FOREST GARDEN

TECHNICAL MANUAL

Trainer Certification
English-Anglaise

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TOPS Small Grant

TREES for the FUTURE

Acknowledgments

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Introduction

Trees for the Future is dedicated to ending extreme hunger and poverty across Sub-Saharan Africa by revitalizing degraded lands using the Forest Garden Approach. The Forest Garden Approach, developed by Trees for the Future, diversifies farming systems with trees and food crops that meet subsistence needs and market opportunities. While conventional agriculture programs focus on one or few crops, the Forest Garden Approach is rooted in diversifying each farm with many food crops and thousands of trees so farming families will be self-sufficient in their production of food, timber and non-timber forest products.

What is the Technical Manual?
This Technical Manual provides everything you need to know to pass the Forest garden Trainer Certification. The Technical Manual is designed for use in conjunction with the Facilitator's Guide to provide technical guidance to trainers on the latest thinking and techniques in agroforestry extension. This book provides all the technical information needed to become a Certified Forest Garden Trainer.

Who should use the Technical Manual?
Anyone aiming to pass the Forest garden Trainer Certification will need to know this manual very well. Trainers, extension workers, specialists, and individuals interested in working with farmers to implement agroforestry techniques while increasing both their income and food security in a restorative way.

Why should this Technical Manual be used?
By guiding massive numbers of subsistence farmers through the phases of protecting, diversifying and optimizing their farms, we can have a permanent impact on the lives of millions of smallholder farming families across the developing tropics struggling to survive on their degraded farms.

How should this Technical Manual be used?
This Technical Manual is divided into fifteen chapters describing detailed technical practices like seedling propagation, grafting, tree care, and permagardening. It is designed to assist trainers in the field and provide answers to questions farmers may ask as they implement the activities laid out in the Facilitator's Guide. It is meant to be used in tandem with the Facilitator's Guide and Farmer's Workbook to provide tools and tips to smallholder farmers participating in the three phases of the Forest Garden Approach.

We look forward to hearing how this resource has helped you and how we can improve it. Feel free to contact us at info@trees.org.

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Chapter 1: Introduction to the Forest Garden

What is a Forest Garden

A Forest Garden is a multi-layered, integrated agricultural system that combines diverse plants and animals into one area to sustainably produce a variety of products and environmental services. It is an agricultural system designed to resemble a forest ecosystem, which is one of the most productive systems on Earth. Forest Gardens maximize use of both horizontal and vertical space, and can be tailored to nearly all agroecological zones. Forest Garden designs incorporate a wide variety of edible plants along with those that provide both timber and non-timber forest products in combinations that maximize beneficial interactions and minimize negative effects on each other and the system as a whole.

Forest Gardening is a practice that incorporates technologies and concepts from both agroforestry and permaculture. Though designs differ dramatically depending on the location and production goals, Forest Gardens incorporate a wide variety of perennial plants that will continue to grow year after year requiring minimal maintenance. Properly managed, it produces fruits and vegetables of higher quality and nutritive value than those produced through monocultures. The innate diversity of Forest Gardens protects crops from devastating pests and disease outbreaks. They also act as a buffer against deforestation by providing an alternative source for goods and services that people would otherwise collect from natural forests. When fully established, a Forest Garden is also temporally optimized to provide a harvest nearly every day of the year.

Food production for consumption and sale is the commonly the primary objective of Forest Gardens, but other products may include, **fuelwood, fiber, fodder, fertilizer, dyes, ornamental/artisan goods and medicinal plants**.

Other Names:
Multi-strata cropping, vertical garden, food forest, stacked polyculture

Major Characteristics of the Forest Garden

- It allows people to sustainably meet their needs and produce a marketable surplus, by making maximum use of the land
- It incorporates the symbiotic relationships among plants, animals and microbes
- It avoids the risk of economic dependence on one, or a very few crops
- It provides a continual supply of food and other crops
- It harnesses natural biological fertilizers and pest controls

Key Concepts

These key concepts will provide the basis for understanding the more detailed characteristics that follow this section.

Forest Garden

- Maximize spatial dimensions of the area planted, evenly distributing plants and efficiently using horizontal and vertical space.
- Maximize utilization of space by ensuring systems, technologies, and species are selected and designed to serve multiple functions wherever possible.
- Take into consideration temporal planning, through staggered planting and harvesting of selected species to provide products to consume and sell consistently throughout the year.
- Are designed following the natural patterns of the plants and site throughout the year, taking into account important factors such as: soils and climatic conditions, production timing of selected plants, and including the movement of wind, water, and sunlight across the site.
- Utilize a large variety of plants that often serve multiple purposes, with each plant type forming a specific layer of the Forest Garden.
- Utilize natural fertilizers and pest control through the conscientious design of plant species' relative locations and attributes. Nutrient management takes place through understanding plant interactions with the soil and other plants. Composting is used whenever possible.

Benefits of the Forest Garden

- Forest Gardens are an important source of diverse and nutritious foods, especially for poor, rural families, and thus are important contributors to the food security and livelihoods of farming communities.
- Forest Gardens provide a safety net for households when food is scarce. These gardens are not only important sources of food, fodder, fuel, medicines, spices, herbs, flowers, construction materials and income, but they are also important

for the *in situ* conservation of a wide range of unique genetic resources for food and agriculture.

- As Forest Gardens incorporate lots of perennials with deep root systems, they are far less vulnerable to destruction from environmental shocks and stresses such as droughts, floods, landslides, etc. than are similar sites planted with annual crops. This makes Forest Garden families less vulnerable and more resilient.
- Mixing of different compatible species is commonly practiced to maximize spatial (intensive use of ground and vertical space) and temporal (staggered planting and harvesting) dimensions of the Forest Gardens.
- The plant diversity in Forest Gardens is characterized predominantly by multi-purpose plants in various vegetation layers, allowing for good utilization of necessary elements like water, nutrients, and sunlight.
- The plant diversity in Forest Gardens serves to enrich the local biological diversity. These systems also do not depend on expensive or fossil fuel-based inputs such as chemical fertilizers, fuel-powered machinery, or pesticides.
- The diversified food products provide a substantial portion of nutritive and energy requirements of the local diet. Moreover, the species diversity and varying production cycles of the different components ensure continuous production throughout the year from the Forest Garden.
- Forest Gardens are considered a shady place to relax and socialize. They provide respite from the hot sun and provide a safe and a safe environment for children to play.

Forest Gardens Compared with Other Cropping Systems

The following are some of the economic, social and/or cultural foundations of Forest Gardening in comparison with other cropping systems under similar situations:

- Lower input and labor requirements once matured – suitable for resource poor and small-holder farming situations.
- Better utilization of resources, greater efficiency of labor, even distribution of labour inputs and more efficient management.
- Diversified range of products from a given area, and increased value of outputs
- Increased self-sufficiency and reduced vulnerability to climatic, biological, or market impacts on particular crops or products.
- Higher income with increased stability, greater equity, and improved standards of living.
- Better use of under-utilized land, labor or capital, while creating capital stocks—increased resilience—to meet intermittent costs or unforeseen shocks or stresses.
- Enhanced food security and an ability to meet the food, fuel, fodder, and timber requirements of the family.

- Increased fulfilment of social and cultural needs through sharing or exchange of produce and recreational opportunities.
- Better preservation of indigenous knowledge.

Forest Gardens and Multipurpose Plants

Most plants provide multiple benefits and, as such, we aim to take advantage of as many of those benefits as possible to maximize the productivity and sustainability of Forest Gardens. Wherever possible we select plants in a Forest Garden to take advantage of their multiple uses, providing useful food or forest products as well as environmental services. For example, an agroforestry tree may be included that reduces wind, controls erosion and fixes nitrogen into the soil. The same tree can also be coppiced for fuelwood and fodder, or the leaves and stems can be used as a mulch or mixed into the soil to increase fertility and moisture retention. Some examples of different roles that plants can serve are:

- **Edible and medicinal plants** (roots, shoots, leaves, fruit, seed, etc.)
- **Woody plants** (typically trees and shrubs that provide timber, poles, and fuelwood)
- **Companion plants** (plants that have an overall benefit to one another)
- **Insectary and nectary plants** (beneficial insects depend on these plants for food, shelter, reproduction etc.)
- **Aromatic Pest Confusers (also called 'Repellers')** (plants that confuse and repel pest insects with strong odors e.g. onions, garlic)
- **Wildlife plants** (birds and other animals rely on the food and habitat these plants provide)
- **Nitrogen fixing plants** (relationship between N fixing bacteria or fungi and plant roots creating free nitrogen to improve growth rates)
- **Dynamic accumulator plants** (mineral miners collect nutrients = free nutrients)
- **Bulbs and large rooted plants** (soil structure diversity, ability to absorb/mine minerals)
- **Ground cover plants** (protects the soil, conserves water, and creates healthy soil-level habitat)
- **Fertility and mulch plants** (free nutrients and green mulch for seasonal chop and drop practices)
- **Animal forage and fodder plants** (reduce outsourcing of food for animals and livestock such as cattle, goats, sheep, and chickens)

Structure of Forest Gardens

Forest Gardens are strategically designed to cultivate plants that fill space both horizontally (across the ground) and vertically (from belowground to the top of trees' canopies). The combination of trees and other plants in a layered canopy

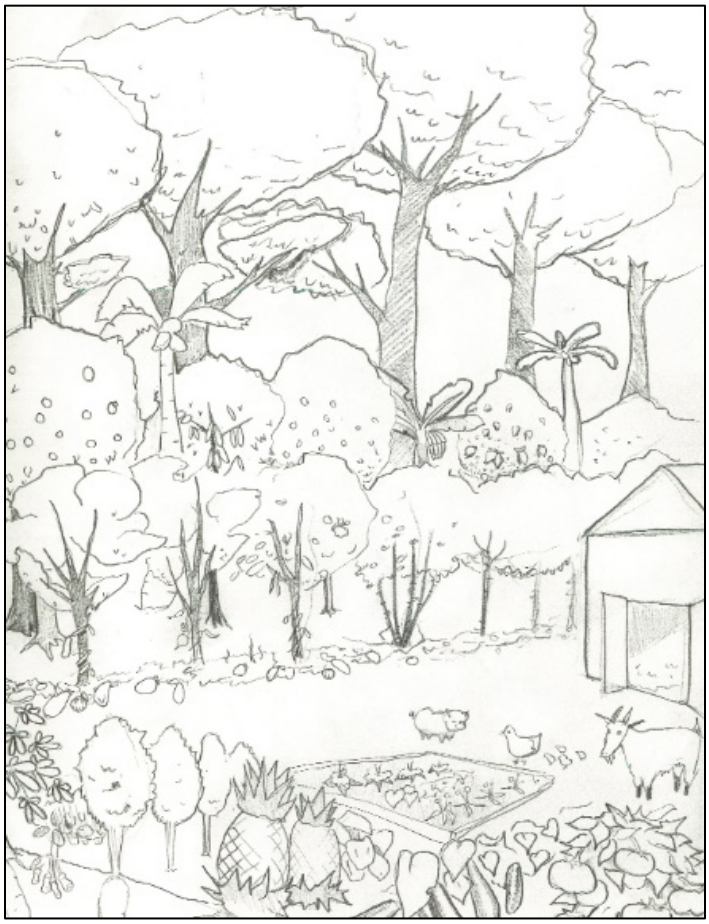
configuration is the most obvious characteristic of all Forest Gardens. The tight space within Forest Gardens results in intimate plant associations.

Use of Vertical Space

In general terms, all Forest Gardens consist of an herbaceous layer near the ground, a tree layer at upper levels, and multiple intermediate layers. The lower layer can usually be partitioned into three, with the lowermost producing below-ground, root products, the next (less than 1 m height) dominated by different vegetable and medicinal plants, and the third (1-3 m height) composed of herbaceous semi-lignified food crops such as cassava, banana, papaya, and yam. The intermediate layer of 3-10 m in height is dominated by various fruiting and/or nitrogen-fixing shrubs, some of which would continue to grow taller. The upper tree layer can also be divided in two, consisting of emergent, fully grown timber and fruit trees occupying the uppermost layer, over 25 m height, while medium-sized fruit trees of 10-20 m occupy the space just below that. This layered structure is never static; the pool of replacement species results in a productive structure which is always dynamic while the overall structure and function of the system are maintained. An example of a vertical arrangement is presented in Figure 1.

Figure 1*. An example of vertical (side view) arrangement of complex Forest Gardens in the tropics.*

Forest Garden Layers



Forest gardens make efficient use of vertical space, both above ground and below ground. This means that when deciding where to place specific plants, the root structure and soil characteristics are taken into consideration along with the branching structure and height of the plants. Looking more closely, Forest Gardens can be divided into seven distinct layers (also called strata or zones), though not every layer necessarily needs to be present. Each layer typically provides specific functions, products, or environmental services. See Photo 1 below.

1. **Canopy plants** – which can be fruit or nut trees, timber species, or pioneer species that grow quickly and produce shade;
2. **Subcanopy plants** – lower plants utilizing shade of the canopy plants, including coffee plants or small fruiting plants such as papaya and banana;
3. **Shrub plants** – large bushes or tall annual crops;
4. **Herbaceous plants** – often edible and medicinal plants;
5. **Vining or climbing plants** – plants that climb their way up subcanopy and canopy plants;
6. **Groundcover plants** – shade and fertilize the soil, conserving moisture, adding nitrogen and organic matter, and preventing soil erosion.
7. **Underground or rooted plants** – become nutrient pumps for the surrounding soil enhancing its fertility, and also often include root vegetables such as potatoes, carrots, tubers, onions, etc.

Photo 1. *Forest garden layers at Kusamala Institute of Agriculture and Ecology in Lilongwe, Malawi with marigold, legumes, yams, roselle, tephrosia, papaya, mango, and more.*

Use of Horizontal Space

Horizontally, looking down from above, Forest Gardens usually follow regular, distorted, randomized or patchy distribution of plants inside the plots; in many cases plant distribution in Forest Gardens is a combination of these patterns. Families could adopt any of those patterns according to their objectives and resources. See Figure 2 and Photo 2 below for examples.

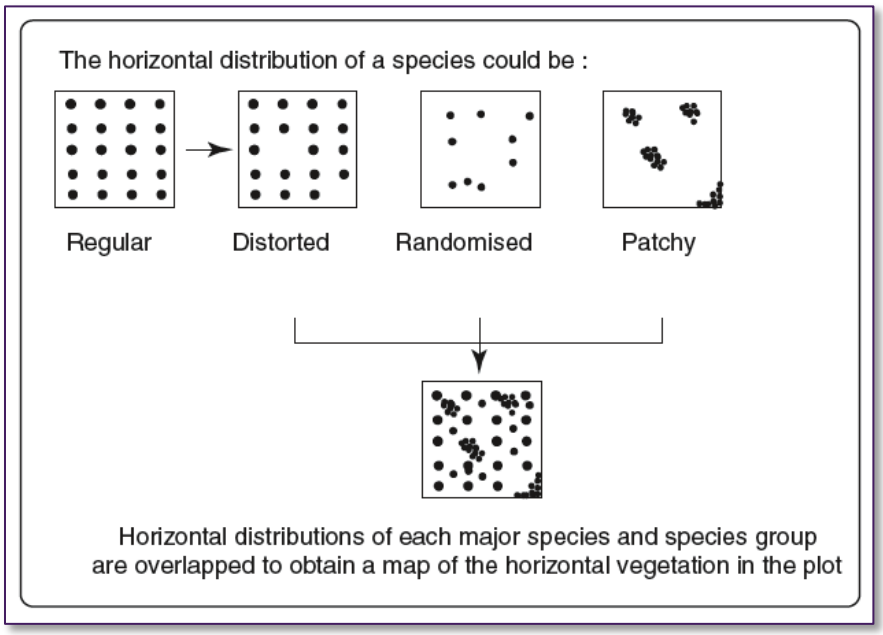


Figure 2. *Horizontal (top view) arrangement of Forest Gardens in the tropics (Lamanda et al 2006)*

Photo 2. *Areal photograph of Kusamala Institute of Agriculture and Ecology in Lilongwe, Malawi using a combination of patterns.*

Forest Gardens make efficient use of space through the intensive cultivation of various types of plants around each other in ways that utilize symbiotic relationships between species of plants as well as animals. The biophysical characteristics or requirements of plants need to be taken into consideration when planning (i.e. light and water requirements, soil preferences, nutrient demands, and interactions with other plants). The first training event in TREES' Forest Garden Approach teaches participants to create maps of their sites to begin designing their Forest Gardens with these considerations in mind.

