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MINISTRY OF AGRICULTURE

german
cooperation
DEUTSCHE ZUSAMMENARBEIT

Co-funded by
the European Union

Gates
Foundation

Implemented by

giz Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH

Innovations for Soil Health

Agroecology, Integrated Soil Fertility Management and Productive Use of Rehabilitated Dry Valleys

TECHNICAL GUIDELINE

Soil Matters

Innovations for Soil Health and Agroecology

Healthy Soils, Healthy Crops, Healthy Livestock, Healthy People

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PURPOSE OF THIS GUIDELINE

This Technical Guideline is for use by Ministry of Agriculture technical experts at Federal, Regional, Zonal, Woreda and Kebele levels as well as their partners and stakeholders. It provides an overview of soil health and fertility challenges and an integrated approach for overcoming them. These include agroecology, integrated soil fertility management practices and rehabilitated dryland valley productive use approaches based on the use of community level participatory planning and learning processes for both highland and lowland areas. It draws on existing knowledge and training material summarising the many soil and agronomic management technologies and practices for soil conservation and the improvement of soil health for sustainable intensification. This is targeted for use by extension workers and development agents working with rural communities, male and female farmers and young people.

Many of the technologies and management practices that are described are area specific and as such specific recommendations for each area will be required to be identified based on soil type and health, altitude, rainfall, market potential and farmers' own preferences.

Scan here to download knowledge products on ISFM, Agroecology & DVRPU

ACKNOWLEDGEMENTS

Acknowledgements are given for contributions, both written and verbal from many individuals, researchers, soil, crop and livestock experts, development agents and farmers, the ultimate creators and end users of the knowledge presented in this guideline..

The Guidelines are available as a free download from the Ministry of Agriculture website and GIZ programme offices.

www.moa.gov.et

Publication has been supported by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Government.

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FOREWORD

The Ministry of Agriculture is pleased to introduce these guidelines, "Soil Matters – Innovations for Soil Health and Agro-ecology," a comprehensive reference designed to support Ethiopia's national efforts to build a productive, resilient, and food-secure agricultural sector. The contents of the guidelines aligns with Ethiopia's Fertilizer and Soil Health Roadmap, the national agroecology strategy initiatives and global commitments toward sustainable food systems. More importantly, it amplifies the role of farmers as innovators and stewards of the land. By equipping field practitioners with clear, user-friendly tools, this work aims to accelerate the transition toward healthy soils, resilient farms, and food-secure communities, which emphasizes restoring soil productivity, improving the efficiency of input use, and expanding climate-smart, locally adaptable solutions.

Healthy soil is the silent foundation of Ethiopia's food security, rural livelihoods, and ecological resilience. Across our diverse landscapes from the highland mixed-farming systems to the lowland agro-pastoral areas soil is more than a medium for crop production. It is a living ecosystem that regulates water, cycles nutrients, stabilizes climate, and sustains biodiversity. When soil is protected, restored, and wisely managed, communities thrive; when it is degraded, the nation's development, prosperity and resilience are threatened.

Ethiopia's food security depends fundamentally on the health of its soils. Yet many landscapes continue to face soil health and fertility problems like soil acidity, soil salinity and sodicity, water logging, soil erosion, nutrient depletion, declining organic matter and climate-induced stresses that constrain agricultural productivity. These guidelines directly respond to these challenges by presenting practical, evidence-based integrated approaches including Integrated Soil Fertility Management (ISFM), agro-ecology and Dry Valley Rehabilitation and Productive Use (DVRPU). These approaches are fully aligned with national priorities to increase agricultural output while safeguarding natural resources and improving the soil health and fertility of the soils

The guidelines further reinforce the country's strategic shift toward balanced fertilization, site-specific recommendations, sustainable land management and restoration and rehabilitation of degraded soils. Its focus on participatory planning, community ownership and continuous learning reflects the direction of national soil health and fertility initiatives, which call for locally tailored and scalable solutions across diverse agro-ecological zones.

We encourage extension workers, farmers, pastoralists, cooperatives and all stakeholders to actively apply and adopt the guidance provided in this document. By scaling these innovations, Ethiopia can accelerate its transition toward a more resilient, productive, and sustainable agricultural system advancing our national vision for healthier soils, improved livelihoods, and long-term food security.

Ato. Lire Abiyo
Soil Resource Development Lead Executive
Natural Resources Development Sector
Ministry of Agriculture

ACRONYMS

AGP	Agricultural Growth Plan
CA	Conservation Agriculture
CLPP	Community Level Participatory Planning
CSA	Climate Smart Agriculture
CWUC	Community Watershed Users Cooperatives
DA	Development Agents
DST	Decision Support Tool
DVRPU	Dryland Valley Rehabilitation and Productive Use
DVUC	Dryland Valley User Cooperative
EFSAC	Ethiopian Food System And Agroecology Consortium
EM	Effective Micro-Organisms
FFS	Farmer Field Schools
FTC	Farmer Training Centre
FYM	Farmyard Manure
ICLF	Integrated Crop-Livestock-Forestry
ISFM	Integrated Soil Fertility Management
LSRP	Lowlands Soils Rehabilitation Project
MoA	Ministry of Agriculture
MoANR	Ministry of Agriculture and Natural Resources
N P K	Nitrogen. Potassium, Potash
OM	Organic Matter
PLA	Participatory Learning Approach
PRA	Participatory Rural Appraisal
RA	Regenerative Agriculture
RWH	Rainwater Harvesting

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INTRODUCTION

These Guidelines on Innovations for Soil Health and Agroecology support agroecological transition by promoting the use of integrated soil fertility management (ISFM) and dryland valley rehabilitation and productive use (DVRPU). The Guidelines seek to scale up proven approaches, technologies and management practices in both highland and lowland areas, building on the lessons of earlier initiatives.

Most important are the use of participatory approaches that empower local communities to increase biomass production, to use organic fertilisers and other agronomic practices, as well as integrated crop-livestock-forestry systems. These include the use of rotational grazing, cut-and-carry livestock feed systems, seed multiplication and the establishment of tree nurseries. The use of participatory approaches ensures local community involvement and ownership in planning and implementing field, landscape and watershed rehabilitation activities. At the same time, behaviour change communication along with context-appropriate agricultural technologies aim to support male and female farmers and agro-pastoralists, especially members of Community Watershed Users Cooperatives (CWUCs). These have the mandate to rehabilitate their respective watersheds in providing entry points for agroecology, ISFM and DVRPU.

These aim to integrate locally appropriate technologies to minimize nutrient and biomass losses, boost the efficiency of agronomic inputs and increase productivity on an intensive and sustainable basis. Key to this are learning groups and farmer field schools supported by model farmer demonstration plots with associated field days. In lowland areas, flood-based farming systems combining agroecological and ISFM approaches are used to enhance soil moisture, reduce soil erosion, increase soil-water retention and promote biodiversity through the planting of fodder grasses, crops and multipurpose trees.

The Soil Resources Development Lead Executive, under the Ministry of Agriculture's Natural Resource Management sector, leads implementation in partnership with regional, zonal, and woreda-level offices. It also works closely with the Ministry of Agriculture's extension, input supply and marketing departments, as well as agencies strengthening local cooperatives organizational capacities. Private sector involvement includes partnerships with CWUCs, together with rural micro, small and medium-size enterprises. It can also involve the Lersha platform, which links farmers to service providers via a network of agents.

Research partners include the Ethiopian Institute of Agricultural Research, regional research centres, the Consultative Group on International Agricultural Research, Universities, the International Fertiliser Development Centre's Transform Program, and the Ethiopian Food System and Agroecology Consortium (ESFSAC), a civil society group. Collaboration with agricultural universities to integrate agroecology, ISFM, and DVRPU into curricula and their outreach programmes is also important.

Initial funding is being cofinanced with the European Union (EU) and the German Federal Ministry for Economic Cooperation and Development (BMZ) with implementation by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

SECTION 1: Soil Health and the Importance of Organic Matter

1.1 What is a Healthy Soil

Soil health is the capacity of a soil to sustain agricultural production by supporting essential soil functions, including nutrient cycling, water regulation and biological activity through context-specific sustainable soil management. It provides the basis for increased yield stability and efficient use of fertiliser and organic inputs across diverse environments. Healthy soils are the foundation of productive and sustainable farming. They produce healthy crops that provide diverse and nutritious diets, supporting healthier people and communities. By maintaining soil fertility and ecosystem integrity, sustainable intensification, strengthened food security and improved livelihoods can be achieved and some of the most pressing development challenges of our time be addressed.

Soil is a mixture of mineral particles, organic matter (typically 2–5%), air, and water. Organic matter feeds soil organisms that break down compounds into forms plants can use. When soils are degraded, their structure, nutrient balance, and water-holding capacity decline, restricting root growth, limiting air and water movement, and reducing crop productivity. In contrast, healthy, fertile soils have a balanced mix of particle sizes that ensure proper drainage and water storage, along with the nutrients and energy needed to sustain healthy, high-yielding crops. (Figure 1.1).

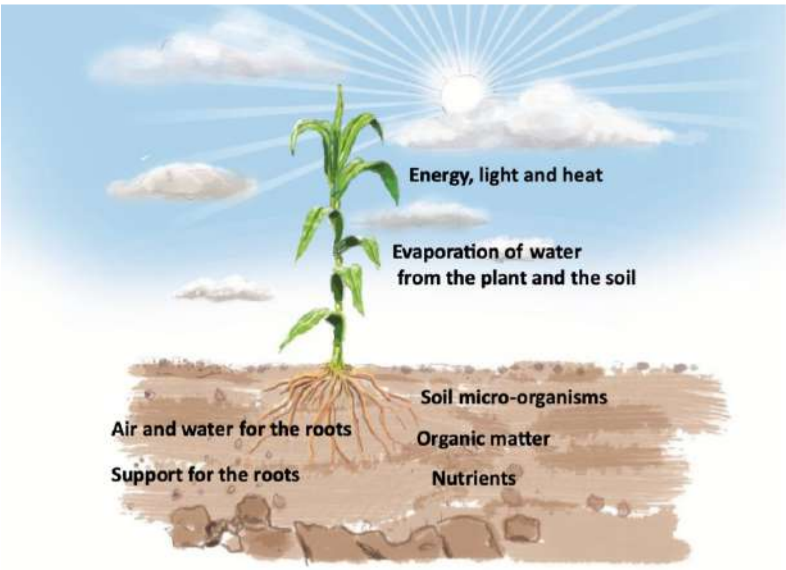


Figure 1: Ingredients required for a healthy crop

Soil organic matter is that part of the soil that includes plant and animal residues at various stages of decomposition. Fresh or undecomposed plant materials, such as litter and straw and animal dung lying on the soil surface, will eventually become part of soil organic matter as they decompose. Organic matter is a major reservoir and source of essential plant nutrients and serves as a soil conditioner. It adds body to sandy soils, increasing soil moisture and nutrient-holding capacity. It promotes granulation in heavy soils, which helps in plant root penetration and entry of water and air into the soil. It is the main food source for soil micro-organisms. It makes cultivation easier, resulting in better seedbeds and reduced surface crusting that can adversely affect the emergence of seedlings. Soil Organic matter is also a significant sink for atmospheric carbon thereby aiding mitigation of climate change.

1.2 Major Soil Health and Fertility Challenges

The Ethiopian Government has for many years prioritized agriculture as the sector to lead national development and to support greater industrialization in the country. The main soil constraints include widespread soil erosion severe soil fertility depletion, especially organic matter and nutrients, soil acidity and in some areas waterlogging and soil salinity (MoANR 2013, Betemariam 2019, Merga and Ahmed 2019, FAO 2020).

Key issues include

- Soil Erosion and Fertility loss: continuous cropping, inadequate fertiliser use, removal of crop residues (often used for livestock feed or fuel), and insufficient soil conservation practices have led to soil erosion and loss of organic matter particularly in the highlands. Other contributing factors include ploughing on steep slopes, deforestation, overgrazing, and high-intensity rainfall.
- Nutrient imbalance: For many years, agricultural practices primarily focused mainly on nitrogen (N) and phosphorus (P) based on “blanket recommendations,” neglecting other essential nutrients (Aleminew and Alemayehu, 2020). This has accelerated depletion of essential macro- and micro-nutrients.
- Macronutrient deficiencies include Nitrogen (N), Phosphorus (P), Potassium (K) and Sulphur (S).
  - N Deficiency: This is the most prevalent and significant macronutrient constraint, observed in almost all soils regardless of soil type or geographic region and the primary nutrient limiting crop yields.
  - P Deficiency: Phosphorus deficiency is also widespread, affecting an estimated 70% of Ethiopian soils. Many soils have inherently low P content, compounded by the strong P-fixing capacity of some Nitisols and acidic soils, which makes available P unavailable to plants.
  - K Deficiency: Most soils are relatively well-supplied with potassium. However, localized K deficiency has been identified in some regions, and its application has shown positive results in specific areas and crops.
  - S Deficiency: Sulphur deficiency is an emerging and significant problem in some areas, especially in areas where N and P fertilizers (like urea and DAP) have been applied without S for many years impacting the yield and quality of crops like wheat.
- Soil micronutrient deficiencies include zinc (Zn), boron (B), and copper (Cu), iron (Fe) and molybdenum (Mo) in some areas, while manganese (Mn) is generally sufficient or can even reach toxic levels (Abera and Kassa, 2017).
  - Zn is the most widespread micronutrient deficiency particularly in Vertisols and Cambisols in the central and Bale highlands.
  - B deficiency is also common especially in acidic soils of the southern and northern highlands.
  - Cu is deficiency especially in Nitisols and Fluvisols in the Jimma Zone and Rift Valley regions

- Low soil organic matter: Limited availability of biomass for maintaining soil organic matter often due to competing uses, such as animal feed, fuel and building material. Organic matter plays a critical role in maintaining soil fertility by increasing water holding capacity, reducing surface crusting, and acting as a buffer against pH changes in the soil.
- Soil Acidity: Soils of a pH of 5.5 or below are considered acidic, particularly found in highland regions. This restricts nutrient availability and can lead to toxic levels of Al and Mn, resulting in poor plant growth, reduced inorganic fertiliser efficiency, reduced microbial activity and increased disease, which can cause crop yields to drop by up to 50% or sometimes total failure.
- Waterlogging: This occurs primarily in Vertisols, which have a high clay content, leading to extreme shrink-swell cycles that cause deep cracks when dry and an impenetrable surface when wet making them difficult to cultivate during wet conditions and significant erosion when cracks close and the surface seals. This also leads to drainage problems, seasonal flooding and salinisation under irrigation.
- Salinity: Poor irrigation management and drainage contribute to increasing soil salinity adversely affecting water quality, soil structure and fertility, seed germination, plant growth and crop yields. Causes include low precipitation, high evaporation, waterlogging, inappropriate irrigation practices, poor drainage systems and excessive use of inorganic fertilisers.

1.3 Addressing the Challenges

The Moa through the National Soil Health and Fertility Improvement Strategy (MOANR, 2017) identified measures to overcome many of these soil health and fertility concerns. These have been successively addressed in some areas on a pilot basis and now requiring promoting on a wider scale. The MoA and its partners have established initiatives such as the Ethiopia Soil Information Service to provide tailored soil extension services and inform better management practices. These are designed to provide customised site-specific soil fertility recommendations and management practices tailored to local needs with priority given to:

- Low productivity in acid soils, saline-sodic soils and vertisols
- Limitations in the utilization and application of organic fertilisers.
- Unsatisfactory results obtained from the use of mineral fertilisers, particularly the absence of integrated soil fertility improvement technologies
- Reduction of soil productivity due to soil degradation, including ploughing on steep slopes, shallow and compacted soils
- Systemic bottlenecks and cross-cutting issues. These including a lack of soil health and fertility technology delivery and dissemination mechanisms, which go beyond the soil sector.

The use of agroecology, ISFM and DVPRU integrated approaches are designed to address these challenges. The associated interventions, intended outputs, outcomes and impact are detailed in Table 1.1 overleaf and described in the sections that follow.

Table 1: Crop Production Interventions, Intended Outputs, Outcomes and Impact

INTERVENTIONS		OUTPUTS	OUTCOMES		IMPACT
• Crop and variety choice • Rotations • Soil tillage • Soil and water conservation • Biomass matter use • Crop residue management	Influence of policy and economic environment	a. Increased soil productivity	i. Yield increase	Sustainable productivity improvement	1. Food security
• Fertiliser sources • Fertiliser rates • Fertiliser pH correction • Fertiliser application		b. Improved yield response to fertiliser	ii. Productivity increase		2. Increased incomes
• Plant spacing • Water management • Weed management • Disease management • Pest management • Harvest and post-harvest management		c. Improved yield response to agronomy practices	iii. Less area expansion		3. Lower food prices

SECTION 2: Agroecological Zones, Agroecology, ISFM and DVRPU

2.1 Agroecological Zones

Ethiopia's agroecological zones are based on physical and environmental factors, comprising major areas of broadly homogeneous land in terms of temperature, rainfall, topography, landscape, vegetation, soils and land use (Hurni 1998). This classification has been modified to identify five broad-based agroecological zones based on moisture availability (Figure 2.1) with a further 33 sub-zones (not shown) used for detailed research (EIAR, 2011).

