pdf**

FAO (2019) Restoring forest landscapes through assisted natural regeneration (ANR) – A practical manual. FAO: Bangkok.
→ **https://openknowledge.fao.org/items/4bc01024-5c69-48b4-bce9-42239242adec?utm=**

6.15 References for practice sheets

FAO (2024) Integrated farming systems: improving land-use efficiency while ensuring food safety. Rome: FAO.

FAO (2025) Guidance on integrated pest management for the world's major crop pests and diseases. Rome: FAO.
→ https://doi.org/10.4060/cd4890en

FAO and ITPS (2015) Status of the World's Soil Resources (SWSR) – Main Report. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome: FAO.
→ https://openknowledge.fao.org/server/api/core/bitstreams/6ec24d75-19bd-4f1f-b1c5-5becf50d0871/content

FAO and ITPS (2021) Recarbonizing global soils – A technical manual of recommended management practices. Volume 1: Introduction and methodology. Rome: FAO. → https://doi.org/10.4060/cb6386en

FAO, IZSLT, Apimondia and CAAS (2021) Good beekeeping practices for sustainable apiculture FAO Animal Production and Health Guidelines No. 25. Rome: FAO. → https://doi.org/10.4060/cb5353en

Florentín, M.A., Peñalva, M., Calegari, A. and Derpsch, R. (2011) Green manure/cover crops and crop rotation in Conservation Agriculture on small farms. Integrated Crop Management, Vol. 12. Rome: FAO Plant Production and Protection Division.
→ https://www.fao.org/fileadmin/user_upload/agp/icm12.pdf

Franke, A.C., van den Brand, G.J., Vanlauwe, B. and Giller, K.E. (2018) Sustainable intensification through rotations with grain legumes in Sub-Saharan Africa: A review, Agriculture, Ecosystems & Environment, Volume 261, Pages 172–185.
→ https://doi.org/10.1016/j.agee.2017.09.029

Freed, S., Kura, Y., Sean, V. et al. (2020) Rice field fisheries: Wild aquatic species diversity, food provision services and contribution to inland fisheries. Fisheries Research, Volume 229, 105615. → https://doi.org/10.1016/j.fishres.2020.105615

6.15 References for practice sheets

Garrity, D.P. and Bayala, J. (2019) Zinder: farmer-managed natural regeneration of Sahelian parklands in Niger. In: van Noordwijk M, ed. Sustainable development through trees on farms: agroforestry in its fifth decade. Bogor, Indonesia: World Agroforestry (ICRAF) Southeast Asia Regional Program. pp 153–174.
→https://www.cifor-icraf.org/publications/downloads/Publications/PDFS/BC19015.pdf

Gassner, A. and Dobie, P. eds. (2022) Agroforestry: A primer. Design and management principles for people and the environment. Bogor, Indonesia: Center for International Forestry Research (CIFOR) and Nairobi: World Agroforestry (ICRAF).
→ https://www.cifor-icraf.org/publications/pdf/books/Agroforestry-primer.pdf

Gebretsadkan, G. (2018) Evaluating The Effect of Integrated Use of Farm Yard Manure and Urea on the Socio economic Performance of Tomato (Lycopersiconesculentum Mill) at Tselemti Woreda, North western Tigray, Ethiopia. International Journal of Environment, Agriculture and Biotechnology, 3(3), 748–755. → https://doi.org/10.22161/ijeab/3.3.5

GIZ (2022) La production d'alevins de carpe en rizières. Support de formation. Projet d'Aquaculture Durable à Madagascar. Bonn: GIZ.
→ https://www.apdra.org/images/Apdra/Pdf/Manuels_fiches_techniques/2305_Flyer_Livre_1_FR.pdf

Gupta, N., Pradhan, S., Jain, A. and Patel, N. (2021) Sustainable Agriculture in India 2021 – What we know and how to scale up. New Delhi: Council on Energy, Environment and Water.
→ https://www.ceew.in/sites/default/files/CEEW-FOLU-Sustainable-Agriculture-in-India-2021-20Apr21.pdf