- **Vegetation patterning** – Plants pattern themselves naturally in a forest in ways that can help regulate insect populations. Forest Garden design looks to mimic these patterns to produce natural insect populations that are beneficial to plant growth.

- **Plant diversity** – Having a large diversity of plant species included in the design will help with creating small plant communities of species that grow well together and maximize the use of space in their growth patterns both structurally, but also in regards to what time of year they need to use the most nutrients to produce fruits, nuts, leaves or roots.

- **Soil horizons** – An understanding of the soil horizons and how they change over the area being used for the Forest Garden is essential. Soil samples should be taken from various locations to better plan where plants will be placed.

- **Guilds –** Creating guilds is an important practice in Forest Gardening. A guild is an association of plants that have common characteristics or habits that grow well together. It is similar to companion planting. Certain plants secrete liquids from their roots into the soil, help certain bacteria to form in the soil that provide beneficial results to the plants growing near them, or attract pest predators or repel pests that affect nearby plants.

Forest Garden with green walls and fruit and fuel trees

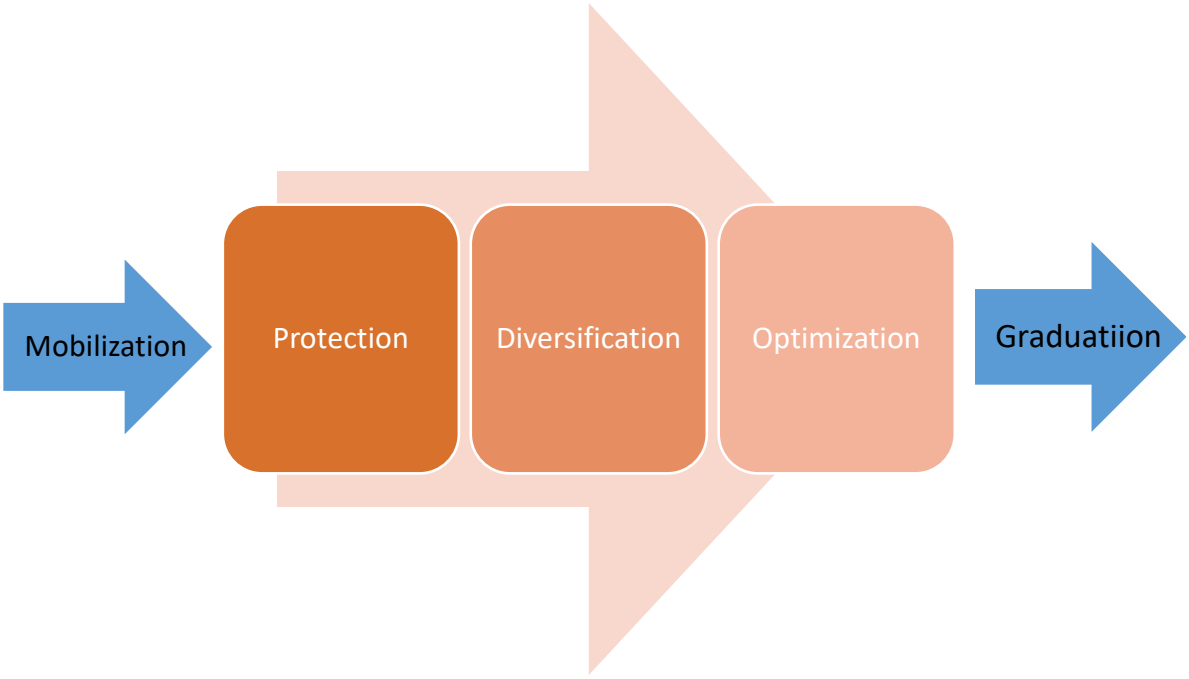
Forest Gardens with fertilizer trees, fruit trees, and field crops

Forest Garden with cashew trees and cassava

Forest Garden with raised beds, earthworks, fruit trees, and vegetables

Chapter 2: Phased Approach

A Forest Garden hosts a wide variety of trees, shrubs, plants, and planting techniques that requires a great deal of knowledge, commitment and patience for families to establish and manage. A Forest Garden cannot be planted overnight, or even over the course of a year. There are just too many steps, needs, and dependencies, as oftentimes one part of the system must be established before another can begin. TREES has developed a phased approach toward establishing a Forest Garden that guides farmers through a series of logical steps, with each step building on the concepts and benefits brought by the previous one. Over the course of up to four years, this phased approach is an effective roadmap that enables families to transition a degraded plot of land into a productive and permanently sustainable Forest Garden. The phases of the approach are described below:



Phase I: Protection

Before farmers begin planting diverse, high-value products in their Forest Gardens, they need to ensure two things: 1) that their fields are well protected from grazing animals, theft, and wind, and 2) that the soils within the sites are being fortified with nutrients to ensure faster maturation and higher productivity. We begin establishing Forest Gardens by providing farmers with the skills and resources to protect their

Forest Garden sites. To protect their sites, farmers plant *green walls* – an enhanced version of a living fence – around the perimeters of their sites. They then plant fertilizer trees throughout their sites, often in alleys among their crops, to further stabilize their soils and enhance fertility.

The protection phase generally takes 1 to 2 years, depending on the state of farmers' sites at the start of the project. Where sites are largely unprotected and the soils are highly degraded, the phase may take two years or more. Revitalization may be impeded when environmental stresses or shocks affect the project area (e.g. droughts, floods or pests).

There is no definite point at which a given farmer group has completed the protection segment, and the diversification segment will overlap with protection. Protection is a continuous process, and farmers should always maintain and manage their green walls and alley trees to ensure on-going protection and soil health.

During the initial years of Forest Garden establishment TREES encourages farmers to continue planting the crops they would normally plant on the Forest Garden sites. Farmers should understand that while they are transitioning their sites to Forest Gardens, they are still able to continue producing what they have in the past. Though they will be planting a lot of new trees in the first year, their crop production area will change very little. However, farmers do need to be aware of where they planted trees so that they can provide them with appropriate protection. Farmers should always avoid ploughing near newly planted seedlings.

Phase II: Diversification

When farmers have begun to establish their green walls and to enhance soil fertility enough to sustain healthy growth of higher-value crops, they are ready to advance to Phase II: diversification. This generally happens toward the end of year one or at the beginning of year two. During the diversification phase, farmers will begin to plant higher-value vegetables, fruit, nut, and timber trees. They will also learn increasingly advanced skills and techniques that will help them manage their Forest Gardens more effectively and sustainably.

Early on in the diversification segment, farmers learn to plant permagardens and fill them with diverse, nutritious vegetables. They will then learn to plant various fruit, nut, and timber trees as they proceed through the project in years two and three. Through training events and follow-up support, farmers' Forest Garden knowledge and experience will increase gradually as they learn, practice, then adopt new and more advanced techniques and concepts. Generally, farmers will have participated in all of the relevant diversification phase training events and adopted the practices they learned to date. The approach then transitions to Phase III: Optimization.

Phase III: Optimization

In the final implementation phase, farmers focus on enhancing the use of space, time, sunlight (or shade), and water. In this phase they will learn advanced Forest Garden management, integrated pest management, and conservation techniques that optimize and ensure the long-term health, productivity, and profitability of their land. They will also integrate new subsistence, protection, and marketable crops into their Forest Gardens to fill in the understory and cover their soils so that they can maximize production in otherwise unused space beneath and between the fruit and timber trees. More advanced utilization of integrated pest management practices is an important component of this phase, teaching farmers to manage pests without expensive chemical pesticides. Use of cover crops and water conservation techniques will supplement the pest management techniques to ensure optimization and long-term sustainability of their Forest Gardens.

Phased Approach		
Phase I: Protection	**Phase II: Diversification**	**Phase III: Optimization**
Establish green walls and alley crops with fast-growing, nitrogen-fixing trees to protect sites and stabilize and revitalize soils	Plant a diverse garden and tree portfolio to meet the family's priority subsistence needs and market opportunities	Adopt Forest Garden management and conservation techniques that optimize the long-term health and productivity of the land

Steps to Grow a Forest Garden

1. Make a **plan** to meet subsistence needs and market opportunities

2. Protect the field with a green wall of trees

3. Stabilize soils with rows of fast-growing trees

4. Diversify the field with vegetables and fruit trees

5. Farmers learn to **optimize** their field with several *layers*

6. Each family achieves **permanent increases** in food security and income

Chapter 3: Facilitation Tools

It is extremely important for facilitators to have a deep understanding of and experience with the technical skills and knowledge associated with Forest Garden Approach. This includes all the technical information needed to plan, grow, plant, and care for trees and other plants in combinations that effectively maximize the productivity, profitability, and sustainability of Forest Gardens in a given location. These skills are covered in the chapters following this one. Before we get into those skills, however, it is every bit as important for facilitators to have strong facilitation skills and an understanding of useful facilitation tools that significantly contribute to effective training that leads to lasting knowledge and application of skills learned by farmers.

This chapter guides facilitators through some of the important facilitation tools and exercises that are introduced in the first training modules in the Forest Garden training program, many of which are repeated in other modules throughout the program. It discusses their purposes as well as how to use them in training to ensure farmers are actively engaged in the activities and grasping the knowledge and skills needed to design and establish their Forest Gardens. Many of the tools and exercises described in this chapter are proven to enhance participant farmers' engagement and understanding of the subject matter. Facilitators should use relevant tools (e.g. songs, dance, stories, and deep-breathing) as needed throughout the program, even when it is not explicitly written into modules' activities, to energize farmers or to help them focus on the lessons.

The table below lists the different facilitation tools covered in this chapter, and where each tool is utilized in the training program's modules.

Tool	Cross-cutting	Specific use
Dream Field		Module 0: Mobilization
Calendars	✓	Module 0: Mobilization Module 5: Forest Garden Review Module 6: Growing Fruit Tree Seedlings Module 8: Gardening for the Market Module 9: Field Optimization Module 13: Advanced Optimization
Top View Mapping		Module 1: Forest Garden Design Module 5: Forest Garden Review Module 9: Field Optimization
Side View Mapping		Module 9: Field Optimization
Storytelling	✓	Module 4: Gardening for the Family Module 11: Gardening for the Future
Learn-and-Teach	✓	Module 3: Planting Agroforestry Seedlings Module 4: Gardening for the Family Module 7: Planting Fruit Tree Seedlings
Action Planning	✓	
Rapid Assessment	✓	Module 5: Forest Garden Review Module 9: Field Optimization

Forest Garden Dream Field

What is it?

The Forest Garden dream field activity is a guided visualization exercise in which farmers are asked to imagine the Forest Garden they would like to grow. As the facilitator, you help members envision how their Forest Garden will meet the needs

of their land and their families, and ultimately provide greater security for their future.

The dream field exercise:

1. **Motivates:** By helping farmers create a powerful mental picture of *their* future Forest Garden, the possibilities and security it could create for their families, and seeding the idea that they *can* get there -- the dream field activity creates commitment towards this long-term goal.
2. **Opens up possibilities:** the questions used as part of the guided visualization - for example, can you feed your family all year long with food from your Forest Garden - can open farmers up to options they had not considered possible before being introduced to the Forest Garden farming model.
3. **Sets expectations:** helps members anticipate and understand that it takes time to grow a Forest Garden, and they may not see many changes before the 2 year mark.

Backed by studies, professional athletes have long used the power of imagery and visualizations to achieve their goals. You can harness this tool to help each farmer build their own vision for their Forest Garden, as you kickstart the training series that will help them get there.

When do I use it?

The dream field activity should be included in the very first training module you facilitate with the farmer group (Module 0).

The activity can also be revisited later in the training if the group is struggling with confidence and motivation. Review the tips section to see how you can adapt the tool if using it for a second or third time with the same group.

How do I use it?

Focusing on steps versus outcomes

Studies show that *mental rehearsal* (imagining doing the steps that lead to a goal) is more effective at improving goal achievement than *positive imagery* (detailed image of a positive outcome). The latter is better at helping reduce anxiety and boost confidence.

As outlined in the introduction, assess the level of confidence, competence, and anxiety or stress about the process that the farmer group is starting out with. For a group feeling:

- *Uncertain and anxious:* spend more time on creating a specific, positive image of the Forest Garden with questions like - what does it look like, what do you

see, how do you feel, who else is there, how is your family feeling, what is your family doing.

- *Confident:* spend more time on how they created the Forest Garden they are imagining with questions like - what all did you do to create the Forest Garden, what got in your way, how did you overcome it, who all helped.

Visualization techniques

Recent neuroscience research indicates that the process of constructing mental pictures of the future uses a network of neural pathways called the Default Network. This network:

- Increases its activity when we are in a state of relaxed concentration. In other words, we are feeling stress-free both mentally and physically; we are contemplating a topic but not focusing on it; we are open to new thoughts as they emerge.
- Is more active when we take a first person perspective, that is imagine the scene as-if we were actually there and experiencing it for ourselves.

You can use this information to help farmers come up with richer images that: (1) they feel more connected to, and (2) ones that offer them more information about the choices they could make.

While there are several ways to facilitate relaxed concentration, we recommend two primary ways you can do this in a training setting:

1. *Cultural songs, dances, and other traditions:* cultures around the world have traditions that can help relax our minds and bodies, while simultaneously creating a deeper sense of community. Identifying a song or dance that resonates with the group can be a great way to get them to relax and will create a playfulness conducive to the visualization exercise.
2. *Deep breathing:* invite members to take in deep breaths, imagining that stressful thoughts and concerns are leaving their body with each exhale. As they breath-in and breath-out, participants should gradually and progressively relax their muscles, starting with their toes all the way to their neck, shoulders and forehead. They can tense each muscle (depending on comfort) with their inhale and relax it with the exhale.

If possible we recommend using both the techniques listed above, starting with a culturally appropriate song-dance that requires some body movement, moving onto deep breathing and transitioning to visualizing the Forest Gardens. Creating a state of relaxed concentration for a new group can take more work - participants might feel like they are entering a new challenge and can be hesitant to let their guard down. Successfully practicing these techniques ahead of time will give you the confidence you need, as their facilitator, to guide the group through this.

Optional: Capturing the visualization

You can choose whether you want group members to capture their Forest Garden visualization using mechanisms like:

- Simple drawings.
- Bringing magazines with relevant images (trees, plants, farming scenes) that farmers can use to cut-out, paste, and create their dream field.

Here are some things to consider when making this decision:

- ***Advantages:*** farmers can take their dream field home, share it with their families, and work with them to further build out shared goals for their Forest Garden. In addition, inviting them to put it up in their houses can serve as a reminder of what they are building, and an initial goal-benchmark to compare against as they make progress.
- ***Disadvantages:*** primary disadvantage is the time it might take to do this. Depending on the time available to you for the initial session, the overall expectations of the group, and urgency of other topics on the agenda - you can determine the feasibility of spending time on capturing the visualization.

Facilitating insight and action

Step 1 - Preparation. Prior to the session identify a culturally appropriate song and dance. It should resonate with the group, be easy to do, and relaxing for the participants. In addition, practice the visualization technique you plan to use so you feel confident in guiding participants through it.

Step 2 - Create small groups, conduct guided visualization. Here are sample instructions - *At this time let us form groups of three. You can go sit or stand with your group members, but stay with the larger group for now. Next I will walk us through a few exercises that will help us relax and get creative as we prepare to visualize and picture what our dream Forest Garden looks like.*

Use the techniques described in the 'Visualization Techniques' section (above) at this time.