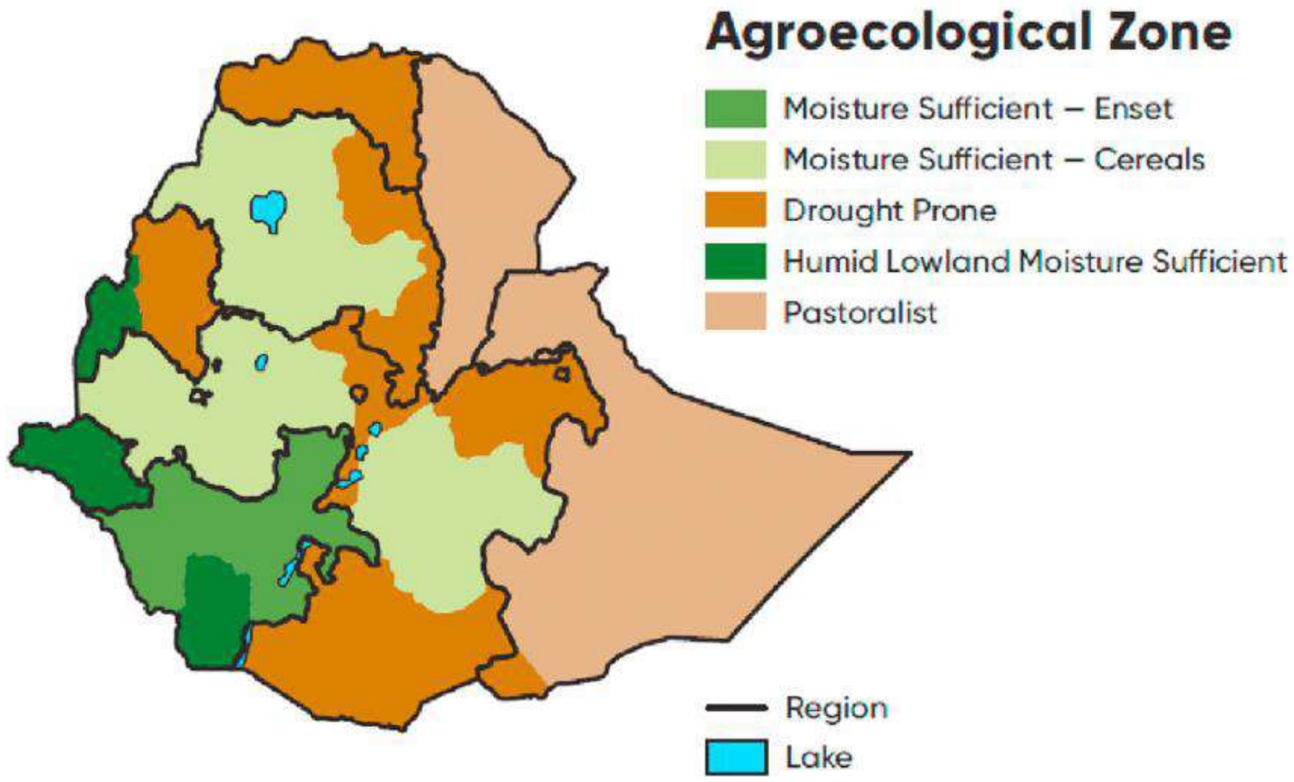


Figure 2: Agroecological zones of Ethiopia (borrowed from Minten et al, 2018)

2.2 Agroecological

Agroecology has now evolved as a multidisciplinary field that examines ecological, social, technological, economic, and political aspects of agri-food systems from production to consumption in all its components (FAO, 2018; Kerr et al, 2023). It has evolved in reaction to modern intensive industrial agriculture, which developed during the 20th century, massively increasing food production but often at a high ecological cost. Today, the scientific community agree that many ecological problems are due to intensive agriculture.

There is abundant evidence related to climate change, biodiversity and land degradation that could be mobilized to better consider their impacts on all dimensions of food security and on the progressive realization of the right to food in diverse ecological, economic and social contexts. Climate change, biodiversity loss and land degradation threaten the very basis of agricultural production, including crops, livestock, forestry, fisheries and aquaculture, creating disruptions along value chains and the entirety of food systems. In addition, negative impacts are and will be particularly important for the most vulnerable populations that are dependent on ecosystems services and goods for their livelihoods and food security (HLPE, 2025).

Conventional agriculture—often marked by the excessive use of inorganic fertilizers and pesticides—has contributed to soil degradation, biodiversity loss, crop homogenization, and the impacts of global warming. At the same time traditional farming systems have become degraded as population has increased and use of natural resources has become unsustainable. Agroecology offers a promising path forward integrating ecological, social and economic principles to create a resilient and productive food system. It recognises the social life of agriculture and especially the collaboration between stakeholders (Tittonell, 2023).

Agroecology is based on five transformation levels, three aims and 13 principles, which can be used for sustainable resource use at field, farm and landscape levels (Gliessman 2016; FAO 2018; HLPE 2019; Wezel, 2020) (Figure 2.2). The agroecosystem operates at three transformation levels suitable for both highland and lowland agroecological zones, which are:

1. Increased resource efficiency and reduction in the use of external, scarce and environmentally damaging inputs.
2. Substitution with agroecological alternatives for conventional inputs and practices.
3. Redesign of agroecosystems based on new ecological processes.

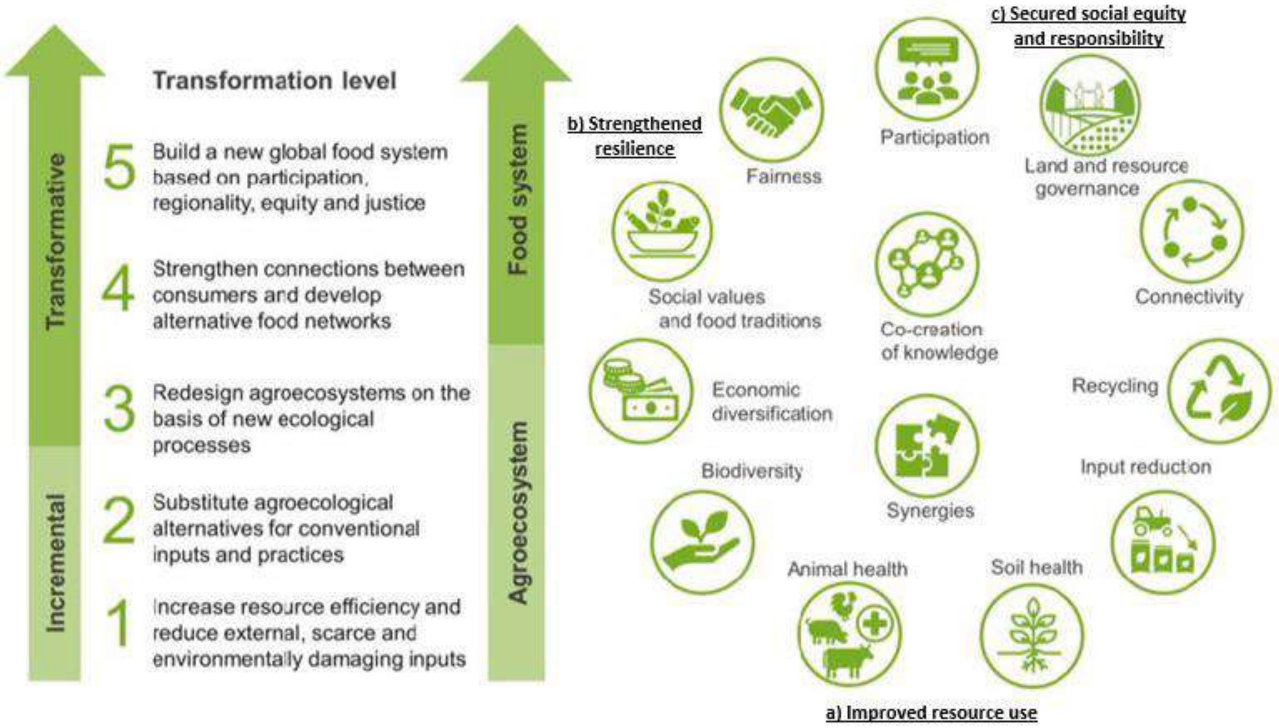


Figure 3: Agroecology's five levels, 13 Principles and three aims (Derived from Gliessman 2016; FAO, 2018; and HLPE 2019).

The three agroecosystem levels can be applied to both traditional low input agriculture and conventional high input/ high productivity agriculture. This requires either smart intensification or smart adaptation (Figure 2.3) to achieve agroecological, diversified, productive and sustainable farming systems.

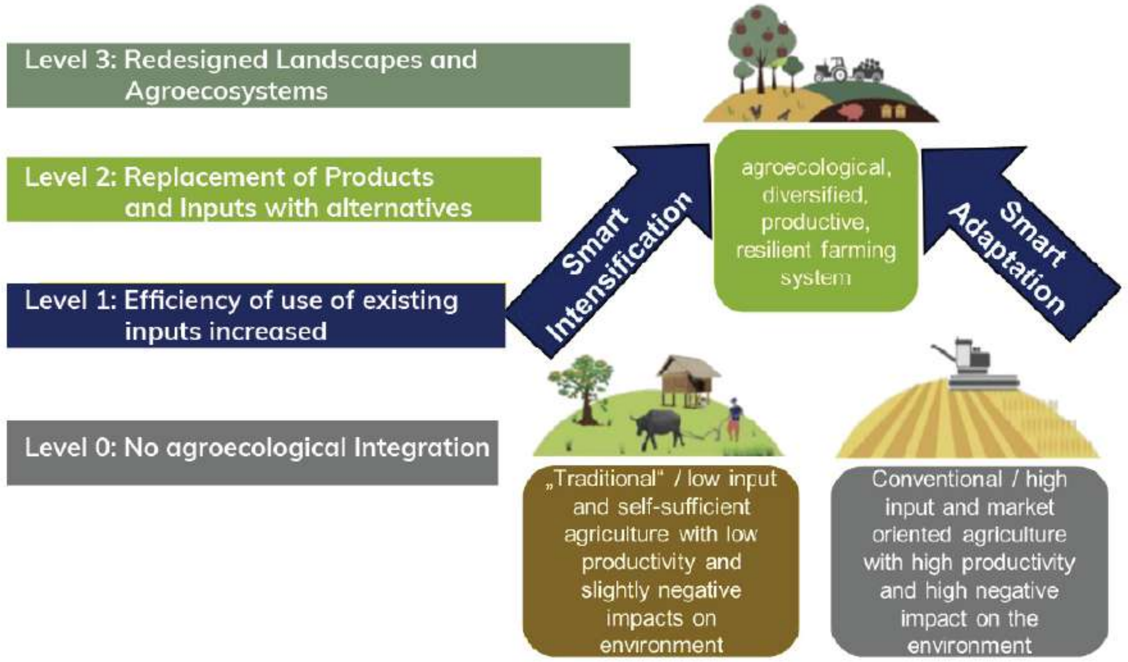


Figure 4: The pathways to an agroecological transition

The three aims and the 13 principles associated with each are:

1. Improved resource efficiency: recycling, input reduction, soil health and animal health.
2. Strengthened resilience: biodiversity, synergies and economic diversification.
3. Secured social equity and responsibility: co-creation and sharing of knowledge, social values and diets, fairness, connectivity, land and natural resource governance and most importantly participation. Many of these occur at an institutional level and may include a legal framework allowing their recognition and promotion. This is often reflected in participatory research and extension with public finances allocated to programmes or projects that encourage participants to produce and consume more sustainably.

These aims and the principles associated with each are interlinked and can be used as a guide for policymakers, practitioners and stakeholders in planning, managing and evaluating agroecological transition and its subsequent performance. When locally applied, they can generate diverse locally adapted agroecological practices through co-creation of knowledge with stakeholders. They can also be used to identify entry points for sustainable agri-food systems. Table 2.1 overleaf details these agroecological pathways showing the levels, principles and the many different approaches, technologies and pathways to bring about sustainable intensification.

Table 2: Agroecosystem and food system aims, levels and principles together with approaches, technologies and management practices

Systems	Aims	Levels		Principles	Approaches, technologies and management practices					
Agro ecosystem	Improve resource efficiencies	Level 1: Increase efficiency of industrial inputs	1	Input reduction	Improved crop/ plant varieties that reduces the use of external inputs.	Reduced use of seed, inorganic fertiliser, pesticides, water and energy	Reduced use of purchased animal feed	Improved animal breeds	-	-
		Level 2: Substitute alternate practices	2	Recycling	Recycling of crop residues	Recycling of wastewater	Use of biomass residues for energy generation or biochar	-	-	-
			3	Improved soil health	Crop rotations	Green manures and cover crops	Conservation agriculture / reduced tillage	Agroforestry	Perennial crops	
			4	Improved animal health	Improved animal welfare and health	-	-	-	-	-
	Strengthen resilience	Level 3: Redesign whole agro-ecosystems	5	Improved Synergies	Integrated crop-livestock systems	Rotational and regenerative grazing	Landscape planning and activity	Integrated pest management by habitat manipulation:	Reforestation and preservation of natural habitats	Climate mitigation through redesigned system
			6	Increased Biodiversity	Ecologically based crop rotations, multiple cropping, agroforestry and the integration of animals with crops.	Improving local seed diversity	Integrated Pest management / Nonchemical pest management	Landscape diversity:	Spatially diversified farms	Enhancing functional agro biodiversity
			7	Economic diversification	Livelihood resilience and mechanisms to reduce vulnerability	Diversification of diets and consumption	Resilience of agroecosystems to extreme weather events and other disturbances	Resilience and adaptive capacity to changing environmental conditions due to climate change	-	-

Systems	Aims	Levels	Principles		Approaches, technologies and management practices					
Food System	Secure social equity	Level 4: Establish connections between growers and consumers, develop alternate food networks	8	Co-creation of knowledge	Connecting farmers to share knowledge	-	-	-	-	-
			9	Social values and diets	Support healthy, diversified and culturally appropriate food traditions and diets	Support the right to adequate and culturally appropriate food	-	-	-	-
			10	Connectivity	Business support for re-establishing the connection between producers and consumers	Supporting regional value generation	Encourage and sensitize for seasonal and regional demand	-	-	-
		Level 5: Rebuild the food system	11	Fairness	Gender and vulnerable group approach	Equity, dignity, inclusion	Support right to sufficient access to food	Creating jobs for rural youth based on agriculture	-	-
			12	Land and natural resource governance	Policy development that rewards agricultural management that enhances biodiversity and the provision of ecosystem services:	Policy development on producer-consumer links:	Policy development on the links between agroecology and global changes	Establishment of equitable governance and rights over natural resources	-	-
			13	Participation	Promote participatory and multi-stakeholder approaches in knowledge generation	Promote formal and non-formal "production and food" education	Strengthen organisational capacities	-	-	-

Source: Adapted from Gliessman, 2016; FAO, 2018; and HLPE, 2019.

2.3 Integrated Soil Fertility management

ISFM is defined (Vanlauwe et al., 2010) as "A set of soil fertility management practices that necessarily include the use of fertiliser, organic inputs, and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at maximising agronomic use efficiency of applied nutrients and improved crop productivity." As such, ISFM has the potential to meet farmers' immediate needs for increased production, whilst also contributing to efficient and sustainable use of resources providing the basis for optimizing the use of nutrients. It has been promoted widely over the past 15 years with research promoting its contribution to sustainable agricultural intensification (Bekunda et al., 2022). Various combinations include the use of improved varieties, line seeding, inorganic fertilisers used in combination with organic ones, legumes inoculated with rhizobia, as well as associated practices of agroforestry, crop residue management, rain-water conservation and lime application on the highly acidic soils found in many areas of the Ethiopian Highlands.

ISFM is an integral component of agroecology, enabling a move from current practices (nutrient mining, insufficient soil organic matter, declining soil fertility, soil health problems and low yields in a stepwise process (Figure 2.4). Although used primarily at a field and farm level, ISFM adapted for each site contributes to transition at landscape and watershed levels (Doldt et al., 2023).

Despite a long history of fertiliser research and development to improve soil fertility management practices, studies have revealed that the agronomic and economic efficiency of fertilisers in Ethiopia shows mixed results. In some localities, increased applications result in increased yields with high agronomic efficiency and productivity, while efficiency in other locations has been marginal or depressing. In explaining fertiliser use efficiency, the key question is whether the right fertiliser is being applied at the right dose, time, and place and whether other yield-limiting factors are being addressed. This is because variations in soils, climate and physiographic factors, together with the crop type and genotypes used, and agronomic management practices play vital roles in determining the performance of fertilisers (Erkossa et al., 2022). It is also highly dependent on farmer management practices related to the financial, physical, social, human and natural resources available to individual households. These include oxen for manure and land preparation, biomass and labour for organic matter production and incorporation in the soil as well as access to the funds to purchase and therefore use improved seed and inorganic fertilisers, which may mean sub optimal rates are used.

Decades of research and field experience have shown that generic solutions are inadequate. The high variability of soils and rainfall requires that inputs be tailored to the unique characteristics of each area. Tailoring these practices to local conditions maximises nutrient efficiency and crop yields. This considers existing soil fertility, the availability of organic inputs and the farmer's own capacity to access and afford the necessary resources. It should be noted that farmers frequently employ locally adapted, integrated soil management methods. Learning from these traditional practices is vital to improving ISFM strategies.

Successful integration of various technologies and practices, both accepted by and profitable for farmers, underpins ISFM. Examples include increasing biomass production, utilizing earthworms to convert poor-quality biomass into high-quality compost, green manuring, increasing livestock productivity and manure output through additional biomass. This requires effective collection, storage, and application of manure and cattle urine.

Four key steps are involved. These build on each other facilitating an agroecological transition from existing practices to long term transformation at field, farm, landscape and watershed levels. These steps include:

Step 1 Quick wins: These include increasing on farm biomass production and introducing practices such as quality seed and improved crop management, addition of organic matter and targeted inorganic fertiliser and lime application of soils with pH below 5.5. Organic fertilisers produced on or near the farm from natural resources are typically low-cost and can improve yields, particularly on poor soils, sometimes outperforming inorganic fertilisers. In many cases, they serve as valuable total or partial replacement for inorganic options. However, organic manures, though often rich in nitrogen, may not provide enough phosphate. In which case supplementing with mineral phosphate in appropriate amounts may be important. Boosting on-farm biomass is crucial for compost production. It should ideally be produced on-site, although some areas now have local markets for organic waste, such as agro-processing industry biproducts.

Step 2 Short-term: This includes reducing nutrient and biomass losses, ensuring sufficient soil organic matter and fertiliser, on-farm nutrient cycling (being the movement and reuse of nutrients, organic matter) as well as the use of external nutrients when needed. ISFM aims to balance these sources efficiently to match crop requirements and reduce losses from volatilization, erosion, runoff, leaching, burning, or soil immobilization.

Step 3 Mid-term: This includes improving resource use efficiency, through introduction of practices such as conservation agriculture, double cropping, the use of green manures and cover crops, cattle urine, bio-slurry and biochar or bone-char if available. It also includes the introduction of agro-forestry and rainwater harvesting techniques to further increase soil moisture and the use of bio-slurries. A soil fertility decision support tool (DST) can be used to help farmers to make specific tailored decisions for nutrient application, soil management practices and overall health improvement.

