



**Preventing Forest Loss, Promoting Restoration, and
Integrating Sustainability into Ethiopia’s Coffee Value
Chains and Food Systems (FOLUR Ethiopia)**

**Manual on Maximizing Shade Tree Cover in Coffee Farms and
Enhancing Intercropping Diversity in Family Farms**

**FOLUR Ethiopia – Southwest Ethiopia Peoples’ Regional State
(SWEPRS)**

December, 2025

Tepi, Ethiopia

Contents

Preface	IV
Acknowledgements.....	V
1. Background.....	1
PART I (MODULE ONE): Maximizing Shade Tree Cover in Coffee Farms of Southwest Ethiopia.....	4
Chapter 1: Why Shade Matters: The Benefits of Shade Trees	4
1.1 Climate Resilience: Buffering Against Stress	4
1.2 Coffee Quality and Yield Stability	5
1.3 Soil Health and Nutrient Cycling	6
1.4 Biodiversity and Pest Management	6
1.5. Economic and Social Benefits	7
Technical Guidance: Selection and Design	8
Chapter 2. Selecting the Right Tree Species	8
2.1. Key Criteria for Selecting Shade Tree Species.....	8
2.2 Indigenous vs. Exotic Species: Balancing Ecology and Utility	9
2.3 The Role of Nitrogen-Fixing Trees (NFTs).....	12
2.4 Tools for Context-Specific Tree Selection	12
Chapter 3. Designing the Optimal Shade System.....	13
3.1 Determining Optimal Shade Density and Percentage	13
3.2 Designing Spatial Arrangement and Spacing	16
3.3 Shade Tree and Fruit/Food Tree Spacing in Coffee Agroforestry	17
3.4 Managing Root and Light Competition.....	19
3.5 Integrating Ecological Principles with Local Knowledge	20
Management & Maintenance Practices	21
Chapter 4. Establishment of Shade Trees	21
4.1 Nursery Management for High-Quality Shade Seedlings	21
4.2 Field Planting Techniques for High Survival	22
4.3 Early Management and Protection.....	23
Chapter 5. Long Term Management for Maximizing Cover.....	24
5.1 Dynamic Management of the Shade Canopy: Pruning Techniques	24
5.2 Soil Fertility Management through Shade.....	27
5.3 Inter-system Pest and Disease Management (IPDM).....	28
Tools & Resources.....	28
Chapter 6. Practical Tools for Assessment and Planning	28

6.1 Field Assessment of Shade Cover Percentage.....	28
6.2 Monitoring Tree Health and Competition	29
6.3 Planning and Implementation Tools.....	30
Annex A: Glossary of Technical Terms	31
PART II (Module Two): Enhancing Intercropping Diversity in Family Farms.....	32
Chapter 7. Benefits of intercropping in coffee farms	32
7.1. Enhance Productivity.....	32
7.2. Diversified Income	32
7.3. Enhance Soil Health and nutrition:.....	33
7.4. Improve Climate Resilience	33
Chapter 8: Common coffee intercropping models in Ethiopia.....	35
8.1. Coffee-shade tree agroforestry system	35
6.2. Coffee-crop combination agroforestry system	36
6.3. Multi-strata coffee agroforestry systems	40
Chapter 9: Crop selection and spatial-temporal arrangements	41
9.1. Choosing the right crop	41
9.2. Spatial-temporal arrangements	43
Chapter 10: Growing and management of coffee and intercrops.....	48
10.1. Sourcing seed for coffee	48
10.2. Sourcing seed for intercrops	51
10.3. Land preparation and planting intercrop.....	52
10.3.1. New coffee garden.....	52
10.3.2. Established coffee garden.....	52
10.4. Maintenance of coffee and intercrops.....	53
10.4.1. Manage soil nutrients.....	53
10.4.2. Manage weeds	54
10.4.3. Shade management	54
10.4.4. Monitor for pests and diseases.....	56
10.4.5. Water Management:.....	57
10.4.6. Harvesting intercrops and coffee	57
Chapter 11: Integrating coffee agroforestry with cross-cutting themes	58
11.1. More secure income for women	58
11.2. Climate-smart practices	59
11.3. Market Access and Value Chains	60
11.4. Policy and Institutional Support	60

Preface

Ethiopia's coffee farms are more than a source of livelihood—they are vital landscapes for biodiversity, climate resilience, and sustainable food systems. Yet, deforestation, land degradation, and climate stress threaten these treasures.

This manual, *Maximizing Shade Tree Cover in Coffee Farms and Enhancing Inter-cropping Diversity in Family Farms*, provides practical guidance for farmers and extension workers to build productive, resilient, and sustainable coffee agroforestry systems. It shows how the right shade trees, diverse inter-crops, and simple management practices can improve soil health, boost yields, enhance incomes, and protect forests.

Structured in two modules, the manual covers both shade tree management and inter-cropping strategies, blending scientific insights with local knowledge to help family farms thrive while safeguarding Ethiopia's unique coffee landscapes.

By applying these practices, farmers can strengthen their farms, support the environment, and secure livelihoods for generations to come.

December 2025

Tepi, Ethiopia

FOLUR Ethiopia – Southwest Ethiopia Peoples' Regional State (SWEPRS)

Acknowledgements

This manual was made possible through the leadership of Dr. Bewuketu Haile (FOLUR Ethiopia Southwest Coordinator), with key contributions from Dr. Tsegaye Babege and Biniyam Asefa of Mizan-Tepi University. The guidance of FOLUR PFM officers and SCDA staff on locally adaptable shade tree species and their constructive input during validation workshops was invaluable, and the generous funding of the FOLUR Ethiopia Project made this practical guide on shade trees and inter-cropping possible.

1. Background

Coffee (*Coffea arabica*) is not just an agricultural commodity; it is a foundation of the Ethiopian economy and culture, originating in the very forests of the Southwest region. In 2024/2025, the sector generated over 2 billion USD, accounting for roughly one-third of total merchandise export earnings. It supports the livelihoods of nearly 15 to 20 million people – across farming, processing, trading and related services. This reliance on coffee also has a macroeconomic dimension. Coffee production is overwhelmingly smallholder-based, where over 95% of output comes from around four million smallholder farmers cultivating coffee on plots typically smaller than one hectare. These farms are categorized into four systems such as garden, semi-forest, forest and plantation coffee. Estimates from the Ethiopian Coffee and Tea Authority (ETCA) suggest that these systems account for approximately 50%, 35%, 10%, and 5% of total national output, respectively.

Sustainable coffee agroforestry involves integrating coffee cultivation with trees, crops, and practices that enhance soil fertility, aiming for a more resilient and productive farming system. Unlike mono-cropping, this approach promotes a diverse and ecologically balanced environment. In Ethiopia coffee is mostly grown in mixed stands that include food crops and shade trees, contributing to relatively sustainable production. Smallholder farmers typically cultivate most of the country's coffee on small family farms. Arabica coffee is grown at 1,300-2,300 meters above sea level. Yet the coffee sectors in Ethiopia and globally are facing threats from climate change. It is projected that suitable areas for coffee production in open plantations could decrease by 60% by 2050 due to climate change. Nevertheless, effective implementation of agroforestry systems has the potential to mitigate these effects.

Integrating coffee with shade trees and food crops is essential for improving productivity and enhancing climate resilience. Intercropping is increasingly being adopted in coffee gardens, especially in regions experiencing significant land pressure due to growing population density. By cultivating short-term crops alongside coffee, farmers can optimize the use of their limited land, diversify their sources of income, and produce fresh food for their families. This practice can enhance labor returns and boost food and income security, as well as offers advantages for coffee production.

Unsustainable coffee farming impacts on the wellbeing of all inhabitants living in the wider watershed of the coffee farms in Southwest Ethiopia, as well as the global issue of climate change. Failure to maintain the ecosystem within a coffee farm leads to environmental degradation that affects all of us (deforestation, soil erosion, loss of biodiversity, and climate change). There is an urgent need to seek sustainable solutions and address the development and climate challenges affecting smallholder farmers and fragile ecosystems in the coffee production sector. One solution to this problem is integrating shade trees and high value food crops in coffee systems, as this aligns with the FOLUR Ethiopia objectives.

In the traditional systems of Southwest Ethiopia, coffee is cultivated in a complex, multi-layered structure that closely mimics the natural forest environment where it originally thrived. This multi-story system is key to the region's environmental and economic resilience, providing both cash income from coffee and food security from other crops. Shade-grown coffee is vital for preserving the ecological balance of coffee landscapes. It enhances habitat connectivity, supports wildlife, and promotes ecological functions that sustain long-term agricultural production. Shade coffee systems also represent a sustainable agricultural model that aligns with the FOLUR project's integrated landscape approach.

The FOLUR Ethiopia Project was launched an initiative focused on integrating environmental sustainability into the coffee value chains and food systems of Ethiopia, especially in four regions, including Southwest Ethiopia. Its key objectives include preventing deforestation, promoting landscape restoration, and establishing deforestation-free coffee value chains, while enhancing biodiversity and ecosystem resilience. This project also focuses on generating actionable knowledge to strengthen support systems for smallholder farmers in sustainable coffee supply chains, as well as to strengthen participatory forest management for restoration and sustainable livelihoods

The SWEPRS FOLUR coordinator plans to develop standardized manuals (i) on maximizing shade tree cover in coffee farms, and (ii) on enhancing intercropping diversity in family farms, with each has the following primary objective/aims

Objectives/aims of module one

- The primary objective of this module is to provide the knowledge and tools needed to maximize the benefits of shade tree cover in coffee farm. This manual aims to provide standardized, technically sound, and field-oriented guidance for farmers and project implementers to strengthen sustainable coffee agroforestry systems. It outlines best practices for selecting suitable shade tree species, designing effective shade systems, and implementing appropriate management techniques.

Objectives/aims of module two

- The second manual/module, in particular, aimed at providing farmers and extension agents with information on optimal conditions for intercropping, guidance on selecting suitable intercrops, and an overview of intercrop production practices. This manual outlines a systematic approach to implementing sustainable coffee-based intercropping systems in Southwest Ethiopia. This module includes the suitable practices that describe how to grow an intercrop in a specific context, along with management strategies for optimal outcomes

PART I (MODULE ONE): Maximizing Shade Tree Cover in Coffee Farms of Southwest Ethiopia

Chapter 1: Why Shade Matters: The Benefits of Shade Trees

Maximizing shade tree cover is not simply an environmental goal; it is a **strategic agricultural decision** that directly influences coffee quality, yield stability, and the long-term sustainability of the farm. Shade trees create a superior **microclimate** that protects the sensitive *Coffea arabica* plant from environmental extremes.

1.1 Climate Resilience: Buffering Against Stress

Shade trees fundamentally adjust the environment in which coffee grows, creating a more stable and favorable microclimate. Shade is the primary defense mechanism for coffee farms in the face of increasing global temperatures and erratic rainfall, offering four main benefits:

- **Temperature Regulation (The "Air Conditioner" Effect):** The canopy of shade trees intercepts solar radiation, significantly **reducing the air temperature** around the coffee plant by as much as 5⁰C during the hottest hours of the day. This cooling effect is crucial, as temperatures above 30⁰C can severely damage coffee flowers and lead to reduced berry development.
- **Water Stress Mitigation:** Shade reduces the amount of solar energy reaching the coffee leaves, which in turn reduces the rate of **evapotranspiration** (water lost from the soil and the plant). By reducing this water demand, shade trees allow coffee to better withstand **drought periods**, stabilizing production when unshaded farms fail.
- **Protection from Extreme Weather:** The physical presence of a robust canopy provides a buffer against heavy rainfall (reducing soil erosion and runoff) and strong winds (reducing physical damage to coffee branches and berry loss).
- **Humidity Maintenance:** Shaded environments maintain higher relative **humidity** throughout the day and night, preventing the coffee leaves from drying out and ensuring that the stomata (the pores for gas exchange) remain open for efficient photosynthesis.

1.2 Coffee Quality and Yield Stability

Coffee is a sciophyte, a plant that prefers shade. It flourishes in the dappled light of the canopy in its natural woodland habitat. Intense, direct sunlight is filtered by shade trees, creating diffuse light. This kind of light encourages the production of chemicals that improve bean flavor and is more effective for photosynthesis in coffee plants. In the long run, shade-grown coffee consistently gives greater quality and more stable yields than unshaded coffee, even if unshaded coffee can produce large yields in the near term (if inputs like fertilizer and water are widely applied).

- **Slower Cherry Maturation:** Shade trees prolong the ripening period of the coffee cherry. This slower maturation allows for the **accumulation of higher levels of complex sugars** within the cherry, which translates directly into superior flavor, aroma, and acidity in the final cup. This is a key factor for specialty coffee markets.
- **Optimum Photosynthesis:** *Coffea arabica* is an understory plant adapted to low light. While full sun may boost initial growth, moderate shade (typically **30% to 50% cover**) provides the **optimal light level** where the plant maximizes energy production without suffering from photo-inhibition (damage from too much light).
- **Leaf Physiology and Plant Stress:** Shaded coffee leaves are typically larger, darker green, and have higher concentrations of chlorophyll and protective compounds. They are more efficient at photosynthesis under low light conditions and are less susceptible to stress from high light intensity and temperature.
- **Disease Incidence:** While very dense shade can sometimes promote fungal diseases by increasing humidity, a well-managed, open canopy can actually reduce the incidence and severity of certain diseases. For example, the splash-dispersed spores of Coffee Leaf Rust (*Hemileia vastatrix*) are less likely to reach coffee leaves under a tree canopy that intercepts rainfall.
- **Reduced Biennial Bearing:** Coffee is naturally prone to **biennial bearing** (one year of very high yield followed by a year of very low yield). The buffering effect of shade helps regulate the plant's energy allocation, leading to more consistent and stable harvests year after year, which is vital for farmer income planning.