Haugen, H.M. (2020) The UN Declaration on Peasants' Rights (UNDROP): Is Article 19 on seed rights adequately balancing intellectual property rights and the right to food? J World Intellect Prop. 2020; 23: 288–309. → https://doi.org/10.1111/jwip.12152

Hawker, J., Smith, M.A.E., Bell, G. and Parker, J.A., (2020) Soil Management and Ecosystem Services. EO4cultivar Project Colombia Management Guide. UK Space Agency International Partnership Programme, Project No 417000001416.
→ https://data.jncc.gov.uk/data/fc25e10e-857b-4c08-a591-30fcd65d96dc/eo4c-colombia-soil-management-guide.pdf

6.15 References for practice sheets

Hilty, J., Worboys, G.L., Keeley, A., Woodley, S., Lausche, B., Locke, H., Carr, M., Pulsford I., Pittock, J., White, J.W., Theobald, D.M., Levine, J., Reuling, M., Watson, J.E.M., Ament, R., and Tabor, G.M. (2020) Guidelines for conserving connectivity through ecological networks and corridors. Best Practice Protected Area Guidelines Series No. 30. Gland, Switzerland: IUCN.
→ https://portals.iucn.org/library/sites/library/files/documents/PAG-030-En.pdf

ICIPE (2015) The "Push–Pull" Farming System: Climate-smart, sustainable agriculture for Africa. Nairobi: The International Centre of Insect Physiology and Ecology. → https://www.push-pull.net/planting_for_prosperity.pdf

IFAD and Kiribati Agriculture Department (2021) Integrated Farming Systems training manual. A pathway to introduce, design and utilize Integrated Farming Systems (IFS) for food security in Kiribati. Tanaea: Ministry of Environment, Land and Agriculture Development (MELAD), Republic of Kiribati.

Jabnoun-Khiareddine, H., Mejdoub-Trabelsi, B., Aydi Ben Abdallah, R., El-Mohamedy, R., & Daami-Remadi, M. (2020) Efficacy of Organic Amendments and Soil Solarization against Wilt Severity and their Effects on Pathogenic Fungi and Tomato Production. International Journal of Phytopathology, 9(2), 93–103. → https://doi.org/10.33687/phytopath.009.02.3317

Kiely, C., Randall, N. and Kaczorowska-Dolowry, M. (2023) The application of allelopathy in integrated pest management systems to control temperate European crop pests: a systematic map. CABI agriculture and bioscience, 4:42.
→ https://link.springer.com/content/pdf/10.1186/s43170-023-00183-1.pdf

Kugonza, D.R. (2009) Beekeeping theory and practice. Fountain improved farming guide series, Kampala: Fountain Publishers.
→ https://www.researchgate.net/publication/235444654_Beekeeping_Theory_and_Practice

Lengwati, D.M., Mathews, C. and Dakora, F.D. (2020) Rotation Benefits From N2-Fixing Grain Legumes to Cereals: From Increases in Seed Yield and Quality to Greater Household Cash-Income by a Following Maize Crop. Frontiers in Sustainable Food Systems. Volume 4. → https://www.frontiersin.org/journals/sustainable-food-systems/articles/10.3389/fsufs.2020.00094

6.15 References for practice sheets

Lindström, S. A., Herbertsson, L., Rundlöf, M., Bommarco, R., and Smith, H. G. (2016) Experimental evidence that honeybees depress wild insect densities in a flowering crop. Proceedings. Biological sciences, 283(1843), 20161641.
→ https://doi.org/10.1098/rspb.2016.1641

Magada, S (2025) Integrated Farming Systems. Mangalore: Arabian Sea Fisheries Management Coordination Committee.