Step 4 Long-term: Agroecological integration at farm and watershed level can be achieved involving crops, pasture, livestock, area enclosure, and forestry resulting in reduced external input use with the farming system providing optimised productivity.

The size of each step and the exact practices to be used in each will depend on the area potential based on soil type, altitude, rainfall and market potential for the crops being grown.

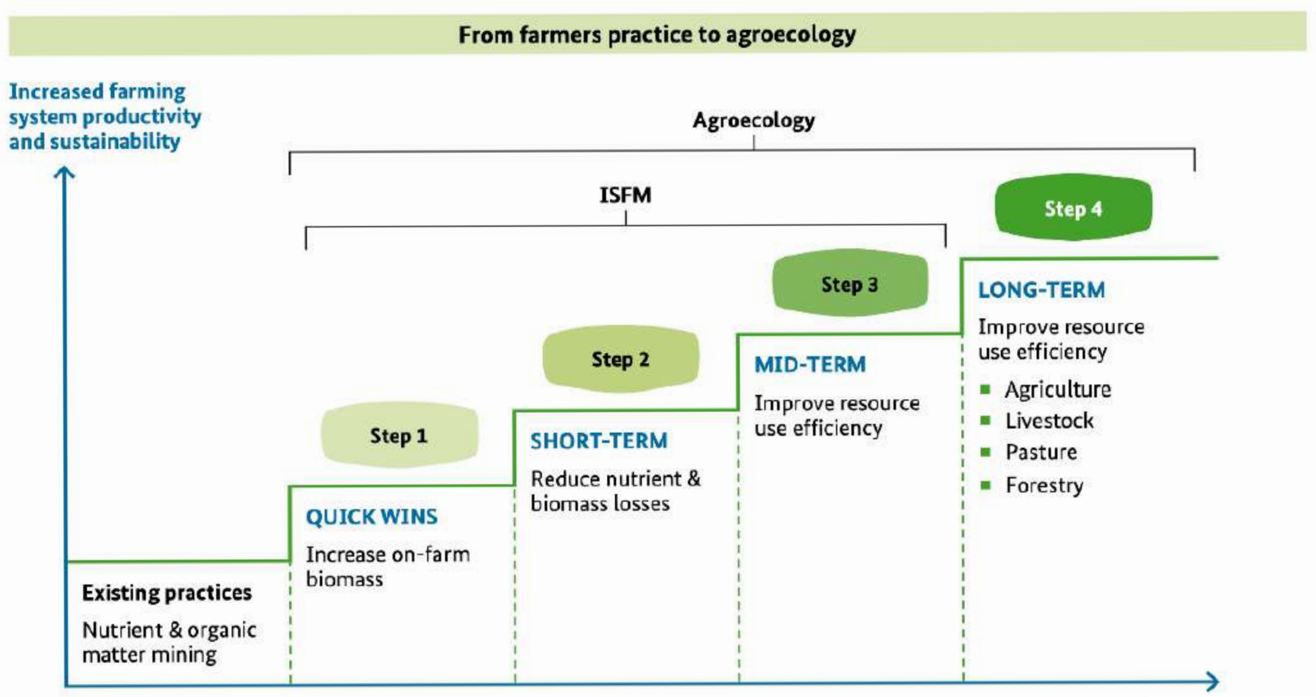


Figure 5: The ISFM-Agroecological continuum based on a four-step approach (Modified from Sanginga and Woomer, 2009).

Addressing both socio-economic and biophysical challenges is necessary for any ISFM strategy. This includes adapting to future shocks and long-term changes, making large-scale ISFM initiatives flexible and responsive to varying market and climate conditions. The use of participatory approaches that build on farmers' knowledge, along with effective soil diagnostics, testing, and mapping, will be key. Emphasizing diversity and flexibility in ISFM design is fundamental to achieving long-term resilience and sustainable development.

A recent study based on over 2,000 farmer-managed ISFM demonstrations over a six-year period compared crop yields from control and ISFM treatment plots showed that yields increased substantially as the number of ISFM practices. It was concluded that ISFM practices are of paramount importance for increasing yields and that further expansion will require considerable effort from stakeholders including the private sector (Doldt et al., 2023).

2.4 Dry Valley Rehabilitation and Productive Use

Dry valley rehabilitation and productive (DVRPU) is primarily targeted at pastoralists and agro-pastoralists that rely on mobile livestock herding in dryland lowland areas who are facing challenges of increased drought, altered rainfall patterns and land and water competition that worsen their food security and existing livelihoods. DRVPU encourages agro-pastoralism through rehabilitation of degraded land and building water spreading weirs. It involves a comprehensive set of measures that fit within an agroecological framework addressing social, technical, biological, economic, institutional, and governance issues (Golli et al, 2024, Nekesa et al, 2024). These are specially designed to ensure the successful rehabilitation of entire dry valleys. Importantly, DVRPU uses agroecology and ISFM in its productive phase.

The core technology employed in rehabilitation is a cascade of water-spreading weirs combined with dry-stone and biological measures that work together to slow the flow velocity of periodic floods. By doing so, the floodwaters can soak into the soil, increasing groundwater level and allowing fertile sediment to settle. This creates tracts of highly productive land which can then be used for both crop and fodder production strengthening food security and resilience of local communities.

DVRPU's implementation follows a seven-step process, starting with the identification of socially and biophysically suitable sites. Thereafter key to success is the active participation and acceptance of local communities, supported with technical expertise and a regulatory framework provided by local government. The approach offers a sustainable solution that not only rehabilitates the land but also empowers local communities to take charge of their own development and create prosperous futures for themselves.

The seven steps as shown in Figure 2.5 are:

Step 1: Satellite Identification and Delineation to identify potential dry valley regions that exhibit erosion or show early signs of degradation.

Step 2: Suitability Assessment to assess the site's suitability for rehabilitation involving a rapid field appraisal to gather information on topography, hydrology, soil, vegetation cover, land tenure and institutional arrangements within the surrounding community. It also provides a detailed understanding of the ecological, social and institutional context of the dry valley. This allows identification of appropriate rehabilitation technologies. If indication of suitability is positive, in-depth key informant interviews follow, involving community leaders, government officials and other relevant stakeholders. This provides more detailed information about the area's potential, opportunities and challenges.

Step 3: Community Participatory Planning is then undertaken engaging local communities. This aims to create awareness and provide a full understanding of DVRPU, its potential and implications before any intervention. This includes the development of byelaws governing the dry valley and agreements on maintenance work and labour provision. It also lays the groundwork for the establishment of User Cooperatives.

Step 4: Establishment of a Dry Valley User Cooperative (DVUC) to manage, protect, and utilize the natural resources of the rehabilitated valley. This involves a participatory planning process with different sub-committees to ensure a strong organisational structure.

Step 5: Technical and Budgetary Planning with active community participation to assess the current situation and addresses the challenges and plans for the next year. This requires ongoing support from Kebele and Woreda teams in regular review meetings.

Step 6: Construction involves the implementation of the planned physical and biological measures based on the community agreements made in Step 3. The participatory approach allows local community members to utilise their knowledge of the area and make their own contribution in planning and construction.

Step 7: Productive Use of the different zones within the rehabilitated area includes crop production, grazing land and dry forest. Planting grasses, crops and trees can effectively prevent soil erosion, improve water retention, and enhance biodiversity. The integration of trees, crops, and livestock provide opportunities for communities to diversify their income streams, reduce vulnerability, and enhance food security. The use of ISFM and agroecological technologies and practices is a key component of productive use.

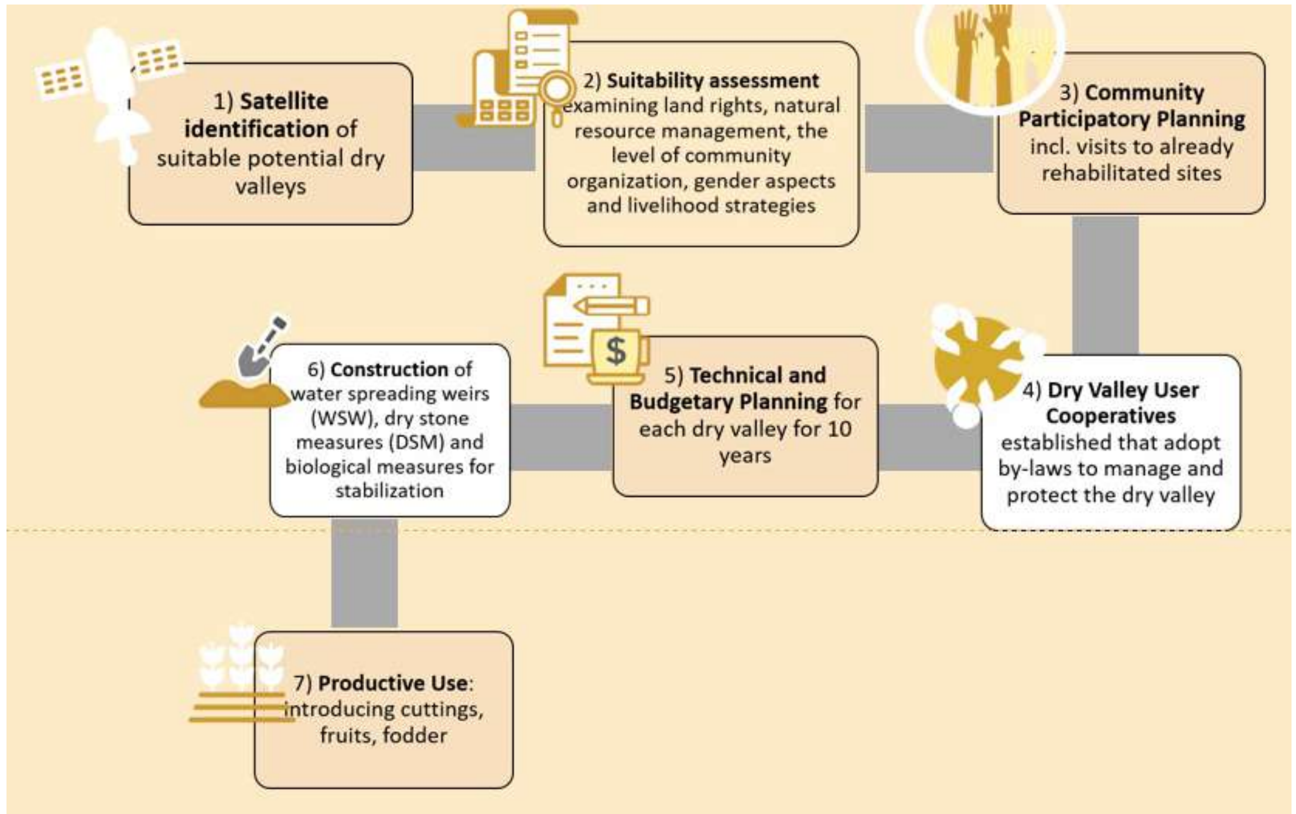


Figure 6: The seven steps of DVRPU (Source: Nekesa et al, 2024)

2.5 Other Approaches

In recent decades there have been numerous nature-based initiatives to develop more sustainable practices in land use that address deforestation and land degradation. They have typically been given different names by their advocates (Leakey, 2024). Although it can sometimes seem confusing as the different approaches may have similar or overlapping objectives, they can usually be regarded as part of agroecology. The different approaches are often complimentary to each other, each having an important role to play in meeting a common set of outcomes, namely:

- Increased agricultural productivity and improved livelihoods on a sustainable and environmentally sound basis.
- Improved human health, food security and poverty reduction.
- Increased capacity of farmers and their households and their farming systems to adapt to climate change.
- Increased carbon capture in the soil and reduced greenhouse gas emissions to mitigate climate change.

These include:

Conservation Agriculture (CA): CA represents a soil management system characterised by three inter-linked principles: minimum or zero-tillage, seeding directly into untilled soil; a permanent ground cover or mulch comprised of crop residues; and diversification of cropping systems through crop rotations or intercropping (FAO, 2017). As such it has many common features with ISFM and is included in Step 2 of the ISFM approach.

Regenerative agriculture (RA): RA is a system-based approach, which includes no-till farming used in conjunction with residue mulching, cover cropping, integrated nutrient and pest management, rotations and integration of crops with trees and livestock These can be fine-tuned to suit site-specific conditions, including biophysical, social, economic, and human dimensions (Lal 2020). The goal of RA is to apply the concept of more produce more from less, less land area, less input of chemicals, less use of water, less emission of greenhouse gases, less risk of soil degradation and less use of energy-based inputs. The aim is to spare land and resources for nature. RA is therefore included in both ISFM and the agroecological approach

Climate Smart Agriculture (CSA): CSA refers to environment friendly and sustainable agricultural practices that take climate change and variability into consideration (Clements, et al, 2011). With temperatures in many parts of Ethiopia expected to rise by more than 2°C and precipitation expected increase in some regions by the 2050s, CSA interventions to mitigate climate change are important (EPCC, 2015). CSA interventions are included in ISFM and agroecology.

Other approaches sometimes referred to include evergreen agriculture, organic agriculture and eco agriculture. These may have a particular niche but can all broadly be included in an agroecology umbrella.

Section 3: Participatory Appraisal, Planning and Learning Approaches

3.1 Community Level Participatory Project Planning

Community Level Participatory Planning (CLPP) is a process of planning, guided by the Ministry of Agriculture's Agricultural Growth Plan (2010). This supports local communities and their institutions to prioritise their own challenges, set solutions, prepare their own plans, mobilise resources, allocate budget and identify ways in which to implement their activities and monitor progress. It utilises existing community based and government institutional structures, NGOs and the private sector in identifying, planning, implementing and monitoring and learning from activities.

Key components include:

- Informing / sensitization / of the community about the participatory planning process
- Problem and need identification and potential / opportunities analysis
- Prioritization of community needs and interventions
- Project planning / community level investments and farmer group projects.

3.2 Participatory Appraisal and Learning Approaches

Participatory Rural Appraisal (PRA) and Participatory Learning Approaches (PLA) complement CLPP for facilitating and guiding communities and farmers to jointly identify and prioritise their challenges and opportunities, action planning, implementation, learning and review. The process can be used to identify and resolve community-identified priority problems.

Fundamental principles include acceptance that farmers are both "practitioners" and "experimenters", that Development Agents are "facilitators" of change; that local communities "own" the demonstrations or experiments and there is recognition of local indigenous knowledge and farming practices. It promotes pear learning whereby farmers learn from other farmers called farmer to farmer extension approach.

This requires

- Engaging communities for planning and action for development.
- Developing equal partnerships between farmers, development agents and the private sector, learning from each other with each contributing their knowledge and skills.
- Strengthening farmers' problem-solving, planning and management abilities.
- Promoting famers' capacity to adapt and develop new and appropriate technologies.
- Encouraging farmers to learn through experimentation and demonstration, building on their own knowledge and ideas, blending these with new ideas through action learning processes.
- Recognising that farmers are not homogenous groups but consist of various social groups often with different interests, resources and capabilities.
- Encouraging the poor and marginalised to participate in the process.
- Facilitation of this process by development agencies.

PLA involves four key phases often tied to the agricultural season that move from initial community engagement to one of action planning, implementation and on to assessment and learning which assist in setting new technologies and innovations in place. This learning cycle can be repeated over many seasons as joint learning takes place.

This four phase learning cycle of PLA (Figure 3.1) comprises:

- **Phase 1:** Community engagement and social mobilisation – entering a community and building trust, identifying local institutions, facilitating communities' analysis of their situation, raising awareness, identifying needs and problems, challenges and opportunities. This might involve exchange visits in searching for solutions and the start of the planning process. This phase is sometimes referred to as participatory rural appraisal.
- **Phase 2:** Community action planning based on a search for solutions and mandating community-based institutions and farmers to identify the opportunities identified.
- **Phase 3:** Implementation - trying out new ideas through farmer demonstration and encouraging farmer experimentation, providing opportunities for monitoring achievements at field days, or further exchange visits as well as training activities.
- **Phase 4:** Sharing experiences, learning lessons and reviewing the process allowing and evaluation and modification in subsequent years or learning cycles and promotion of findings to other farmers. This phase is particularly important for addressing the costs (or challenges) and benefits of the new practices after farmers have gained some experience of them.

Facilitation and capacity development are crucial components during all phases.

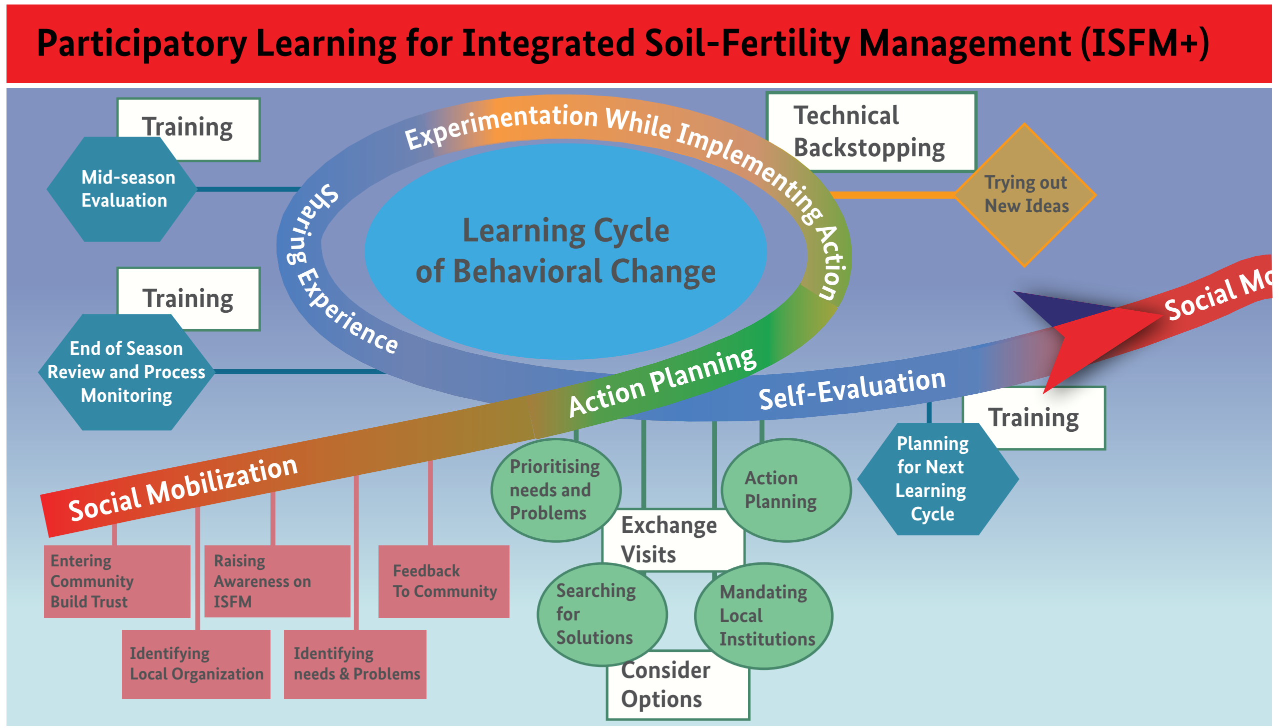


Figure 7: Participatory learning cycle (ISFM+)

3.3 The Role of Community Based Farmer Groups, Model Farmers and Cooperatives

During the social mobilisation stage of PLA, the identification of community leaders, local institutions, and organisations representing or working with local people is important. It is from these that farmer groups, men, women and youth can be identified and supported during further phases of the PLA cycle including the identification of model farmers and the selection of options for demonstration and learning. Local institutions and their leaders can also play a key role in the establishment of cooperatives, if and when required.