1.3 Soil Health and Nutrient Cycling

Healthy soil is the foundation of a productive farm. Shade trees are powerful allies in building and maintaining soil fertility. Shade trees are considered as biological engineers of soil health, providing services that dramatically reduce the need for external, costly fertilizers and improve the physical structure of the farm soil.

- **Natural Fertilization (Nitrogen Fixation):** Many recommended shade species, particularly those in the legume family (e.g., *Albizia* species), are **Nitrogen-fixing trees**. They host bacteria in their roots that capture inert atmospheric Nitrogen (N₂) and convert it into forms that are readily available to the coffee plant.
- **Organic Matter and Mulch:** Healthy soil is the foundation of a productive farm and shade trees are powerful allies in building and maintaining soil fertility. Fallen leaves, branches, and pruned material from the shade trees decompose on the forest floor, creating a continuous supply of **rich organic matter**. This mulch not only adds essential nutrients (Phosphorus, Potassium, and Calcium) but also improves the soil's **water-holding capacity** and structure.
- **Erosion Control and Water Infiltration:** The force of rains is tempered by the tree canopy, which keeps soil particles from being removed away and loosened. The enormous root systems of trees tie the soil together, retaining it in place on slopes and avoiding gully erosion. The regular input of organic matter from leaf litter enhances soil structure, increasing its ability to store water (water infiltration and retention). Tree root systems tie the soil together, reducing erosion, especially on the steep slopes common in SWEPRS. The canopy breaks the impact of heavy rains, ensuring that water slowly infiltrates the soil rather than producing surface runoff.

1.4 Biodiversity and Pest Management

Coffee farm with diverse trees is not a monoculture; it is a complex agroecosystem that supports a wide range of life. A diverse coffee agroforestry system creates a habitat for numerous species, including natural enemies of coffee pests. This leads to a more balanced and cost-effective method of pest management.

- **Pest Predator Habitat:** A diverse canopy provides shelter and food for **natural predators** of coffee pests, such as parasitic wasps, spiders, and insectivorous birds. For example, studies have shown that shade can reduce the incidence of the devastating

Coffee Berry Borer (CBB) by providing habitat for its natural enemies. Research has shown that farms with greater shade cover and tree diversity have significantly lower populations of major coffee pests like the Coffee Berry Borer (*Hypothenemus hampei*) and the coffee leaf miner (*Leucoptera coffeella*).

- **Disease Suppression:** While very dense, unmanaged shade can sometimes promote certain diseases, *optimal* shade cover is linked to lower severity of key diseases like **Coffee Leaf Rust** (*Hemileia vastatrix*). This is because the healthier, less-stressed coffee plant under shade has a stronger natural resistance, and the cooler microclimate is often less conducive to the pathogen's spread compared to hot, sun-exposed conditions.
- **Pollinator Support:** Shade trees, especially those that flower at different times of the year, provide a continuous food source (nectar and pollen) for bees and other pollinating insects. Healthy populations of native bees have been shown to increase coffee fruit set (the percentage of flowers that develop into cherries) by up to 20%, directly boosting yields.
- **Carbon Sequestration:** As trees grow, they absorb carbon dioxide (CO₂) from the atmosphere and store it in their wood, leaves, and roots. This process, known as carbon sequestration, helps mitigate climate change. Coffee agroforestry systems can store significant amounts of carbon, often 50-100 tons per hectare, making them an important tool for climate action.

-

1.5. Economic and Social Benefits

The ecological benefits translate directly into tangible economic and social advantages for the farming family.

- **Diversification of Farm Income:** Shade trees are a living bank account that provides a range of non-coffee products that can be harvested or sold as needed, including firewood, high-value non timber products, fodder for livestock, traditional medicines, and fruits. This diversification makes the household more resilient to coffee price shocks or crop failures.
- **Food Security and Livelihood Products:** The fodder from trees helps maintain livestock, which are a crucial source of manure for compost and a form of savings. Fruits

and other edible tree products can supplement the family diet, improving nutrition and food security.

Technical Guidance: Selection and Design

Chapter 2. Selecting the Right Tree Species

The selection of appropriate shade tree species is the single most critical decision in establishing a healthy, productive, and resilient Coffee Agroforestry System (CAS). A poorly chosen tree can compete too aggressively with coffee, for water and nutrients, harbor pests, or create too much shade while a well-chosen tree acts as a crucial **ecological partner**.

2.1. Key Criteria for Selecting Shade Tree Species

An ideal shade tree in the SWEPRS coffee context must provide maximum benefits while minimizing negative competition with the coffee plant. The selection process must assess a combination of biological features, economic utility, and ecological function.

Criterion	Description	Why it Matters for Coffee
Canopy Morphology	The shape and density of the crown (e.g., broad, umbrella-shaped, or narrow).	Should provide diffused, filtered shade (not dense, unbroken shade) to allow optimal photosynthesis.
Litter Quality and Quantity	The rate at which leaves drop and their chemical composition (e.g., carbon-to-nitrogen ratio, C: N).	High-quality, fast-decomposing leaf litter (low C: N ratio) provides rapid nutrient release, acting as natural fertilizer .
Rooting Habit	The depth and spread of the root system.	Must be deep-rooted (taproot system) to minimize direct competition for shallow water and nutrients with the fibrous coffee roots.
Phenology	The timing of leaf shedding and flushing (e.g., deciduous vs. evergreen).	Deciduous trees that drop leaves during the dry or flowering season can temporarily increase light and reduce water competition when coffee needs it most.

Allelopathy	The release of chemical compounds that inhibit the growth of other plants.	The tree must not release chemicals harmful to coffee or soil microbes.
Non-Coffee Products	Potential for fruit, fodder, fuel wood, timber, or honey production.	Provides essential diversification and additional income for the farming household.
Pest and Disease Compatibility	Avoid tree species that are known hosts for major coffee pests or diseases, such as certain nematodes or fungi.	introducing or maintaining host species near coffee crops significantly increases the risk of infestation or infection, leading to negative consequences for farm productivity, economic viability, and environmental sustainability

2.2 Indigenous vs. Exotic Species: Balancing Ecology and Utility

Both indigenous (native) and exotic (introduced) tree species have a place in a robust CAS, but their roles and management differ significantly. A diverse system containing both is generally the most resilient.

A. Indigenous (Native) Species

Indigenous trees are naturally adapted to the local environment and are vital for supporting local biodiversity and they should form the backbone of any shade system. Indigenous trees are those that naturally occur in the Ethiopian forest environment that are crucial for maintaining local biodiversity and ecosystem integrity.

- **Ecological Advantages:**

Climate Adaptation: Already adapted to local soils, rainfall, pests, and diseases, leading to high survival rates.

Habitat Provision: Provide native habitat for local fauna, birds, and beneficial insects (pest control).

Cultural Acceptance: Often integrated into local knowledge and forest management practices.

- **Common Examples in SWEPRS:**

A. Indigenous (Native) Species. Indigenous trees are naturally adapted to the local environment and are crucial for supporting local biodiversity. For instance,

- ***Albizia gummifera* (Sassa):** Fast-growing legume, excellent **nitrogen fixer**, deep roots, and moderate canopy. Excellent for improving soil fertility through nitrogen fixation. Produces abundant leaf litter for mulch. Highly recommended.
- ***Cordia africana* (Wanza):** Highly valued for durable timber, good canopy structure, and wide adaptability. It will Provides excellent, dappled shade. Its leaves decompose rapidly, providing high-quality mulch. It is also a valuable source of fodder for livestock and its wood is used for light construction and beehives. It is excellent for supporting bee populations.
- ***Millettia ferruginea* (Birbirra):** a medium sized and excellent Nitrogen fixer and provider of leafy biomass. Compared to Albizia, its crown is smaller and more compact. Is perfect for offering mild, long-lasting shade. Additionally, because of its large root system, which produces good mulch and fodder, it is very successful at conserving soil and controlling erosion. Slower to grow than Grevillea or Albizia. It is preferred and a great all-purpose shade tree, especially when planted in between larger canopy trees or on smaller plots.
- ***Croton macrostachyus*:** fast leaf litter decomposition (adds nutrients), common in farmer mixes.
- **Ficus spp. (e.g., *Ficus vasta*, *F. sur*):** dense canopy, microclimate and biodiversity benefits.
- ***Acacia abyssinica*/Abyssinian Acacia/Girar:** Nitrogen-fixing, drought-tolerant species suitable for degraded or dry areas. - Open canopy allows balanced light penetration.
- ***Erythrina abyssinica*:** Another effective Nitrogen fixer, often used in other coffee regions, but local experience must guide its use.
- ***Cassipourea malosana* (sasipaga):** Its crown provides moderate shade without overly dense canopy that suppresses coffee growth. It has ecological benefits such

as habitat for bees and improved microclimate which is helpful in coffee agroforestry systems.

- **Gulo (*Ricinus communis*)** (Castor bean): It is a temporary shade which is commonly used around young coffee plots, boundaries, homesteads, and disturbed sites. It is very fast growth that provides quick shade during coffee establishment. Additionally it is easy regeneration (seeded naturally, low management). Large leaves give immediate partial shade. Beside to above it will be used as traditional medicine, oilseed crop and live fencing.

B. Exotic (Introduced) Species

Exotic species must be carefully maintained to prevent becoming invasive or excessively competitive, even though they may provide specialized, valuable functions (such as extremely rapid growth or a particular kind of timber). As a result, when appropriately chosen, exotic species can enhance native trees and offer certain advantages like incredibly quick growth for timber.

Cautions: Exotic species should only be promoted where their non-invasive behavior has been confirmed through long-term local experience and regular management is feasible.

- **Water Competition:** Some species (e.g., *Eucalyptus*) are highly competitive for water and should be **strictly avoided** or planted far from coffee stands.
- **Invasiveness:** Potential to outcompete native flora if not properly controlled.
- **Selectively Recommended Examples:**
 - ***Grevillea robusta* (Silky Oak):** Popular in agroforestry due to its **narrow, non-spreading crown** and deep, non-competitive root system.
 - Sometimes known as Silky Oak, is an evergreen tree native to Australia that grows quite quickly. It has a very open, tall canopy and a characteristic fern-like leaf. One of the fastest-growing trees on the market, it offers instant shade and a quick return on investment in the form of wood and firewood.
 - It's perfect for coffee because of its open canopy. In the majority of Ethiopia's coffee regions, it is not invasive. It doesn't fix nitrogen. It may self-prune, falling

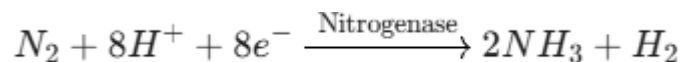
branches that, if planted too close, could harm coffee. The most well-liked and frequently suggested exotic species for Ethiopian coffee plantations.

C. Fruit / income-generating companion trees (good to integrate)

- *Persea americana* (avocado), *Mangifera indica* (mango), *Citrus spp*, *Musa spp.*(Banana/Enset) That give farmer income and partial shade; choose species/varieties suited to altitude.

2.3 The Role of Nitrogen-Fixing Trees (NFTs)

NFTs are biological powerhouses essential for sustainable coffee production. They convert atmospheric nitrogen (N₂) into usable ammonia (NH₃) through a symbiotic relationship with *Rhizobium* bacteria in root nodules.



The nitrogen provided by NFTs is transferred to the coffee plant in two ways:

1. **Decomposition of Leaf Litter:** When the nutrient-rich leaves drop and decompose, the nitrogen is released into the soil.
2. **Root Exudates:** Some nitrogen may be directly transferred through root interactions (though litter decomposition is the main pathway).

Action Point for Farmers: Prioritize the selection and retention of native legume species like *Albizia gummifera* and *Millettia ferruginea* to reduce reliance on costly and often unavailable synthetic fertilizers.

2.4 Tools for Context-Specific Tree Selection

Extension agents and PFM officers must use local knowledge alongside technical data to advise farmers. The final choice should be based on site-specific factors:

- **Soil Type and Topography:** On steep slopes or areas with shallow, poor soil, select hardy, deep-rooted species that offer superior soil stabilization.

- **Altitude and Climate:** Ensure the selected species is adapted to the specific elevation and microclimate of the farm.
- **Farmer Preference and Needs:** If the farmer requires fuel wood or additional fruit for income, prioritize species that provide these co-benefits without compromising coffee health.