Manda, J., Tufa, A.H., Alene, A., Swai, E., Muthoni, F., Hoeschle-Zeledon, I. and Bekunda, M. (2023) The income and food security impacts of soil and water conservation technologies in Tanzania. Frontiers in Sustainable Food Systems 7(2023).
→ https://www.frontiersin.org/journals/sustainable-food-systems/articles/10.3389/fsufs.2023.1146678

Marden, E., Sackville Hamilton, R., Halewood, M. and McCouch, S. (2023) International agreements and the plant genetics research community: A guide to practice. Proc Natl Acad Sci U S A. 2023 Apr 4;120(14):e2205773119.
→ https://pmc.ncbi.nlm.nih.gov/articles/PMC10083609/

Mensah, A., Adams, F., Asante, B.O. et al. (2024) Effect of shade management practice on cocoa seedling mortality: micro evidence from the Amansie-West district of Ghana. Agroforest Systems 98, 2727–2745. → https://doi.org/10.1007/s10457-024-01062-y

Mhango WG, Snapp SS, Phiri GYK (2013) Opportunities and constraints to legume diversification for sustainable maize production on smallholder farms in Malawi. Renewable Agriculture and Food Systems. 2013;28(3):234–244.
→ https://www.cambridge.org/core/journals/renewable-agriculture-and-food-systems/article/abs/opportunities-and-constraints-to-legume-diversification-for-sustainable-maize-production-on-smallholder-farms-in-malawi/B4B3E45A545A82C7AEA3640584D0E484?utm_

Mohler, C.L. and Johnson, S.E., editors (2009) Crop rotation on organic farms : a planning manual. Cooperative Extension NRAES; 177. → https://www.sare.org/wp-content/uploads/Crop-Rotation-on-Organic-Farms.pdf

6.15 References for practice sheets

Munroe, G. (2007) Manual of On-Farm Vermicomposting and Vermiculture. Org Agric Centre of Canada. → http://edn.link/dh4nh9

Namatsheve, T., Cardinael, R., Corbeels, M. et al. (2020) Productivity and biological N2-fixation in cereal-cowpea intercropping systems in sub-Saharan Africa. A review. Agron. Sustain. Dev. 40, 30 (2020). → https://doi.org/10.1007/s13593-020-00629-0

Oberthür, Sebastian et al. (2011) Intellectual Property Rights on Generic Resources and the Fight against Poverty. European Parliament, Brussels. → https://www.ecologic.eu/11982

Onduru, D.D. and Muchena, F.N. (2011) Cost-Benefit Analysis of Land Management Options in the Upper Tana, Kenya. Green Water Credits Report 15. Wageningen: World Soil Information. → https://www.isric.org/sites/default/files/isric_gwc_report_k15.pdf

Owoputi I, Booth N, Luginaah I, et al. (2022) Does Crop Diversity Influence Household Food Security and Women's Individual Dietary Diversity? A Cross-Sectional Study of Malawian Farmers in a Participatory Agroecology and Nutrition Project. Food and Nutrition Bulletin. 2022;43(4):395-411. → https://doi.org/10.1177/03795721221126787

Paparella A, Petsakos A, Davis K, Song C, and De Falcis E (2025) Crop rotation. Agricultural Management Practices to Mitigate Nature Loss Brief 13. Washington, DC: International Food Policy Research Institute and Alliance of Bioversity International and CIAT. → https://hdl.handle.net/10568/177489

Paparella A, Petsakos A, Davis K, Song C, and De Falcis E (2025) Multipurpose trees. Agricultural Management Practices to Mitigate Nature Loss Brief 15. Washington, DC: International Food Policy Research Institute and Alliance of Bioversity International and CIAT. → https://hdl.handle.net/10568/177491

Paparella A, Petsakos A, Davis K, Song C, and De Falcis E (2025) Intercropping. Agricultural Management Practices to Mitigate Nature Loss Brief 14. Washington, DC: International Food Policy Research Institute and Alliance of Bioversity International and CIAT. → https://hdl.handle.net/10568/177490