Figure 8: Community based discussions (Photos ISFM+)

Section 4: Integrated Crop-Livestock-Forestry and Area Enclosures

4.1 Integrated Crop-Livestock-Forestry Management

Farmers have pursued forms of integrated crop-livestock-forest (ICLF) for many generations. A variety of systems exist alongside each other with different degrees of integration and benefit. These include use of manure for improving soil fertility and oxen for land preparation, threshing and weeding. Building on these traditional systems, incorporating rotational land use, introducing improved fallows, mixed cropping, improved fodder species, specific soil and water conservation measures in combination with agroforestry and more productive livestock breeds, will make traditional systems stronger and more versatile, especially when improved use of area enclosures can also be included. Including animals and trees in farm systems increases sustainability and reduces reliance on external inputs.

ICLF Management systems (Figure 4.1) can be both environmentally productive and sustainable, providing many opportunities for both recycling nutrients and sustained intensification with many options including grain legumes, green manures, agroforestry, fodder legumes, composts and fertilisers.

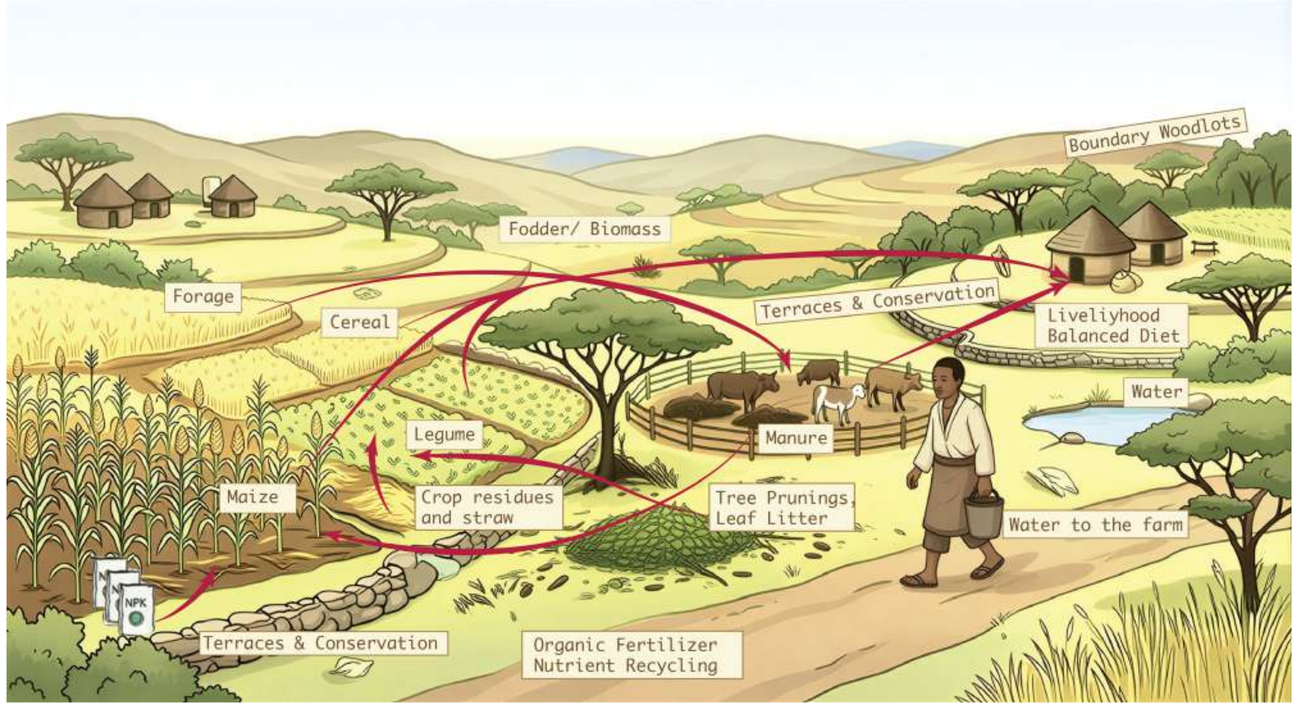


Figure 9 :Integrated Crop-Livestock-Forestry Management Systems (Source: Giller, 2025)

ICL systems creates synergies, making optimal use of resources with the waste products of one component serving as a resource for the other. For instance, manure and urine from livestock can be used to improve soil fertility and increase crop production, whilst crop residues and other biproducts, such as grass, weeds and processing waste, can provide supplementary feed for animals. Grass and prunings from forestry trees and nitrogen-fixing legumes grown in improved crop rotations, are further potential sources of biomass and fodder. At the same time livestock provide draft power and transport, as well as meat, milk and hides.

Such systems tend to be well-adapted to climatic variability because of their diversity and flexibility – especially when soil and water conservation, water harvesting, agroforestry and woodlands are integrated into the system.

4.2 Agroforestry

Planting trees on farmland through agroforestry provides many direct and indirect benefits. The most common agroforestry systems are designed for providing both livestock fodder and soil improvement, particularly for nutrient recycling and as a nutrient source for arable areas. Fruits and nuts from trees are also important in the diversification of diets in addition to the provision of wood for construction and fuel. Indirect benefits include rainfall capture through infiltration that enhances recharge of aquifers, and enhanced nutrient cycling to maintain soil fertility (de Haas and Gillar, 2025)

Land can be left fallow as a means of resting depleted soil so that it can regain some of the fertility lost through continuous cropping. While natural fallow consists of allowing land that has been cultivated to remain uncultivated, improved fallow involves planting multipurpose trees, often legume species to enrich the soil in a shorter time. Recycled nutrients are deposited through leaf litter or biomass that is harvested and incorporated into the soil. Alternatively, it can be used as a livestock fodder. Natural regeneration of acacia species such as Faidherbia albida (referred to as a fertiliser factory) and Ziziphus spina Christi along the borders or within the farms can significantly increase biomass of the soil from fall of leaves, fix atmospheric nitrogen, feed for animals, fencing and as source of fruits.

The ideal tree species is fast-growing, N-fixing and efficient at nutrient capture and recycling. Examples of promising species include Crotalaria grahamiana, Tephrosia vogelii, Cajanus cajan (pigeonpea) and Sesbania sesban (sesbania). Coppicing species can also be used, such as Gliricidia sepium (gliricidia) and Calliandra calothyrsus (calliandra). These have become increasingly popular with farmers in Kenya, Malawi and Zambia because they are perennial and, unlike the non-coppicing species, there are no costs involved in replanting them once they are cut back.


Figure 10: Fertiliser trees in a soybean field (Photo FARA)


Figure 11: Tree lucerne for fodder or biomass transfer (Photo ILRI)


Figure 12: Sesbania trees for biomass transfer (Photo ILRI)

Ethiopia is home to numerous indigenous multipurpose trees that are essential for agroforestry, environmental conservation, and local livelihoods (Table 4.1).

Table 3: Key Indigenous Multipurpose trees

Name	Common Uses	Agroecological Services
Cordia africana	Timber, high-value fruit, fodder, bee forage, medicine, fuelwood	Soil fertility improvement, shade for coffee farms
Milletia ferruginea	Fodder, fuelwood, timber, beehives, medicine	Soil fertility improvement (nitrogen fixation), erosion control
Croton macrostachyus	Fuelwood, timber, medicine, shade, beehives	Soil fertility improvement, erosion control, climate change mitigation
Albizia gummifera	Timber, fuelwood, medicine, shade for coffee	Soil fertility improvement (nitrogen fixation)
Ficus vasta	Fodder, fruit, wood, shade, cultural uses	Soil fertility, erosion control, significant carbon sequestration
Erythrina brucei	Fodder, medicine, live fences, national tree of Ethiopia	Soil fertility improvement (nitrogen fixation), erosion control
Faidherbia albida	Fodder (leaves and fruits), fuelwood, timber	Significant soil fertility improvement (unique reverse phenology), windbreaks
Vernonia amygdalina	Fodder, medicine (gastric burn treatment), bee forage	Soil conservation, erosion control

Source: Lelamo (2021)

These trees provide a wide range of productive and service roles for local communities (Lelalomo, 2021). These include.

- **Productive Roles:** They provide essential products like food (fruits from Cordia africana, Ficus species), high-quality timber and fuelwood, animal fodder, honeybee forage, and cash income for farmers.
- **Agroecological Services:** These species are vital for maintaining ecosystem health. Many species, particularly legumes like Millettia and Albizia, enhance soil fertility through nitrogen fixation. They also help in controlling soil erosion, mitigating climate change through carbon sequestration, and conserving biological diversity.
- **Traditional Medicine:** A wide variety of these trees, including Croton macrostachyus and Vernonia amygdalina, are used in traditional medicine to treat various ailments.
- **Management:** Farmers typically manage these trees within traditional agroforestry systems and home gardens, employing practices such as natural regeneration, pruning, and pollarding to harmonize their growth with food crops.

Biomass transfer involves harvest and transport from trees in or around crop fields for application as mulch or incorporation into the soil usually before or sometimes after the crop is planted.

Alternatively, hedgerow cropping along contours is regarded as a valuable means of soil fertility maintenance as well as a means of erosion control. In alley cropping, annual crops are sown in lanes that are formed by rows of perennials hedgerows. The aim is to preserve soil fertility when fallow periods (as in shifting cultivation) become increasingly shorter or are discontinued altogether. On flat land, hedgerows should be planted in an East-West direction 4-8 metres apart in parallel rows, with 0.5 metre between the plants. On sloping land hedgerows should always be placed on the contour. At the beginning of each rainy season the trees are pruned to a height of 0.5 to one metre. The twigs and leaves are laid in the lanes as mulch, and the branches used as firewood or stakes. The crops are sown between the lanes through the mulch layer. During the growing season, the trees must be pruned regularly to prevent them from shading the crop. For trees that quickly produce shoots, a height of 0.5 m is best; trees that grow slower can be pruned higher. The leaves can be applied to the crop as a "top-dressing" or they can be fed to cattle. After the crop has been harvested, the tree's shoots can be allowed to grow, so that the trees can provide enough shade to inhibit weed growth.

Figure 13: Examples of stone wall and tree lucerne, hedgerows, alley cropping and fruit trees (Photos ISFM+)

4.3 Community Tree Nurseries

Access to tree seedlings of the quality and quantity required is a challenge to enable small-scale producers to plant valuable tree species for income and restore ecosystems and degraded landscapes.

Community tree nurseries (CTN) are an important component of Ethiopia's reforestation and livelihood initiatives. They provide a number of ecological, social and educational benefits and can empower local communities to produce and plant suitable species. These include fruit and fodder trees, which help to protect the environment, increase local ownership, reduce costs and improve livelihoods. Key challenges are ensuring use of quality seed, provision of training in nursery establishment and management, and market access and coordination

CTNs can vary in size and structure from small groups to larger organised cooperative enterprises. These are fundamental to the success of CTNs. Cooperatives, who are already organised around the production and commercialisation of food commodities, have the potential to become providers of tree seedlings, if trained on establishing and management of a tree nurseries as a business activity. Embedded locally they can also become promotors to the local community about the benefits of trees in agroforestry-based production systems. The introduction of high-value crops like apples, avocados and coffee, for example, supports local value chains and creates opportunities for small-scale enterprises.

Figure 14: Example of a community nursery (Photo DVRPU)

Figure 15: Recently planted fruit trees (Phot DVRPU)

4.4 Productive Use of Area Enclosures

The term "grazing, forest or woodland enclosure" applies to any area under full or partial protection by implementing measures intended to mitigate human and livestock pressures placed on existing common property resources. The current Ethiopian enclosure policy was initiated in the Highland areas, and to some extent has been based on traditional system of land management used by farmers for many years (Carswell, 2002). Measures that have been introduced include:

- Controlling water runoff and loss of land by erosion, through gully reclamation and control.
- Increasing water infiltration for water conservation and more soil moisture through stonewall and ditch construction.
- Creating favourable conditions for vegetation recovery through natural regeneration through total exclusion of livestock and human use.
- Protecting endangered tree and wildlife species through conservation strategies.
- Developing pastoral areas for livestock fodder and providing woody biomass for local communities through agroforestry schemes.

Figure 16: Alfalfa / lucerne (Photo ILRI)

Figure 17: Napier grass (Photo: ILRI)

4.5 Cut and Carry Systems

Cut and carry systems, sometimes called zero-grazing, involves cutting fresh forage and transporting it to be fed directly to housed livestock, often milking animals. This offers increased fresh material in the diet, better land management for fragmented or wet areas. However, it can be labour intensive requiring careful management of the forage supply, nutrition and housing.

Figure 18: Control of free grazing with a cut and carry system for livestock (Photos DVRPU)

Figure 19: Zero-grazed goats (Photo A4D)

Figure 20: Zero grazed dairy cows

Figure 21: Cattle in agroforestry (Photo Civil Eats)

The acceptance of a new area enclosure will be greatly facilitated by livestock “Cut and Carry Systems” using grasses such as napier or even lucerne for livestock feed.

Other improved forages include grasses like Pennisetum purpureum (now Cenchrus purpureus) and Brachiaria spp. (now Urochloa spp.), herbaceous legumes like Stylosanthes guianensis, Mucuna pruriens, dual-purpose food-feed legumes (like Lablab purpureus and Vigna unguiculata) and forage shrubs/trees such as, Calliandra calothyrsus, Sesbania sesban, and Leucaena trichandra (Place et al., 2009; Paul et al., 2020d). When integrated in suitable niches, improved forages play a crucial role in soil fertility management by reducing soil erosion, fixing nitrogen, supporting nutrient cycling and improving water use efficiency and carbon sequestration.

4.6 Rotational Grazing

Communal grasslands can contribute significantly to multiple ecosystem services, from infiltration of rainfall and prevention of erosion to carbon storage in soils and root biomass, to habitat that sustains indigenous biodiversity (Rossiter et al. 2017). Improving the management and productivity of communal grasslands would increase the proportion of livestock feed coming from these lands, and support livestock-based livelihoods. However, poorly managed grazing areas can result in serious land degradation, which in turn leads to invasion by unpalatable plant species and a decline in the quantity and quality of pasture. On the other hand, well-managed grazing areas offers several benefits for both livelihoods and sustainable use of natural resources. It can significantly improve feed availability, livestock production, and the income of farmers who rely on livestock (Sircely and Eba, 2021).

Rotational grazing involves rotating livestock between different areas to prevent overgrazing, soil erosion and allow land to recover. It promotes stronger plant root systems and increased biomass, enhances forage production and improves livestock nutrition. Soil nutrient cycling is enhanced by promoting faster decomposition of manure and other organic matter. Healthy well managed pastures are more resistant to drought.

While some communities have sophisticated grazing systems these are increasingly being challenged by expanded cropping areas and climate change. Livestock grazing is often heavy and often unorganized, leading to competition among farmers to extract resources. The lack of a grazing plans puts communal grazing areas at risk of ongoing degradation. In addition, subdivision into individual crops or for plantation forestry places even heavier grazing pressure on the remaining grassland.

Strategies to introduce or further improve rotational grazing need to be context and appropriate specific considering local climate conditions and the needs of the community. For instance, resting a grazing area for a 90- day period before grazing offers some benefits. This requires discussion with users of the grazing areas and typically would involve grazing and rest periods according to land type and season of the year. This would then require agreement or by-laws for enforcement of the plan on the rights and obligations of users to follow up and implement the terms of the agreement.

User groups often voice a need for support in preparing, documenting and enforcing the management plan. Engaging woreda officers from the woreda (district) level can help motivate more detailed planning. Facilitators can play an essential role in a participatory planning process that uses local knowledge to fit local management practice into an improved system. For example, asking about periods in which rest is feasible can lead to identification of resting periods when alternate feed sources are available. Often the period most feasible for resting is toward the end of the rainy season, as farmers make use of their individual grazing areas near their farms; resting during the belg early rains and dry season may be feasible. In contrast, resting during the main kiremt rainy season may be challenging, requiring other options such as partial enclosure for cut-and-carry and hay preservation to provide supplementary feed for the period of feed scarcity (Sircely and Eba, 2021).

4.7 Social Arrangements for Crop-Livestock Integration

The opportunities and challenges for each practice often depend on households’ comparative wealth, access to resources and social status. Alternative pathways are particularly important for women and marginalised groups, who have limited access to high quality land and other productive resources.