Chapter 3. Designing the Optimal Shade System

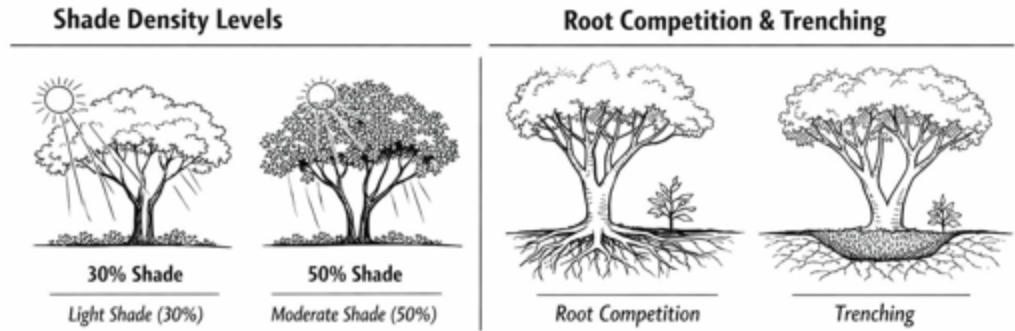
The intentional spatial arrangement and density management of shade trees are paramount for creating a resilient and productive Coffee Agroforestry System (CAS). Once the appropriate tree species have been selected (Chapter 3), the critical next step is the **spatial design** of the agroforestry system. Effective design ensures that trees fulfill their ecological functions without excessive competition, thereby maximizing both the health of the coffee and the desired shade cover. This chapter details the technical principles and practical considerations for designing a shade system that optimizes microclimate benefits while mitigating potential competition with coffee plants

3.1 Determining Optimal Shade Density and Percentage

Optimal shade is a moving target influenced by altitude, climate, and coffee variety. Generally, *Coffea arabica* in the high-altitude, traditional systems of SWEPRS performs best under **moderate shade levels**, avoiding the extremes of full sun (high stress) and deep forest shade (low yield).

A. The Target Range

- **Optimal Shade Cover:** For high-quality *Arabica coffee* in resilient agroforestry systems, the target shade cover typically ranges between **30% and 50%**.
 - **30% Cover:** Suitable for lower altitudes or highly fertile soils.
 - **50% Cover:** Recommended for higher altitudes, steeper slopes, or areas highly susceptible to drought and temperature extremes.



B. Calculating Tree Density

Tree density is expressed as the number of shade trees per hectare (stems/ha). This density is determined by the target shade percentage and the expected **canopy radius** of the mature shade species.

Formula for Tree Density (D):

To determine the number of trees needed to achieve a specific canopy coverage, consider the land area (10,000m² for one hectare) and the effective ground area shaded by a single mature tree.

$$D = \frac{\text{Target Shade Percentage} \times 10,000 \text{ m}^2}{\text{Area Covered by One Mature Tree}}$$

Where the Area Covered by One Mature Tree $\approx \pi \times (\text{Canopy Radius})^2$.

Illustrative Example:

If the chosen shade species (*Albizia gummifera*) has an estimated mature canopy diameter of **10 meters** (thus, a radius of **5 meters**), and a target shade percentage of **40%** is desired:

1. **Area per tree:** $\pi \times (5 \text{ m})^2 = 3.14159 \times 25 \text{ m}^2 \approx 78.5 \text{ m}^2$
2. **Total shaded area needed per hectare:** $0.40 \times 10,000 \text{ m}^2 = 4,000 \text{ m}^2$
3. **Required Density:** $D = \frac{4,000 \text{ m}^2}{78.5 \text{ m}^2/\text{tree}} \approx \mathbf{51 \text{ trees/ha}}$

This suggests an initial planting density of approximately **50-60 trees per hectare** is appropriate for most robust shade species in SWEPRS, which aligns with research findings for sustainable coffee production.

Key Takeaway: For most SWEPRS smallholder farms aiming for 40-50% shade, the required tree density often falls between **40 to 100 trees per hectare**.

Extension Note: Shade percentage should be reassessed every 2–3 years as trees mature, rather than relying only on initial planting density.

Shade trees are essential for *Arabica coffee* production in Southwest Ethiopia. However, as shade trees **grow and mature**, their canopies expand and may provide **too much or too little shade**, which affects,

- Coffee flowering and yield
- Pest and disease occurrence (e.g. Coffee Leaf Rust)
- Soil moisture and microclimate

Therefore shade should be assessed

- Every 2–3 years as shade trees mature
- After major pruning operations
- Before peak coffee flowering

Coffee Plant Indicators

- Healthy green leaves and good flowering = balanced shade
- Dark green, few flowers = too much shade

Benefits of Regular Shade Reassessment

- Improved coffee yield and quality
- Reduced disease pressure
- Better microclimate regulation
- Long-term sustainability of coffee agroforestry systems

3.2 Designing Spatial Arrangement and Spacing

The arrangement of shade trees significantly affects light distribution, root competition, and ease of management. The physical layout of shade trees is as critical as their density. Proper arrangement ensures equitable resource distribution, facilitates farm management, and enhances environmental services.

A. Multi-Storey vs. Single-Storey Systems

Traditional coffee systems in Ethiopia are inherently **multi-storey** mimicking natural forest structure. This vertical stratification is key to maximizing ecological benefits and provides the highest resilience.

- **Upper Canopy Layer:** Composed of tall, long-lived shade species (e.g., *Cordia africana*, *Albizia gummifera*). These provide the primary long-term microclimate regulation.
- **Mid-Storey Layer:** Consists of medium-height trees, often selected for additional products (e.g., fruit trees like Mango, Avocado; or fodder trees), or shorter, faster-growing shade species that can be managed through pruning. This layer further filters light and enhances biodiversity.
- **Understory Layer:** The coffee shrubs (*Coffea arabica*) themselves, along with beneficial groundcovers that help suppress weeds and conserve soil moisture.

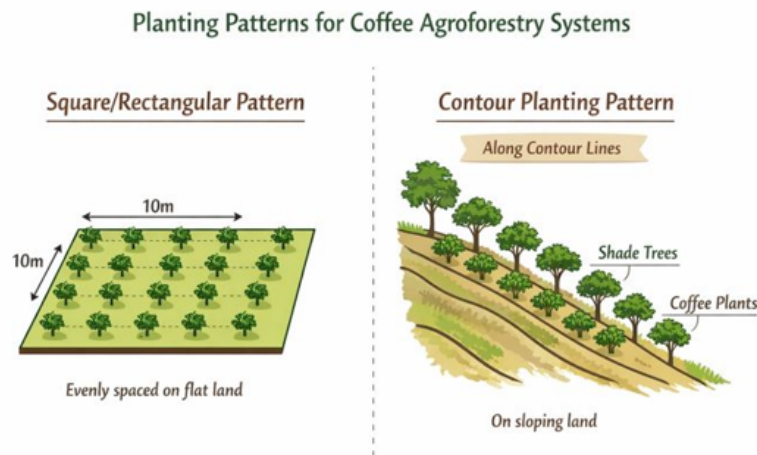
B. Geometric Arrangement Patterns

While forest coffee often lacks a rigid pattern, managed systems benefit from geometric planning to ensure even light distribution and easy access for management (harvesting, pruning).

- **Square/Rectangular Pattern:** This is the most practical pattern for planning and management. Trees are planted at fixed intervals (e.g., 10m x 10m spacing or 12m x 8m). This simplifies counting and management and allows for easier movement of people and equipment.
- **Contour Planting (Crucial for SWEPRS):** On sloping land, trees must be planted along **contour lines** (lines of equal elevation). This arrangement is essential for **water management**, reducing runoff velocity, and anchoring the soil to prevent severe erosion.
 - **Erosion Control:** Tree roots and canopy break the force of rainfall, significantly reducing soil erosion on slopes.
 - **Water Infiltration:** Contour lines create natural barriers that slow water runoff, increasing infiltration into the soil and reducing water loss.

- **Soil Stabilization:** Trees act as living terraces, stabilizing the soil structure.
- **Optimal Spacing:** As a general guideline, permanent shade tree spacing should be no less than **8–10 meters** between individual trees to prevent excessive root competition with mature coffee plants and allow for adequate light penetration after pruning.

Management Note: Always ensure the permanent shade tree row spacing allows easy passage for farmers and livestock, typically a minimum of 8–10 meters between large trees.



In Southwest Ethiopia, proper geometric planning especially contour-based arrangements is essential not only for shade regulation but also for long-term soil and water conservation in coffee agroforestry systems.

3.3 Shade Tree and Fruit/Food Tree Spacing in Coffee Agroforestry

The objective of maintaining 30–50% optimal shade for coffee production while integrating shade and fruit/food trees in southwest Ethiopia. Proper spacing can regulate light availability, reduce competition for water and nutrients and improve air circulation and coffee health.

Summary Table Professional Field Guide)

Species	Spacing (m)	Density/ha	Management Notes
<i>Cordia africana</i>	10×10 – 12×10	70–100	Broad crown; regular thinning; long-term shade
<i>Albizia spp.</i>	10×12 – 12×12	60–85	Large canopy; prune to avoid over-shading coffee
<i>Erythrina abyssinica</i>	8×8 – 8×10	125–155	Light canopy; coppice/pollard; early coffee shade
<i>Croton macrostachyus</i>	10×10	90–110	Fast-growing; removed/pruned later
<i>Millettia ferruginea</i>	10×10 – 10×12	80–100	Moderate canopy; periodic pruning
<i>Ficus spp.</i>	15×15	25–45	Large canopy; boundary/sparse planting
Avocado	10×10 – 12×10	70–100	Moderate shade; prune to avoid coffee suppression
Mango	≥12×12	50–70	Edge planting; prune to reduce shading
<i>Citrus spp.</i>	7×7 – 8×8	150–205	Smaller canopy; prune to control shade
Banana	5×5 – 5×6	330–400	Early shade; remove excess suckers
Enset	6×6 – 7×7	200–275	Boundary/contour; avoid dense blocks
<i>Cassipourea malosana</i> (commonly sasipaga)	20 × 20 - to 25 × 25	16–25	A tall stem with a moderate crown. Wider spacing prevents over-shading and reduces competition for light and moisture in mature coffee.
<i>Gulo</i> (<i>Ricinus communis</i>) (Castor bean)	6 × 6	278	provides quick shade during coffee establishment and Easy regeneration (seeded naturally, low management)

- **Key Recommendation:** Maintain 30 to 50% shade through proper spacing and pruning, not by increasing tree numbers. This guide is fully aligned with professional coffee agroforestry standards in southwest Ethiopia.

3.4 Managing Root and Light Competition

The primary challenge in CAS design is balancing the beneficial effects of trees with their inherent competition with coffee.

A. Root Competition Management (RCM)

Root competition for water and nutrients is often more damaging than light competition. RCM is achieved by:

- **Species Selection:** Choosing deep-rooted, non-aggressive species. Prioritize deep-rooted shade species that tap into deeper soil profiles, minimizing direct competition with the shallow, fibrous root system of coffee (Chapter 3).
- **Root Pruning (Trenching):** For species with more aggressive lateral root growth, or when competition is observed, a root-barrier trench can be created. This involves digging a circular trench (0.5m deep and 0.2m wide) around the shade tree or along coffee rows every 1-2 years to sever superficial tree roots. This encourages deeper rooting in the shade tree and reduces competition with coffee roots.

B. Light Competition Management

While shade is beneficial, excessive or unmanaged shade can reduce coffee yields, this is controlled primarily through **pruning** (Chapter 6). Light levels are highest at midday. Optimal shade trees should have a canopy that provides:

- **Canopy Architecture:** Select species that naturally develop an open, high canopy (e.g., *Albizia*) rather than a dense, low-spreading one. Diffused light (light scattered by the canopy) is better than direct sunlight.

- **Dynamic Adjustment:** Managed through thinning and pruning the canopy to achieve the 30-50% target. The designed shade density is a starting point. Mature shade trees require regular pruning to maintain the target light penetration, especially during flowering and berry development stages when coffee needs more light.

3.5 Integrating Ecological Principles with Local Knowledge

Successful CAS design must integrate traditional local knowledge with the technical principles above.

- **Farmer Input:** Extension agents must consult farmers on traditional shade species known to be successful on their specific land and those trees traditionally valued for non-coffee products (e.g., fuel, construction, medicinal uses). Design efforts must involve local farmers, drawing upon their deep understanding of local microclimates, traditional species performance, and farm-specific challenges. Traditional shade trees or existing natural regeneration should be integrated into the design.
- **The "Weed Tree" Myth:** Farmers must be trained to recognize that many young, volunteer trees are not weeds but valuable future canopy components that need protection and management, not removal.
- **Phased Introduction:** For existing, open-sun farms, shade maximization should be a phased process, starting with small, fast-growing trees and gradually thinning them as the long-term, permanent shade trees (like *Cordia* or *Albizia*) mature. This prevents a sudden, drastic drop in coffee yield.
 1. **Initial Phase:** Plant fast-growing, often temporary, shade trees (e.g., *Erythrina* species, if locally appropriate and non-invasive) to provide rapid cover.
 2. **Intermediate Phase:** Concurrently plant long-lived, permanent shade trees (e.g., *Cordia*, *Albizia*).
 3. **Mature Phase:** As permanent shade trees mature, gradually thin or prune the temporary shade trees to achieve the desired long-term density and avoid over-

shading. This phased approach minimizes initial yield drops and allows coffee plants to adapt.

Traditional shade trees retained through natural regeneration should be considered a priority before introducing new seedlings.

Management & Maintenance Practices

Chapter 4. Establishment of Shade Trees

The successful maximization of shade tree cover is fundamentally dependent on the proper establishment of high-quality seedlings. This process involves precise care in the nursery and meticulous application of scientifically sound planting techniques in the field. Failure at the establishment phase directly translates to low tree survival rates and delayed canopy development.

4.1 Nursery Management for High-Quality Shade Seedlings

The nursery acts as the critical preparatory environment, ensuring the seedlings are genetically sound, physiologically robust, and free from structural defects before transplantation.