6.15 References for practice sheets

Paparella A, Petsakos A, Davis K, Song C, and De Falcis E (2025) Mechanical soil and water conservation. Agricultural Management Practices to Mitigate Nature Loss Brief 6. Washington, DC: International Food Policy Research Institute and Alliance of Bioversity International and CIAT. → https://hdl.handle.net/10568/177482

Paparella A, Petsakos A, Davis K, Song C, and De Falcis E (2025) Agro-silvo-pastoralism. Agricultural Management Practices to Mitigate Nature Loss Brief 7. Washington, DC: International Food Policy Research Institute and Alliance of Bioversity International and CIAT. → https://hdl.handle.net/10568/177485

Paparella A, Petsakos A, Davis K, Song C, and De Falcis E (2025) Organic fertilizers. Agricultural Management Practices to Mitigate Nature Loss Brief 3. Washington, DC: International Food Policy Research Institute and Alliance of Bioversity International and CIAT. → https://hdl.handle.net/10568/177479

Paparella A, Petsakos A, Davis K, Song C, and De Falcis E (2025) Integrated pest management. Agricultural Management Practices to Mitigate Nature Loss Brief 12. Washington, DC: International Food Policy Research Institute and Alliance of Bioversity International and CIAT. → https://hdl.handle.net/10568/177487

Paparella A, Petsakos A, Davis K, Song C, and De Falcis E (2025) Farming with alternative pollinators. Agricultural Management Practices to Mitigate Nature Loss Brief 8. Washington, DC: International Food Policy Research Institute and Alliance of Bioversity International and CIAT. → https://hdl.handle.net/10568/177484

Paparella A, Petsakos A, Davis K, Song C, and De Falcis E (2025) Biocontrol. Agricultural Management Practices to Mitigate Nature Loss Brief 2. Washington, DC: International Food Policy Research Institute and Alliance of Bioversity International and CIAT. → https://hdl.handle.net/10568/177492

Paparella A, Petsakos A, Davis K, Song C, and De Falcis E (2025) Minimum tillage. Agricultural Management Practices to Mitigate Nature Loss Brief 1. Washington, DC: International Food Policy Research Institute and Alliance of Bioversity International and CIAT. → https://hdl.handle.net/10568/177417

6.15 References for practice sheets

Paparella A, Petsakos A, Davis K, Song C, and De Falcis E (2025) Sustainable manure management. Agricultural Management Practices to Mitigate Nature Loss Brief 9. Washington, DC: International Food Policy Research Institute and Alliance of Bioversity International and CIAT. → https://hdl.handle.net/10568/177483

Paparella A, Petsakos A, Davis K, Song C, and De Falcis E (2025) Green manure. Agricultural Management Practices to Mitigate Nature Loss Brief 4. Washington, DC: International Food Policy Research Institute and Alliance of Bioversity International and CIAT. → https://hdl.handle.net/10568/177480

Paterson, P.D. (2021) Beekeeping in tropical Africa. Independently published, not available online.

Priyadarshana TS, Martin EA, Sirami C, Woodcock BA, Goodale E, Martínez-Núñez C, Lee MB, Pagani-Núñez E, Raderschall CA, Brotons L, Rege A, Ouin A, Tscharntke T, Slade EM. Crop and landscape heterogeneity increase biodiversity in agricultural landscapes: A global review and meta-analysis. Ecol Lett. 2024 Mar;27(3):e14412. → https://pubmed.ncbi.nlm.nih.gov/38549269/

Qiu Y, Fu Q, Yang Y, Zhao J, Li J, Yi F, Fu X, Huang Y, Tian Z, Heitman JL, Yao Z, Dai Z, Qiu Y, Chen H. (2024) Soil and stone terraces offset the negative impacts of sloping cultivation on soil microbial diversity and functioning by protecting soil carbon. J Environ Manage. 2024 Oct; 369:122339. → https://pubmed.ncbi.nlm.nih.gov/39222589/