Not all individuals have equal access to livestock. Typically, households with insufficient production resources look to sharing, paying cash or exchanging labour. For instance, households who do not own a pair of oxen for their own draught power needs often use alternative arrangements, such as:

- Borrowing or sharing oxen without cost. This is often an arrangement between family or friends or within a church or other community group.
- Borrowing and using oxen in exchange for labour, cash or land or through harvest sharing arrangements. Similar arrangements may exist for ownership of small stock, where offspring are shared. Such arrangements are often entered into by women seeking to increase their small stock.
- Sharing profit arrangements. For example, one individual owns or buys the animal and gives it to the other person to manage and use. Ploughing is then shared between the two. When the animal is sold, the owner may keep all or share the profit. Any costs fall on the person looking after the animal.
- Asset creation. through income generating activities

Many of these arrangements may also enable households to acquire access to manure.

With regards livestock feed, typical systems include:

- Group grazing management systems. These may involve several households' livestock, which are herded together and taken out for grazing by each participating household in turn.
- Paying cash, providing labour or exchanging crop harvest for fodder. This may entail such an arrangement with the owner of a fodder field allowing the payer to cut grass whenever it is needed.

Although crop-livestock systems have operated traditionally for many years, there are challenges in encouraging further integration, key being farmer awareness and understanding of the available technologies including the benefits and challenges.

SECTION 5: Soil Organic Matter Production and use

5.1 Farmyard Manure

Although use of farmyard manure (FYM) is a well-established management practice, many farmers still underestimate its value. Due to lack of appreciation, it may not be recognized as a source of organic matter or nutrients. In some areas with limited fuel sources, dried FYM is used as a cooking fuel. By burning FYM, large quantities of organic matter and nutrients are lost from agricultural systems. An alternative fuel source can be created by planting trees for firewood as living fences.

The quality of FYM is directly influenced by the quality forage provided to the animals. If they have been fed with poor-quality forage or grazed on poor soils, their manure will be of poor quality. If they have been fed good-quality feed, the manure will be rich in nutrients. Another factor which affects quality is storage and handling conditions. FYM storage and handling practice by farmers is sometimes poor. If it is stored in the open and exposed to rain, many of the nutrients will be washed away. Furthermore, time and method of application affects the quality of FYM.

Improved FYM management: The following management options are helpful to consider for improvement of manure quality:

- Manure can be improved through feeding a high-quality combination of fodder, such as straw/ napier grass and Sesbania sesban, Calliandra and Leucaena to animals.
- Manure should be allowed to age (mature) for at least 3 months before being used.
- Using manure in compost: To improve both the quality and quantity of compost, farmers should be encouraged to use FYM in their compost. This allows manure to increase its value, kill parasites and weed seeds, and decrease the volume of waste. It can also help to stabilize the nitrogen in the FYM.
- To minimize nutrient losses, the FYM should be protected from sun, wind and rain. This can be done by covering the manure heap with a polythene film. Farmers can also use locally available covering materials or shades to improve FYM storage conditions. Storing FYM in pits is particularly suitable for dry areas and dry seasons.
- It is also important to incorporate applied FYM into the soil as soon as possible to protect loss of nutrients from evaporation

5.2 Compost

Composting is most rapid when conditions that encourage the growth of microorganisms are established and maintained. The most important conditions include: the climate, the carbon to nitrogen ratio, aeration, moisture, material size and regular turning. All are vital to the composting process.

Materials for composting include:

- The main components of materials required for preparing quality compost include green materials, dry or brown biomass, animal manure, and water

- Dry and green plant materials such as weeds, grasses and any other plant materials cut and collected from fields, wastes from cleaning grain, cooking and cleaning the house and compound, making food and different drinks, particularly coffee, tea, home-made beer, crop residues: stems, leaves, straw and chaff of all field crops – both big and small – cereals, pulses, oil crops, horticultural crops and spices, from threshing grounds and from fields after harvesting, garden wastes – old leaves, dead flowers, hedge trimmings, grass cuttings, dry grass, hay and straw left over from feeding and bedding animals and stems of cactus, such as prickly pear (crushed or chopped up).
- Animal material including urine, dung and droppings from all types of domestic animals, including horses, mules, donkeys and chicken, from night pens and shelters, or collected from fields.
- Water is needed to wet all the materials and keep them moist, this can be rainwater, wastewater and urine.

A challenge in making good compost is labour shortage specially in properly aerating the piles. Piles must be turned frequently, or they risk becoming anaerobic and putrefying. When this happens, foul smelling gases such as ammonia and mercaptans are produced, and harmful bacteria proliferate. This makes for angry neighbours, numerous flies, and a potentially disease inducing finished product. The problem with continually turning the piles to prevent putrefaction is two-fold. One, it is very labour intensive and even frequent turning is not 100% efficient and anaerobic pockets may begin to putrefy in the piles. Water and green material shortages are also challenges in making compost. The use of Compost and Effective Microorganisms (EM) can help overcome these challenges.

Figure 22: Compost making (Photo ISFM+)

Figure 23: Manure ready for application (Photo ISFM+)

5.3 Rapid composting

Rapid composting can be achieved using Effective Micro-organisms (EM), which consist of a mixed culture of beneficial microbes including lactic acid, bacteria, and yeasts. Compost 21 facilitator is an organic extract that is added to a compost that leads to maturity of the compost in just 21-days. And it is a composting method using green (nitrogen rich), manure and brown (carbon-rich) along with mineral boosters. It allows varied methods of compost preparation depending on the composting materials available. The addition EM into the composting process can stop odour problems and establish beneficial microbial growth by preventing anaerobic pockets from putrefying. When carefully managed, Compost 21 facilitator and EM have the potential to reduce the frequency of turning the piles, saving water, labour, time and money. Compost 21 facilitator and EM solutions can be purchased from a local distributor.

5.4 Green Manures and Cover Crops

Green manures, sometimes referred to as cover crops, are plants that are deliberately grown for the purpose of incorporation into the soil to improve organic matter content and soil fertility. Leguminous plants are mostly used for green manuring due to their ability to fix nitrogen, their drought tolerance, quick growth, and adaptation to adverse conditions. While the main purpose of growing a cover crop is to cover the soil with a low vegetation cover to protect the soil from exposure to sun and rain as well as to suppress weeds, they also have a root system that holds the soil in place. They are grown with the prime purpose of building as much biomass as possible. After incorporation into the soil, the biomass is quickly decomposed by soil organisms within about two weeks under humid and warm conditions. Most nutrients are then readily available to a new crop. A small proportion is also transformed into stable soil organic matter, contributing to better soil structure, better aeration, improved drainage and increased soil water and nutrient holding capacity.

In Ethiopia, some of the crops used for green manuring include lupins, lablab and vetch. Vetch is adapted to altitudes ranging between 1800-2500 metres above sea level (Seyoum and Cajuste 1980), while lablab has been grown in the 'Kola' and 'Weina dega' agro-ecological zones.

Figure 24: Lablab cover crop (Photo ILRI)

Figure 25: Vetch underplanted a maize crop (Photo ILRI)

Figure 26: Cowpea fodder (Photo ILRI)

Lupins (Lupinus species) have been successfully grown in several areas in Amhara region, where they are a hardy annual leguminous green manure that has tap roots that dredge up minerals. They also fix nitrogen more so than peas or beans. The long roots also help to break up and aerate heavier soils and allow more soil moisture retention with the addition of humus from the breakdown of the roots in the soil. They produce a blue flower, although it is best to cut the plant down and dig in before flowering to prevent seeding and consequently becoming a nuisance in other crops. Other green manures that can be considered include Crotelaria, Mucuna, Canavalia, Tefrosia and Stylosanthes species. In some locations weeds such as Argemone Mexicana are also used as cover crops, later after flowering are incorporated into the soil.

Green manures are often grown prior to cereals to avoid or reduce competition with the crop. For instance, in Amhara, lupin should be planted typically in March using a high quality, inoculated legume seed, aiming for incorporation into the soil in June, prior to planting a cereal crop. In other situations, the green manure can be sown toward the middle or the end of the growing season, when the main crop is well established or near maturity. In this situation, known as relay cropping, major growth of the green manure occurs during the dry season after the harvest of the main crop. This has the advantage that the green manure uses land that normally would not be under cultivation

Green manures are ideally allowed to grow up to the flowering stage, when biomass is greatest and the plant material will still easily decompose, as it is still green and not yet woody. The green manure is then incorporated into the soil during land preparation. The biomass is then broken down quickly by soil organisms, allowing the nutrients to become available. Within a few months the green material will be completely decomposed.


Figure 27: Lupine planted as a green manure (Photo ISFM+)


Figure 28: Lupine being ploughed in prior to planting a crop (Photo ISFM+)

Green manuring as a soil fertility management option is a recent innovation for most Ethiopian farmers and consequently not often practiced, the main reason being a lack of awareness about the potential benefits. Also, many farmers seek an immediate economic product, such as grains, from the crop that is grown.

5.5 Vermi-culture, Vermi-compost and Vermi-tea

Vermiculture is continuous breeding of earth worms to produce a continuous supply of high-quality compost (Figure 5.1, 5.2 and 5.3). This requires the continuous breeding of earth worms in boxes to produce vermi-compost. This is the excreta of the earth worms, which is rich in humus.

Vermi-composting converts biodegradable waste into humus with the help of earthworms. It is a fast method of preparing enriched high-quality compost. It is one of the easiest methods to recycle agricultural wastes and to produce quality compost.

Compost worms need five basic ingredients: A hospitable living environment, called “bedding”, a food source; adequate moisture (greater than 50% water content by weight); adequate aeration and protection from temperature extremes. Vermicomposting can be carried out in different types of containers. There are only a few requirements for a good worm pit, the most important being good ventilation; the pit needs to have more surface area than depth (wide and shallow) and it needs to have low sides. The base of the worm pit is prepared with a layer of sand then alternating layers of shredded dry cow dung and degradable dry biomass and soil are added.


Figure 29: Bedding for the worms and a worm box (Photo ISFM+)


Figure 30: Vermi-compost in preparation (Photo ISFM+)


Figure 31: Vermi-worms (Photo ISFM+)


Figure 32: Vermi compost ready for application to the soil (Photos ISFM+)

Vermi tea is a liquid fertiliser made by steeping the vermi-compost in water, which can then be used either as a foliar spray or soil drench and is reported to also act as pest control agent. It is made by soaking a bag of worm castings in water leaving it to soak for up to two days. The bag of castings can be used as a mulch or added to any compost being made. The dark liquid of vermi-tea should then be diluted until it is light brown in colour and used to water or spray on the plants.

Figure 33: Vermi-tea application by knapsack sprayer on plant leaves (Photos ISFM+)

Figure 34: Comparison of faba beans produced with and without vermi-tea (Photos ISFM+)

5.6 Bio-Digesters, Bio-Gas Slurry Management, Use And Challenges

A bio-digester is a closed, airtight vessel in which organic material is deposited to support anaerobic digestion, a process that leads to degradation of the material by bacteria in the absence of oxygen and producing a methane and carbon dioxide mixture, which can be used for cooking and / or lighting. Bio-digesters range from simple plastic bags on beds of straw that produce small amounts of gas to complex systems capable of producing several megawatts of electricity. They produce waste organic material from both animal and human waste, or other organic materials.

Figure 35: A biogas pit and its components parts (Photos ISFM+)

The Government has been a key supporter of biogas technology promoting its use as a clean energy source, replacing fuelwood, charcoal, and other unsustainable energy sources for cooking and lighting. However, for many households, not only in Ethiopia but also in other countries, the digestate is often regarded as being the main benefit (World Bank, 2019). This is the sludge residue after the fermentation process also known as “bio-slurry” or “digestate”.

Figure 36: Bio-slurry production (Photos ISFM+)

Being fully fermented, bio-slurry is odourless and does not attract flies. Pathogens present in the manure are reduced in bio-slurry when compared to raw manure and even further when the bio-slurry is composted. It is also known to repel termites and other pests that may be attracted to raw manure. It is an excellent soil conditioner, adding humus and enhancing the soil’s capacity to retain water and has been reported to reduce weed growth by up to 50%.

Bio-slurry can be separated into liquid and solid fractions and stored separately, the solid fraction being stored in a similar manner to compost or FYM. These allows the separated fractions to be handled more easily. Transport of the solid fraction will be less costly compared with large volumes of liquid digestate. It can also be sold as a valuable fertiliser, while the liquid fraction can be used close to the bio-digester. As such the bio-slurry can be used in different ways:

- The liquid component can be mixed in a 1:1 composition with water and applied directly to the soil around vegetables or fruit crops. In this form it is particularly beneficial for root vegetables, sugarcane, fruit trees, and for nursery seedlings. For large quantities, application along irrigation channels can be undertaken.
- The solid fraction can be added to compost and used on field crops or sold as a bio-fertiliser.

Bio-slurry has a lower organic and a higher ammonium content in bio-slurry matter than FYM with the effects of bio-slurry application being comparable to the effects of the application of chemical fertilisers.

Challenges in using bio-slurry include:

- **Storage:** Bio-slurry needs to be stored since it will only be required in specific periods of the growing season, while the bio-slurry will be produced continuously. Options for storage include vessels or tanks, closed or uncovered ponds or lagoons.
- **Incomplete digestion:** If anaerobic digestion is not fully complete, additional digestion will occur during storage, when CO2, CH4 and NH3 will be released losing nutrients and producing damaging gases (Nicholson et al., 2002).
- **Food safety risks:** The risk of pathogen contamination is lower for fresh bio-slurry than for fresh manure, although after storage pathogen risks are similar.

5.7 Cattle Urine Collection and Use

Cattle and other animal urine can be a valuable and sustainable fertiliser when diluted and used correctly (EIAR, 2023). Urine is rich in nitrogen, phosphorus and potassium and can be used as an alternative to urea. It can be applied to plants/crops in combination with other ingredients or on its own as both a fertiliser and a pesticide. It can also be used in a balanced mixture with manure as a liquid natural fertiliser or as an ingredient for compost preparation. As a fertiliser it is suitable for all types of crops with priority usually given to crops that have high economic value, such as vegetables and fruits.

The urine can be collected directly or through a canal or pipe into a prepared pit or buried container. It can be used fresh applied to crops or soil within 24 hours of collection or after storage for at least three weeks. This is the most common method. It can also be fermented by adding ingredients that trigger fermentation or processed by extracting and enriching the substances contained in the urine and used subsequently.

There are three methods of urine application. Firstly, directly to the soil in a straight line 3-4 cm from plants and then covered. Diluted urine can also be applied directly to the root zone of plants avoiding application in intense sunlight. Secondly, by foliar spraying directly onto the plant as both a fertiliser and a bio-pesticide. In this case, it should be diluted at least three times with clean water and applied carefully using appropriate equipment and protective clothing. Thirdly, soaking seeds or the roots of seedlings in urine to improve emergence and increase the number of roots on the seedlings.

Rates of application advised by EIAR (2023) are shown in Table 5.1.

Table 4: Volume of cattle urine (litres) required to spray selected crops on selected areas

Crop vegetable	N recommendation (kg/ha)	Urine required to supply full N^1 for 1 ha	Urine required to supply half N^2 for 1 ha	Urine required to supply full N for 0.25 ha	Urine required to supply half N for 0.25 ha
Teff	60	6000	3000	1500	750
Maize	88	8800	4400	2200	1100
Onion	105	10500	5250	2625	1313
Garlic	105	10500	5250	2625	1313
Lettuce	69	6900	3450	1725	863
Wheat	60	6000	3000	1500	750

*Full N: when all recommended N is to be supplied from urine.
**Half N: when half recommended N is to be supplied from urine
Source: EIAR (2023)

Figure 37: Urine collected from cattle shed being diluted with water (Photos ISFM+)

Figure 38: Comparison of wheat demonstration plot with and without cattle urine application (Photos ISFM+)

5.8 Biochar and Bone-char

Biochar is a form of biomass that has been heated in low oxygen conditions, typically 300-400OC. Bone char is made from animal bones in a similar manner. Biochar includes a wide range of organic materials such as wood, crop residues and manure. Both chars have a black granular appearance and are composed of calcium phosphate and can be enriched with other substances to improve soil quality. They increase soil organic matter and like other organic fertilisers, improve physical structure, water infiltration and retention, nutrient exchange, and reduces nutrient leaching. They can raise pH in acid soils and affect microbial activity related to decomposition and nitrogen transformation and boost fertiliser effectiveness and contribute to better crop health. They can also help immobilise chemical pollutants, which makes plants more resilient to stresses such as disease, pests, drought, and salinity.

Benefits are greatest in poor sandy or acidic soils low in organic matter, while yield improvements in fertile soils tend to be modest.

Potential risks include:

- Competition for limited organic resources, especially when biochar is produced on-site using crop residues or other materials that could be used as animal feed or mulch.
- High energy consumption and transportation costs from distant sources, which can affect overall costs.
- Contamination of source material, which may result in soil pollution. This risk can be reduced they are produced domestically or sourced from recognised suppliers.

The production process involved for bone-char includes gathering animal bone waste, grinding the full-sized bones into smaller pieces, charring in a batch kiln at about 400 C, further grinding the charred bone pieces into a fine dust, and pelletizing the dust with a starch water binder (Ahmed, 2023)

Key issues to consider are include:

1. What biochar and bone char feedstocks are available and are there any potential contaminants in the feedstocks?
2. Have they been produced sustainably, without overusing organic resources?
3. Has research been undertaken on specific crops or soil types?
4. Are there any recommended application rates?

Figure 39: A small batch charring kiln for production of biochar or bone char (Photo: Ahmed)

Figure 40: Bone char ready for application to the soil (Photo Ahmed)

5.9 Ensuring Efficient use of Good Quality Organic Fertilisers

Since a lot of time and effort is invested in making good organic fertiliser, it is worthwhile to put time and effort into using it properly in the field. Mature compost or FYM is best stored in a pit or heap until it is needed. If it is kept dry and covered, it can be stored for several weeks without deteriorating. It should never be left uncovered in the rain or in the sun. It should be kept in a sheltered place, such as under the shade of a tree or in a shed and covered with leaves and/or soil and sticks to prevent the nutrients escaping to the atmosphere, and animals trampling on and damaging the mature heap.

When organic fertiliser is taken to the field, it should be taken early in the morning or late in the afternoon. Spreading should be done in a single day otherwise loss of nitrogen will be incurred, especially if it is left uncovered. The best conditions for application are when there is sufficient soil moisture, just before planting. Application in a dry soil causes loss of nitrogen.