A. Seed Collection, Viability, and Preparation

1. **Source Material and Genetics:** Seeds must be collected from **superior phenotypic trees** (known as *plus trees*) within the local area, which exhibit desirable traits such as straight stems, well-formed crowns, and resistance to local pests. This ensures the planted population is well-adapted and genetically diverse.
2. **Viability Testing:** Before large-scale sowing, conduct a simple viability test (e.g., the float test/discarding seeds that float or germination testing on a small batch) to ensure a high germination percentage and avoid wasting nursery space and resources.
3. **Breaking Dormancy (Scarification and Stratification):** Many indigenous shade tree seeds (e.g., *Albizia*, *Acacia*) possess **hard, impermeable seed coats** that require pre-treatment to initiate germination (dormancy breaking).
 - **Thermal Scarification:** The most common method involves pouring **near-boiling water (80-100° C)** over the seeds and allowing them to soak for 12–24 hours as the water cools. This softens the seed coat without damaging the embryo.

- **Mechanical Scarification:** Carefully scraping or nicking the seed coat, typically at the opposite end of the embryo, using a knife or abrasive paper. This technique requires precision to avoid injury to the seed's interior.

B. Potting Media and Root Morphology Management

1. **Growing Medium Substrate:** The quality of the potting mix directly affects root development. A standardized, robust mixture is recommended, typically composed of **Topsoil: Sand: Decomposed Manure/Compost** in a ratio of **3:1:1**. The sand ensures good drainage, while compost provides essential organic matter and nutrients. Where possible, the medium should be solarized or properly composted to reduce pests and diseases.
2. **Container Management:** Use containers that promote **vertical root development** and discourage **root spiraling** (root-binding). Root-bound seedlings suffer from a constricted root system that often fails to anchor and establish properly in the field.
3. **Root Pruning and Training (Key Practice):** This is perhaps the most crucial step for producing field-ready seedlings.
 - **In-Bag Pruning:** For seedlings grown in polythene tubes, regular root pruning (often by cutting the base of the bag and exposing the taproot to air) prevents the taproot from curling, thereby training the tree to develop a straight, deep-diving taproot necessary for drought resilience.

4.2 Field Planting Techniques for High Survival

The aim of field planting is to minimize transplanting shock and provide the optimal starting environment for rapid growth.

A. Timing, Spacing, and Site Preparation

1. **Optimal Timing (The "Rain Window"):** Planting must be precisely timed to coincide with the **onset and establishment of the main rainy season** (in SWEPRS, typically April-May, but local variations apply). The seedling needs at least 3-4 months of consistent rainfall to establish a stable root system before the next dry season.

2. **Hole Specification:** Planting holes must be significantly larger than the seedling's root ball to loosen the surrounding soil, facilitating initial root growth and water percolation. Recommended dimensions are **60cm x 60cm x 60cm**.
3. **Micro-Catchment Design (Water Harvesting):** In dry or moderately sloping areas, leave a small, raised earthen rim (berm) around the circumference of the planting hole to create a small **micro-catchment**. This simple structure helps to capture and concentrate rainfall directly toward the seedling's root zone, dramatically enhancing initial water availability.

B. Precision Planting Procedure

1. **Soil Separation:** Always separate the richer **topsoil** from the infertile **subsoil** when digging the hole.
2. **Enrichment and Backfilling:** Mix the topsoil with 1–2 handfuls of **well-decomposed organic manure** or compost. Use this enriched mixture to backfill the hole, placing the nutrient-rich soil immediately beneath and around the seedling's roots.
3. **Root Collar Placement (The critical check):** The seedling must be planted so that the **root collar** (the point where the stem transitions to the root) is **perfectly level with or slightly above** the adjacent ground surface. Planting too deep leads to stem rot and suffocation of the root system.
4. **Compaction and Mulching:** Lightly firm the soil around the seedling with the hands to eliminate air pockets. Immediately apply a thick layer (5–10 cm) of **organic mulch** (e.g., dried grass, coffee parchment, leaf litter) around the base.
 - **Mulch Function:** Mulching is essential. It **conserves soil moisture** by reducing evaporation, **suppresses weed competition**, and buffers soil temperature.

4.3 Early Management and Protection

The first two years are the most vulnerable for the shade tree. Intensive, strategic care during this period determines survival and establishment success.

A. Competition Control

- **Weed Ring:** Maintain a **weed-free ring** of at least a 1m radius around the young tree for the first 2-3 years. Competition from grasses and weeds for water is the leading cause of shade tree mortality in the field.
- **Intercropping Management:** If food crops are intercropped near the young shade trees, ensure that their planting is non-competitive; maintain the weed-free ring and avoid planting deep-rooting or high-nutrient-demanding crops immediately adjacent to the seedling.

B. Physical Protection

- **Livestock Exclusion:** In many parts of SWEPRS, free-grazing livestock (cattle, goats) pose the greatest threat to young trees. **Physical barriers** are non-negotiable. Use locally available materials to construct robust protective cages or fences (e.g., thorny branches, woven bamboo, or wood stakes) around each individual tree until it is fully established and above the browsing height (typically >1.5m).
- **Pest and Disease Monitoring:** Regularly inspect seedlings for signs of major pests (e.g., termites, boring insects) or fungal attack. Early detection allows for localized, organic intervention (e.g., using ash or neem extracts) before the issue escalates.

Chapter 5. Long Term Management for Maximizing Cover

The successful integration of shade trees into a productive coffee system requires proactive, long-term management that ensures the trees remain ecological partners rather than competitors. This chapter focuses on the dynamic control of the tree canopy through pruning and the optimization of soil health beneath the shade.

5.1 Dynamic Management of the Shade Canopy: Pruning Techniques

The most important management task in an established Coffee Agroforestry System (CAS) is pruning. Coffee output and quality are strongly impacted by the strategic use of wood removal as a technique to control light, canopy size, and nutrient cycling.

A. Rationale for Pruning Shade Trees

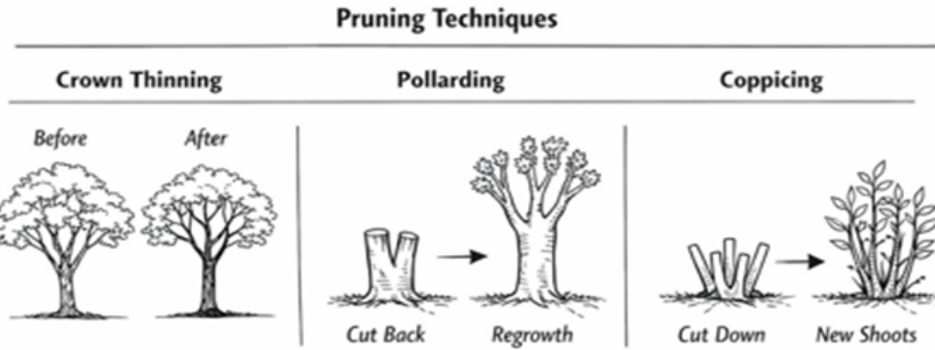
Pruning is performed to achieve two primary objectives:

1. **Light Regulation:** To maintain the optimal shade cover (30–50%) by controlling canopy density and height, ensuring sufficient light penetration for the coffee during critical growth phases (e.g., flowering and fruit set).
2. **Competition Mitigation:** To limit the physical extent of the shade tree, especially the lateral spread of the canopy and the shallow roots, thereby reducing competition with the coffee bushes for water and nutrients.

B. Key Pruning Techniques

The type of pruning depends on the species, the tree's size, and the management goal.

Technique	Description	Management Goal	Timing
Crown Thinning	Selective removal of smaller, secondary branches and internal growth within the canopy.	Light Control: Increases the uniformity and quality of light reaching the coffee below by breaking up dense patches and creating "light wells."	Typically performed right before the main flowering season.
Crown Raising (Lifting)	Removal of the lower-most branches from the trunk.	Competition Reduction: Increases light near the coffee, improves air circulation (reducing disease risk), and allows for easier movement and harvesting.	As trees mature, to raise the canopy height above the coffee.
Pollarding/Lopping	Cutting the main branches or stem back to a specific, common height.	Biomass Generation & Competition Control: Stimulates the growth of numerous new, thin shoots, producing high volumes of leaf biomass (green manure/mulch) for soil fertility.	Annually or biennially, depending on biomass needs and shade levels.
Coppicing	Cutting the tree completely down to the stump (stump height of 10–50 cm).	Complete Regeneration & Biomass: Used for species with high regenerative capacity (e.g., <i>Albizia</i>) to produce large amounts of wood (timber/fuel) and restart the shade structure.	Every 5–10 years, or when the tree is overly large and difficult to manage.



C. Pruning Timing and Methodology

1. **Timing:** Pruning should primarily occur during the **mid-to-late dry season** or just before the onset of the main rains. This timing:
 - Reduces water competition with the coffee during the dry period.
 - Ensures that new growth (foliage) appears to provide protection as the hottest part of the year approaches.
2. **Clean Cuts:** All cuts must be **clean and angled** to shed water, minimizing the risk of fungal infection and insect entry. Avoid tearing the bark. For large branches, use a three-cut technique to prevent stripping the bark down the trunk.
3. **Controlled Removal:** When removing large branches, carefully lower them to avoid physical damage to the coffee bushes below.

Safety Note: Pruning of large branches should only be conducted by trained personnel using appropriate tools and protective equipment.

1. Use sharp, clean and well maintained tools to prevent accident and plant disease.
2. Wear protective gear such as glove, footwear and goggles.
3. Check for electric power lines before pruning tall trees.
4. Cut away from your body and maintain stable footing/standing.
5. Do not over climb (use proper ladder to reach out the top).
6. Disinfect tools to avoid contamination or disease.
7. Collected and dispose pruned material safely.

5.2 Soil Fertility Management through Shade

Shade trees are central to the strategy of reducing reliance on synthetic fertilizers by continuously adding organic matter and fixing atmospheric nitrogen.

A. Harnessing Nitrogen Fixation (The Biological Input)

Nitrogen-Fixing Trees (NFTs), such as *Albizia* and *Millettia*, are paramount in this system.

- **Nitrogen Cycling:** NFTs biologically convert inert atmospheric nitrogen (N_2) into usable forms (NH_4^+ and NO_3^-) through a symbiotic relationship with *Rhizobium* bacteria in their root nodules (Chapter 3).
- **Biomass Transfer:** The vast majority of this fixed nitrogen is transferred to the coffee soil through the **decomposition of leaf litter and pruning residues**. Pruning practices (like Pollarding) are a direct way to harvest this nitrogen and make it available to the coffee at critical times.

B. Management of Leaf Litter and Green Manure

Leaf litter is not waste; it is **natural fertilizer and mulch**. Management should prioritize its retention and integration into the coffee understory.

1. **Mulching:** Allow pruning's (leaves and small branches) to remain on the ground beneath the coffee bushes. This green manure:
 - Adds **Macronutrients** (N, P, K) and **Micronutrients** (Ca, Mg) back into the soil system.
 - Provides a continuous layer of **mulch**, which reduces soil temperature, limits water evaporation, and suppresses weed growth.
2. **Composting/Trenching:** Large woody branches should be removed or chipped, but smaller woody materials and large volumes of leaf litter can be incorporated into shallow trenches dug between coffee rows. This slow decomposition process further builds soil organic matter and improves aeration.
3. **Soil Organic Carbon (SOC):** The constant input of organic matter from shade trees is essential for increasing **Soil Organic Carbon (SOC)**. Higher SOC levels directly improve soil structure (aggregation), increase water-holding capacity, and serve as a long-term nutrient reservoir, securing the productivity of the farm.

5.3 Inter-system Pest and Disease Management (IPDM)

Long-term shade management reinforces the farm's natural immunity against pests and diseases.

- **Air Circulation:** Pruning the lower branches (Crown Raising) is critical for **improving air circulation** within the coffee understory. Poor air movement creates high humidity, which can promote fungal diseases like **Coffee Leaf Rust** (*Hemileia vastatrix*). Well-managed shade ensures cooler temperatures but does not impede air flow [12].
- **Natural Enemies:** Maintaining a diverse, multi-storey canopy provides a stable habitat for a wide variety of **beneficial insects, spiders, and insectivorous birds** (natural predators). These predators provide continuous, free-of-charge control of major coffee pests, such as the Coffee Berry Borer (CBB) and leaf miners.

-

Tools & Resources

Chapter 6. Practical Tools for Assessment and Planning

For Woreda PFM officers and extension agents, effective intervention requires moving beyond theoretical knowledge to **quantifiable field assessment**. This chapter provides the practical tools and methodologies necessary to accurately measure shade cover, monitor tree health, and utilize this data for informed decision-making and farmer training.

6.1 Field Assessment of Shade Cover Percentage

Accurate estimation of shade percentage is necessary to determine if a farm is under-shaded (needs more trees) or over-shaded (needs pruning). While sophisticated equipment exists, practical field assessment relies on simple, cost-effective methods.

A. The Densiometer Method

The spherical densiometer is a specialized, mirrored instrument that provides a high-precision estimate of the overhead canopy coverage.

- **Principle:** The curved mirror surface reflects the canopy directly over the observer, and the reflection is overlaid with a grid of 17 or 24 squares. The observer counts the number of filled squares (where canopy obstructs the view of the sky) and calculates the percentage.
- **Procedure:**

1. Take measurements at pre-defined points (e.g., in a grid pattern) within the coffee plot.
 2. At each point, hold the densiometer level and take readings facing the four cardinal directions (North, East, South, and West).
 3. Record the count for each direction and calculate the average.
- **Result Interpretation:** The final average count represents the **percentage of canopy cover** at that specific point. For a field average, calculate the mean of all measured points.