As you transition from deep breathing to the visualization, you can use the following sample script that walks you through the stages in the visualization process. Make sure to use a slow, calming tone and pace of voice. Provide plenty of pauses after each question to give participants room to picture their dream field.

1. **Setting the scene**: *let's keep our eyes closed. Imagine a morning on a beautiful day a few years from now. You are walking into your rich and thriving Forest Garden. Breathe in the fragrance of the plants and trees you are growing. Start to notice what's around you, how does the soil feel beneath your feet.*

2. **Focusing on outcomes**: *what all do you see? What plants, trees, or crops are growing? How do you feel? What do you smell? What do you hear? Are others there? What are they doing? Are there animals or livestock?*
3. **Focusing on steps**: *as you hold the image of this dream field in your mind, what steps do you see yourself taking to make this a reality? What all did you do to make this dream a reality? What's the biggest obstacle you faced? Now let's go back to that image, the picture of the thriving Forest Garden - how did you overcome these obstacles to accomplish this? Who helped you? What helped you persevere?*
4. **Closing**: *continue to hold this image in your mind, make a note of what all feels important to you. Now let's take another deep breath and open our eyes.*

Step 3 - Small group discussions. At this time invite members to find a spot with their assigned small groups. Members should take turns sharing their dream field with others, what obstacles they identified, and how they imagined overcoming them. Ask the farmers to think through the following factors and see if they want to add to or further build-out their dream field:

- **Variety of plants and crops:** Would you grow one item? Would you grow many?
- **Type of plants and crops:**
  - Would you choose items that would make you money?
  - Would you choose items that would feed your family?
  - Would you choose items that would protect or support the soil on your land?
  - Would you grow trees? Why?
  - Would you grow garden crops? Why?
  - Would you grow field crops? Why?
- **Animals:** Would you incorporate animals? Why? How?
- **Year long food and income:**
  - Can you feed your family all year-long with the food products from your design? (not from buying food with garden product sales revenue)
  - Will your design produce food harvests high in vitamins and nutrients?
  - How often throughout the year would your crops be planted and cultivated?
  - How many times would you harvest from your design each year?
- **Soil and land protection:**
  - When cultivating your design on the same piece of land year after year, does the quality of the land improve or degrade?
  - Is it easy to protect your design? What can destroy your designed field? How would you protect your designed field?
- **Timeline:** What is the work timeline for your design?

Step 4 - Capture (optional) and Share. Time permitting, pick from one of the options identified earlier and ask farmers to record or capture their dreamfields. Next invite 3-5 farmers to share their fields with the large group, including what crops, plants, and trees they included, and other insights they had as they worked through the exercise.

Tips

Slow pace, match words and tones to be conducive to the visualization
For re-use:

- Are they tracking behind?
- Are they tracking ahead?

Calendars

What is it?

Calendars are an analysis and planning tool. They help farmers anticipate how things change across seasons and times of the year. Calendars help participants think long term and avoid decisions that are based simply on what is happening right now (or happened last season).

An effective calendar includes 3 elements: a time unit (e.g., months of the year) mapped across columns, a relevant variable (e.g., food availability, crop harvests) mapped in each row, and data collected in the cells of the calendar (e.g., checkmarks).

When do I use it?

In the context of Forest Gardens, you can use Calendars for two primary purposes:

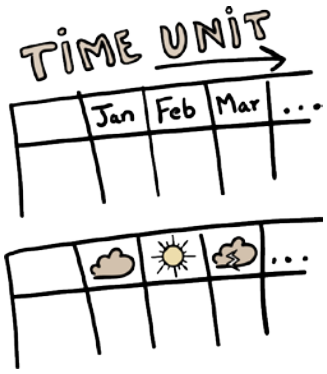
- **Generating data and insights**: helping farmers analyze patterns that reveal critical information for the design of the Forest Garden. Examples include mapping:
  - Months when food is scarce.
  - Months in which their field does not yield harvests.
  - Seasonal changes in the sales price of their crops.
  - Effort and labor needed for a given activity at any one time in the year.
- **Planning**: helping farmers map out when they should be undertaking specific activities to implement their Forest Garden design.

Equipped with this information farmers can start optimizing what they get from their fields (e.g., food for consumption, produce for sales, market price for products) and what they put in (e.g., effort, methods of pest control, seeds).

How do I use it?

Basic components of a calendar

1 - Columns



The horizontal axis of a calendar, or the columns, represent time.

As a first step, work with the farmer group and understand the unit of time they use in their day-to-day lives. This could be the western 12-month calendar unit, seasonal calendars, or other religious calendars.

Calendars can start at different times of the year. For example, you can choose to start a calendar mapping food security at harvest time, or start a crop planning calendar with the rainy season. We recommend using the same month (or other equivalent) so farmers can compare calendars across sessions and build on their understanding.

2 - Rows

The rows of the calendar include the variables you need to map. Let's look at two commonly used calendars to understand the differences between a *single variable* and *multiple variable* calendar.

Single Variable Calendar: Seasonal Market Analysis

The figure below provides an example of a calendar that maps the market prices of different vegetables being grown by a farmer. The purpose of this calendar is to generate data and insights that will help farmers identify:

- Months during which they could get higher prices for their produce.
- Ways to store or harvest produce to sell during those months.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bean Prices												
Sorghum Prices												

Figure 1: Seasonal market analysis. This can be done by month or by season. You can use vegetable names or cutouts of pictures.

Since we are mapping the same type of information - prices for vegetables - this is an example of a single variable calendar.

Multiple Variable Calendar: Seasonal Farming Analysis
The seasonal analysis compares the inputs and outputs farmers get from their fields, along with nutrition and food needs of their families. It helps them identify:

- Family needs: lean months when their family needs more food and nutrition than available.
- Outputs: all harvests they get from their fields across food crops, vegetables, fuelwood and fodder.
- Input: the amount of effort they are expending on their fields at any given time of the year.

This analysis can help farmers move from cropping methods that require intensive effort during specific months, are at greater risk of crop failure, and associated with inconsistent food availability -- to perennial cropping that distributes both effort and produce more consistently across the year.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
												
Availability of food for family												
Harvests												
Farming Effort												

Figure 2: Seasonal farming analysis. This can be done by month or by season. You can write crop and produce names or use picture cutouts in the cells, or list them in separate rows and use checkmarks to indicate harvests across the year.

Since the calendar maps three different types of variables - food availability, harvests, and effort - this is an example of a multiple variable calendar.

3 - Cells
The cells in the calendar capture the data you need for each item listed in the corresponding row. Here are the four ***types of information*** you can capture, along with ideas on how to capture this data:

- ***Lists.*** example includes names of produce listed or drawn within cells (illustrated in Figure 2).

- *Presence or absence.* example includes checkmarks used to indicate months in which farmers get harvests from their fields.
- *Categories.* example includes 3 types of smiley faces to indicate high, medium, or low prices for vegetables (illustrated in Figure 1).
- *Quantity.* example includes dots or bars to indicate volume of overall effort expended on the farm (illustrated in Figure 2).

Facilitating insight and action

Step 1: Clarify goals. For each calendar activity provide a clear checklist of what needs to happen by the end of the calendar exercise.

Step 2: Provide instructions and draw a sample. Draw a sample calendar clearly illustrating the columns or time unit, the rows (e.g., food scarcity, crops, effort), and the type of data needed for each (e.g., check boxes, smiley faces, bars). Provide materials needed to complete the activity.

Step 3: Facilitate group completion of the calendar tool. When working with a large group, create subgroups of 4-5 members. Each group should then complete the calendar exercise as per the instructions and sample shared with them. Let the groups know the amount of time they have to complete their calendars, and provide a 2 minute reminder before the time is up to help them wrap-up their discussions.

Step 4: Ask follow-up questions that facilitate learning. Provide an opportunity for calendars to be shared across subgroups, draw out insights and conclusions that help the farmers protect, diversify, and optimize their crops.
Using the two sample calendars we covered earlier in the 'Basic Components of a Calendar' section, here are examples of follow-up questions you can ask for each:

- *Market Analysis* - when are prices high, what makes them high? When are they low, what makes them low? Which months would you like to sell in? What could you do to sell more in those months?
- *Seasonal Farming Analysis* - What time of year does the Forest Garden produce the most? What time of year does the Forest Garden produce the least? Who among you has plants in your Forest Garden that you harvest during the lean months? Which plants yield something of value in the lean season, and how do you harvest them? What plants can you add to your Forest Garden to have something to harvest during the lean months? What are the top three gaps to fill to improve the use of time in the Forest Garden?

Tips
Add links to intro skills: create inclusive space, resolve conflict.

Top View Mapping

What is it?

Top view mapping (also called horizontal mapping) helps create a diagrammatic representation of the group member's farm. The map is drawn to approximate scale, and can be used to estimate the actual land area and border lengths. It includes: (1) farm boundaries, (2) key physical features within the farm, (3) neighboring features relevant to farming, and (4) an arrow to indicate North that helps orient the map.

Forest gardens are strategically designed to cultivate plants that fill space both horizontally (across the ground) and vertically (from belowground to the top of trees' canopies). The top view mapping tool equips the farmer with the perspective and information they need to fully utilize the horizontal land area available to them.

When do I use it?

Top view maps should be used to:

1. Inform the initial design of the Forest garden.
2. Inform decisions about which trees, plants, and crops will best diversify the Forest Garden.
3. Periodically evaluate and assess opportunities to better utilize and optimize the Forest Garden.

How do I use it?

Materials

The ability to erase and redraw with ease is essential when drawing maps. Materials most conducive to easily drawing maps include A4 paper sheets (tip: grid paper, if available, makes it easy to approximate scaled distances on paper), pencils, and erasers. Alternate, and more easily available materials can include chalk and boards/cardboards that are easy to carry but allow participants to make corrections as needed.

Scale

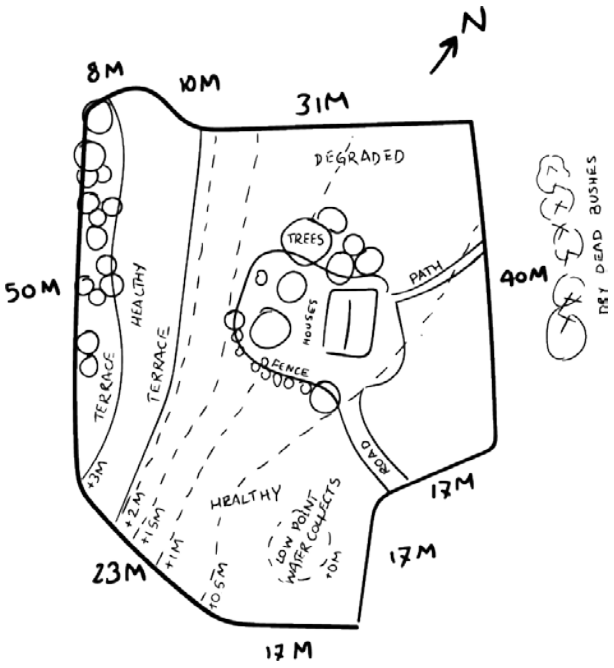
In order for the maps to help farmers make decisions about usage of space (e.g., how many trees of a certain span they can plant and what distance apart), it is important that the lines on the map represent the distance on the ground. If available, farmers can use a measuring tape to capture the length of the border and determine an approximate scale (e.g., 10 meter on land equals 1 cm on paper).
For the purposes of the Forest Gardens, it is adequate if farmers use their steps to measure distances, and equate one step to 1 meter of distance.

Key Components

1. Boundaries.

When drawing the map of the farm, the boundary is the first feature to be defined. Spending time upfront to create an accurate border - shape of the farm is clearly defined and length of lines represent distances on the ground - makes it easy to complete the remaining map by simply adding in key physical features.

There should be no dispute regarding the boundary being drawn. The first step in the Forest Garden process is to plant a fence made of trees, a *green wall,* to secure the land. The trees provide protection and future income to the farmers, and could be at risk if planted on a disputed border.



2. Cardinal Directions.

Outside the boundary of the farm drawn on the paper, the map should include an arrow that indicates North. This allows participants to draw the map to best fit the paper (or surface) they are drawing on, while including directional information that can be used to orient the map to its surroundings.

3. Key Physical Features.

Maps should include key physical features. The following checklist can help participants observe and capture more complete information:

1. Immovable manmade structures (houses, storage rooms, latrines, sheds)
2. Water sources (taps, wells, rivers, streams, springs)
3. Erosion and flooding impact (swamps, seasonally flooded areas, gullies)
4. Immovable physical features (terraces, bunds, termite mounds)
5. Major variations in slope, identifying high points and low points
6. Soil type and quality (e.g. very healthy, healthy, degraded, very degraded)
7. Current vegetation (e.g., agroforestry trees, fruit trees, vegetable garden)

4. Neighboring Area.

The map includes things that can be easily seen outside the immediate boundary of the farm and can affect the farm. Examples include:

- Neighbors who are rearing bees.
- Dead trees or brush piles next to the field that may attract pests or fire.
- Other fields where pesticides are sprayed.

Facilitating insight and action

Step 1 - Preparation. Familiarize yourself with the lead farmer's field that you will use to demonstrate top view mapping. In addition, get permission from one of the lead farmer's neighbours for their farm to be used by participants to practice mapping on the own. Make sure relevant map-drawing materials are available.

Step 2 - Demonstration. Show the group how to develop top view maps.

- Boundaries: Start in one corner of the farm and walk the entire border, using your steps to estimate the length of each side of the field. Each time you arrive at the end of a straight line, draw an equivalent line on paper with the number of steps written next to it. When you make a turn, reflect the angle of the turn or curvature in the line you draw on the paper. Continue this process till you have completed the farm perimeter on the map.
- Cardinal Directions: Add an arrow outside this border to indicate North.
- Key Physical Features: Next add in key physical features within the field itself.
- Neighboring Area: Finally add any neighboring features that could impact the farm.

Step 3 - Members practice in small groups. Divide the large group into sub-groups and have each group map a neighboring farm using the steps you demonstrated.

Step 4 - Large group discussion. Bring the entire group together and provide an opportunity for each sub-group to share their maps, and share what they learned about creating effective maps. If you notice key variations in the maps presented, ask questions to draw out unique perspectives that may have contributed to the group including certain land features - what are key differences? How does our perspectives influence the features we include or miss? How can we create more complete representations?

As the groups present their maps, make a note on a flipchart of all the crops, plants, and trees they list as currently growing on the farm. You will use this Growing Potential table when helping the group design their Forest Gardens.

What we grow	What we want to grow
Maize	Maize
Tomatos	Mangos
Onions	

Example of *Growing Potential* Table to draw on flip chart, wall, or floor. Use words or pictures depending on literacy of the group.

Finally invite the group to vote and pick a map that looks most like the field.

Tips

The use of the top view map aligns with the three key phases of Forest Garden establishment, described Chapter 2. Your role as a facilitator in generating action based on the top view map will evolve and change in each phase.

Phase I (Protect). Top view mapping is the very first activity you will undertake with members in module 1 of the Forest Garden training. In this module you will be combining the vision the farmers have for their dream fields with the reality of the current farms as reflected in the maps they create.

Creating a flourishing Forest Garden takes time, and depending on the gap between their farms today and what they want, the results of the maps can make the group (and the lead farmer) feel overwhelmed. As a facilitator:

- Pay attention to *how the group members are feeling* in addition to what they are saying.
- Use open ended questions to *help the group share their concerns* - what are you excited about? What are you concerned about? What would keep you from moving forward towards your goals?
- *Share stories of success, and celebrate accomplishments* - including the group signing up to create their Forest Gardens, and starting the process of *dreaming, mapping, and designing* these.

Phase II (Diversify and Optimize). When you use top view mapping in the subsequent phases, farmers should be seeing changes and progress in their fields. This includes the start of a functioning green wall, fruit trees, a more diverse vegetable garden, and improved soil quality.

If the group is not seeing these benefits - use the Structured Dialogue method described in the introduction to uncover blockers and help the group make progress. For a group that is beginning to see benefits of this new farming approach, your goal as a facilitator evolves to encouraging more analytical and critical thinking:

- Use questions to draw attention to aspects they can fine tune (e.g., plant sizes, light requirements, sun directions, soil requirements and impact, effect on pests), gaps they can fill, and plant interactions that will help create thriving plant guilds.