RECOFTC, ICRAF and AWG-SF. (2020) Agroforestry for climate-resilient landscapes, Bangkok, RECOFTC. → https://www.recoftc.org/sites/default/files/press-release/attachments/recoftc-0000369-0003-en.pdf

Ricketts, K. and Shackleton, C. M. (2019) Integrating livelihoods and forest conservation through beekeeping in northern KwaZulu-Natal. Development Southern Africa, 37(4), 661– 677. → https://doi.org/10.1080/0376835X.2019.1698408

Rinaudo, T., Muller, A., Morris, M. (2019) Farmer Managed Natural Regeneration (FMNR) Manual. World Vision Australia. → https://fmnrhub.com.au/wp-content/uploads/2024/05/FMNR-Field-Manual_DIGITAL_FA-2.pdf

6.15 References for practice sheets

Robinson, T.P., Thornton P.K., Franceschini, G., Kruska, R.L., Chiozza, F., Notenbaert, A., Cecchi, G., Herrero, M., Epprecht, M., Fritz, S., You, L., Conchedda, G. and See, L. (2011) Global livestock production systems. Rome, Italy: FAO and Nairobi, Kenya: ILRI. → https://www.ilri.org/knowledge/publications/global-livestock-production-systems

Schroth, G., da Fonseca, G.A.B., Harvey, C.A., Gascon, C., Vasconcelos, H.L. and Izac, A.M.N., editors, (2004) Agroforestry and Biodiversity Conservation in Tropical Landscapes. Washington, Covelo, London: Island Press. → https://library.uniteddiversity.coop/Permaculture/Agroforestry/Agroforestry_and_Biodiversity_Conservation_in_Tropical_Landscapes.pdf

Sirami, C., Gross, N., Baillod, A.B. et al. (2019) Increasing crop heterogeneity enhances multitrophic diversity across agricultural regions, Proc. Natl. Acad. Sci. U.S.A. 116 (33) 16442–16447. → https://www.pnas.org/doi/full/10.1073/pnas.1906419116

Smith, A., Snapp, S., Chikowo, R., Thorne, P., Bekunda, M. and Glover, J. (2017) Measuring sustainable intensification in smallholder agroecosystems: A review, Global Food Security, Volume 12, 2017, Pages 127–138. → https://doi.org/10.1016/j.gfs.2016.11.002

Sullivan, P. (2003) Intercropping principles and production practices. National Center for Appropriate Technology (NCAT), ATTRA Sustainable Agriculture program. → https://attra.ncat.org/wp-content/uploads/2019/05/intercrop.pdf

Tauro, T. P., Mtambanengwe, F., Mpepereki, S., & Mapfumo, P. (2021) Soil macrofauna response to integrated soil fertility management under maize monocropping in Zimbabwe. Heliyon, 7(12), e08567. → https://doi.org/10.1016/j.heliyon.2021.e08567

Taylor, P. and Beniest, J. (2003) Training in agroforestry. A toolkit for trainers. Nairobi: The World Agroforestry Centre (ICRAF). → https://www.cifor-icraf.org/publications/downloads/Publications/PDFS/b12460.pdf

Teenstra, E., De Buisonjé, F., Ndambi, A., and Pelster, D. (2015) Manure Management in the (Sub-)Tropics. Training Manual for Extension Workers. Wageningen, Wageningen UR (University & Research centre) Livestock Research, Livestock Research Report 919. → https://www.ccacoalition.org/sites/default/files/resources/161025_training_manure-management-subtropics_EN.pdf

6.15 References for practice sheets

Tengnas, B. (1994) Agroforestry extension manual for Kenya. Nairobi: International Centre for Research in Agroforestry. → https://www.cifor-icraf.org/publications/downloads/Publications/PDFS/B08037.pdf