B. The Photographic or App-Based Method

Modern mobile technology offers a rapid and accessible alternative to the traditional densiometer.

- **Canopy Apps:** Applications (e.g., *Canopeo* or similar ecological apps) use the phone's camera to take a photograph of the overhead canopy. The app then uses image analysis algorithms to digitally separate the sky (gaps) from the canopy (foliage) and automatically calculates the percentage of cover.
- **Advantages:** This method is fast, requires minimal training, and provides a permanent, georeferenced record (the photograph) for future monitoring and validation.

C. The Visual Estimation Method (Farmer Training)

While less precise, visual estimation is essential for rapid assessment and for training farmers to self-monitor.

- **Procedure:** Ask the farmer or extension agent to visually estimate the proportion of the area where the sun's direct light is blocked by the shade canopy at midday.
- **Calibration:** This method should be calibrated against the Densiometer or App method during initial training to improve the accuracy of visual estimates. Use the visual estimate to confirm if the farm falls within the desired **30% to 50% range**.

6.2 Monitoring Tree Health and Competition

The design and management success is confirmed by the health of both the shade tree and the coffee.

Observation Parameter	Indicator of Problem	Management Action
Shade Tree Health	Stunted growth, yellowing leaves (chlorosis), insect damage, or severe canopy dieback.	Check for root-binding (Chapter 5); inspect for specific nutrient deficiencies (especially Iron or Zinc); address pest issues.
Light Competition	Coffee plants have elongated, thin stems (<i>etiolation</i>); few flowers; or leaves are dark green and soft.	Pruning: Initiate Crown Thinning or Crown Raising (Chapter 6) to increase light penetration toward the coffee.
Root Competition	Coffee plants are pale and wilt easily, even when soil moisture seems adequate; coffee yield is stable for a few years then drops suddenly.	Root Pruning (Trenching): Dig root-barrier trenches around the shade trees (Chapter 4) and ensure regular mulching to mitigate water stress.
Soil Erosion	Visible rills or gullies on the ground surface, especially after heavy rain.	Establish Ground Cover: Plant additional ground cover or reinforce contour lines (Chapter 4) using stone bunds or Vetiver grass.

6.3 Planning and Implementation Tools

Extension agents must utilize the manual's information for practical planning exercises with farmers.

A. The Farm Sketch Map and Inventory

Before any intervention (planting or pruning), the agent should help the farmer create a simple farm sketch map.

1. **Mapping:** Sketch the boundary of the coffee plot, mark major topographical features (e.g., slopes, streams), and plot the current location of all existing shade trees.
2. **Inventory:** For each existing shade tree, record its species, estimated canopy diameter, and health status.
3. **Gap Analysis:** Use the map to identify areas that fall below the 30% shade threshold (based on the density calculation in Chapter 4) and mark these as **Priority Planting Gaps**.

B. The Management Decision Matrix

Use the data gathered to guide farmer decisions using a simple matrix based on the current shade level:

Shade Cover (%)	Management Recommendation	Target Action
< 30% (Under-shaded)	Establishment Phase: Increase density rapidly.	Plant new, fast-growing shade seedlings (Chapter 5) in marked Priority Planting Gaps .
30% – 50% (Optimal)	Maintenance Phase: Monitor and manage.	Maintain current density; regular Crown Thinning every 1–2 years (Chapter 6); focus on soil fertility.
> 50% (Over-shaded)	Intervention Phase: Reduce density and control competition.	Severe Crown Thinning or Pollarding/Lopping of selected trees (Chapter 6) to reduce canopy volume.

Annex A: Glossary of Technical Terms

Term	Definition in Context
Agroforestry System (CAS)	A land-use system integrating trees, crops (coffee), and sometimes livestock on the same land.
Root Collar	The point at the base of the stem where the shoot and root systems join; must be level with the soil during planting.
Phenology	The study of cyclic and seasonal natural phenomena, especially in relation to climate (e.g., timing of leaf drop or flowering).
Root Spiraling	A condition where a seedling’s roots circle the inside of a container, leading to poor stability and growth in the field.
Biennial Bearing	The tendency of coffee to alternate between a year of high yield and a year of low yield. Shade management helps stabilize this.
Densiometer	A specialized tool used to measure the percentage of canopy cover overhead.

PART II (Module Two): Enhancing Intercropping Diversity in Family Farms

Chapter 7. Benefits of intercropping in coffee farms

Implementing intercropping within coffee systems provides significant advantages for smallholder farmers, enhancing both ecological sustainability and economic viability. The main benefits of coffee intercropping are described below.

7.1. Enhance Productivity

Coffee agroforestry systems play a significant role in enhancing the resilience and productivity of farming practices. Intercropping allows farmers to utilize the space between coffee trees, which can increase income per unit of land. These systems typically enhance both coffee production and quality, as coffee grown in shaded settings often yields larger, heavier cherries. This phenomenon can be attributed to reduced overbearing and a moderating effect on biennial yield fluctuations due to extreme weather conditions. Furthermore, by intercropping temporary food crops, farmers can cultivate additional food for their households, ensuring sustenance during the off-seasons of coffee.

7.2. Diversified Income

Multi-strata coffee agroforestry offers advantages for smallholders who have land between 0.25 and 2 hectares. This system allows the production of various commodities, which can contribute to more stable income for smallholders. Intercropping can mitigate the impact of income loss when the main commodity's price falls. It enables farmers to diversify their income and reduce dependence on a single income source, thereby decreasing risk and increasing livelihood resilience. Some farmers may choose to intercrop different crops with varying production cycles alongside coffee, enabling more efficient use of labor and generating income throughout the year. This approach reduces reliance on seasonal income from coffee and distributes financial risk across multiple crops or livelihood activities.

7.3. Enhance Soil Health and nutrition:

Reduces soil erosion on sloped land, increases soil organic matter through leaf litter and biomass returns, and fosters a healthier soil micro-biome. The incorporation of leguminous trees, such as Albizia, enhances soil fertility through the process of nitrogen fixation. Leaf litter and organic matter from shade trees and intercrops contribute to improving soil structure and moisture retention, helping to maintain soil humidity, especially during extended periods of drought and rising air temperatures. A diverse range of plant species within the agroforestry system aids in water regulation and helps prevent soil erosion.

7.4. Improve Climate Resilience

Intercropping system creates a more stable and favorable microclimate (reduced temperature fluctuations, higher humidity) and makes farms more resilient to droughts. Integrating trees and other food crops in coffee systems, is an effective way of increasing resilience to climate change. Agroforestry creates a more stable microclimate with reduced temperature fluctuations and increased humidity, making farms more resilient to droughts. It can help mitigate the negative effects of extreme climate conditions on plant growth and production. Shade trees within agroforestry systems provide a buffer for coffee plants against rising air temperatures, decrease soil erosion, and enhance microclimates, contributing to the overall resilience of farms and their surroundings.

Greater biodiversity in coffee agroforestry systems plays a key role in reducing the impact of coffee pests and diseases through various mechanisms, including the spatial disruption of pest dynamics and the conservation of natural predators. Climate-smart strategies, such as integrating coffee with other crops, can effectively sequester atmospheric carbon in both trees and soil while promoting sustainable productivity. Diverse and multi-strata coffee agroforestry increases the organic matter in the soil, which improves nutrient availability and water retention, enhancing the resilience of coffee and other crops to drought. Farms with a varied vegetation structure, both above and below ground, demonstrate greater resilience to climate-related stresses such as droughts, heavy rains, and pest outbreaks compared to farms with a simpler vegetation structure. Figure 1 describes the significance of intercropping in coffee-based agroforestry system to achieve the Sustainable Development Goal



Figure 1: Simple schemes showing benefits of Coffee-based Agroforestry system

Chapter 8: Common coffee intercropping models in Ethiopia

8.1. Coffee-shade tree agroforestry system

Shade trees provide protection for coffee bushes from strong winds and excessive light, help prevent soil erosion, and regulate temperature and humidity (Fig. 2). Shade trees can enhance coffee quality and resilience to climate change, as well as improve nutrient cycling by absorbing nutrients from deeper soil through their roots and providing leaf litter on the surface.

Based on the components, there are two types of agroforestry:

- Simple agroforestry: contains 2 to 5 tree species besides the main dominant agricultural crops. Besides yielding products (fruit, timber, etc), the trees usually serve as shade for companion crops and form a single layer of canopy.
- Complex agroforestry: contains more than 5 tree species besides the main dominant agricultural crops. Besides yielding products (fruit, timber, etc), the trees usually serve as shade for companion crops and form a multiple layers of canopy.



Figure 2. A typical tree-coffee agroforestry system at Bebeka-Coffee plantation

Table 1 below shows the recommended shade trees for coffee agroforestry. Yet its list of tree species is not exhaustive: we advise trainers and extension agents to work with farmers to identify other locally adopted species for coffee agroforestry. Many farmers are willing to share observations about how their coffee performs when integrated with certain tree species.

6.2. Coffee-crop combination agroforestry system

Integrating various food and cash crops alongside coffee, is a widespread and profitable model, offering significant revenue potential and food security.

a) Coffee-Annual food and cash crops

- Intercropping young, non-bearing coffee trees with annual food and cash crops partly compensates for the high investment cost of establishing a new coffee garden.
- The best choice of intercrops is often short-rotation, fertilized vegetables as the coffee trees will benefit from the added fertilizer, improving coffee productivity. Short-rotation crops can also be grown outside the period of peak labor demand for coffee
- Legumes such as beans, cowpeas, horse bean, haricot bean, will provide the coffee trees with additional soil nitrogen
- Intercropping with cash crops, like turmeric, ginger, cardamom, black pepper which thrive in shaded bushes is also possible.
- It is possible for long-term intercropping of coffee with short-term crops as long as there is enough space between the coffee trees to minimize competition between the crops for water, nutrients, space and light, and to allow sufficient air movement
- When establishing a new coffee garden, if intercropping is to become a permanent activity during the coffee off-season, it is recommended that a wider spacing be used when planting the new coffee seedlings

Table 1. Selected multipurpose agroforestry tree and shrub species, associated benefits and management

Agroforestry tree and shrub species	Description	Benefits and management in coffee farming systems
<i>Cordia Africana,</i>	Deciduous tree in Boraginaceae Family. Grows at altitude range 550–2,600 m asl. Likes warm and moist areas. Often grows along riverbanks	Mature fruit have sweet edible pulp; Timber: furniture, beehives, boxes, mortars; Medicine: bark, roots; Fodder (leaves in dry season) & bee forage; Shade and mulch for coffee plants; Soil conservation, boundary marker Increased spacing (>12m) increases branch and crown diameter, making it a good agroforestry tree species; 40% pruning regime recommended at 6-month intervals; High coppicing ability: multiple sprouts around cut branches should be frequently removed after pruning to regulate shading
<i>Albizia coriaria</i>	Deciduous tree in Fabaceae family. Pioneer species with height up to 36m and requires High light intensity	Initially slow growing; Nitrogen-fixer; Provides fodder, bee forage, medicine from bark and roots, shade (fat, spreading crown); 12x12m spacing recommended; 30% annual canopy pruning regime recommended for mature trees (with sound safety measures for pruners and coffee plants below: use ropes to direct-cut branches in spaces without coffee)
<i>Ficus natalensis,</i>	Evergreen tree with 12-30 m in height. Has Upright branches and Dense, drooping crown. Aerial roots may hang down from branches. Base of trunk is often a mass of interwoven roots	Fast growing; Used for making bark cloth; Living fence around homes; Attracts birds and insects which can be potential pollinators, while providing ecological benefits; At wide spacing, useful for shade in coffee, cocoa and banana plantations; Commonly propagated through stem cuttings with varying spacing; Spacing of 12x12m and 50% pruning regime recommended
<i>Ficus mucuso</i>	Evergreen shrub or tree. Usually around 12m high, but can grow up to 30m. has Straight trunk, Large	Fast growing; Easily coppices; Good nurse tree for banana and coffee Plant at wide spacing (>12m) for shade in homesteads; Intercrop with coffee or banana

	spreading branches and Open crown	
<i>Ficus ovata</i>	Grows in deciduous woodland, wooded grassland, riverine and lakeside areas. Height 12-15m	Plant cuttings or seedlings widely spaced (>12m) as mature tree has a spreading crown; improves soil fertility when interplant with crops
<i>Calliandra calothyrsus</i>	A Nitrogen fixer shrub. Large, Multi-stemmed and has spreading branches: 4-6m	Fast growing on good sites; Easily coppices when cut back; Vigor of stand declines with age (lasts 7-12 years): good to integrate into system early; Enhances soil fertility through nitrogen fixation; Bee forage to attract pollinators; Soil erosion control; Fodder for livestock; Spacing of 1x1m with cutting-back/pruning frequency of 9 weeks optimal for forage and soil organic carbon; Can be integrated into a coffee system as hedgerows/strips; Use as a fast-growing firewood source reduces pressure on other agroforestry tree species in coffee farming systems, thus enhancing their integration and retention to provide shade
<i>Sesbania sesban</i>	Deciduous Nitrogen fixer and Short-lived shrub grows up to 8m. Prolific seeder: approx. 110,000 seeds/kg with High germination rate	Firewood; Poles; Fodder (leaves); Mulch; Soil conservation and improvement; Nitrogen fixation; Shade (especially for young coffee); Fibers (young stems); Soap (from leaves); Fast growing, short rotation period; Easily coppices when young, requires regular pruning; Can harbor root-knot nematodes, which have been found to attack coffee in Central America: may not be suitable where these are common
<i>Gliricidia sepium</i>	Fast growing shrub <ul style="list-style-type: none"> • Leafy • Leguminous • Fabaceae family 	Fast-growing; Firewood; Charcoal; Fodder (from leaves, shoots, pods); Bee forage; Mulch (conserves soil moisture, reduces runoff); Shade; Nitrogen fixation; Soil conservation and improvement; Living fence; Living stakes; Intercropping with coffee provides green manure, soil stabilization

b) Coffee-fruit crops agroforestry systems

- In this system, farmers integrate fruit crops into coffee farms (Fig. 3). Suitable perennial or long-term fruit crops, such as banana, avocado, guava, pineapple and others can be grown in coffee gardens at low planting densities so they do not compete with the coffee trees
- Coffee grown under a diverse canopy of fruit shade trees (e.g. avocado, mango) that provide optimal light conditions (around 25% shade is often ideal).
- Intercrops such as bananas provide temporary shade and mulch for new coffee trees while slower-growing permanent shade trees are becoming established



Figure 3. A typical coffee–banana agroforestry system in Southwest Ethiopia

c) Coffee-root crops agroforestry systems

- Suitable perennial root crops, such as taro, yam, ensets, can be intercropped with coffee in an agroforestry production system (Fig. 4).
- Coffee-Enset intercropping is a common and cost-effective model, especially in Southwest Ethiopia, offering significant revenue potential and food security.