Advanced Skills

As participants gain deeper understanding of the Forest Garden approach and techniques, you can begin to include the following advanced skills when using Top View Mapping:

- How to identify slopes, and measure slope elevation.
- How to draw top view maps that show tree and plant circumference, and planting patterns

(Not covered in the tool).

- Helps the group draw advanced top view maps that show tree and plant circumference, and can be used to plan patterns and groups of plants that complement each other.

Side View Mapping

What is it?

A side view map (also called a vertical map) is a hand drawn picture of the different layers and heights of plants that grow on a farm. This information in turn can be used to identify gaps that can be filled with new and complementary plant species.

Forest gardens are strategically designed to cultivate plants that fill space both horizontally (across the ground) and vertically (from belowground to the top of trees' canopies). Creating tightly knit plants and tree groups that optimize the use of the vertical space available can substantially improve yields even from farm units that are smaller in size.

When do I use it?

Side view maps should be used to:

1. Inform decisions about which trees, plants, and crops will best diversify the Forest Garden.
2. Periodically evaluate and assess opportunities to better utilize and optimize the Forest Garden.

Not recommended in the Protect Phase (Phase I, typically year 1-2)

In the first 1-2 years of the Forest Garden training, farmers are focused on better protecting their farms by planting and growing agroforestry and fruit trees. At this stage there is not enough diversity in plant and crop types for side view mapping to be a productive assessment activity.

Recommended in Diversify and Optimize Phases (Phase II & III, typically year 3 - 4)

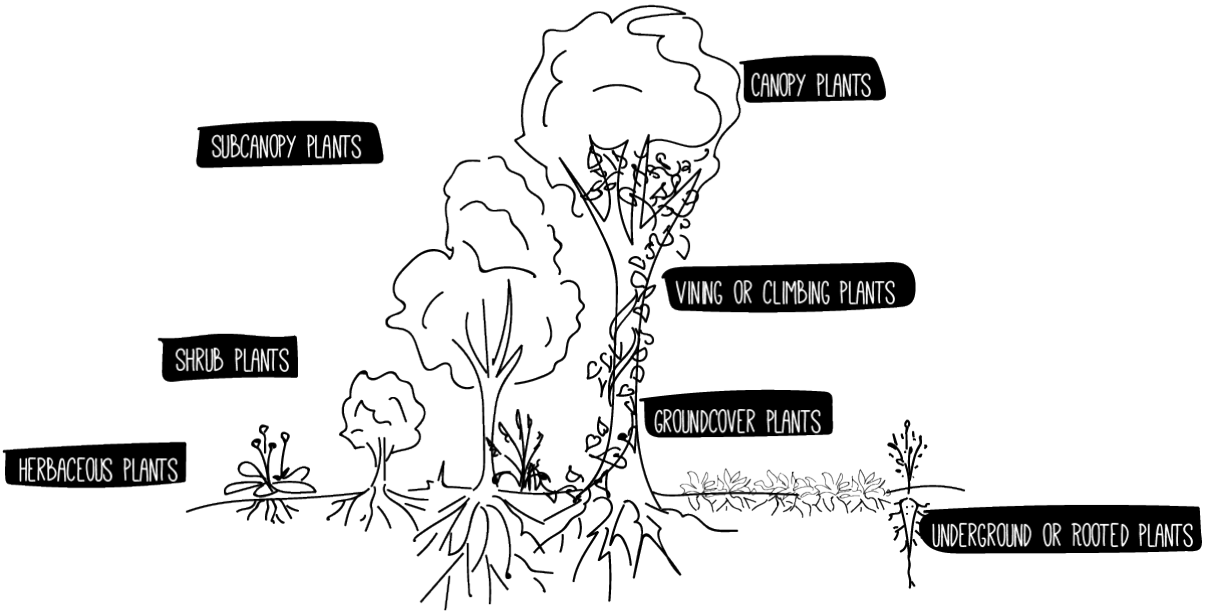
Once members have a functioning green wall and have fruit trees growing on their farms, side view mapping helps identify spaces where they can introduce new species to diversify and optimize their fields.

How do I use it?

The typical Forest Garden can be divided into seven layers, here is a quick summary of each:

1. **Canopy plants:** which can be fully grown fruit or nut trees, timber species, or pioneer species that grow quickly and produce shade. This is the tallest layer, averaging over 25 m in height.

2. **Subcanopy plants:** lower plants utilizing some shade of the canopy plants, including coffee plants or small trees such as banana.
3. **Shrub plants**: large bushes or tall annual crops.
4. **Herbaceous plants**: often edible and medicinal plants.
5. **Vining or climbing plants**: plants that climb their way up subcanopy and canopy plants.
6. **Groundcover plants**: shade the soil conserving moisture and prevent soil loss, can be nitrogen fixing.
7. **Underground or rooted plants**: become nutrient pumps for the surrounding soil enhancing its fertility, these often include root vegetables such as potatoes, carrots, tubers, onions, etc.



Vertical layers of Forest Gardens (side view)

Based on your knowledge and through talking with experts in your area you can identify specific species that fit in each of these layers. To make the best decision about which new plants will work well, evaluate the following:

1. Branching structure and height
2. Overall circumference
3. Root structure
4. Soil characteristics and the plant's interactions with the soil (nitrogen-fixing, weed suppression, moisture retention)
5. Sunlight and water requirements

Understanding a Transect Walk

When creating side view maps, we use a method called a *transect walk* - often used in participatory research and learning efforts. A transect walk involves working with community members to systematically identify and walk along a predefined path. The goal of the transect walk is to generate relevant information using observation and open ended questions.

A transect is a path that runs through a farm and creates a representative cross-section of the plants and trees that are growing on it.

The very first step when facilitating the side view mapping activity is to identify the transect you will use during the exercise. The goal is to get a true snapshot of the different layers growing on the farm. Consider the variations in planting patterns (or areas) on a farm, and make sure they are all represented in the path you identify.

Focus on generating information

During side view mapping, farmers are asked to draw out the trees, shrubs, and plants that are growing on a farm. Make sure the group members feel comfortable undertaking this task. Emphasize that the goal is not drawing detailed sketches of the plants; the goal is to quickly generate information on vertical gaps and places where new species can be added. Rough, simplistic drawings are ideal and the sample you share with the group should illustrate that.

Facilitating insight and action

Here are the key steps when facilitating the side view mapping activity:

Step 1 - Preparation. Before the session:

- Draw an example of a side view map on a flip chart paper. Base the sample on a Forest Garden that members have visited, this helps them visualize how they would translate various trees and crops to a simple drawing.
- Identify the transect or path that will be used for the session - most likely on the lead farmer's field.
- Review the Technical Guide to identify multiple options for perennial plants that the group can grow to fill in the vertical layers of their Forest Gardens.
- Secure materials - roll of flipchart paper, tape, and markers.

Step 2 - Instructions and sample. Provide a simple explanation to the group on what a side view map is - "*just like the top view map shows us what the farm looks like when we look down on the land from above, the side view map shows the different layers of plants in the garden as we see them while walking along a path through the Forest Garden, called a transect walk*".

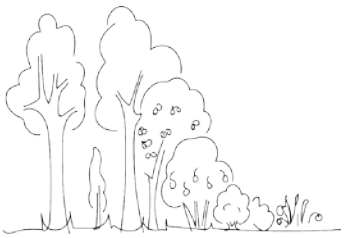
Show the group a sample of a side view map from a field they have visited as part of the project:

- Ask the group what layers they observe in the sample. Use questions and discussion to help them identify the seven layers of the Forest Garden.
- Next, ask them what plants and trees could fill those gaps. This will help orient the group towards the end goal of the activity.

Step 3 - Small groups create side view maps of the host farmer's Forest Garden. Form small groups of 4 - 5 people and have them collect materials. Ask each group to take the transect walk and complete the map. This takes approximately 30 minutes.

Step 4 - Small groups present side view maps and select best ones. Have small groups present their maps and have the group select one map that best represents the vertical diversity of plant species on the farm.

Step 5 - Discuss and identify gaps from the side view map
Use a flipchart, wall, or an open ground area to create the following table. You can use chalks for floors or walls, or a stick when working on a dirt floor to draw out the chart. Simply place the side view maps at the top as shown below.

		?
	What we grow	**What we want to grow**
Canopy plants		
Subcanopy plants		
Shrub plants		
Herbaceous plants		
Vining or climbing plants		
Groundcover plants		
Underground or rooted plants		

Example of *Growing Potential* Table to draw on flip chart, wall, or floor. Use words or pictures depending on literacy of the group.

Based on the map, list out the plants that are currently growing on the farm. Ask the group:

- What are the top three gaps to fill to improve the use of vertical space in the Forest Garden?
- Which trees and plants can best fill these gaps?
- Once the group has identified ideas for new plants that can be added, help them think through the following criteria for each to assess fit:
    - Will its branching structure and height fit with existing plants?
    - When fully grown, will its circumference work with the existing plant groups?
    - Will its root structure work with existing plant groups?
    - Will the plant's soil nutrient contributions and needs work with the current soil?
    - What are the sunlight and water requirements? Do they work with what will be available?

Tips

- When combining side view mapping with other assessment activities (e.g., seasonal calendars, top view mapping) simplify Step 5 to simply brainstorming ideas for trees and plants that could fill vertical gaps. Evaluating whether the identified species are a good fit for the farm given nutrient, water, height, and root considerations can be done after you have completed all the assessment activities.
- Transect walks represent a point-in-time snapshot. For example, the vertical diversity in plant species might look different depending on the season during which the activity is conducted. When listing out plants and trees currently growing on the field, ask the host farmer to share names of seasonal plants that the group cannot currently observe on the field.

Storytelling

What is it?

Stories are a powerful learning tool. When used effectively stories can:

1. further cooperation and trust within a group by highlighting shared challenges.
2. help farmers better understand and remember key information.
3. shift strongly held beliefs and behaviors.

A well-constructed story includes an aspirational goal, a 'plot twist' or obstacle, a struggle that reaches a tipping point, and an ultimate resolution. By weaving information into dialogue, and using the intrigue and ultimate joy of overcoming obstacles, stories can provide us the motivation we need for changing our attitudes and behaviors.

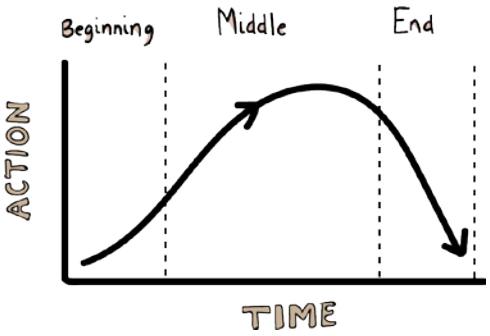
When do I use it?

Stories are a highly adaptable tool. Here are just some scenarios in which you can use stories to improve group learning:

- Illustrate how the Forest Garden can solve a key challenge for the farmers.
- Inspire commitment by asking farmers to share Forest Garden success stories.

How do I use it?

Constructing your story

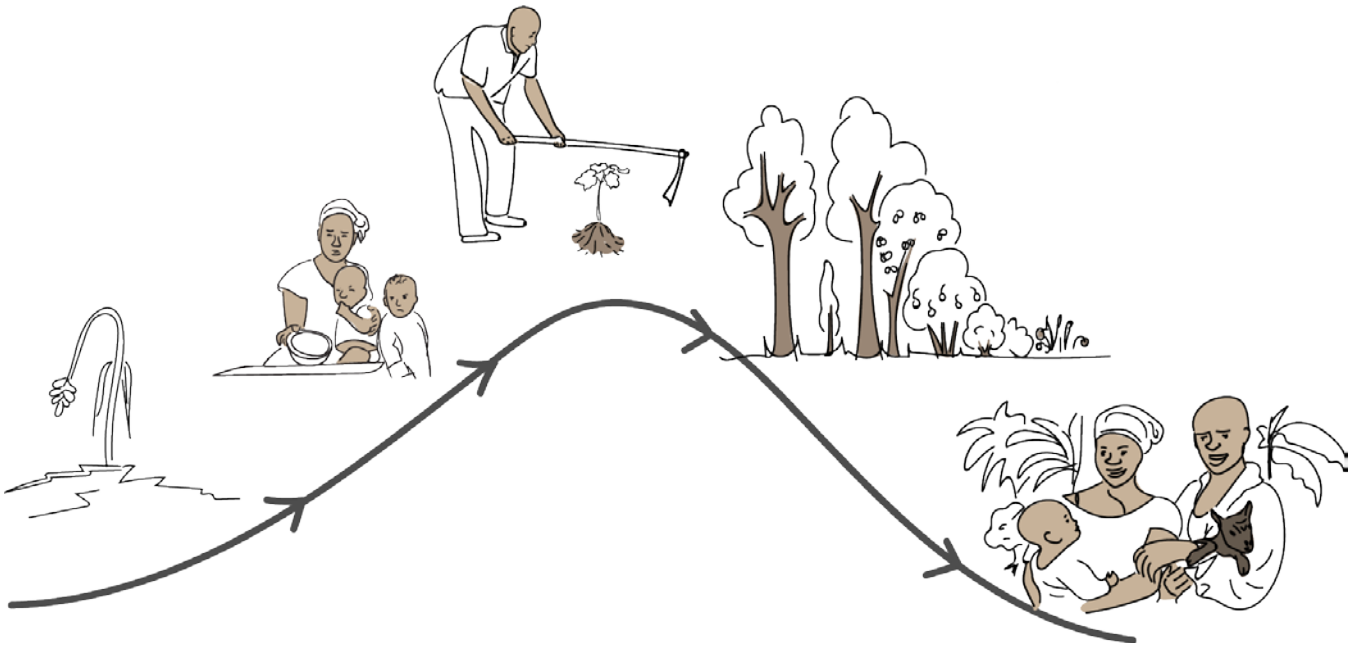


A story is built with a series of events and elements outlined below. In addition, a story has a rhythm and a structure - a beginning, middle, and end. With the middle typically being longer than the beginning and the end. The action, or pace of the story, builds to a climax as characters struggle with and ultimately resolve a crisis by creating a path to a 'big' aspirational goal.

Relatable characters. When setting the stage for your story, introduce your participants to characters that evoke empathy and understanding. In a story designed for learning, participants should be able to identify with the main characters - so learners can see themselves applying the lessons illustrated in the narrative.
Including both men and women as primary actors can help engage a broader audience as the story unfolds.

A 'big' goal. A story revolves around a goal that gets our attention. Think of a relevant shared goal, and then look at the big underlying challenge it relates to. For example, a story on good nutrition could choose to focus on one balanced meal. Instead, introducing the opportunity to provide good food to one's family through drought and flood is a much more compelling and aspirational goal.

An obstacle. Once you have set the stage with the characters, you introduce an obstacle through a twist or unexpected problem. An obstacle instantly connects us to the challenge at hand, and keeps us wanting to know more.



Climax and a path to resolution. Next, the characters struggle with the obstacle as the problem builds up to a climax, but ultimately resolve it by finding a way to overcome the problem and achieve the big goal. We remember emotions more clearly than information - highlight the joy and hopefulness that comes with the close of the story for a good ending.

As the storyteller you can make some choices here. In a story designed to:

- shift behavior or challenge attitude it's best to focus on one big idea and limit details.
- teach a new way of doing something, you will want to weave in important information related to the topic.

Delivering stories effectively

Keep your story as short as possible and ideally no longer than 7 minutes of narrative. How you deliver a story -- raising and lowering your voice, changing the speed and pace of the words, enacting emotions, matching your body language to what is happening in the plot -- can make the difference between learners that are engaged and a bored audience.

Narrating vs playacting. The first choice you make as a facilitator is deciding whether you will narrate the story or invite members of your farmer group to play out the characters in the plot.