Theisen-Jones, H. and Bienefeld, K. (2016) The Asian Honey Bee (Apis cerana) is Significantly in Decline. Bee World, 93(4), 90 – 97. → https://doi.org/10.1080/0005772X.2017.1284973

Tokatlidis, I. and Vlachostergios, D. (2016) Sustainable Stewardship of the Landrace Diversity. Diversity. 2016; 8(4):29. → https://doi.org/10.3390/d8040029

Toker, P., Canci, H., Turhan, I., Isci, A., Scherzinger, M., Kordrostami, M., & Yol, E. (2024) The advantages of intercropping to improve productivity in food and forage production – a review. Plant Production Science, 27(3), 155 – 169. → https://doi.org/10.1080/1343943X.2024.2372878

Tosi, S., Sfeir, C., Carnesecchi, E., vanEngelsdorp, D., Chauzat, M.-P. (2022) Lethal, sublethal, and combined effects of pesticides on bees: A meta-analysis and new risk assessment tools. Science of The Total Environment, Volume 844. → https://doi.org/10.1016/j.scitotenv.2022.156857

Vaagt, G., Schuler, B. and Rieckmann, U. (2018) Integrated Pest Management in international cooperation projects with partner countries A Guideline. Bonn, Eschborn: GIZ. → https://giz.de/en/downloads/giz2018-en-IPM-guideline-web.de.pdf

Volsi, B., Bordin, I., Higashi, G.E. and Santos Telles, T. (2020) Economic profitability of crop rotation systems in the Caiuá sandstone area. Ciência Rural, Santa Maria, v.50:2, e20190264. → http://dx.doi.org/10.1590/0103-8478cr20190264

Walitang, D. I., Kim, K., Lee, Y., Heo, T.-Y., & Sa, T. (2023) Nitrification and Denitrification Gene Abundances under Stable Soil Chemical Properties Established by Long-Term Compost Fertilization. Applied Sciences, 13(20), 11146. → https://doi.org/10.3390/app132011146

6.15 References for practice sheets

Weidmann, G., Kilcher, L. and Garibay, S. (2007) IFOAM training manual for organic agriculture in the arid and semi-arid tropics. FIBL, IFOAM and SIPPO. → https://www.fibl.org/fileadmin/documents/shop/1446-manual-arid-semiarid-tropics.pdf

Wojcik, V.A., Morandin, L.A., Davies Adams, L. et al. (2018) Floral Resource Competition Between Honey Bees and Wild Bees: Is There Clear Evidence and Can We Guide Management and Conservation? Environmental Entomology, Vol 47. → https://doi.org/10.1093/ee/nvy077

Xie, J., Liang, F., Xie, J., Jiang, G., Zhang, X., & Zhang, Q. (2022) Yield Variation Characteristics of Red Paddy Soil under Long-Term Green Manure Cultivation and Its Influencing Factors. International journal of environmental research and public health, 19(5), 2812. → https://doi.org/10.3390/ijerph19052812

Yaseen, U., Devnita, R., Nurbaity, A. et al. 2025 Soil erosion and food security in Asia's most populous nations: a systematic review from China, India, and Indonesia. Discov. Soil 2, 60 (2025). → https://doi.org/10.1007/s44378-025-00091-y

Zander, S.V., Jacobs, K., and Hawkins, H.-J. (2016) The impact of crop rotation on soil microbial diversity: A meta-analysis, Pedobiologia, Volume 59, Issue 4, 2016, Pages 215 – 223. → https://doi.org/10.1016/j.pedobi.2016.04.001

Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn

Friedrich-Ebert-Allee 32 + 36
53113 Bonn, Germany
T +49 228 44 60-0
F +49 228 44 60-17 66

Dag-Hammarskjöld-Weg 1 – 5
65760 Eschborn, Germany
T +49 61 96 79-0
F +49 61 96 79-11 15

E info@giz.de
I www.giz.de