Figure 4. Sample pictures of taro/enset-coffee agroforestry systems with different configurations

6.3. Multi-strata coffee agroforestry systems

- It is also known as Homegardens systems, where Complex systems mimicking natural forest structures with multiple vertical layers, optimizing resource use and biodiversity.
- These may include a combination of trees, perennial food crops and coffee (Fig. 5), or a combination of trees, coffee and an understory shade-tolerant annual crop, supplemented by small-scale animal husbandry for household food security
- Multi-strata coffee agroforestry improves the ecology, productivity and diversity of income from coffee farming. It strengthens the ecological and economic resilience of both the farmers and landscape. It is an affordable and profitable example of Ecosystem-Based Adaptation by smallholder coffee farmers. It is a ‘win-win’ land use that has the potential to deliver both adaptation and mitigation at a national scale.
- In multi-strata coffee agroforestry, spacing between individual plants is usually irregular, and management of the system is usually extensive.



Figure 5. Sample pictures of a more complex coffee agroforestry system with trees and food crops, Southwest Ethiopia

Chapter 9: Crop selection and spatial-temporal arrangements

9.1. Choosing the right crop

Suitable crops for intercropping vary depending on location. It is better for farmers to choose suitable crops based on established guidelines. Early success increases the chance of the farmer choosing to continue with intercropping. Successful intercropping depends heavily on selecting compatible species and managing their arrangement in space and time to minimize competition. This depends on

- **Compatibility:** Choose plants with different root depths and nutrient needs to avoid direct competition for resources
- **Market Potential:** Select intercrops with a good market to ensure profitability. Select species that have good market potential and can contribute to household income.
- **Environmental Suitability:** Match crops to the local climate, altitude, and soil conditions.
- **Nitrogen Fixation:** Prioritize leguminous shade trees to improve soil fertility.
- **Labor requirements:** Planting the right intercrop at the right time of the year means the labor demands of the coffee and the intercrop will not compete. Do not grow intercrops that

have high labor requirements during the peak of the coffee season, when labor is needed for coffee harvesting and processing.

Table 2. Detailed guide while choosing the suitability of food crops for intercropping with coffee

Types of food crop	Example	Suitability Remarks
Vegetables	Cabbage, kale, carrot, tomato, onion, beetroot, chili, cucurbits	<ul style="list-style-type: none"> ○ Can be grown in new and mature coffee gardens and suitable if sufficient light. Some intercrops harbor predators of coffee pests (e.g. pumpkin and cucumber attract ladybirds that control green scale) ○ Most are suitable agro-ecologically; with cabbage and Kale require cooler climates while adjustment on PH is need for beetroot. Not that carrot may harbor aphids, and avoid using during sensitive times
Legumes	Soya bean, horse bean, haricot bean	<ul style="list-style-type: none"> ○ Can be grown in new and mature coffee gardens and suitable if sufficient light, but PH adjustment is required for horse bean (6.5-7.5)
Root crop	Potato	<ul style="list-style-type: none"> ○ Can be grown in new and mature coffee gardens and suitable if sufficient light. ○ At higher elevations, it is excellent choices that thrive in a coffee-based system and can provide additional income
	Taro, yam, enset*	<ul style="list-style-type: none"> ✓ May be used when the coffee garden is young or after coffee tree stumping, but not recommended in a mature coffee garden ✓ Harvesting may damage coffee tree roots. Some varieties attract pests of coffee ✓ Agro-ecologically all are suitable to intercrop with coffee, with enset at higher elevations and taro and yam at mid and lowland.
Fruit crops	Pineapple	<ul style="list-style-type: none"> ✓ Can be grown in new and mature coffee gardens and Suitable if sufficient light. ✓ It can be suitable for intercropping with coffee, particularly at lower altitudes.
	Banana	<ul style="list-style-type: none"> ✓ Provides shade for young coffee seedlings ✓ Can be grown in mature coffee gardens if there are few permanent shade trees
	Avocado, citrus, guava, mango, papaya*	<ul style="list-style-type: none"> ✓ May be used at low planting densities. But, some such as citrus and guava may host coffee green scale. Citrus coffee leaf rust (CLR) and pink disease
Spices	Ginger, turmeric, cardamom, black pepper	<ul style="list-style-type: none"> ✓ Can be grown in new and mature coffee gardens and suitable if sufficient light. ✓ Ginger, turmeric, and korarima are excellent choices that thrive in a coffee-based system, mainly in low and midlands

*Can be grown, but not suitable in all circumstances

9.2. Spatial-temporal arrangements

The productivity of the intercropping system in terms of the land equivalent ratio (LER) will be used to measure the yield advantage of coffee-based intercropping over the sole crops. Thus, LER will be calculated by using the following formula;

$$\text{Land equivalent ratio (LER)} = \left(\frac{Y_{ij}}{Y_{ii}}\right) + \left(\frac{Y_{ji}}{Y_{jj}}\right)$$

Where, Y is the yields of component crops per unit area, Y_{ii} and Y_{jj} sole yield of coffee and intercrops and Y_{ij} and Y_{ji} are intercropped yields of coffee and intercrops, respectively.

When the value of LER >1, shows the intercropping system favors the growth and yield of the component crops in mixes. In contrast, if the value of LER demonstrates <1, the intercropping system negatively affects the growth and yield of the component crops grown in mixtures.

Evidences show that strip Intercropping, i.e., planting crops in alternating strips (e.g., a 3:1 ratio of coffee to enset/banana or 1:3 coffee to vegetables and cash crops and pineapple has shown high LERs). For smallholder coffee farms aiming at providing 40-50% shade, the tree density between 35 to 40 trees per hectare is appropriate for most perennial fruit trees and has shown high LERs.

Marking Spacing for Each Component

a) Horizontal spacing

Establishing proper spacing ensures healthy growth, access to light, and efficient resource use.

- **Coffee Plants:** generally planted at spacing of 2 m × 2 m. This spacing allows for air circulation and canopy development while enabling intercropping. But dwarf coffee varieties can be planted at a spacing of 2 m x 1 m. Mark each planting hole with a small wooden stake.
- **Fruit crops:** banana can be planted at spacing of 6 m × 6 m, interspersed among coffee (Fig. 6). Avoid overcrowding; bananas need room for sucker development and sunlight. Other fruit crops such as avocado can be planted at a spacing of 10 m x 10 m.
- **Shade Trees:** they can be planted at a spacing of 10 m × 10 m to 12 m x 12 m depending on the tree species (refer Table 1). These trees grow tall and spread wide; the spacing ensures they provide shade without over shading.

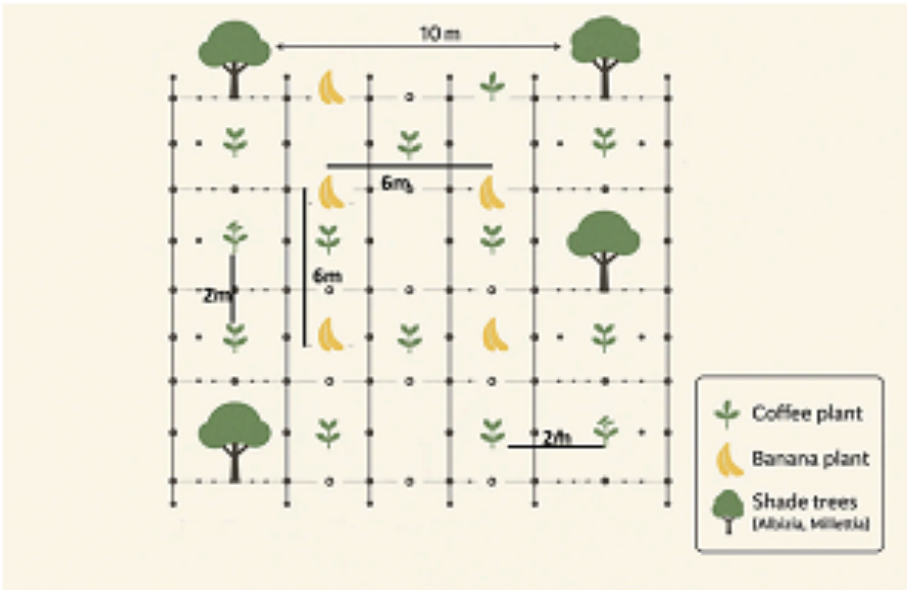
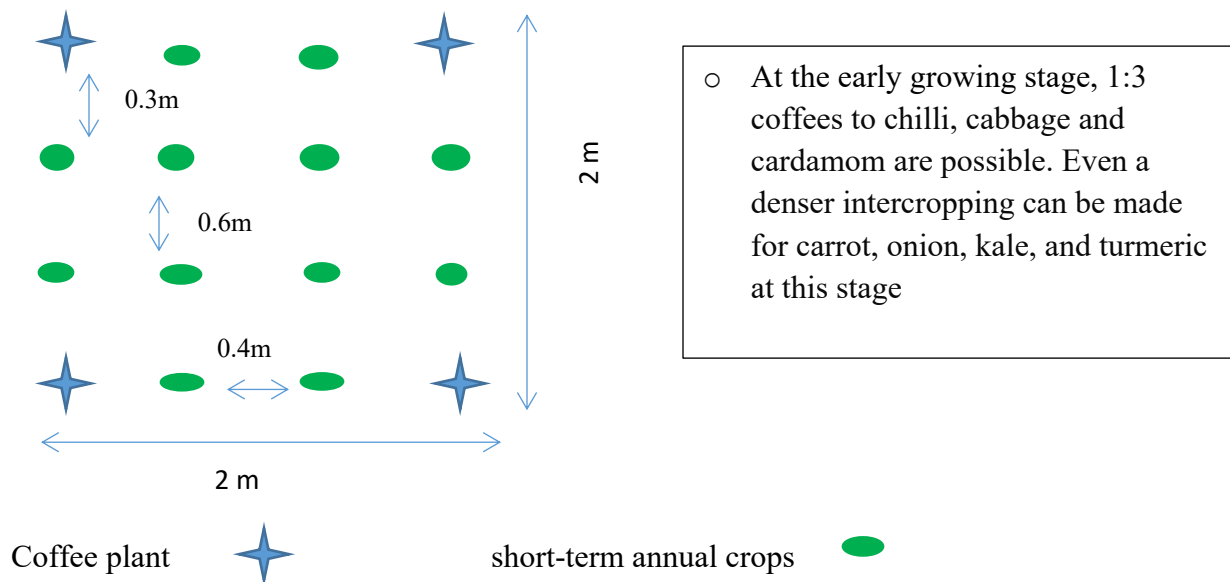


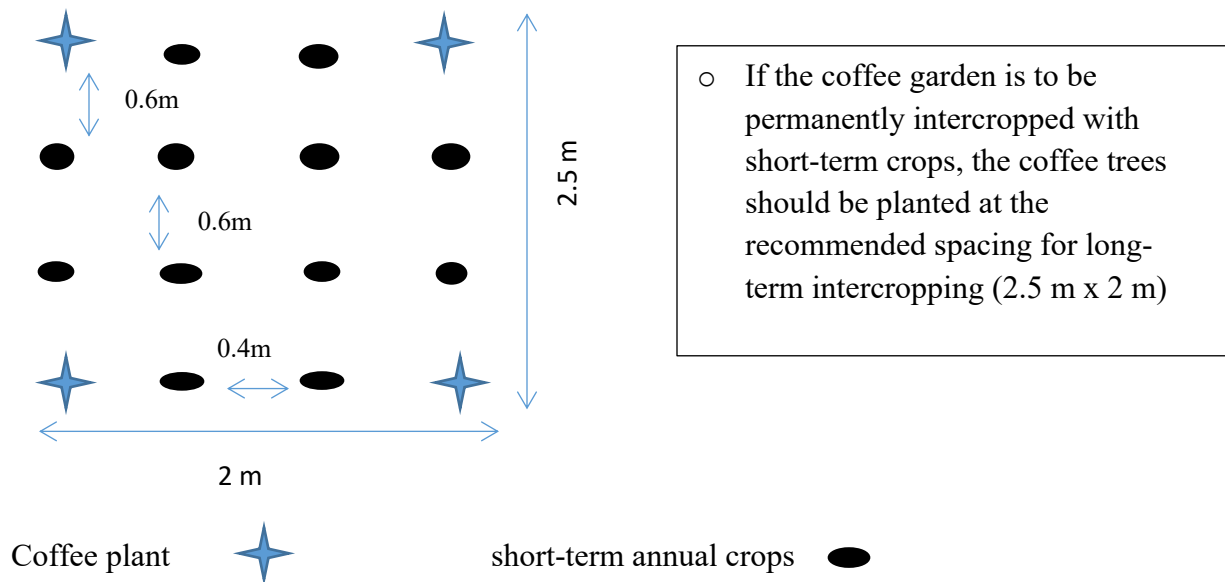
Figure 6. Sample pictures showing banana-coffee-shade tree agroforestry systems

- Food and cash Crops (e.g., legumes, vegetables, spices, etc.): Intercrop in rows or alleys between coffee rows. Select short-duration crops that don't compete heavily for sunlight or nutrients (see the examples below)

Example of agroforestry design in the first four years



Example of agroforestry design to be used permanently intercropped with short-term crops



b) Vertical spacing

Maintain a distance between the coffee canopy and the shade canopy of at least 2 m for young coffee plants and 5 m for productive coffee plants (Fig 7).