- When the story is short, is being used as a quick illustration, or transition to-or-from a topic - and the goal is to keep the group moving through a sequence - you can narrate the story yourself.
- When the goal is to introduce a new concept, help the group reflect on and absorb the narrative, and change underlying behavior - invite members of

your farmer group to playact the story. We recommend this method of delivery since it empowers farmers to own the learning process. Your story should be written as dialogues between characters for this method of delivery.

Practice and feedback: In order to make sure the story and its delivery is effective, practice before delivering it to the larger group. Practicing a story ahead of time helps you:

- make sure the delivery is effective and does not distract from the main content of the story.
- get feedback and test the story: does it get the point across? Is it appropriate for the culture? Could changes in length, language and delivery make it better?

You can invite families of the farmers helping with the playacting to provide feedback as you practice. Make the feedback process safe by asking them to share one thing they liked about the story and one thing they wished was different or better. And then practice again.

When others are the storyteller

When farmers share stories directly with one another, these are grounded in hard earned experience and carry more weight. They can teach, inspire, and connect all at the same time.

It also carries a risk - *what if the story goes against a fundamental Forest Garden principle?* For instance, a farmer could share a story that relies on pesticides as a preferred solution, or use an approach that places an undue burden on the women of the family.

Instead of disagreeing or stepping in to provide the answer, validate the shared challenge and use questions to broaden the conversation and draw other experiences from the group: “It is terrible to lose a whole crop of vegetables to pests. We have all experienced this challenge. Has anyone here used crops like marigold or onions as pest control? Can you share your experience with the group?”

In rare instances, where someone shares a story illustrating a common and widely-held practice that is harmful to the soil and long-term health of the Forest Gardens (for example, burning crop residues to clear fields) - it is appropriate to step-in respectfully and share information that will help the group reach their goals via more sustainable farming practices.

Facilitating insight and action

Follow-up each story with open ended questions that help the group identify key lessons: what are you feeling and thinking after hearing the story? What’s the main

challenge the family faces? What do they do to overcome this challenge? What do you want to do differently after hearing the story?

Tips

The most common mistake when using stories is taking too long to get to the 'hook' or twist that engages the listener. Try writing out your story and then cut out details to see if the story still works. Only add back what is absolutely needed for the story to work.

AP Notes: update tips - use stories to build timelines for conflicts, or understanding issues, or when participants feel stuck

Learn-and-Teach

What is it?

Learn-and-teach is a training technique that helps farmers better recall what they learned during the Forest Garden training sessions and apply it in their farming practices.

In its simplest form it involves three steps: (1) an expert, someone with previous knowledge or experience of the skill, ***teaches*** a group member a farming technique, (2) the group member ***practices*** what they learned, (3) and in-turn teaches the technique to another group member.

Learn-and-teach leverages two principles of effective learning transfer:

1. ***We learn by doing.*** We are more likely to retain and transfer new skills to our life when the process of learning involves doing the task as opposed to listening or reading about it.
2. ***Active learning is more effective.*** Methods that require us to mentally organize, make sense of, and share what we learned result in better recall of materials. One recent study found that with two groups of learners - one expecting a test and the other expecting to teach a skill - the group expecting to teach had better recall of the materials.

When do I use it?

Learn-and-teach can be used any time farmers are mastering an *unfamiliar* farming or gardening technique that they will get a *chance to practice* during the session.

Learn-and-teach allows the facilitator to make better use of time for activities that are:

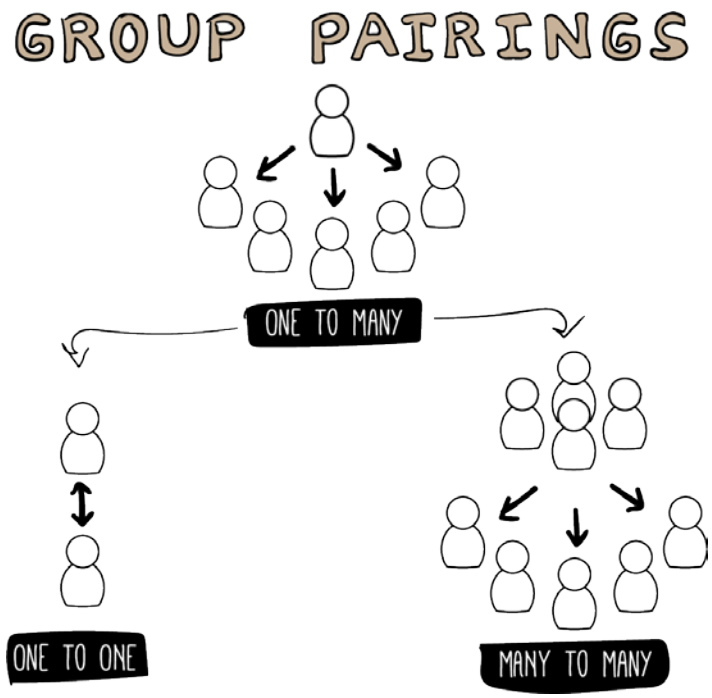
- ***Sequential***: a skill that involves mastering a sequence of steps (e.g., steps involved in outplanting fruit seedlings) or
- ***Parallel***: a skill that involves key variations depending on the subject at hand (e.g., best practices in planting various vegetable types).

For ***stand-alone tasks***, like pruning a fruit tree, it is more time effective for the facilitator to work directly with the large group - leveraging demonstrations and discovery (learning guided by open ended questions and experimentation).

How do I use it?

Understand group pairing

As the facilitator you must determine what will be the most effective group setup and pairing for the learn-and-teach activity. For each pairing you need to have at least one person who has previous experience or knowledge of the task at hand (expert).



- ***One-to-many:*** one person teaches a group a skillset and then each learner gets a chance to practice what they learned. This is the default pairing when you have only a few people who have experience or knowledge of the task at hand. It is often used as the first step in the learn-and-teach process.
- ***One-to-one:*** members teach each other a skill in a one-to-one pairing and then practice what they learned. This pairing allows for every member of the group to experience both teaching and practicing a skill. This works especially well in situations where you can pair group members and each has something they can teach the other.
- ***Many-to-many:*** a sub-group teaches a skill to a larger group, and then volunteers from the larger group practice or demonstrate what they learned. This pairing minimizes the time needed for both the teaching and practicing aspects of the activity. The downside is that not every member of the group will get a chance to teach and practice the skill.

In most instances you will use a combination of these pairings. Typically you will start with one person teaching a group, and then depending on the time available end with either a *one-to-one* or *many-to-many* pairing in order to give most members a chance to teach what they learned.

Determine set-up

Depending on *the activity type* (sequential vs. parallel), *the ratio of experts and learners*, and *the time available* you can have several variations of how you set-up the Learn-and-Teach activity. Let us review an example to see how you can adapt the tool to your needs.

Sequential - outplanting Fruit Trees

Outplanting fruit trees consists of three sequential steps: (1) dig holes with proper spacing and prepare soil, (2) properly extract and transport seedlings, and (3) planting the seedling. The facilitator selects the second and more complex step as suited for the learn-and-teach approach.

Step 1 of the sequence:

- For the first step, the facilitator works directly with the large group and uses open ended questions to help them learn about proper spacing, depth, and preparation of holes for the seedlings.

Step 2 of the sequence using learn-and-teach:

- As the large group practices digging holes, the facilitator takes 5 members to the nursery and teaches them how to properly extract seedlings (*learn-and-teach, one-to-many pairing*), using questions to facilitate understanding around technique variations for different types of fruit trees.
- These 5 members practice and extract one seedling each.
- Next, these 5 members bring a new group of 5 members and work one-on-one with them (*learn-and-teach, one-to-one pairing*) to transfer what they learned. The new group practices and extracts one seedling each.
- This learn-and-teach cascade continues till every member in the group has had a chance to extract a fruit seedling.

Step 3 of the sequence:

- The members who get done extracting seedlings move on to the third and final step of planting these. With farmers supporting each other through extraction of the seedlings, the facilitator is available to provide support to those ready to plant.

Facilitating Insight and Actions

Minimize your role as a teacher. As the facilitator your primary focus is creating a safe place, inviting members to share their knowledge, and helping them discover and learn new information through open ended questions and hands-on practice. Depending on the competence and confidence level of the group you may be called

upon to teach specific farming techniques that are unfamiliar to the group, and are key to the success of their Forest Gardens. A few things to keep in mind here:

- Do not assume you are the only one who has expertise on the topic. Before you set-up the exercise ask farmers to share what they know so you can truly leverage the experts from the group.
- Do not underestimate the ability learners have to teach themselves a new skill, especially when given access to relevant information. To the extent possible use open ended questions to spark thinking before you provide answers even as you play the role of a teacher.
- For tasks where you are starting out as the teacher or expert, shift to farmers teaching each other once you have completed an initial demonstration.

When others are the teachers. When the learn-and-teach setup involves group members teaching other group members, set them up for success:

- Prepare for the sessions by identifying which members will be starting the teaching process before the the activity begins.
- Walk these group members through a list of key questions that can serve as a guide when they are helping others learn the skill.
- Provide an opportunity for them to ask for additional information or support so they feel confident in their roles.
- Participate in the teaching sessions being facilitated by others. You can circulate between sub-groups if needed. If you think a group is missing an important aspect of the technique being taught, watch for a natural opening in the conversation to directly share the relevant information. You can also use the 'what if' feedback technique to spark a conversation that will help the group discover how to do do the task effectively.

Tips

AP Note: links to following sections from intro: role of the facilitator; giving and providing feedback.

Action Planning

What is it?

Action Planning is an activity that helps farmers take ownership of their learning, identify personalized goals that fit their needs, and create a timeline or list based plan for the exact steps they will take to apply and implement their Forest Garden training.

The primary benefit of an action plan is identifying a sequence of actions that will help farmers achieve their Forest Garden goal.

In addition, a thoughtfully conducted action planning exercise can help farmers:

1. Assess their level of confidence in implementing what they learned during a training session.
2. Anticipate obstacles and challenges they might face when applying their learning to their own Forest Garden.
3. Identify ideas and options to overcome these challenges, including helping one another as a community.

Setting goals that encourage learning, anticipating the details of when and how the goal will be implemented, and creating support systems - all bridge the gap between learning and application.

When do I use it?

Action planning should be used at junctures when farmers are about to plan and implement a series of actions over a period of time. Successfully planting green walls, setting up a perennial vegetable garden, identifying and planting fruit trees are examples of activities that typically happen over a span of several months and require a specific activity sequence in order for the end goal to be met.

How do I use it?

Adapting action plans

At the most basic level an action plan is a list of actions that will be taken to achieve a goal. You can adapt this tool and add details (when a task will be done, who will do it, what resources are needed, etc.) or adapt it to a visual format to make the tool more useful to your audience.

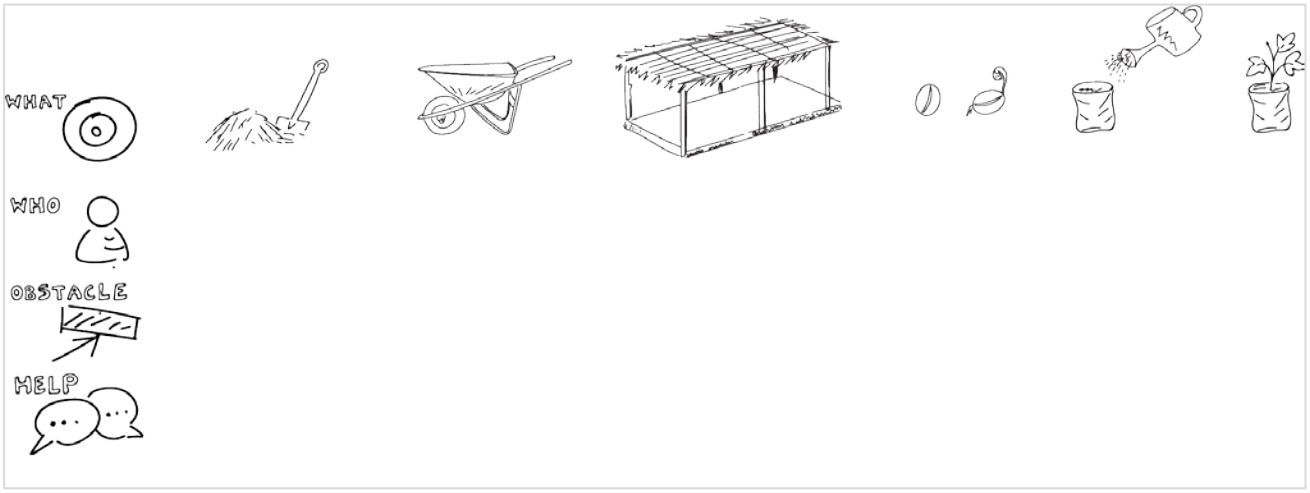
Here are some samples you can adapt and use:

Sequential. This is best used when working with groups that have a basic level of literacy. Activities should be listed in sequential order in the first (*what* or *task*) column.

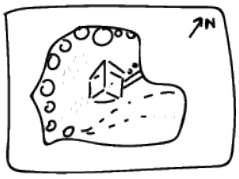
What	When	Who	Challenges	Resources and support
Prepare potting medium				
Level ground and clear bushes to create room for a nursery			Will need more help to move the extra soil	Partnering with neighbour to help one another
Build a tree nursery site				

Prepare seeds				Lead farmer will bring seeds
Sow seeds				
Water, weed, and thin seedlings				

Pictorial timeline. This is a pictorial version of the sequential action plan. As the name implies, it is visual and well-suited to groups that would prefer to work with symbols and drawings. We recommend you agree upon common symbols for obstacles, support or resources, and goal achievement in order to facilitate mutual understanding when members share their plans with one another.



Calendar. This is an adaption of the Calendar Tool. You can use both words, and symbols or drawings when working with this tool. It is best used for long term planning (e.g., 4 month plan to prepare and outplant tree seedlings), as opposed to mapping out the details of a task (e.g., treating seeds, preparing nursery beds, and planting seeds). When starting out with the Forest Garden training, we recommend planning for only 3-5 months at a time. This makes sure that farmers do not feel overwhelmed and can focus on the immediate task at hand.

Mar	Apr	May	Jun
			
			

Facilitating insight and action

Step 1 - Preparation. Based on your understanding of the group's capabilities and level of confidence, identify the Action Plan type that will be a good fit. Create or hand draw a sample that focuses on the specific activity you will be using it for (e.g., establishing a tree nursery.)

Step 2 - Introduce the Action Planning activity. Focus your instructions on the specific goal you want the group members to achieve. Here is a sample of what you could say - "Let us take the next 30 minutes to plan how we are going to establish our own [insert task] (eg. tree nurseries). I will ask all of you to discuss these questions in small groups. Please make sure each member gets a chance to share their answers, and provide support to one-another when thinking through challenges and obstacles."

Step 3 - Small group discussion. Divide the large group into sub-groups of 3-4, and provide them with paper sheets and pencils/pens for each farmer.
Have the group discuss and complete their personal Action Plan:

1. **Initial Action Plan:** Let's take 5 minutes to complete/draw-out our Action Plan.
2. **Confidence:** Select how you feel about creating your own [insert goal] (e.g., tree nursery):
    a. I don't think I can do this
    b. I think I can do this but need more help
    c. I feel confident that I can do this

3. **Obstacles:** What might get in the way of me doing this (obstacles, challenges, issues)?
4. **Options:** What ideas and options could help me overcome these obstacles?
5. **Support:** What kind of additional support, if any, might I need to do this? Could we help each other in providing this additional support?
6. **Complete Action Plans:** Let's take a few minutes to make adjustments and additions to our Action Plan based on our discussion.

Step 4 - Large group discussion. Bring the large group together, and discuss each item in the checklist, documenting each new/unique response on a flipchart:

1. **Confidence:** *how did your group generally feel about completing this task?* Record this for each group to get an overall idea of how confident members are feeling. You can record each option as a smiling, thinking, or sad face to keep it visual.
2. **Obstacles:** *what were some obstacles and challenges you identified in your groups?*
   Add new and unique responses to the flipchart. For responses that are repeated, add an 'x' next to the obstacle each time it is listed to identify the most common issues.
3. **Options:** *what ideas and solutions did you come up with to overcome the obstacles? What other options can we come up with?*
4. **Support:** *In addition to the solutions we discussed, is there any additional support that would help you do this? Were you able to identify ways in which you could help each other get this support?*
   Where appropriate you can make a mental note of farmers who might need one-on-one follow-up support from either you or the lead farmer.
5. **Action Plan:** ask a few farmers to share their action plans with the larger group, and have the group celebrate the commitments they have built towards their goal in a culturally appropriate way at the end of the activity.