Guidelines for use include:

- **For crops sown by broadcasting:** The organic fertiliser should be spread equally over the field or that part of the field chosen to be treated. It should be incorporated and mixed with the soil to prevent loss of nutrients from exposure to the sun and wind.
- **For row planted crops:** Organic fertiliser can be spread along the row with seeds or seedlings, for example in maize, sorghum and vegetables.
- **For trees:** The organic fertiliser should be placed at the bottom of the planting hole and covered by some soil when the seedling is planted. It can also be dug into the soil around the base of a tree seedling after planting.

Application rates: Ideally the quantity of organic fertiliser applied should be based on the crop type and variety, expected yields and soil type. It will also depend on the nutrient content. Guidance on the rates of application may be obtained from a nearby Agricultural Research Station. However, it is recognised that more research is needed to find out how much is required to get good yields in Ethiopia's different agro-ecological zones.

Where no guidance is available, the following general recommendations can be applied.

- **For field crops.** When compost or FYM is the only fertiliser source available, it should be applied at rates between four and 12 tonnes per hectare. The optimum rate may vary between 8-10 tonnes per ha. Ideally the rate of application should not be less than five tonnes per ha with other nutrients provided by application of inorganic fertilisers..
- **8–10 tonnes per hectare.** This can be achieved in areas where there are plenty of composting materials, a good water supply and labour is available. Farmers working in groups are more likely to be able to produce large quantities of good quality compost than farmers working alone..
- **Around 6 tonnes per hectare.** This can be achieved where there are medium amounts of organic materials, and water and labour are available. These quantities have been achieved by farmers working in Central Tigray near the town of Axum.
- **Around 3.5 tonnes per hectare.** This can be achieved even in those areas with low availability of materials if there is sufficient water to moisten the composting materials. In drier areas, it has been observed that 3-6 tonnes of compost per hectare can give greatly improved yields, as good as if not better than those from using chemical fertiliser. In wetter areas, farmers found that 5–8 tonnes per hectare can improve crop yields significantly.
- **Smaller quantities of organic fertiliser.** If only small quantities of are made, it is important to apply it to a small area of land to make it as useful as possible, instead of spreading it thinly over a wider area. Where there are only insignificant amounts of composting materials, for instance where farmers have small plots of land, labour is short supply, possibly for women-headed households, working together to fill a common pit or heap can make better quality compost than working alone.
- **Time between applications:** Soil given organic fertiliser, especially compost or FYM in one year will not need it again the next year as the effects last for more than a single growing season. New compost or FYM can then be used for the part of the field that had no compost the previous year. Farmers that can apply the equivalent of 8–10 tons per hectare say that the effects last for up to three years.

Section 6: Agronomic Practices to Ensure Efficient Input Use

6.1 Agronomic Principles

Yield-building practices include the land preparation, tillage and planting methods with appropriate soil and water conservation practices, fertiliser and crop varieties that are resistant to major diseases. It includes practicing suitable crop rotations, such as cereal-legume ones and regular monitoring of crops to ensure timely interventions. Crops are susceptible to weeds, pest and diseases with losses occurring at various stages including seedling establishment, crop growth and development, harvesting and in storage. This requires integrated weed, pest and disease management practices to minimize crop yield losses. Weeding needs to be timely and effective, with pest and disease control using, as far as possible, non-chemical pest and disease management practices. If agrochemicals are required, application should be by trained and knowledgeable persons complying with established safety and maintenance standards. Timely harvest is also important to minimise in-field yield losses with subsequent drying and storage management also being important (Tables 6.1 and 1.1).

Table 5: Interventions that determine yields, productivity and incomes achieved by farmers

Crop choice and land management	Soil fertility practices	Other practices
• Crop, variety and rotation selection • Land preparation / soil tillage • Soil and water conservation management • Planting method	• Fertiliser sources • Fertiliser rates • Fertiliser pH correction • Fertiliser application	• Weed management • Pest and disease management • Harvest and post-harvest management • Input acquisition and output marketing practices

6.2 Crop Rotations

A Crop rotation means changing the type of crop grown on a particular piece of land from year to year. It provides many benefits associated with building healthier soil, breaking weed and pest life cycles. It can also increase organic matter in the soil, improve soil structure, reduce soil degradation, decrease synthetic pesticide and fertiliser requirements and can result in higher yields and greater farm profitability in the long-term. Crop rotation can also assist mitigate the effects of climate change.

Leguminous crops in the rotation fix atmospheric nitrogen and bind it in the soil, increasing fertility and reducing the need for synthetic fertilisers and pesticides. In the Highlands, a legume (Faba beans, field pea, or lentils) rotated with a cereal (maize, wheat or barley) and in the Lowlands (lowland pulses with maize or sorghum).

When planning a crop rotation program, it is necessary to consider several factors, including:

- Growing the same crop only once each year on the same piece of land to decrease the likelihood of insects, diseases, and nematodes becoming a problem.
- Inoculating legumes with biofertilisers at planting in order to enhance biological nitrogen fixation.
- Following a legume crop with a high-nitrogen-demanding crop such maize or vegetables to take advantage of the nitrogen.
- Growing some crops that will leave a significant amount of crop residues like beans, to help maintain organic matter levels.

6.3 Intercropping

Intercropping is a cropping system involving the growing of two or more crops on the same piece of land at the same time, often a cereal and a legume. It can include either in- or between row intercropping, strip intercropping, mixed cropping or relay intercropping. The main reason for intercropping is the improvement and maintenance of soil fertility with the leguminous crop fixing nitrogen. An example is when a cereal crop is intercropped with a legume such as haricot bean, cow pea, mung bean or soybean.

Intercropping is regarded by many farmers as a practice that reduces risk in crop production. If one intercrop fails, the other may survive and compensate in yield, giving the farmer an acceptable harvest. Pest levels are often lowered in intercrops, as the diversity of plants hampers movement of certain pest insects and in some cases encourages beneficial insect populations. In addition, intercropping can be an ideal cropping system for carbon sequestration since it can enhance biomass accumulation both above and underground.

In row intercropping is when the main crop and intercrop are grown in separate rows, for example, haricot bean and maize or sorghum. In mixed intercropping, the seeds of two or more crops are sown with no arrangement. For example, faba bean seed may be scattered amongst wheat plants.

Cereal legume-intercropping is a widely applied traditional practice in Ethiopia with 85% of the sorghum produced in eastern Ethiopia being intercropped with beans. Haricot bean, mung bean, cow pea and soybean are the most common legumes used for intercropping with maize and sorghum. Common crop combinations in intercropping systems are cereal-legumes, particularly maize-cowpea, maize-soybean, maize-pigeon pea, maize-groundnuts, maize-beans, sorghum-cowpea, millet-groundnuts.

With maize/sorghum-cowpea/haricot bean intercropping, maize/sorghum is planted in rows 75 cm apart, cowpea/haricot bean is planted in rows midway between maize/sorghum rows with in-row spacing of 15 cm. Haricot bean/cow pea could be planted simultaneously during maize/sorghum planting.

Figure 41: Maize-bean intercropping and mixed cropping (Photos ISFM+)

6.4 Push–pull intercropping

Push-pull is a climate-smart innovation based on companion or inter-cropping, which addresses three constraints in cereal production, declining soil fertility, stem borer and Striga, while increasing grain yield without the use of external inorganic inputs. A perennial intercrop provides live mulching, agro-biodiversity and a food web of natural enemies of stem borers (Khan et al, 2014; Midega et al, 2015). Furthermore, it improves soil health and conserves soil moisture. These companion plants release behaviour-modifying stimuli (plant chemicals) to manipulate the distribution and abundance of stem borers and beneficial insects for management of the pests (Figure 6.1). The system relies on an in-depth understanding of chemical ecology, agro-biodiversity, plant-plant and insect-plant interactions.

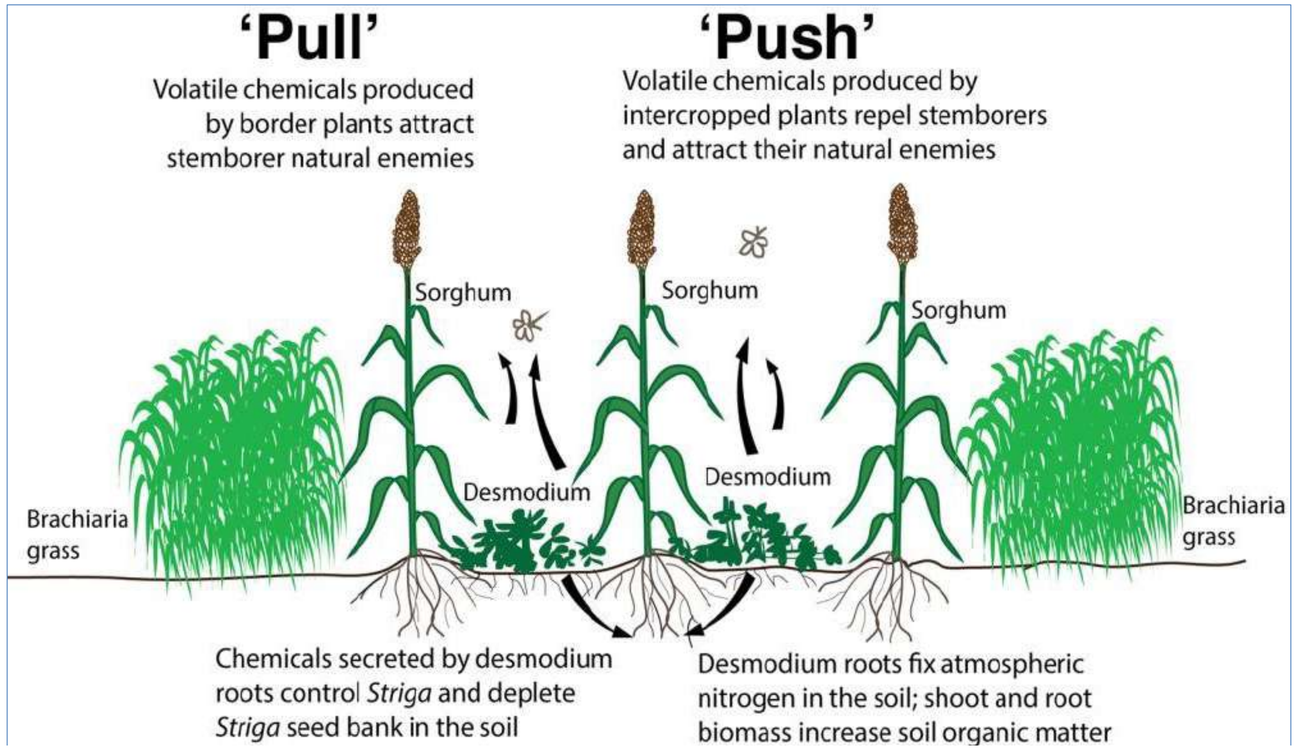


Figure 42: Push-Pull technology (Source: Khan et al, 2006)

Push-pull involves intercropping cereal crops with a moth repellent forage legume Desmodium (the Push) and an attractive trap plant such as Napier or Brachiaria grass (the Pull) planted as a border crop around the intercrops. Stem borer females are repelled from the main crop and are simultaneously attracted to the trap crop. Desmodium can be effective in suppressing the Striga weed, while improving soil fertility by fixing nitrogen and improving soil organic matter. Both companion plants can provide valuable fodder

6.5 Land Preparation, Reduced Tillage and Conservation Agriculture

Various improvements in the care and management of soils have become increasingly widespread with the adoption of appropriate forms of minimum or no-till farming systems, now known worldwide as Conservation Agriculture (CA). CA is characterised by three inter-linked principles: minimum or zero-tillage, seeding directly into untilled soil; a permanent ground cover or mulch comprised of crop residues; and diversification of cropping systems through crop rotations or intercropping. As such it has many common features with ISFM. CA can be most effective in healthy soils with high organic matter and good ground cover resulting in reduced erosion and stabilized crop production, for various reasons, the CA principles are not always fully implemented by farmers and results not as favourable as expected (Giller et al., 2009). Constraints include increased labour demand for weeding when soils are not ploughed and crop residues are often highly valued for feeding to livestock rather than leaving as mulch. No-till without mulch can be disastrous, leading to soil capping, and extreme run-off exacerbating rather than controlling soil erosion.

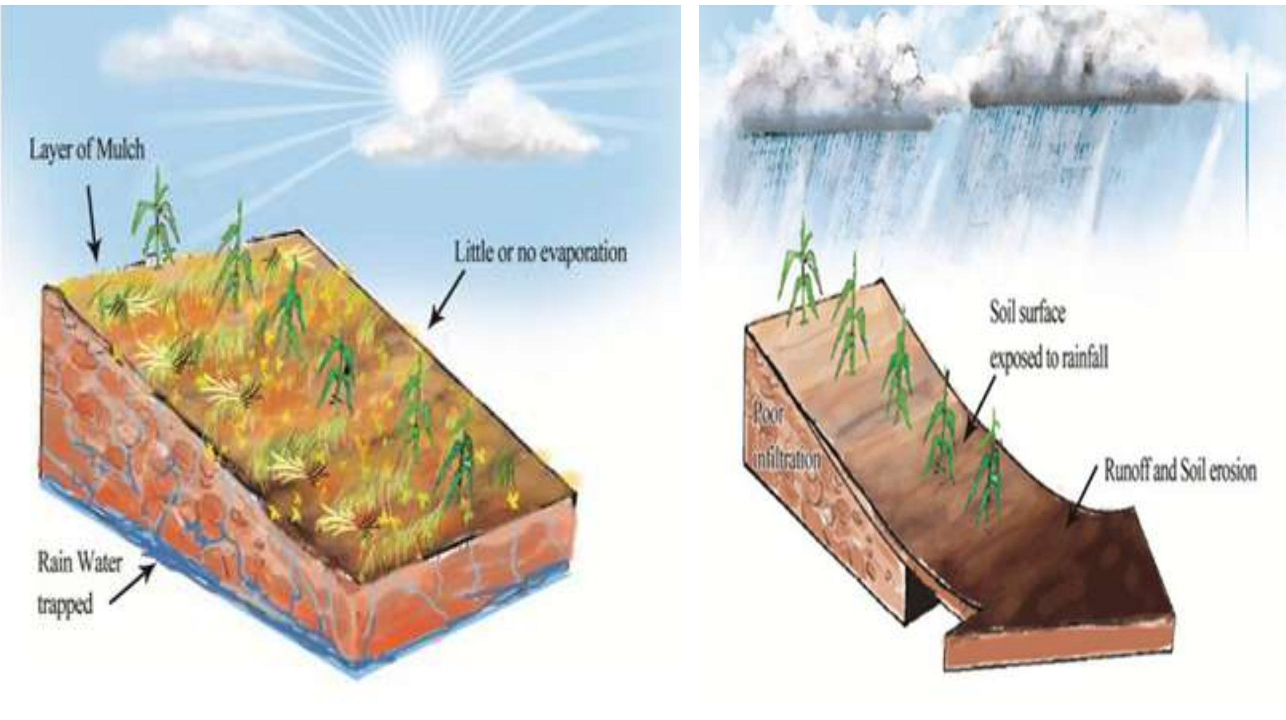


Figure 43: Advantages of reduced or zero tillage with crop residue mulch for soil surface protection

Notwithstanding, ISFM technologies are compatible with those embodied within CA, the major difference being that CA is based on no-till practices and a permanent ground cover from the outset. Although these remain important, it is recognised that crop residues used as ground cover mulch have other important uses such as livestock feed that farmers may value more highly especially in the early adoption of ISFM.

6.6 Crop Residue management and mulching

Mulching is the covering of the soil with crop residues such as straw, weed biomass, leaf litter and dry grasses. Once they have rotten and decomposed, mulch forms humus and adds to the organic matter in the soil. It is important for the prevention of soil erosion, addition of organic matter and nutrient recycling, regulating the soil temperature, increasing soil microorganism and biological activity, weed suppression, increasing water retention, and decreasing evaporation from the soil surface. It is important to ensure that sufficient mulch is maintained as soil cover to reduce evaporation of soil moisture and to discourage growth of weeds.

There are many alternatives for using crop residues: 1) mulching, 2) animal feed, 3) composting, and 4) burning. Although using residues as a mulch is the best option for soil health, it is recognised that crop residues are also important for providing livestock feed and making compost as well as for building fences and homesteads, and as fuel for cooking and household energy use. It is a precious commodity, and often little, if any, is left behind on the field as mulch in many circumstances

Figure 44: Maize stover left as a mulch (Photo FARA)

Figure 45: Well mulched maize field using crop residues (Photo FARA)

Figure 46: Maize planted in small pits and mulched. (Photo FARA)

6.7 Biological Nitrogen Fixation for Legumes

Rhizobia inoculants are selected strains of beneficial soil micro-organisms cultured in a laboratory. They are crop-specific, low cost and an environmentally friendly source of nitrogen. Inoculation involves the addition of the rhizobia to leguminous seeds prior to planting to promote nitrogen-fixation. The inoculant is coated onto the legume seed before planting enhancing the growth and yield of the crop and providing nitrogen and organic carbon for subsequent or associated crops (Figure 6.2).