Figure 7. Sample pictures showing vertical distance between shade trees and coffee in agroforestry systems

Crop calendar (spatial arrangements)

Utilizing annual crops that are harvested before the coffee reaches its peak resource demand, ensuring resource availability throughout the year. In southwest Ethiopia, nursery establishment for coffee carried out from late October to early January, then planting takes place during rainy season (June to August). Coffee harvesting takes place from late September to late November. Once the coffee farm is established, high labor is required for harvesting and processing of coffee. Likewise, periods of high intercropping labor demand occur during intercrop establishment and harvest. Some labor is also required for maintenance, such as weeding and fertilizing during the growth phase.

Adjust the planting time of intercrops so that their peak labor demand periods (e.g. harvesting) do not coincide with the coffee harvesting and processing periods. The information provided in Table 3 can guide growers to select the right intercrops that have different production cycles both to each other and to coffee. Based on the data provided in Table 3, time of planting from January to February or April to May can be recommended for most of the intercrops. This is because their harvest periods (March to August) do not coincide with the coffee harvesting and processing periods, so that labor can be used efficiently.

Table 3. Detailed planting guide and management system of intercrops tailored for Southwest Ethiopia

Intercrops	Planting period	Management practices	Harvest time
Tomato	Jan-Feb, Sept-Oct	Sow in the nursery then transplant after 6 weeks. Use well aerated loam soil (PH=6). Stake vines, fertilize compost. Watch for pests; companion with basil; lettuce; avoid brassicas, potatoes	Harvest begins 55 to 75 days after transplanting; crop lasts 150 to 195 days
Cabbage	Jan-Feb, April-Jun, Sept-Oct	Transplant into well-drained loam soils (PH 5.5 to 6.5). space at 60*40 cm.	55 to 85 days after transplanting (2 to 3 month)
Carrot	Jan-Feb, April to Jun, Aug to	Directly sow in row 7 cm apart, thin to 2 to 3 cm. weed 2 to three times; earth	90 to 120 days from sowing (3 to 4 month)

	Oct	up to suppress weeds and protect roots.	depending on varieties and elevation
Beetroot	Jan-Feb, May to Jun, Sept to Oct	Sow in 10 cm row spacing, thin seedlings. Use compost; moderate N. companion with onion, cabbage; avoid beans/tomato	55 to 70 days after sowing
Potato	Aug-Feb, May-Jun, Oct-Nov.	Plant into well-drained loam soils (PH 6 to 7.5). Space at 75*30 cm. use compost free plant, earth up multiple times. Intercrop with onion, garlic, beans, avoids brassicas & tomato.	55 to 85 days after planting; full season 150 to 180 days
Banana	Year-round (sunny seasons)	Irrigation in dry seasons. Desucking, apply manure, mulching, and weed protection	9-12 month after planting; constant harvest every few month
Enset	Jan-April	Apply manure, mulching, regular weeding, and disease control	4-7 years depending on variety and conditions
Haricot bean	Late June to July	Composting, timely weeding, pest and disease control	70-90 days after planting (Sept-Oct)
Avocado	End of the rainy season (Aug-Sept)	Prune to control apical dominance, irrigation in dry period, mulch with crop residue, disease and pest control, tinning fruit for quality	3-5 years after planting; then annually between Sept-Feb

Chapter 10: Growing and management of coffee and intercrops

10.1.Sourcing seed for coffee

When establishing your coffee garden it is important to use planting material that is going to produce strong, healthy and high producing coffee trees. There are two options for selecting planting material for coffee

1. The best option is to grow your seedlings in a nursery using certified seed
2. The second best option is to grow your seedlings in a nursery using seed collected from your best performing coffee trees

Option 1: Certified seed

- ✓ The Coffee Research Institute (Jimma Research Institute) or the Coffee plantation farms (Bebeka State Farm) produces very good coffee seed which is called certified seed. It has been selected from high yielding, disease-free trees, early maturity stage, etc. Certified seed is a very reasonable price. In 2025 1 kg of certified seed from Bebekka State Farm cost 1,500 ETB. Select certified seed of a coffee variety that is suitable for your area; if a disease is prevalent in your area, choose a variety that can tolerate that disease; if your area can sometimes be unusually dry choose a variety that can tolerate long dry periods. It may be advisable to grow more than one coffee variety to increase biodiversity and sustainability, and reduce risk. For example, different varieties can vary in their nutrient requirements and uptake and their susceptibility to pests and diseases

Option 2: Seed from your best and highest producing coffee trees

- Seeds from your most productive, and healthy trees may be used to establish a new coffee garden. The good qualities of the parent trees will be in the new plants. If the parent tree produces a lot of cherry and is resistant to pests and diseases then it is likely that the new trees that grow from the seeds will also be high producing and resistant to pests and diseases

How do you obtain seed from trees?

- Obtain large, very ripe, bright red cherries from pest and disease free, high-yielding trees
- To ensure the seeds are healthy put the cherries in a bucket of water. Select only the cherries that sink (good ones)

- Remove the pulp by hand or by using a pulpier
- Soak the beans in water for 24 hours to remove the mucilage
- Wash the beans
- Air-dry in a shaded area with lots of airflow for at least 4 days. It is better not to dry them in the sun as they may dry too quickly and die
- Remove any pea berries and broken or insect infested beans
- If the beans are dried properly, the outer skin or parchment should peel off easily by hand or by itself
- If air-drying does not remove the parchment it can be removed by rubbing the beans in the palms of both of your hands

How much seed will you require?

1 kg of certified coffee seed contains approximately 4,500 seeds. Allowing for non-viable seeds and nursery culling about 75% (3,375) will grow into transplantable seedlings. Using the rectangular spacing of 2.5 m x 1.5 m, 1 kg of seed will produce sufficient seedlings to plant 1.25 ha of land. Any surplus seedlings could be used for infill in existing coffee gardens where trees have died or they could be shared with relatives so that there is no wastage

Table 4. Coffee tree spacing and seed requirements

Planting type	Spacing	Tree density ha ⁻¹	Area planted using 1 kg of seed	Seed quantity ha ⁻¹	Remarks
Rectangle	2.5 m x 1.5 m	2,667	1.25 ha	0.80 kg	Tall varieties in pest & disease prone areas, with food crops at early stages
Rectangle	2.5 m x 2 m	2,000	1.70 ha	0.60 kg	Spacing for long-term intercropping with food crops
Rectangle	2 m x 2 m	2,500	1.35 ha	0.60 kg	Spacing for long-term intercropping with shade tolerant food crops
Rectangle	2 m x 1 m	2,500	0.675 ha	1.48 kg	Catimor (dwarf variety), single upright per tree

How do you store coffee seeds?

- ✓ Coffee seeds should not be collected more than three months before they are to be sown as they may die. It is best to collect them just prior to sowing
- ✓ Store dried seeds in containers or plastic bags, in a cool area where there is no moisture. If they take up moisture from the air they may germinate before they are sown

The coffee nursery

Starting your coffee garden with the best planting material helps ensure that the garden has the potential to be highly productive and generate a good income. This means using good quality seed and appropriate soil and nursery management practices to ensure that the seedlings are healthy and ready for transplanting at the beginning of the wet season. A coffee nursery is an area where young plants are grown from seed to a size where they can be transplanted into the coffee garden. There are two nursery options recommended for coffee growers. These are bare root and polybag nurseries. Bare root nurseries are much cheaper than polybag nurseries and so is the preferred option for smallholders. They will be the focus of this module.

What is involved in setting up a coffee nursery?

- ✓ The reason for having a coffee nursery is to produce good quality seedlings ready for transplanting at the beginning of the wet season
- ✓ This will mean planning ahead so that you have good quality well composted soil mix, a simple nursery structure where the shade level can be adjusted, a water supply nearby and, very importantly, good quality seed
- ✓ Seedlings are ready for transplanting when they have 2-3 primary branches or 8-9 leaf pairs
- ✓ The time taken from sowing to when the seedlings are ready for transplanting into the coffee garden is 6-9 months
- ✓ It is important to be ready to sow the seed at the appropriate time so that the seedlings are ready for transplanting when the rains arrive at the start of the wet season

Prepare the bed and Plant the seed

- ✓ Use wooden planks, bricks or bamboo as sides for seed beds which should be about 20 cm high and 1 m wide.
- ✓ Mark out the beds. Make the beds 1 m wide and 10 m long in order to produce around 200 transplantable seedlings per bed. It is best to sow the seeds 20 cm apart, so a bed this size will accommodate 5 rows of seedlings with 50 in each row, totaling 250 seedlings. This will allow for some excess seedlings for infilling
- ✓ Water the seedbed before planting.
- ✓ Using a pointed stick, make furrows 4 to 5 cm deep across the bed and 10 cm apart.
- ✓ Plant seed flat side down, with seeds 5 cm apart within the row.
- ✓ Cover seed with soil mixture.
- ✓ Cover beds with rice straw mulch to give extra heat and to retain soil moisture.
- ✓ Water gently. Make sure the seed is not exposed when watering.
- ✓ As germination time is highly dependent on soil temperature, it may take from 30 to 50 days before shoots appear. Use of plastic/polythene tunnels to retain heat will speed up germination.

10.2.Sourcing seed for intercrops

To produce a healthy and uniform intercrop, it is best to source good quality seed.

Procedures of raising seedlings

- Seedlings of most short-term vegetable crops should be ready for transplanting 4–6 weeks after sowing
- In a new coffee garden, seedlings can be transplanted at any time
- In a mature coffee garden, it is preferable for seedlings of short-term intercrops to be transplanted into the inter-rows just after the coffee flush season
- Seeds for the intercrop should be sown to allow sufficient time for the seedlings to establish and be strong and healthy and ready for transplanting at this time
- For best results it is preferable to grow the seedlings in a raised bed (preferably lightly shaded, or in a shade house) close to the house so that they can be tended to regularly
- Using healthy soil, sow the seeds at high density and thin out the seedlings once germination occurs, to allow air movement and space for growth

10.3.Land preparation and planting intercrop

10.3.1. New coffee garden

Key considerations for intercropping new coffee gardens

- Planting of intercrops can be done while a new coffee garden is being established. The suggested spacing for coffee trees is 2 m x 2 m. For tall coffee varieties, a spacing of 2 m x 1.5 m is recommended, while for shorter varieties like Catimor, a spacing of 2 m x 1 m is appropriate. These arrangements provide adequate space for intercropping.
- Keep a distance of at least 30 cm between the newly planted coffee trees and the intercrop to avoid competition for nutrients and water
- Intercropping 30 cm or more from young coffee trees can be done for two to three years or until the coffee trees produce too much shade, limiting light access for intercrops
- Intercropping with temporary shade trees (e.g. banana) will provide shade for the young coffee trees while the permanent shade trees are establishing
- If the coffee garden is to be permanently intercropped with short-term crops, the coffee trees should be planted at the recommended spacing for long-term intercropping (2.5 m x 2 m)

10.3.2. Established coffee garden

Key considerations for intercropping in established coffee gardens

- Open spacing with low levels of shade is required for intercropping in an established coffee garden. In addition to rejuvenating the coffee trees, pruning of coffee trees after the coffee flush season will open up the canopy and allow some light for intercropping
- Land preparation for intercrops between the coffee rows should be done after the coffee flush season. It is better to grow intercrops after the coffee flush season to avoid competition for family labor. Avoid damaging the coffee tree roots during intercrop cultivation
- At the end of the coffee flush season there is an abundance of coffee pulp remaining from processing which is often left at the pulping station. The pulp is rich in nutrients, particularly potassium, which is required in large quantities by vegetable and other food crops (and coffee). The pulp should be applied promptly to the prepared land to improve soil fertility and avoid nutrient leaching

- Some intercrops may require an application of additional nutrients in the form of inorganic fertilizers. Fertilizer should be applied at planting, during growth and again when the crop is maturing
- When preparing for intercrops, ensure there is sufficient space between the coffee trees and intercrops to manage competition. Keep a distance of at least 60 cm between the coffee and the intercrop to avoid competition for nutrients and water

10.4. Maintenance of coffee and intercrops

10.4.1. Manage soil nutrients

Many vegetable crops have high nutrient demands. Apply inorganic fertilizer or organic matter such as coffee pulp, kitchen waste, crop residues and animal manures to intercrops to improve crop health. The coffee trees are also likely to benefit from the fertilizer. Apply fertilizers appropriately based on the specific needs of all crops. While applying fertilizers, avoid the use of excess N fertilizer the fact that it is leached into the soil and, through microbial denitrification, converted to volatile N₂O and released into the atmosphere.