Tips

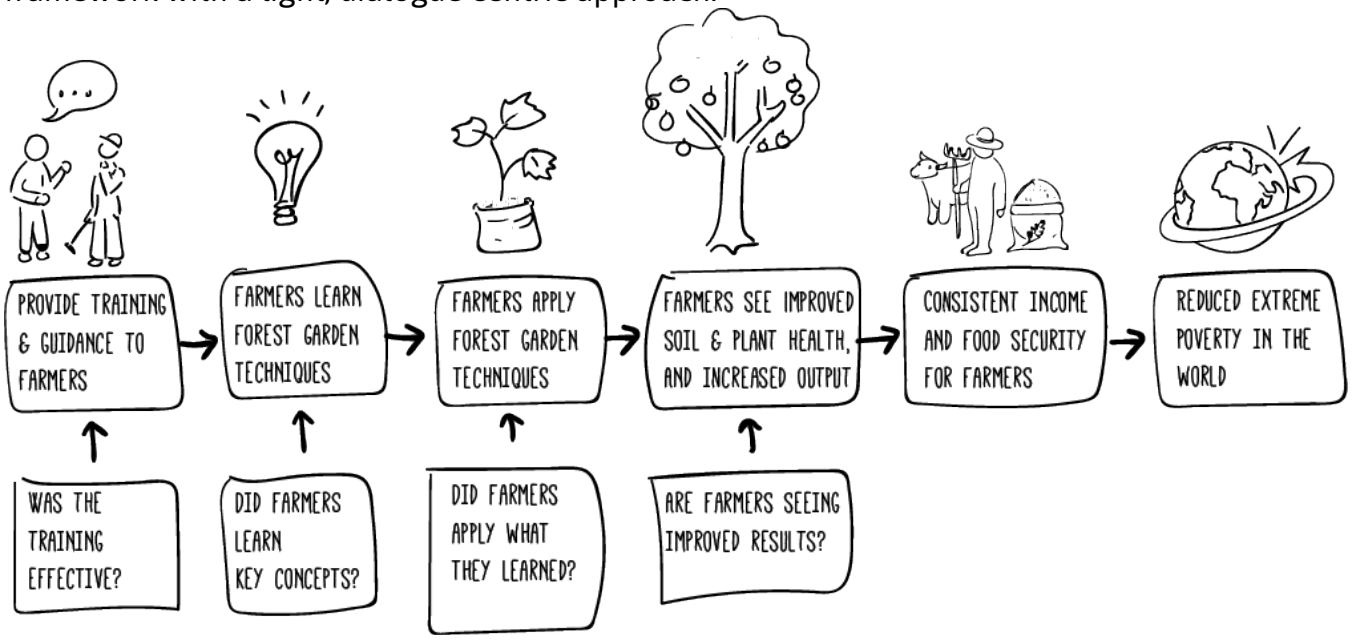
AP Note: need to think thru what would be useful here

Rapid Participatory Assessment

What is it?

A rapid participatory assessment allows you to quickly evaluate if the Forest Garden training is meeting its objectives. It is a simple, yet powerful set of tools that creates room for critical reflection and enables you and the farmer group to identify what is going well, where there is room for improvement, and collectively make adjustments.

Fundamentally, the Forest Garden program is based on the following logic and assumptions. The Rapid Participatory Assessment tools allow you to test this framework with a light, dialogue centric approach.



As shown in the graphic above, as the facilitator, you can do a rapid participatory assessment at four levels:

1. Was the **training effective**
2. Did the farmers **learn** key concepts
3. Did the farmers **apply** what they learned
4. Are farmers seeing improved **results**

As the name implies, the rapid assessments are intended to be participatory exercises. You, as the facilitator, are not judging or assessing the group separately. The assessments are conducted jointly by the entire group, with the goal of facilitating insight and identifying actions that further the overall goals of the farmer group.
Rapid assessments create greater ownership for both learning and action and can be a powerful tool for leading change. By enabling the farmer group to adjust and adapt to their realities, these assessments produce improved results, and ensure the growth of Forest Gardens that are uniquely suited to the specific local contexts.

When do I use it?

As the facilitator, you can determine how you weave the assessments into your training sessions. For each level of assessment, keep the following recommendations in mind when determining the frequency and timing of conducting them:

1. **Was the training effective:** in conducting this assessment you need to provide enough time for participants to fully experience the Forest Garden training

and its methodology. On the other hand, you do not want to wait too long and run training sessions that are not meeting the needs of the group. At a minimum, we recommend assessing training effectiveness after conducting two sessions with the group; and then re-assessing every 2-3 sessions.

2. **Did the farmers learn key concepts:** research shows us that repetition boosts learning retention. Using a quick activity (like the Ball Toss discussed later) to capture learning is a great way to reiterate key concepts and solidify knowledge transfer for the group. You can use this single-question learning assessment to both close the day, and kick-off the following training session to maximize learning.
3. **Did the farmers apply what they learned:** as part of the Forest Garden training, lead farmers are required to do an on-site visit for each member. These combined with one-on-one visits by the facilitator are the primary mechanism to assess the degree to which farmers are applying Forest Garden techniques on their own farms. In addition, you can weave in dialogue based assessment and reflection at key junctures like the start of a new year or end of a topic series.
4. **Are farmers seeing improved results:** Since it takes approximately two years for farmers to start seeing improved results from their Forest Garden, we recommend assessing results and outcomes in year 3 & 4.

How do I use it?

Method 1 - Ball Toss

The Ball Toss activity is a great way to assess learning and progress, especially when you have limited time during the session to commit towards assessment.

To prepare for the activity:

- Procure a small ball that will be easy to toss from person to person.
- Determine the assessment level (training effectiveness, learning, application, results) and the specific topic or training sessions you will focus on (e.g., nurseries, vegetable gardens, pruning etc.) Here are samples you can adapt for each assessment level:
    - **Was the training effective:** For the Forest Garden training and support being provided to you - share one thing you like, and one thing you wish could be improved.
    - **Did the farmers learn key concepts:** Share what we learned in the last Forest Garden session.
    - **Did the farmers apply what they learned:** Share the Forest Garden techniques you are applying in your farms, and lessons you are learning.

- **Are farmers seeing improved results:** Share the successes and challenges you have experienced with your Forest Gardens so far.

To conduct the activity, invite everyone to stand in a large circle. Start the activity by sharing your response to the focus question, and toss the ball to someone who has not spoken. Continue the activity till everyone has had a chance to share their response.

Method 2: Structured Dialogue

The Structured Dialogue (covered in-depth in Section II: Core Facilitation Skills - Enable Group Problem Solving) is especially well suited to assessing the first three assessment levels: effectiveness of training, learning and retention, and application of techniques. Please review the Structured Dialogue chapter to get a deeper understanding of the method and its underlying thinking and approach.

Here are sample questions you can use to adapt the tool to conduct a Rapid Participatory Assessment:

Stages	Was the training effective?	Did farmers learn key concepts	Did farmers apply what they learned
Experience	What training methods did we use? What did we do together? What did you observe me doing? What materials did I provide?	What did we learn? What was critical in the information we covered? What all do you remember about the information we covered?	What are you doing differently in your fields? What techniques have you implemented? What are you seeing and observing?
Feel	How do you feel about the training? What did you like most? What did you struggle with?	How do you feel about what you are learning? What has surprised you? What has been hard?	What are you excited about? What are you struggling with? How do you feel about the steps you have taken?
Think	In what ways is the training meeting your needs? How could you get more value from it?	Of the things we learned, what can have most impact for you? Of the things you struggled with - what about it was hard?	What are you learning as you apply these techniques in your field? What impact will it have on you and your family? Of the things that are challenging - what is getting in the way?
Do	What are 1-2 things we can test during the next training sessions to make these more effective?	What is one thing you could try to improve your learning from these sessions? What could we try as a group?	What is the most common thing that is getting in our way? What are possible solutions? Which ones could we test and try?

Before the activity:

- Determine the assessment level (training effectiveness, learning, application) and the specific topic or training sessions you will focus on (e.g., nurseries, vegetable gardens, pruning etc.)
- Finalize the questions you will use for each stage in the Structured Dialogue (adapted from sample above).
- Set-up flip charts on the wall for each of the four Structured Dialogue stages.

When facilitating the activity:

- Provide instructions to the group, here is sample language you can adapt: "*We are going to spend the next 30 minutes assessing how effectively we are applying the techniques we have learned for establishing vegetable gardens. I will ask a series of questions focused on the techniques we are applying and what we are observing, how we feel about our progress, evaluate what we think about how we are doing, and finally identify what we could be doing differently or better."*
- As you ask the questions, use keywords or short phrases to capture the responses the farmers provide to the questions.
- At the end, go around the room and have each person share what they will personally be doing differently based on their insights from the dialogue. Model accountability by sharing what you will be doing differently to provide better support in the current context.
- If the group agrees on collective actions or decisions, clearly call this out at the end. Outline what the action is, who all are accountable for it, what it is going to look like, and how or when it will happen.

Method 3: Checklists

For the last level of the assessment - evaluating improved results and outputs - a checklist of questions can provide a more complete picture of what is working and what needs improvement. The open ended rapid assessment techniques we discussed above (i.e., structured dialogue, ball toss) can miss components that are critical to the overall success of a Forest Garden.

Step 1: Finalize what you want to assess.

Using a checklist to assess the results farmers are seeing from their Forest Gardens can be an intense activity and can take more time than the other methods described here. Make sure you select components that have already been covered with the group and allow enough time to pass for the group to start seeing results from specific techniques (e.g., a minimum of two years for Green Walls, Windbreaks, Contour Planting, Fruit Trees).

You can adapt this checklist and pick components that are most relevant for the group at that specific point-in-time:

Forest Garden components	Focus	Successes	Challenges	Possible solutions
Green Walls	Overall health, gaps and need of additional trees, pruning, shaping & harvesting			
Soil Health	Changes, organic matter, beneficial insects, water retention, soil supplements			
Water	Movement of water and soil through the field especially with heavy rains, use of contour planting, berms and swales			
Wind	Movement of wind through the tree			
Fire	Protection from fires in the dry season			
Pests and disease	Protecting vegetables, trees, and crops from pests and diseases			
Outside factors	Drought, flood, etc.			
Food for consumption	Ability to meet family food needs from farm produce			
Produce for sale	Ability to maximize profits by selling at higher prices, more consistent output throughout the year			
Vegetable Gardens	Overall health, seeds, nurseries, transplanting, rotating soil givers and takers, plants to limit pests and disease, mulching			
Animals	Incorporating and meeting needs of livestock from Forest Garden, cut-and-carry techniques, fodder management			
Fruit and timber trees	Overall health and output, seed selection, nurseries, outplanting, pruning & harvesting, cuvettes			
Variety and health of plants (guilds)	Overall plant health and output, variety of products, use of horizontal & vertical space			

For 4-5 checklist topics, facilitate a gallery walk.

1. Set up a flip chart for each component on the checklist, using words or symbols depending on the literacy level of the group.
2. Create as many sub-groups as charts on the wall, for example create 4 subgroups if you are assessing four components. Assign 4-6 members per sub-group.
3. At the start of the activity assign a chart (component) to each sub-group.
4. Give the group 5-7 minutes to discuss successes, challenges, and possible solutions for their assigned topic. Ask them to add their insights to the chart with words or symbols.
5. At the end of the 7 minutes, rotate the sub-groups to the next chart or component. Repeat this till each group is back at their original chart.
6. Ask each group to report out their insights, inviting members from the larger group to add to the dialogue for each topic being discussed.
7. Help identify and call out any concrete actions or next steps identified by the group.

Use voting for rapid assessment of more than 5 components, and do a deep dive on the most challenging area.

If you are conducting a Rapid Participatory Assessment for more than 5 components at the same time, utilize voting to identify overall successes and pain points.

1. Draw out the checklist on flipcharts, or on a wall or floor area.
2. Provide members with 3 green and 3 red stickers each when working with flipcharts.
   If stickers are not available, you can instruct members to draw checks and x's - restricting themselves to no more than 3 of each. You can also use different colored leaves if working with a table made on the floor.
3. Members are instructed to put the green dots (or their equivalent) in the successes column, and red ones in the challenges column. They can choose to spend all of their 3 dots on one component- to indicate intensity of their success or struggles - or distribute the dots across different components.
4. Once members are done voting, the group should be able to clearly identify components working well and areas where members are struggling.

As the next steps:

- Identify the area with the most green dots and conduct a Ball Toss to share success stories.
- Identify the area with the most red dots and conduct a Structured Dialogue to identify underlying issues and next steps for resolving the challenges.

Tips

- When discussing training effectiveness - stay impartial, receptive, and objective. It is natural to feel judged or reactive towards constructive

feedback and comments that focus on you as the trainer and facilitator. Acknowledge the feedback, paraphrase and reflect back what you heard. Resist the urge to justify or offer explanations, simply listening to what is being shared and allow the group the space to navigate the dialogue, as you would with any other topic.

- For more involved challenges, you can follow this up with action planning to implement the ideas generated by the group.

Chapter 4: Seeds

Every time you choose to plant something on your land you are making a decision to use the space that could otherwise be used for something else. When planting annual crops, you can make a different decision the next season if what you planted does not provide the benefits you hoped for. With trees and other perennials, you want to be satisfied with the decision you make for a long time, as trees will often fill that space for many years. And in some case, you may not reap the benefits of them for several years. Just like any other living thing, if the tree you plant gets off to a poor start, for lack of nutrients or water or pests or disease, it is far less likely to grow into a healthy, fully productive tree. It may suffer from stunting, or be more susceptible to disease, or less resistant to drought. Ultimately an unhealthy seedling will likely provide produce of low quality and quantity. Yet it can still take up the same amount of space that a healthy tree would.

So it is particularly important that the trees you plant have a high likelihood of providing you with the maximum benefits you hope to reap from them. Growing a healthy tree starts long before you harvest the first fruit. It starts before you plant the tree, or even water the seedling for the first tie. It all starts in the nursery, with the seed you sow. In the following sections, we will explore the importance of selecting high quality seed, what to look for in the parent trees, and how to harvest and store the seed.

Seed Quality

Good quality seed yields good quality trees. So often we have seen seeds of poor quality planted that grow into poor quality trees and produce poor quality products. The tree from which seed is collected is called the parent (or 'mother') tree. Seed selection is the first, most essential, step of the propagation process. The quality of the seed has to do with its genetic makeup (which is directly influenced by the parent trees), its physical characteristics of the seed (if the seed is physically damaged, the tree is more likely to be as well), and the growing conditions of the parent tree (the seed is adapted to the climate from which it was collected). Here are some reasons why seed quality, and where you source your seed from, is important:

- Improved survival, better productivity and economic returns
- Inferior seeds lead to the poor performance of the trees, eroding tree planting incentives
- The higher the quality of the trees, the more likely farmers will continue planting them

- Seed collected from the agroclimatic zone in which it will grow will yield the best results

It is extremely important to pay close attention to the characteristics of the parent tree from which your seed is collected, as the growth habits of the parent will be passed to the offspring. If you are collecting it yourself, then the information below will teach you what to look for and how to collect and store the seed. If you are purchasing it from another supplier, this information frames the questions you should ask to ensure they collected the seed from good quality sources.