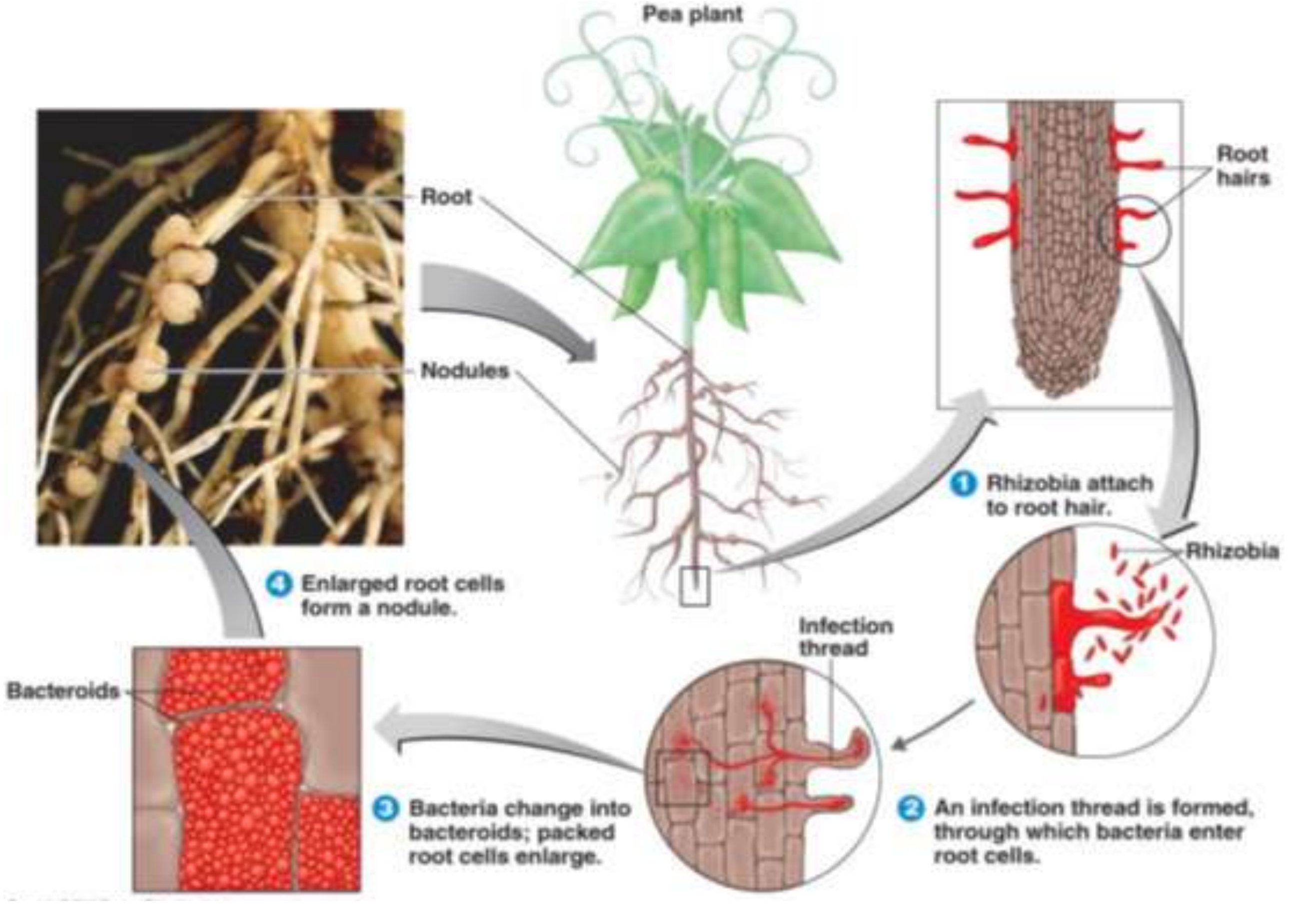


Figure 47: Formation of root nodules on a pea plant

Rhizobium inoculants can increase legume grain yields by up to 45 per cent and since they are low cost, they are a cheap way to increase legume yields. Also, inoculant use helps to make phosphorus fertilisers viable. P-fertiliser is much more expensive than inoculant and the additional yield obtained due to inoculation when applied together with P fertiliser more than covers the cost of the fertiliser and other inputs.

Although inoculant rhizobia can remain viable in the soil without the presence of a legume for a few years ready to form nodules when its host plant is sown, inoculation is required when the field has no history of growth of a particular legume. This is also recommended if the field has been out of host plant production for a number of years or under unfavourable environmental conditions, such as when the pH is below 6.0, or in extremely sandy or highly degraded soils with low organic matter content, or where soils are periodically flooded.

Experience has shown that as improved legume technologies are adopted, there is often increased demand for legume inputs, including improved seed varieties. Access by farmers can be a challenge. Local seed producer groups can bridge the gap in the legume seed sector as commercial seed companies or cooperatives are often less interested in promoting grain legume seeds as farmers can re-use improved seed varieties for several years.

The best conditions for sowing inoculated seed are when the rains are well established on cloudy days early in the morning or late in the afternoon and the soil is moist. If it is either too wet or too dry germination will be retarded and colonization of the roots by the bacteria in the inoculant will be slow. Farmers should inoculate only the amount of seed that can be planted that same day considering the labour that is available. Seeds should be covered immediately with soil to protect the seeds from the damaging effects of sunlight.

Figure 48: Seed inoculation with rhizobium (Photo ISFM+)

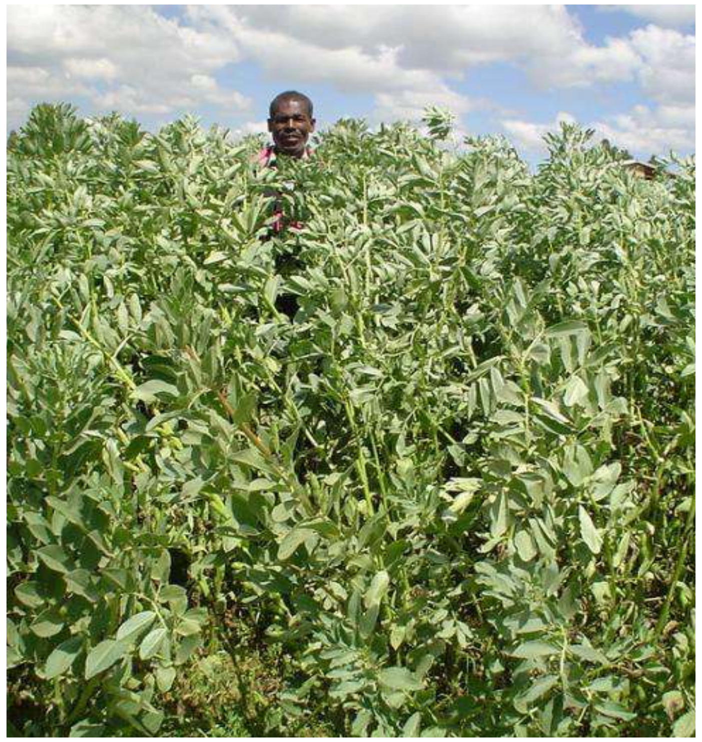


Figure 49: Faba bean crop AFTER rhizobium inoculation (Photo ISFM+)

6.8 Soil Acidity Management

Soil acidification is a complex set of process resulting in the formation of an acid soil. Soil acidity is a term used to describe soils with a pH value of less than 5.5. The major causes of soil acidity include excessive rainfall, leaching of the soil's basic elements (Ca, Mg, Na, and K), an acid parent material, continuous application of ammonium fertilisers, decomposition of organic matter and removal of nutrients through harvest of crops. These are largely found in some soils in the highlands, which receive or have historically received high rainfall and have warm temperatures much of the year. These occur in the west, north-western, south-western, central and southern part of the country and accompanying lowlands. About 43 % of Ethiopian arable land is affected by soil acidity, of these about 28% of soils are dominated by strongly acid soils (pH 4.1-5.5) (Abdenna et al, 2007). Nearly one-third of these also has an aluminium toxicity problem and are usually infertile because of Al and Mn toxicities and micro-nutrient deficiencies. These deficiencies reduce fertiliser use efficiency and adversely affects biological activity of soil microorganisms.

There are different methods to reclaim acidic soils and improve their productivity. Both international and local experience show that use of agricultural lime is considered a universal method to reclaim acid soils. Lime requirement for crops grown on acid soils is determined by the quality of liming material, status of soil fertility, crop species and varieties, crop management practices and economic considerations. However, it is also realized that lime alone cannot bring the long-term intended result. Integrated use of lime with organic and inorganic fertilisers and other crop management packages are therefore recommended. In most cases, this means that crops can also withstand high concentrations of aluminium. Crops vary in their tolerance to soil acidity. Therefore, selecting and growing species and varieties adaptable to acidic soils can be considered, although yields can be disappointing

Unfortunately, the increase in pH after adding agricultural lime is temporary. Findings from ISFM long-term demonstration plots indicate that lime may need to be applied every 5-7 years (Doldt et al., 2024).

Figure 50: Lime spreading and incorporation (Photo ISFM+)

Figure 51: Demonstration plot showing the effect of liming (Photo ISFM+)

6.9 Soil Salinity Management

Salinity problems have developed in Lowlands areas of Ethiopia and have resulted in huge crop losses with many farms going out of production in the last two decades. Saline soils have a high pH over 8.5, due to the presence of excessive sodium. This leads to poor soil structure, reduced moisture and air movement and sodium toxicity making these soils unsuitable for most crops. Therefore, mitigating existing soil salinity problems and preventing further spread in irrigated areas and rehabilitated dryland valleys is of vital importance.

Desalinization of sodic soils can be achieved by applying a calcium amendment like gypsum (calcium sulphate) or calcium chloride to replace excess sodium with calcium ions. Improving drainage is crucial to flush these salts from the root zone. Additionally applying organic matter will improve soil structure and drainage.

Adverse effects of salinity and sodicity can also be reduced using biological and agronomic reclamation practices. Supply of adequate nutrients to soils and promoting proper soil, water and crop management practices helps in the management of salt-affected soils. These include proper drainage systems, practicing minimum tillage to avoid soil compaction, using good quality water for irrigation, encouraging leaching to evacuate salt from the root zone, adopting efficient on-farm water management practices to avoid over-irrigation and improving water use efficiency, selecting appropriate crops according to soil type and zone, and avoiding mixing drained water with the river water for irrigation.

Growing salt-tolerant crop species can provide a long-term solution, as well as temporarily using highly saline and sodic soils for the production of improved pasture under flood irrigation.

6.10 Plant Nutrient Management

If the supply of nutrients in the soil is ample, crops will grow well and produce high yields. If only one of the nutrients needed is in short supply, plant growth will be limited and crop yields reduced. Therefore, to obtain high yields, it may be necessary to apply both organic and inorganic nutrient resources to supply the soil with the nutrients needed for crop growth.

Achieving the best yields requires good nutrient management, which depends on four things(4Rs) - using the right mix of nutrients, the right application rate of nutrients to supply the quantity needed, the right time of application of nutrients for effective use and the right placement in the soil for the nutrients to be accessible by crop roots. All four need to be correct for optimal crop nutrition to ensure increased crop yields, as well as maintaining soil health.

In assessing the right mix and application of nutrients, it is recognised that fertiliser represents a major financial investment. So, it is essential to target its use to variable soil fertility, climate and market conditions thus ensuring viable crop productivity. This includes poorly responsive but fertile areas, responsive areas and poorly responsive low-fertility areas (Giller et al., 2019).

Nutrients sourced from both organic and inorganic material essential for crop growth contain Nitrogen, Phosphorus and Potassium (N, P and K). Apart from organic materials, there is a wide range of commercially available inorganic multi-nutrient fertilisers, which contain these nutrients.

In areas with highly acid soils, the use of inorganic fertiliser should be limited until the pH is corrected by addition of lime.

Advantages to using inorganic fertilisers include ease of handling, transport and storage; ease of application; even distribution of nutrients when applied in the field; balanced distribution of nitrogen, phosphorus and potassium, available from crop germination and in accordance with plant requirements, and at a lower cost of application due to labour saving.

Once the right source of nutrients is determined, fertiliser should be applied to provide the required plant nutrients in sufficient quantities, in balanced proportions, in an available form, and at the time when the crop requires them. The guidelines for determining the right rate of fertiliser application are:

- **Considering all available nutrient resources and past management practices.** For most farms, this includes quantity of manure, composts, crop residues, crop rotations as well as the inorganic fertilisers that are available
- **Selecting a yield target that farmers can attain.** This should be realistic, based on soil and rainfall and other climatic conditions. A yield target provides an important guide on the estimation of the total amount of nutrients required by the crop
- **Assessing the amount of nutrients required by the crop.** Yield is directly related to the quantity of nutrients taken up by the crop until maturity
- **Assessing the capacity of soil to supply nutrients.** Methods used include soil and plant anal-

ysis, and fertiliser response experiments. Where these are not available, simple methods such as crop production history and knowledge of soil types can also be used.

Guidelines for the right time for a nutrient application include:

- **Applying nutrients to match seasonal crop nutrient demand.** This depends on planting date and crop growth characteristics.
- **Assessing dynamics of soil nutrient supply.** Mineralization of soil organic matter supplies some nutrients, but if the crop's uptake needs are not matched by the release of nutrient, crop yields will be limited.
- **Recognising the dynamics of soil nutrient loss.** For example, nitrogen is easily lost especially in sandy soils and should be applied in two or even three split applications during the season, when growing cereal crops.
- **Considering labour availability.** Timing of nutrient application should not delay other time-sensitive operations such as planting. For example, manure application demands a lot of labour and should be applied before the rains to avoid delays in planting.

Correct placement of fertiliser requires placing nutrients in the soil where the crops can easily access them. This depends on factors such as crop type, tillage practices, plant spacing, crop growth stage, crop rotation or intercropping as well as weather variability. The main considerations for the correct placement of nutrients include:

- **The tillage system.** In conservation tillage systems, special equipment may be used to apply fertiliser under the soil, while maintaining crop residue cover. This can help to conserve both nutrients and soil moisture.
- **Where the crop is growing.** Nutrients need to be placed where they can be taken up by growing roots when needed.
- **The mobility of nutrients in the soil.** Nutrients that move little in the soil, such as phosphorus, should be concentrated in bands or holes close to the plants to improve availability.
- **Manage differences in spatial variability of soil fertility across a landscape, between different fields or even within a field.** Most farms consist of fields that are managed differently and vary in soil fertility status. For instance, more fertilisers and manure are often used on fields closest to homesteads than on fields further away. Differences in management due to soil type or position on the landscape also contribute to differences in soil fertility. Such differences should be considered when decisions are made on where to apply limited fertilisers.

Whenever fertiliser is applied, it should be incorporated immediately after application to avoid losses due to runoff and erosion. Incorporation of urea and ammonium-based fertilisers will also reduce losses due to loss of ammonia to the air. When fertiliser is applied by hand, care should be taken to distribute nutrients uniformly and at the exact rates. Where fertiliser application equipment is used, it should be adjusted to ensure uniform spreading and correct rates. Any equipment used should be well maintained.

Figure 52: Farmer ISFM demonstration plots of wheat together with a mid-field compost making (Photo ISFM+)

Figure 53: Farmer ISFM demonstration plot of maize

Section 7: Soil and Water Conservation Practices

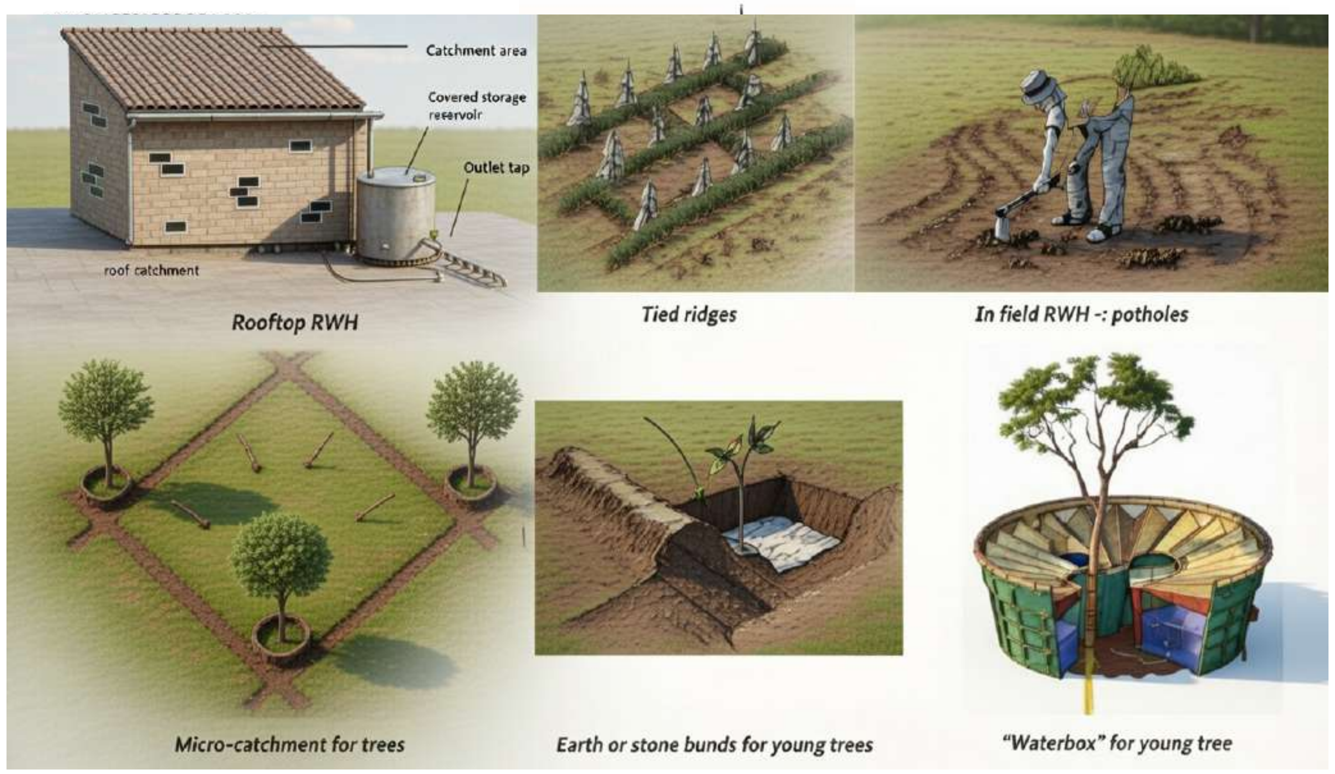
7.1 Rainwater Harvesting

Rainwater Harvesting (RWH) is defined as the collection of rainwater runoff from different sources for its productive use. It can be an important component for improving crop and fodder yields. It can help to increase the soil's capacity to receive, retain, release and transmit water, and can reduce soil erosion and at the same time, improve water quality and use efficiency. It can be an integral component of ISFM, as well as a climate change adaptation and a mitigation measure.

RWH practices include:.