Soil nutrient management is critical to the general health of the plant, particularly where coffee is grown on poor soils with low nutrient levels. For Arabica in particular, the nutrient that most limits growth is nitrogen, and applications of 50 - 100 kg of nitrogen per ha per year can improve growth. However, the continuous use of inorganic fertilizers has a number of problems associated with it, including the depletion of soil organic matter, the deterioration of soil structure, and the acidification of the soil.

The use of organic fertilizers such as compost can address many of these problems, and is important for maintaining healthy soils. Items that can be used to make compost include:

- Coffee pulp
- Debris from your food garden including weeds and harvest debris
- Debris from clearing the site for the coffee nursery or the new coffee garden
- Kitchen waste like potato peelings and black ash from the fire
- Animal manures - large particles of animal manure may burn the roots of seedlings and therefore should be broken into finer particles. Animal manure is very high in nutrients so use only half the quantity you would use if using coffee pulp

Composted coffee pulp

Well composted coffee pulp is ideal for the soil mix in the nursery beds

- Coffee pulp and skin contain many nutrients which are very important for plant growth
- Fresh pulp should be heaped and then turned and mixed every 3-4 days. Cover the heap with banana leaves to help retain the heat but allow some air to escape
- Nutrients can be quickly lost from decomposing coffee pulp. Covering the heap will also help minimize the loss of nutrients
- If the above procedures are strictly followed coffee pulp takes approximately 4-6 weeks to break down sufficiently to use in the soil mix in your coffee nursery
- You will know when your coffee pulp is ready for use in the nursery as weeds will begin to grow in any parts that are not covered

- Mulch can maintain soil humidity during prolonged drought. Utilize organic mulching from pruning residues to add nutrients and retain soil moisture. Recommended mulch thickness is 10–15 cm of rice straw, grass or litter leaves

10.4.2. Manage weeds

- Keep the area around each coffee plant clean and free of weeds, especially during the first 2–3 years. Remove weeds from around the intercrop to avoid competition for nutrients and moisture
- Weed debris may contain weed seeds, so it is better to remove weeds prior to them flowering and producing seed
- Nutrients taken up by weeds can be recycled by using the weed debris as mulch around the intercrop or coffee trees. As the mulch decomposes, the nutrients within it are made available to the intercrops or coffee trees
- Perform manual weeding or shallow hoeing every 6–8 weeks, depending on weed pressure.

10.4.3. Shade management

Shade trees are vital components of the coffee agroforestry system. They contribute to long-term sustainability by enhancing soil fertility, regulating microclimate, and providing valuable by

products. However, active management is essential to balance shade benefits with the needs of coffee and intercrops.

Regularly prune shade trees to maintain the ideal 30-40% shade level, crucial for coffee quality and microclimate regulation. In agroforestry systems, pruning is also done to minimize the negative effects of shade, including competition for light and below-ground water and nutrients. It also prolongs the intercropping period where farmers can introduce understory annual crops such as common beans

Pruning & Thinning Schedule – Maintain 30–40% Canopy Cover

- Target Shade Cover: Maintain 30–40% shade in coffee plots—enough to protect coffee but allow light for flowering and fruiting.
- Pruning Timing: Prune once or twice a year, ideally before the main rainy season or flowering period. Remove dead branches, low-hanging limbs, or overgrown crowns that block sunlight.
- Thinning: After 3–5 years, assess spacing. Remove poorly performing or crowded trees to maintain ~10 m × 10 m spacing.

Key considerations for pruning in coffee agroforestry systems

i) Ensure minimal crop damage

- Rope branches to be cut; make sure the rope doesn't interfere with free fall when making the second cut
- Carefully lower cut branches onto the ground and place between coffee rows
- Prune just after coffee harvest season, before flowering
- Prune when there is no other crop below the coffee to avoid trampling.

ii) Lower risks for pruners

- Minimize risk by using experienced pruners with protective gear—including helmets
- Climber should secure tools when not in use
- Don't prune straight after heavy rain, as trunks will be slippery
- Remember some tree branches are weaker than others

iii) Identify appropriate pruning regime

- The farmer should decide how much of the canopy to remove for light: this will vary by tree species, age, size and pruning frequency.
- Most mature trees need a 30-40% pruning regime \geq once/year, where trees (such as *Cordia africana*) produce multiple sprouts after pruning, remove re-growths \geq every six months.

10.4.4. Monitor for pests and diseases

Regularly monitor for pests and diseases. If infestations of pests or disease infections are low, they may not cause a significant problem and can be ignored. In some instances, pests may be removed by hand and diseases remedied by removing the part of the plant affected. For significant impacts of pests or diseases, follow the following principles

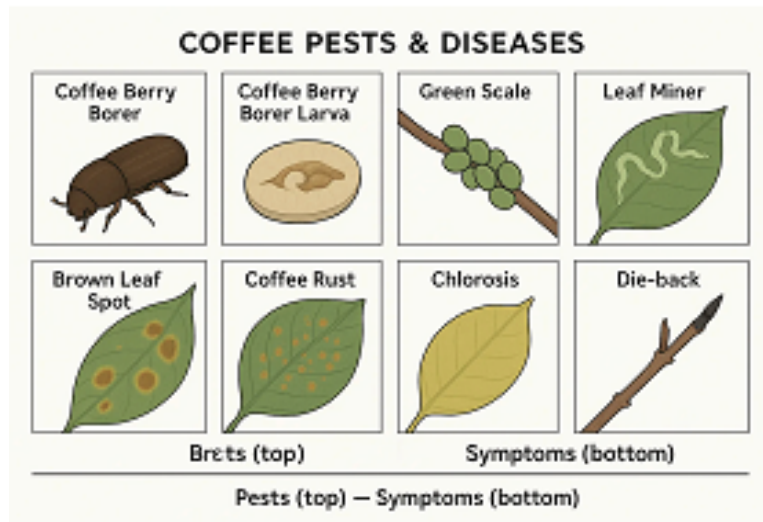
Principles for controlling pests and diseases

- Manage tree shade: This is a critical on-farm practice for smallholders; poor shade management can increase pests/diseases.
- Avoid sharing farm equipment: It's common for farmers to share, but this should be avoided where possible as it can transfer pests/diseases.
- Undertake coffee agronomic practices: Managing coffee through weeding, pruning and rehabilitation minimizes pest/disease risk.
- Regularly sanitize farm equipment: This is especially a key when it is likely to be shared between farms.
- Avoid integrating tree species that are alternative pest hosts or unfriendly to coffee, e.g., *Albizia chinensis*, *Eucalyptus*, and *Measopsis eminii*. Seek and implement extension advice: Strictly follow guidelines on pest/disease control, and report outbreaks as early as possible.

Farmers should learn to identify early signs of common coffee pests and diseases using simple indicators. Red Flags to Watch For:

- Yellowing or spotted leaves
- Small black or brown lesions (leaf rust or anthracnose)
- Berry borer: tiny holes in coffee cherries

- Aphids or scales: visible insects on leaves or stems
- Wilting or stunted plants (may indicate root issues)



Encourage beneficial insects (ladybugs, spiders) and avoid overuse of chemicals. Promote early reporting and removal of infected parts to limit spread. Rotate mulch and remove fallen leaves if disease symptoms are observed.

10.4.5. Water Management:

- Implement supplementary irrigation during dry periods, especially for water-intensive intercrops like bananas
- Manage ground cover effectively to reduce soil evaporation.

10.4.6. Harvesting intercrops and coffee

- Ensure the coffee tree roots or branches are not damaged while harvesting intercrops
- Unless they are diseased, leave the roots and stems of the intercrop in the ground where they will add to soil structure and return nutrients
- If tidying up harvested intercrops for marketing to improve presentation, remove residues (e.g. excess leaves) before the produce is removed from the coffee garden
- Leaving the leaves or other residues in the coffee garden will help minimize nutrient loss

Harvesting coffee – Selective Picking

Coffee should be harvested selectively: High-quality coffee begins with careful selection at harvest.

- Only pick fully ripe cherries (deep red in color).
- Leave green or partially ripe cherries to mature further.
- Avoid strip-picking, as it mixes immature and overripe berries, lowering coffee quality.
- Train harvesters on color and firmness as picking criteria.
- Harvest frequency: Return to the same tree every 10–14 days during peak season.
- Use clean collection baskets and avoid placing cherries on the bare ground.

Chapter 11: Integrating coffee agroforestry with cross-cutting themes

Coffee-based agroforestry systems inherently link with broader sustainability goals and cross-cutting themes.

11.1. More secure income for women

- Women’s contribution to coffee production has declined in recent decades because of what they perceive as underpayment of their labor in coffee. Many women now prefer to invest their labor in livelihood activities like food gardening for markets because they have more control over the income earned. However, when women are paid adequately for their labor in coffee they can contribute to coffee production, especially in harvesting and processing, and the additional income strengthens family well-being. The extension materials in these modules seek to enhance women’s engagement and participation in coffee on a fair and equitable basis in ways that benefit them and their families.
- Men tend to have more control over coffee and the income it generates, while women have more control over the income from food gardening
- Intercropping gives women additional access to land for production of short-term crops to feed their family or earn money – this is particularly important in areas where there are land shortages. Income from coffee is only seasonal, so growing short-term crops at different times of the year provides women with a more regular income, making it easier to care for their families

- Ensuring benefits (income diversification, food production) are equitably distributed within households and communities, with access to resources considered.

11.2. Climate-smart practices

The climate-smart agricultural practice is an integrated approach to developing technical, policy and investment conditions to achieve sustainable agricultural development for food security under climate change. Coffee-based agroforestry system is one of the climate smart crop production systems—which is common in Ethiopia’s highlands.

It generally has the following importance

- **Productivity:** Sustainably increase agricultural productivity and incomes, thereby enhances achievement of national food security.
- **Adaptation:** Increased resilience to drought and extreme weather events. Multi-strata coffee agroforestry is a land use which can deliver large scale adaptation because it addresses local needs –i.e. addressing the demographic and socio-economic pressures. It is an example of Ecosystem-Based Adaptation that should be supported within the National Adaptation Plans (NAPs) and climate change funding.
- **Mitigation:** Carbon sequestration or reduce greenhouse gas emission in the multiple layers of vegetation. Tree crops also sequester carbon and thus contribute to the ‘mitigation’ of climate change. In addition to carbon sequestered in the trees, protecting the ground from sunlight and maintaining ground cover increases soil organic matter. Perhaps more importantly, multi-level agroforestry prevents deforestation and the release of carbon currently stored in woodland soils and trees into the atmosphere.
- **Biodiversity Conservation:** Agroforestry plots serve as important habitats, conserving biodiversity compared to monocultures.
- **Soil health and soil fertility:** improve soil health and retain moisture in the soil.
- Agricultural practices are a significant source of greenhouse gas emissions, including carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O). Key sources include livestock, particularly from enteric fermentation and manure, and soil management such as tillage, fertilizer use, and burning or tilling of crop residues. Additionally, land-use change, particularly clearing forests and other natural ecosystems for agriculture leads to the release of carbon stored in soils

and biomass. This module covers important management aspects of CSA—which improves resilience to climate impacts, and sequesters more carbon than mono-cropping systems.

- Throughout the modules there is an emphasis on coffee farming methods that generate ecosystem services, which in turn improve the sustainability of coffee production. Considered in these modules are low-cost, labor efficient methods to promote ecosystem services which enhance nutrient recycling, reduce the impact of pests and diseases, suppress weeds, and reduce or eliminate the need for fertilizers, pesticides and herbicides. For example, having adequate shade can suppress weeds and reduce the need for manual weeding or the use of herbicides.

11.3. Market Access and Value Chains

- Linking diversified products (fruits, vegetables, spices, and coffee) to different markets can enhance overall farm profitability.
- If an intercrop is to be grown for marketing, it is important to consider if there will be demand for the crop
- If many farmers are already supplying markets with a particular crop, the price may decline and returns on labor may not be adequate
- If the market is not within a reasonable distance, transport costs will be higher and time to market will be longer, both of which can reduce profit (spoilage and damage rates can increase with road distance to market)
- A method of transport must be available to transport the crop
- Forming a new farmer group or cooperative, or joining an existing group, may increase opportunities for market access and enable members to share transport costs. It may also enable better access to seeds, fertilizers and other farm inputs

11.4. Policy and Institutional Support

- The need for supportive policies that recognize and promote agroforestry as a sustainable and resilient land-use system, moving beyond a focus on sole crops.
- Agriculture policy should incentivize agroforestry over conventional coffee farming and other practices that lead to deforestation or degradation of agricultural land.

- Multi-strata coffee agroforestry should be promoted within National Adaptation Plans and Nationally Appropriate Mitigation Actions.
- Agriculture, forestry, and environmental policies should be coordinated so that: agricultural policies insist on ecological integrity; forestry policies accept multi-strata coffee agroforestry as a legitimate land use; and, environmental policies use adaptation and mitigation strategies to incentivize ‘win-win’ practices such as multi-strata agroforestry