Characteristics to look for with Parent Trees

It is important to collect seed from healthy parent trees that display the characteristics that you are looking for in your Forest Garden. This will increase the chances that the trees you plant will exhibit similar characteristics. You also want to ensure that the seeds you sow have good genetic diversity, which increases resilience to climate, pests, and disease. The greater the genetic diversity represented in your tree seeds, the more likely your trees will adapt to the conditions in which they grow, and survive under adverse conditions. Here is what you need to look for when selecting parent trees and ensuring genetic diversity:

When selecting parent trees, look for those that exhibit the following qualities:

- **Good Health** – A healthy tree that is free from disease, pests, or physical damage (this extends to the seeds themselves; do not plant seeds that are deformed, stunted, or damaged by pests or disease).
- **High-quality production** – Whether the tree is selected for its fruit, timber, fodder, or anything else, it should yield products of the best quality possible.
- **High-quantity production** – The tree should yield an abundance of the product(s) you desire
- **Good Form** – The tree should have the shape and growth traits you desire of that species
- **Adapted to your local environment** – Trees, like any plant, are subject to specific biophysical limits (e.g. altitude, annual rainfall, and soil conditions). Be sure to collect seeds from trees that are well adapted to the agro-climatic zones where you will plant them.
- **Drought tolerance –** Look for trees that performed best in water stressed years without irrigation, as they will be more likely to survive droughts and require less irrigation
- **Pest and disease resistance** – Look for trees that have both survived and recovered from an attack, or that are in pest prone areas but took minimal damage. This will help preserve their resistant genes in future generations.

- **Mature but not too old** – Young trees and very old trees may produce a lot of seeds but the seed quality is generally not as good as healthy trees at the peak of maturity. Young trees are more likely to produce underdeveloped seeds, which will result in undesirable growth characteristics, whereas seeds from trees at the end of their life are likely to be less vigorous. Age can be difficult to determine for a tree, so when in doubt, collect seed from trees that appear to be well established, full-grown, and thriving in their environment.
- **Production timing** – Different trees of a given species may flower and fruit at different times of the year. When selecting fruit trees in particular, trees that are fruiting out-of-cycle relative to other trees in your area are a good way to capture market share with off-season produce

You can maximize genetic diversity in the seeds you plant by following the guidelines below, collecting your seeds from:

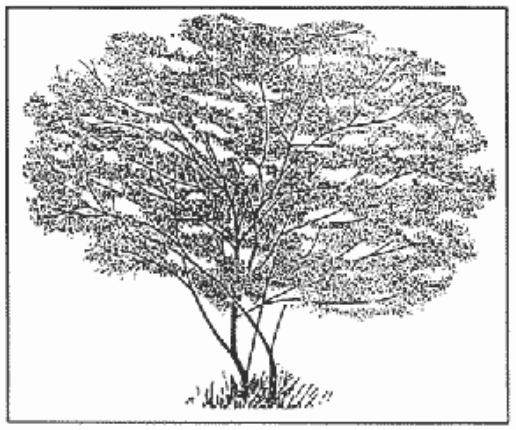
- **Multiple parent trees** – To promote genetic diversity within your seed bank, aim to collect seeds from a variety of parent trees that display the characteristics you desire.
- **Trees from throughout the growing range** – Identify trees that are growing at the highest and lowest altitudes within the species' range, as well as in-between. Healthy trees growing at the limits of their growth range demonstrate strong adaptive qualities, which is a good indicator of vitality and resilience in their genes.
- **Trees that are growing among other healthy trees of the same species** – Many tree species cross-pollinate with other trees of the same species near them. This naturally increases their genetic diversity, and if the surrounding trees are also healthy, high-quality trees, the seeds you collect are more likely to display the same genetic characteristics. Avoid collecting seeds from trees grown in isolation, as they are less likely to cross-pollinate and will have less genetic diversity represented in their seed.
- **Trees that are at least 100 meters apart** – Select mother trees that are not likely to cross-pollinate with other mother trees. Mother trees should be near other healthy trees of the same species but at least 100 meters from another mother tree from which you are collecting seeds.

Desired Parent Characteristics for Different Products

When identifying parent trees for your seed sources, the characteristics you are looking for very much depend on the product you want to harvest from the tree. Here are the characteristics to seek out for some of the main products you will raise in your Forest Garden, including fodder and fuelwood, fruit, and timber.

For fodder and fuelwood, good parent trees should:

- Be fast growing.
- Be multi-stemmed and multi-trunked
- Grow new leaves quickly after fodder harvesting.
- Grow back quickly when cut (coppiceable)
- Display fast and abundant production of leaf matter and pods preferred by local animals.
- Preferably produce leaves throughout the year

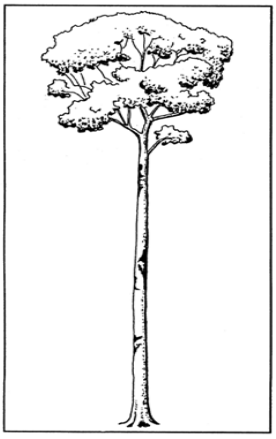


For fruit trees:

- Collect seed from trees of local varieties producing good quantities of tasty, healthy fruit of marketable size
- It is best to collect them from trees in your community. Collect them from market fruit as a last resort, but be sure they were grown nearby, in conditions similar to your farm
- Low branching trees are generally preferable as parent trees as it is easier to pick fruits from low branches
- For fruit trees, high quality varieties are usually grafted onto rootstock. To learn about grafting, read the Grafting section in this manual.

For timber trees:

- Parent trees should be fast growing, very straight, and have few, thin branches



Collecting Seed

Timing of Seed Collection - Trees produce seeds in a variety of ways. Most often, they are produced in seed pods, flowers, or fruits. In any case, be sure the seed is fully-developed before harvesting them. The optimum time for collecting seed is as soon as the seed is mature. Seed pods are generally mature when the pods turn brown, just before or after they open. On flowers, the seed is mature just before or after they fall from the flower. Fruit seeds are generally mature in a fruit when the fruit is ripe for eating.

Seed Collection Methods - There are various methods for collecting seed, some of which are described below. Trees produce and disperse their seed in different ways, often making some collection methods more suitable than others.

Collecting Seeds from the Ground – Collecting seeds that fall to the ground is sometimes easier than collecting seeds that are still on a tree, especially for larger trees that produce seed from pods or flowers. However, seeds on the ground are often more exposed to insects, moisture, and other environmental factors that can decrease their quality or viability. If seeds are small and of a similar color as the ground cover, it may be difficult to find the seeds, and more time-consuming to clean them before storing.

If you decide to collect seeds from the ground, there are few ways to simplify and expedite the process. When seeds begin to mature, place a tarp or a sheet beneath the tree to catch seeds that fall. Each day, check for seeds that fall on the tarp. Fold the tarp over to consolidate the seeds that fall from the tree and separate them from unwanted debris.

Do the following to encourage seeds to fall to the ground:

1. Shake the tree by its trunk or branches. Slight movements can dislodge loosely attached seeds from within the tree.
2. Beat low hanging branches with a stick to detach the seeds from the pods or flowers.
3. Use a rope to throw over a branch and strip the seed-baring branches of their seed.

Collecting Seed from a Tree - In some cases it is better or easier to collect seeds while they are still on the tree. When harvesting seed from fruits, it is usually better to pull fruits from branches when the fruit is ripe. Fruits often spoil quickly after falling to the ground, and are more prone to pest attacks. Some trees have seed pods or flowers that open to release winged seeds that fly far from the parent tree and are difficult to find after dispersal. Other trees produce pods whose seeds are highly susceptible to insect damage or mold once open. For such trees it is best to collect the pods or flowers after the pods mature, but before they release the seed.

Below are two common methods for collecting seeds on a tree:

1. Use a ladder or any other stationary object that allows you to reach seeds on the tree.
2. Using caution, climb the tree to collect the seeds from the branches.

Collect Seeds from Throughout the Tree's Crown –Seeds from different parts of the tree's crown cross-pollinate with different trees at different times. When collecting seed, try to collect them from all parts of a mother tree's crown (i.e. top, bottom, sides and center). In many cases, collecting from the top or outer most branches will prove very difficult.

Use safety measures (e.g. ropes, harnesses, etc.) and a great deal of caution when collection necessitates climbing the tree. Keep in mind that some trees' branches can be brittle and prone to breaking when climbing on them. If you are not able to collect seed safely from all parts of the tree, do your best to collect what you can with your available resources.

Seed Extraction and Drying

Some tree species release their seeds without any effort needed on the part of the seed collector. In these cases, seeds simply fall to the ground, ready for collection, further drying, and planting or storing. However, with many trees, you will harvest seeds from the mother tree when they are still inside or attached to their seed pods, flowers or fleshy fruit. In these cases, you can use either the *wet* or *dry* extraction methods to extract seeds.

Wet Extraction – Use wet extraction for separating seeds from fleshy membranes, usually in fruits or berries. To do this, remove as much flesh from the seed as possible, then submerge them in water and allowing them to become soft enough to separate the pulp from the seed. This may take as much as 2 to 3 days. When the flesh loosens around the seed, scrub the remaining flesh away with your hands, or against a wire screen. After removing the flesh from the seed, rinse it with fresh water and then either sow them or dry them for saving.

Dry Extraction – Use dry extraction for seeds enclosed in seed pods or other dry, organic material. You can remove seeds by dry extraction using one of several methods.

If you collected seed pods or cones containing mature seeds that did not open yet, place them in an area that is well ventilated and dry to encourage the pods to dry out, open, and release their seeds. If the seeds are small and light, place a tarp or cloth underneath the seed pods or cones to catch those that fall out. After the seeds are free, separate them from non-seed debris and set the seed aside for further drying.

If mature seeds are difficult to separate from pods or cones by hand or by drying, you may need to break them open. Two possible methods for breaking them open would be to: A) place encased seeds in a grain sack and beat it with a stick, or B) place seed pods in a mortar and use a pestle to crush the pods from the seeds. The strength of the pod or cone, and the sturdiness of the seed will determine the method you use. Be sure not to damage the seed. After the seeds are free, separate them from non-seed debris and set the seed aside for further drying.

Orthodox &. Recalcitrant Seeds – Before drying your seed, determine whether or not your seeds are orthodox or recalcitrant (non-orthodox) seed. Trees employ various methods to disperse seed and encourage germination under different conditions. Orthodox seeds refer to seeds that, due to their ability to maintain very low moisture content, can remain dormant (inactive) for long periods of time (from about 10 months to several years) under the appropriate conditions.

Recalcitrant seeds, on the other hand, do not maintain low moisture content, and therefore do not remain viable for long. Some recalcitrant seeds should be sown within weeks of being removed from their seed enclosure. Recalcitrant sees are usually bigger in size than orthodox seeds and need to be extracted from a moist environment using *wet extraction* methods. You should not allow recalcitrant seeds to dry completely. Either plant recalcitrant seeds immediately after extraction and cleaning, or store them in a moist place with good air circulation.

Drying Methods for Orthodox Seeds- After extracting orthodox seeds, using the dry or wet extraction method, you will need to dry them further to reduce the moisture content as much as possible. The best way to dry seeds is to place them in a lightly-shaded, well-ventilated area that is protected from pests. Extreme heat can damage most seeds. Avoid exposing them to intense heat from direct sunlight, or drying them on dark surfaces that increase the heat of the seeds. Thinly spread the seeds one layer thick on the drying surface, and turn them with a stick 2 to 4 times a day to be sure they dry evenly. For quick drying, use a mesh rack, cardboard, or anything that allows air to circulate around the seed.

Storing Seed

Orthodox Seed, Recalcitrant Seed, and Storability –Orthodox and recalcitrant seeds require different storing conditions to maintain their viability, vigor, and the amount of time they can be stored. Knowing that your seeds have more recalcitrant or orthodox properties will help you determine storage methods.

Storing Orthodox Seeds–Orthodox seeds can withstand low moisture content. You should dry them well before placing them in containers. Storage containers can be made of a variety of materials (e.g. plastic, glass, metal, or clay). For long-term

storage, it is important that the containers you select are water proof, air tight, and preferably opaque. Be sure the container lid forms a tight, air and water-proof seal when closed. For storage, keep the containers in a cool, dry, and dark place. With the right storage location and containers, some orthodox seeds can remain viable for several years or even decades.

Storing Recalcitrant Seeds –Recalcitrant seeds require moisture to remain viable for germination. However, maintaining high moisture content also makes them more prone either to germination during storage, or to pest and disease attacks, which makes storing difficult. To store recalcitrant seeds, maintain seed moisture by placing the seeds within a grain sack or other porous container that allows for airflow. According to volume, add 1 part of moist saw dust, charcoal, or peat moss for every 3 parts seed. You can leave the storage sack covered or uncovered, but keep them in a dark room, and off of the floor. Check on moisture content and seed conditions twice a week to be sure the seed remains moist and free of pests, and mold. Generally, recalcitrant seed can only be stored for a few weeks, up to several months, depending on the species.

Labeling Seed – Always record and clearly label the seed you are storing. This is particularly important if you are collecting and storing seed for sale. The label should have the following information:

Species Name – Many seeds of different species can look alike. Be sure to label the name of the species at the very least, to be sure you know what it is later on.

Date Collected – The viability of a seed deteriorates over time, so label each batch of seed you collect with the date it was collected. Do not mix seed collected during different periods.

Name of Seed Collector(s) – It is good to know who collected the seed in case there is a need to know, for instance, how the seeds were collected or details about the parent trees.

Seed Collection Sites – Include information on the location from where the seeds were collected. This information is useful for seed purchasers, both to inform them on the agro-ecological zones from which they were produced, as well as to verify the mother trees, if needed.

CHAPTER 4: REFERENCES

1. FAO Seed Collection and Saving - http://www.fao.org/ag/save-and-grow/en/index.html

Chapter 5: Seedling Propagation

Though it is possible to plant seeds directly onto your Forest Garden site, and sometimes this method makes sense, it is not advisable for most trees. Seed germination rates can be poor or birds and other animals may eat them, meaning you may have to sow and re-sow seeds many times before they germinate and grow; rains may wash seeds out of place, leading to trees growing in places where you may not want them; and you would have to continuously carry water around your entire site to keep them watered, especially when very young. A better option is to raise your seedlings from seed in a tree nursery, so that you can more easily protect and care for them. A nursery is a designated space for raising trees and other plants from seed or cuttings until they are mature, healthy, and strong enough to survive in the environment where you plant them. In nurseries you can provide seedlings with care under optimal conditions where you have complete control, raising the maximum amount of seedlings with minimal inputs. Nurseries can be very labor intensive, as they need constant attention, but the final result is far more efficient than any other way of producing trees. The following section explains all that you need to know to establish a tree nursery, and to raise healthy tree seedlings that, when planted in your Forest Garden, will have a much better chance of growing into productive trees.

Selecting Your Nursery Site

After you have identified the trees you want to plant in your Forest Garden, and developed your Forest Garden design, it is time to establish your tree nursery. It is important to remember that you want to plant your tree seedlings in your Forest Garden at the beginning of the main rainy season. This will ensure the seedlings have plenty of moisture through the (hopefully extensive!) rainy season to allow them to fully take root in preparation for the forthcoming dry season. With that in mind, you will want to start your nursery several months before the start of the rainy season. The specific amount of time depends on the germination and growth characteristics of the species you are planting, but for most fast-growing agroforestry trees, 12 to 15 weeks will usually suffice.

Site Selection

Before establishing your nursery there are a number of things you need to consider. You will need to provide daily care to the seedlings in your nursery. The seedlings need plenty of water, sunlight (but not too much), good soil, and protection from animals (especially goats!) that will want to eat them. You also need enough space to raise them, which depends on how many seedlings you would like to grow. Below

are a list of things you must consider when selecting a nursery site, followed by a more detailed explanation of each consideration:

- **Water** – you must have a nearby, reliable source of good quality
- **Suitable soils** – you need good growing medium to raise healthy seedlings (see soils section)
- **Accessibility and labor** – you have to care for your seedlings DAILY; be sure your nursery is easily accessible so you can provide constant care
- **Protection** – livestock tend to be the biggest threat to your seedlings, so you need a fence around your nursery to protect it from them; wind protection is also important as it can dry out or damage/stunt your seedlings.
- **Appropriate drainage** – do not allow water to collect around your nursery beds
- **Sufficient area** – the area needed depends on how many seedlings you raise

Water: Water quantity and quality is extremely important. If you do not have enough, or if it is too saline, your seedlings will either be stunted or will die. As your nursery requires water every day, and sometimes twice a day when seedlings are very young, the water source should be close to the nursery. It also must be a reliable water source, certain to provide enough water throughout the year. As you will be raising your seedlings in the months leading up to the rainy season, it is the typically the driest part of the year when the water is needed. We have seen too many nurseries fail for lack of water. If water is a particular challenge in your area, try to find a site with a backup water source in case the primary source runs dry. Do not forget to consider the distance that your water source is from your nursery. Pulling water is difficult enough. If you also have to carry that water over a long distance, you will be less likely to water your nursery each and every day. The closer the water source is to the nursery, the better off the trees will be and the more successful your Forest Garden will be.