Rooftop RWH: This is one of the easiest ways of providing drinking water at household level and sometimes small-scale irrigation. All that is required is the presence of roofs to provide the necessary catchment area, guttering and tanks to collect the water

In-field RWH: This includes those techniques that are often constructed as part of normal land preparation activities. They include tied ridges and potholing techniques that can be used for annual crops and individual trees.



In addition, small "water grow" boxes made from either plastic or preferably recycled biodegradable material can be used as plant holders, sheltering newly planted trees and the ground around them from the heat of the sun, while providing water for the plant. The lid collects water from rain and nighttime condensation, which is then stored in a bucket. The water-filled reservoir releases small amounts of water into the ground by a wick to water the tree and to encourage the tree to develop a root structure. These are sometimes used in arid and semi-arid environments.

Micro-catchment or in-field RWH: Sometimes referred to as in situ, short slope or a within-field catchment system, where run-off water is harvested from a small catchment, typically less than a 30-metre slope with runoff stored in the soil. Typical ratios of catchment to cultivated area vary from 1:1 - 3:1 with no provision for overflow. It includes those techniques in which rainwater is harvested and stored within the soil profile and includes terraces, pitting and bunding methods including trapezoidal bunds. Areas with annual rainfall in the range 200- 1200 mm rainfall can all benefit.

Figure 54: Infiltration pits dug along a contour drain or ditch (Photo ISFM+)

Rainwater Storage Ponds: These include storage of runoff water in small ponds and pans collected from springs and open surfaces, such as roads, homesteads, hillsides, open grazing lands and may include runoff from watercourses and gullies. These can be implemented anywhere, where local site conditions permit considering soil type and geology to avoid seepage problems (RELMA, 2005).

External catchment RWH: Sometimes referred to as long slope or outside field catchment overland water or rill flow, where run-off water is harvested and stored in the soil profile. Catchments varies typically from 30 to 200 metres in length with a ratio of catchment to cultivated area varying from 2:1 to 10:1 usually with provision for overflow water.

Floodwater RWH: Sometimes referred to as water spreading, run-off water is harvested either by diversion or spreading within a channel bed or valley floor with water stored in the soil profile. This uses a long catchment, often several kilometres with a ratio catchment to cultivated area typically more than 10:1 with provision for overflow of excess water. It includes a variety of water harvesting techniques including provision of water for domestic and livestock use, for crops, fodder and tree production and less frequently for fish and duck ponds. This includes those that have been used in dryland valley rehabilitation.

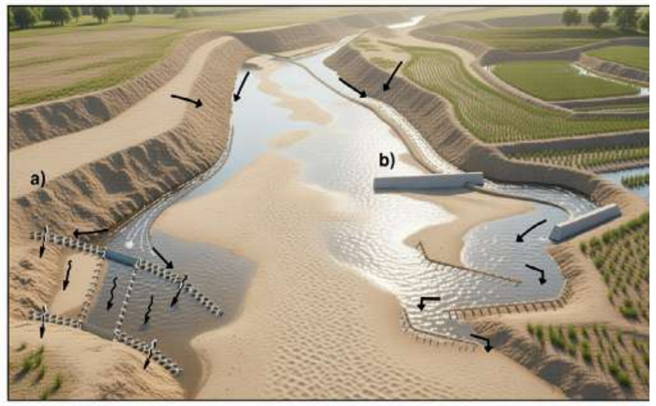


Figure 55: Floodwater farming systems: (a) spreading within the channel bed; (b) a diversion system

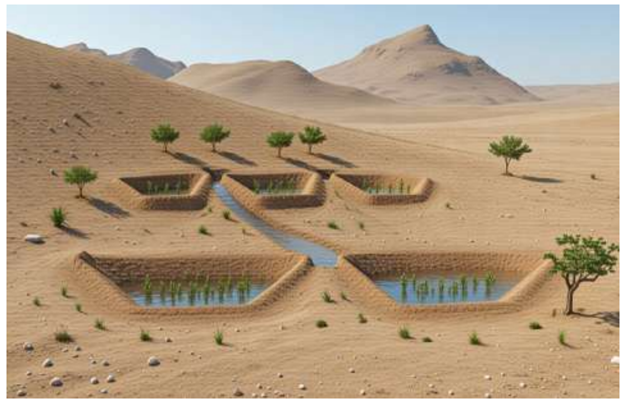


Figure 56: External catchment system: trapezoidal bunds or ponds for trees or crops

Figure 57: Floodwater farming system with a hierarchy of canals

Sand dams: These are weir storage structures built across seasonally dry water course with potential to store water in sand trapped in the weir. The potential of sand dams depends on the availability of sand rivers, a topography and a geology that allows weir storage. Water is filtered through the sand and can be used for domestic, livestock and irrigation purposes during the dry season.

7.2 Other Measures for Rehabilitating Dyland Valleys

Every dryland valley needs to be considered individually and holistically to realize its full potential. Stabilization of the upper part is critical to reduce water velocity, increase water infiltration, and prevent further erosion. The core technologies are a cascade of water spreading weirs, gabion check dams, dry stone and biological measures. Using these allows water to infiltrate into the soil increasing groundwater levels and allowing fertile sediment to settle creating highly productive land (Nekesa et al,2024)

Valleys can be divided into different productive zones, each fulfilling a function in protecting

Figure 58: Dry Stone Measures, Water Spreading Weirs, Biological Intervention (DVRPU)

Figure 59: A water spreading weir successfully stopped erosion and trapped lost soil two years after construction (Photo DVRPU)

the valley, while also contributing to economic diversification (Figure 7.1 and 7.2)

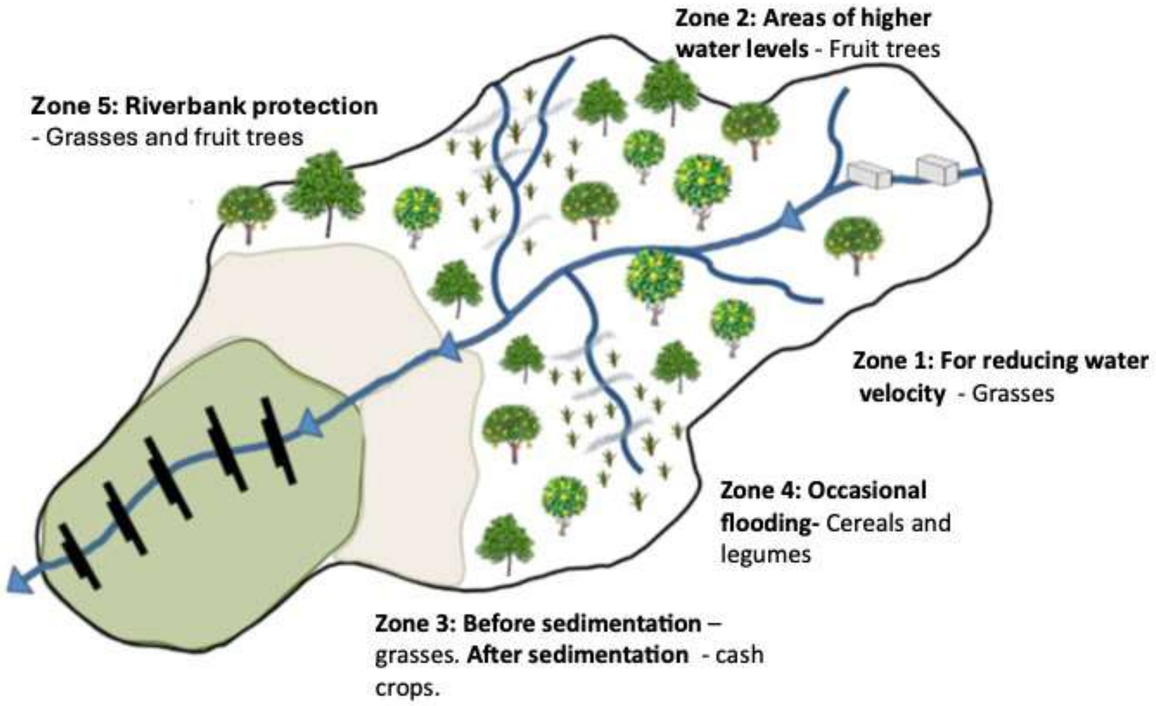


Figure 60: Typical Cropping Zones in a Rehabilitated Valley (DVRPU)

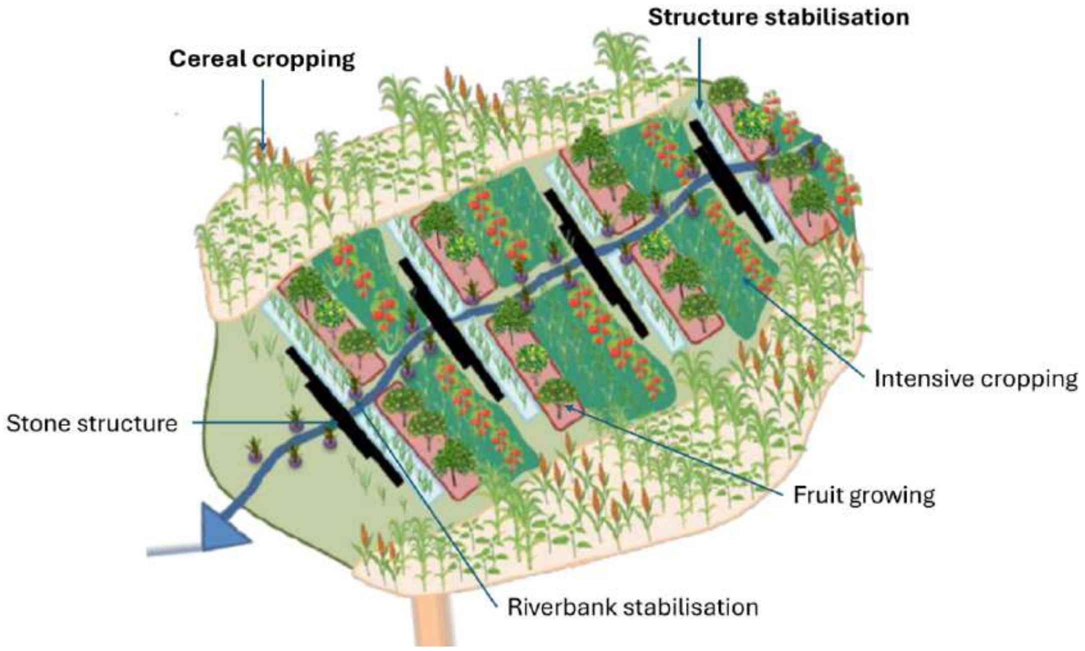


Figure 61: Another example of cropping and agroforestry area in a Rehabilitated Valley (DVRPU)

Suitable Crops for Flood-Based Farming (FBF) in each zone include:

Zone 1: Grasses are planted to reduce water velocity, protect structures, prevent soil erosion, and provide additional biomass for livestock feed. These include Napier/ Elephant Grass (Pennisetum purpureum), Bermuda Grass (Cynodon dactylon), Guinea Grass (Panicum maximum), Sudan Grass (Sorghum ×drummondii) and sugarcane (Saccharum officinarum)

Figure 62: A water spreading weir shortly after construction (Photo DVRPU)

Figure 63: The same weir one year later with grasses able to slow water velocity (Photo DVRPU)

Zone 2: Trees such as Moringa (Moringa oleifera), Mango (Mangifera indica), Papaya (Carica papaya), Avocado (Persea americana), Lemon (Citrus limon), Guava (Psidium guajava) are grown to take advantage of higher water levels. Initial establishment in the drier areas of the valley needs continuous attention. There are technologies available described under rainwater harvesting to obtain a high establishment rate of seedlings with minimum water requirements.

Zone 3: This area is particularly well-suited for growing cash crops. However, there is a change in the type of crops planted before and after the area undergoes the pre-sedimentation phase. By adapting the crop selection based on the sedimentation status of the area, the DVRPU FBF system maximizes the potential of planting zone three for cash crop production while considering the specific requirements and challenges posed by waterlogging.

During the pre-sedimentation phase, specific plant species that are resistant to waterlogging are selected and cultivated in zone three. This ensures that the crops maintain optimal growth and productivity. The following crops are suitable for the pre-sedimentation phase: Napier / Elephant Grass (Pennisetum purpureum), Sugarcane (Saccharum officinarum). After sedimentation zone three is the most fertile area with the longest moisture retention. Therefore, it is primarily used for cash crop production such as Onions (Allium cepa), Sunflowers (Helianthus annuus), Garlic (Allium sativum), Safflower (Carthamus tinctorius), Green beans (Phaseolus spp.), Tomatoes (Solanum lycopersicum), Mung beans (Vigna radiata), Chili peppers (Capsicum spp.), Sesame (Sesamum indicum), Watermelon (Citrullus lanatus)

Zone 4: consists of elevated land that is susceptible to occasional flooding. This higher area, although prone to periodic inundation, presents unique opportunities for specialized cultivation including Maize (Zea mays), Sorghum (Sorghum bicolor), Millet (Pennisetum glaucum), Mung beans (Vigna radiata)

Zone 5: is dedicated to the critical task of stabilizing riverbanks. This area plays a crucial role in preventing soil erosion, maintaining riverbanks and preserving the ecological balance of the surrounding areas. Initially they should be protected with similar grasses to those shown in Zone 1. In addition, fruit trees mentioned under planting zone 2 can be integrated. However, special care must be taken during the initial establishment phase.

In addition, dry forests in or near rehabilitated valleys are crucial for biodiversity, grazing, and local livelihoods. Drought-tolerant forage trees provide essential fodder for livestock year-round, especially in dry seasons, supporting pastoral economies. Some tree species yield valuable gums, resins, and timber, offering income and materials to communities. Charcoal production is also important but requires sustainable practices to prevent deforestation, including selecting appropriate species and efficient technologies. Effective management relies on collaboration among communities, agencies, and conservation groups. Sustainable land use and environmental protection strategies are needed to help balance economic gains with ecosystem health.

Figure 64: Zone 5 stabilising riverbanks with grasses, shrubs and fruit trees (Photo DVRPU)

Section 8: Community Groups, Cooperatives, Value Chains and Market Linkages

8.1 Community Groups and Cooperatives

There are many forms of community groups and cooperatives, both formal and informal whose aims vary but include promoting natural resources management, sustaining socio-cultural values and practices, reducing inequality through resource sharing, and enabling participation of women and youth in decision-making spaces. Supporting and building on existing groups and institutions, whether formal or informal, that are already established with governance mechanisms is likely to be more effective than building new groups.

Such groups include savings groups, learning groups (farmer field schools or research groups) producer groups, self-help groups, producer/market associations, and farmer cooperatives and water users' associations (Figure 8.1)

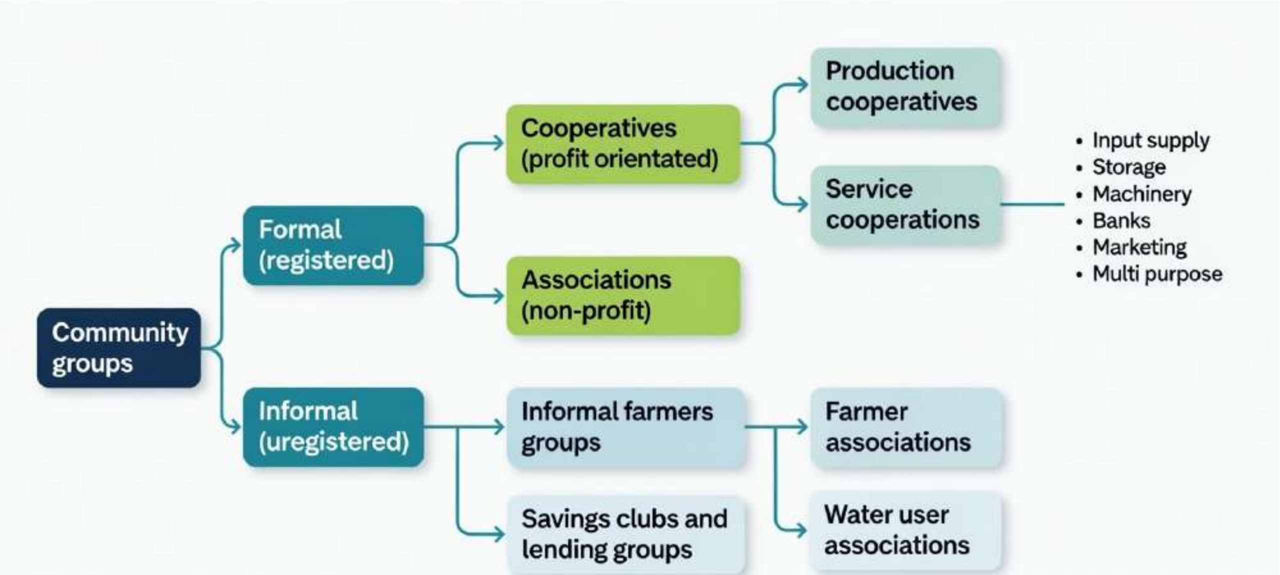


Figure 65: A Hierarchy of Community and Farmer Groups and Cooperatives (Source: CARE, 2023)

8.2 Value Chains and market Linkages

An agricultural value chain comprises all the steps involved in growing and rearing food, storing and processing it, transporting and selling it. Agricultural value chains are complex, involving producers, agro-dealers, input suppliers, food processors, transporters, traders, retailers, exporters and others. Small-scale farmers often do not or cannot participate in value chains. They may be far from a market and transport costs may be high. Some may have limited business skills or are not part of an organization to pool their resources. Often, small producers simply do not have bargaining power and can end up earning significantly less than their larger competitors.

Strong value chains and better access to markets allow small producers to reliably sell more quality produce at higher prices. When farmers get a good price for their produce, they are encouraged to invest in their businesses and increase the quantity, quality and diversity of their produce. This helps them earn more, ensuring their families' food security and building their economic resilience to withstand setbacks. Value chain development creates opportunities for rural people to establish businesses that meet local needs and produce diverse nutritious food.

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Published by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Registered offices Bonn and Eschborn, Germany

Division Rural Development, Agriculture G500
Friedrich-Ebert-Allee 36+40 D-53113 Bonn, Germany

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Text Jim Ellis-Jones

GIZ is responsible for the content of this publication

As at October 2025

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