Typically a nursery requires about ten liters of water for every square meter of nursery beds. Using a watering can is highly encouraged, not only due to ease of watering, but also to capture some of the organic matter that might be found in the water source.

Soil Quality: In general, both bareroot nursery beds and seed sack beds will require soil of higher quality than local conditions normally provide (we will discuss soil quality later). As you will often need to carry soil (whether it is sand, topsoil, forest soil, or compost) to the site, be sure that these materials are relatively accessible..

Accessibility: Nurseries require daily care, so consider how accessible the nursery is to work in. The nursery must be watered twice a day early on, and close attention must be paid to pests, weeds, and adverse weather conditions. So be sure it is not too far to prevent you from visiting it each and every day. The ideal location is within your family's compound, or immediately outside. A common alternative to having the nursery in a family compound, especially if it is a group nursery, is to place it in a community or family garden, which receives similar attention to a nursery. This helps

to ensure that the nursery site is well monitored as well, mitigating damage from goats and other animals.

Also be sure, if there is a chance you are not able to visit your nursery every day, that someone else—a family member or neighbor—will be available to care for it while you are away. Even one missed day can stunt or even kill your seedlings.

Protection: Proper protection is one of the most important factors to consider when starting a nursery. The site must be protected from pests, animals, and wandering children. We have seen too many nurseries beds destroyed in only a few minutes when wandering goats have found their way in. We don't want this to happen to you. The best forms of protection are dead fences made of thorny branches, or living fence hedges. Although more expensive, wire fences also serve the purpose well.

Your nursery also must be protected from wind and sun. Wind will dry out your soils, requiring more frequent irrigation, and it can stunt or kill your seedlings. Siting your nursery in your family compound, or surrounded by a living fence, can provide the needed wind protection. Seedlings need sunlight to develop properly, but too much will damage the young plants. To minimize sun, it is important to build shading structures over your beds. This can be done with wood and grass or palm fronds, discussed in more detail below.

Appropriate Drainage: Do not site your nursery in a place where water collects. Too much water will waterlog your seedlings or lead to increased risk of fungal attack. It is best to have a slight slope of about 1% to prevent water from collecting around your beds.

Sufficient Area: The size of your nursery is primarily influenced by the number of trees you want to grow, and by the amount of space each seedling requires. To determine the number, make calculations based on your Forest Garden design, factoring in each species, the planting systems or agroforestry technologies used, and the spacing requirements. The space required by each seedling is determined by the species, and whether you raise them in bareroot beds or tree sacks (also called poly bags or pots). Most agroforestry seedlings do well in 8 to 10 cm diameter sacks, where fruits and timber trees, especially as they often require more time in the nursery, may be better with 10 to 12 cm sacks. As bareroot seedlings can be sown more closely together in beds, they normally require less space than those sown in sacks. The table below shows the approximate number of seedlings that can be raised per meter, depending on the method or sack size.

Approximate Number of Seedlings per Square Meter

Method and Size of Tree Sack	**Seedlings in 1m²**
Small sacks (8cm in diameter when filled)	~150
Medium sacks (10cm in diameter when filled)	~100
Large sacks (12cm in diameter when filled)	~65
Bareroot beds (10 rows/meter with a spacing of 5cm between seeds within a row)	~200

Photo 1. *Nursery site at Kusamala Institute of Agriculture and Ecology in Lilongwe, Malawi with shade, compost, and appropriate drainage.*

Tools and Materials for Establishing Your Nursery

Now that you have identified your nursery site, it is time to begin establishing your beds. The following tools and materials will help you to do so. Not all of the materials are necessary. A short description of the materials is provided below the list.

Tools and Materials:

- Seeds
- Topsoil or Forest Soil
- Sand
- Compost
- Spade
- Wood for building shade structures
- Nails, rope, or twine for building shade structures
- Shading material
- Watering can
- Water
- Rope for lining straight beds (not essential)
- Hoe (not essential)
- Wheelbarrow (not essential)

Seeds: Read the chapter on *Seeds* to learn more about sourcing your seed.

Topsoil, forest soil, sand, and compost: Usually can be found somewhere around the community, if not on your family's compound. If you do not have compost, you can use dried manure or humus-rich forest soil.

Spade: Usually farmers own or can borrow some sort of digging tool for collecting dirt and digging holes. If a spade is not available, any other digging tool will work.

Wood: For building the shading structures. Narrow poles 5cm in diameter work fine. You need them to run the perimeters of your bed, with four somewhat sturdy poles 1-1.5m long to hold them up on each bed.

Rope: This is mainly for delineating beds. Small pieces of rope can sometimes be found and tied together to make pieces large enough. Lining beds is a one-time quick activity; you can borrow a rope if needed. Rope can also be used in place of nails to join the wood for the shade structures over the beds.

Shading material: You will need to cover your shade structures with shading material. Palm fronds or grasses work just fine, though you may need to tie them down. Do not use grasses that have gone to seed, unless you really enjoy weeding your seedling beds.

Watering can: If not available, there are alternatives. Uses an old large tomato can with small holes poked into the bottom and pour the water through this sieve onto the plants. Or use small plastic bottles like bleach bottles or oil bottles and prepare them by poking small holes in the bottoms and cutting off the top while keeping the handle attached. To use: dip, it into water and hold over the nursery. If a large nursery is desired tit is best to invest in some watering cans.

Hoe: Most families own some sort of weeding tool, whether it is a hoe or not. The tool is used for digging and turning over soil, breaking up chunks of dirt, and leveling the surface.

Wheelbarrow: For carrying soil and seedlings. If you don't have a wheelbarrow, buckets or any other carrying/hauling device will work.

Soils

As we have said before and will say again: healthy soils yield healthy crops. They are the basis of any agricultural system and are vital for providing your crops with the mineral nutrients and moisture they need, when they need it. Enhancing the air, water, and organic matter in your soil, and protecting all the beneficial organisms that live within it, will result in sustainably higher yields of better-quality crops, be it vegetables, field crops, fruits, timber, or anything else that grows in your soils. With the Forest Garden Approach we aim for long-term health and productivity of soils, and this often starts with revitalizing highly degraded soils. This can be accomplished through utilization of the agroforestry technologies you have already learned, and it can be enhanced through the addition of locally available soil amendments and proper soil management. In your tree nurseries, you will want to give your seedlings a great start in life by providing them with healthy, fertile soils in which to grow. Keep reading for a basic description of soils and amendments for your nursery.

Soil Texture

There are many different types of soils, with complex systems for classifying them by their distinguishing characteristics. What we are most concerned with—or at least what is easiest to begin with—is the soil texture. Soil texture is classified by the size of mineral particles present in it, of which there are three: sand, silt, and clay. The soils we normally come across are often a mix of the three, and the amount of each in the soil determines the texture: how it feels, how it holds water and nutrients, and how it should be managed.

Sandy soil is the largest in particle size, and because of this, water drains through it rapidly, carrying nutrients with it. Fewer plants are able to grow in sandy soils as their roots do not have the chance to absorb the water and nutrients that flow quickly through them. Sand is often found in riverbeds and streams. Silty soil is made of particles much smaller than sand, and is able to retain water for longer. Clayey soils

have the smallest particles of the three types. Water is much slower to drain in clay, and it holds nutrients much better. However, it can become very hard and dense, especially when dry, making it difficult for plants to get the air they need to grow.

The best soil, which we aim to raise our seedlings in—both in sacks and bareroot—is loamy soil, or loam. Loam contains a balance of the three soil materials mentioned above, plus humus - dark, nutrient-rich material formed by the decomposition of organic matter. Loam is dark in color, and is soft and crumbly in your hands. It holds water and nutrients well, but also allows for drainage and movement of air between soil particles and through the root zone. If you don't have easy access to humus, which can generally be found on the surface of healthy forests, you can substitute compost or even dried manure, which both host the same characteristics of rich organic material teeming with nutrients and microorganisms.

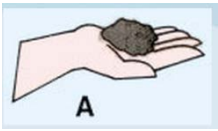
Finding the Right Soil for your Seedlings

As with plants in the Forest Garden, the seedlings you raise in your nursery will grow best if you raise them in a loamy medium. A perfectly loam is not always easy to create, but we can often get close by mixing the soils we have access to, along with some humus, compost, or dried manure, to provide nutrients for our seedlings. A good mix of soils for use in raising your seedlings can be made from 3 parts topsoil to 1 part humus-rich soil to 1 part sand.

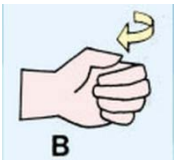
Both before and after you mix your growing medium, a simple way to determine what type of soil texture you have—and whether or not you need to add more of other types—is through a simple soil test

Simple Soil Test

A. Grab a handful of soil, make a fist with it, and stick it in a bucket of water, holding it tight

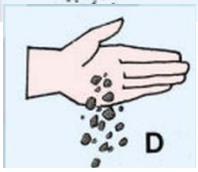


B. Remove your hand from the water and crush the soil between your fingers

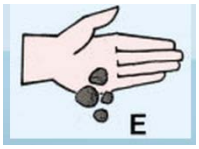


C. If there is little resistance and the sample falls into dust, it is mostly sand and lacking in clay

D. If there is medium resistance, it is silty clay or sandy clay



E. If there is great resistance and the sample remains intact, it is mostly clay



In conducting the Simple Soil Test, if you find that you have mostly sand (c), you can add humus, compost, or dried manure to create a better texture. If you have great resistance (E), you can add sand from a nearby river or streambed. In all cases, unless you are blessed with soil that is already fertile and well-structured, you should amend your planting medium to ensure your seedlings have the nutrients they need to thrive, both in the nursery and while growing in your Forest Garden. We will talk more about amending your soil below.

Soil Amendments

A soil amendment is any substance added to the soil to improve plant growth. Soil amendments can add nutrients, enhance soil structure, improve water retention, protects plants' roots against pests and disease, or change the soil pH level. When working with highly degraded soils, amendments are needed to improve both the nutrient content and structure of your Forest Garden soils. Below is a list of some of the major soil amendments and their effects on soil.

- **Bone meal** – Made from crushed bones, this slow-release soil amendment contains large amounts of phosphorus and calcium. Adding bone meal to the soil makes it a good part of a long-term soil correction strategy for pH problems (i.e. it decreases soil acidity) and calcium leaching. Bones are easier to crush if they have been cooked in a fire for several hours.

- **Biochar/charcoal powder** – This purified form of organic carbon is most useful for water retention, as it can hold up to six times its weight in water. Additionally, charcoal is covered in micropores, which provide living space for beneficial bacteria in the soil. A balanced microbial content in your soil helps with nitrogen fixation, nutrient release, and pest suppression.
- **Compost** – The nutrient content of compost is variable, and is entirely dependent on the materials which were used to make it. As compost is fully decomposed, the nutrients are easily absorbed by plants. Naturalized soil bacteria are abundant in compost as it is generally formed from local organic materials As the material in compost is fully broken down and the structure is stable, it is also the best amendment for improving soils with poor water retention or severe compaction. Look at the Compost section to learn how to make it.

- **Egg shells** – Egg shells are high in calcium and especially good for cabbage family crops. They are often available in large quantities from local breakfast vendors.

You can pound them into a fine powder before adding them directly to the soil, or into your compost pile.

- **Coffee Grounds** - Grounds are an excellent and, depending on location, abundant source of organic nitrogen. It is already in a stabilized form and is slowly released into the water in the soil for uptake. Coffee grounds can be added to the compost pile, mixed directly into the soil during the double digging process, or added as a soil amendment when planting trees or other plants around the homestead.

- **Leaves (green and brown)** – Decomposing quickly due to their size, leaves are useful for quick nitrogen and carbon inputs. As we've discussed, leaves can be a very useful green fertilizer or mulch. Depending on species, they will have varying effects on soil structure, nutrient loads, pH, and pest problems.

- **Manure –** One of the most readily available soil amendments in rural farming communities, manure is heavily loaded with nitrogen and decomposers. Manure will slowly break down, releasing nutrients and slightly improving soil structure. Be sure to let the manure decompose or dry out before use to prevent the potassium and phosphorus from "burning" the plant in their raw state. However, manure can attract termites, and can contain large quantities of weed seeds, so compost is preferable when available.

- **Wood ash** – This quick-release pH stabilizer contains soluble potassium and phosphorus. It does not have the long-lasting effects of bone meal and biochar, so should be reapplied annually to counter severe pH problems. NOTE: It is common in some places for people burn large quantities of plastic in a fire. Be sure that the wood ash you collect comes from a pure wood fire, as plastic is toxic to the soil and harmful to your health.

Building Your Nursery

Bed Size and Working Space

The width of each bed within the nursery should be about 1m. This width allows for easier watering and weeding. If the beds are too wide, it can be difficult to reach all the way to the center. The length of a nursery bed varies based on the size and shape of the nursery site, as well as the number of seedlings you are raising. Leave between 60cm to 1m between nursery beds to allow for room to walk, work and carry tools and materials between them.

Other factors that influence the size of your nursery include a place for soil dumping and mixing, and space for packing soil into pots. It is important to have space to work freely, so plan accordingly. It is also a good idea to leave space for compost piles, which can provide the amendments needed for healthy growing medium.

After an appropriate nursery site is determined that meets all of the criteria, and the tools and materials are collected, it is time to start preparing your nursery beds

before sowing the seeds. There are two basic methods for producing your seedlings: tree sacks or bareroot. The method you use will determine the next steps. It is likely that you will use a combination of the two methods in your nursery, depending on the species you raise.

Nursery Methods

Double Digging

It is best to double dig and amend your beds before sowing seeds. This will ensure proper aeration and healthy root growth. The purpose of double digging is to loosen the soil and add soil amendments within it.

Before double digging your beds, gather the following tools and materials:

- A spade and, if available, a digging tool
- 4 shovels full of Compost or Manure per square meter
- 1 shovel full of Charcoal Powder per square meter
- 1 shovel full of plastic-free Wood Ash per square meter

When you have your tools and materials at hand, begin double digging:

1. Start by marking the corners where you want your nursery bed to lie. The bed should be one meter wide. The length depends on the size of your site but should be no more than 10 meters long so that you can move from one side of the bed to the other easily.
2. Remove the cover vegetation and transfer it to an area that is out of the way (alternatively, add it to your nursery's compost pile).
3. Start at one side of the bed and mark an area about 2 shovel widths (25 cm) down the length of the bed. Using a shovel, pickaxe, or digging tool, remove the topsoil from the first section you marked off, down to the depth of the hardpan (or about 25 cm where there is little to no topsoil). Place the topsoil you dig out at the end of the bed.
4. Dig the next 25 cm of subsoil below the topsoil you just removed. Do not remove this subsoil, but loosen it, breaking up the larger pieces of dirt. It makes the process much easier to have a partner with you to alternate digging out topsoil then loosening the subsoil.
5. Move down to the next 50 cm section that you marked off. This time, instead of putting the soil to the side as you remove it, shovel it to the first section that you dug out and add the topsoil to fill that hole.
6. While you fill, place 2 shovels of manure or compost, and a half shovel each of wood ash and charcoal powder on top and mix it all in well to amend the soil.
7. Then loosen the subsoil from the second section you just dug out. Continue this process of moving the topsoil, amending it, then loosening the subsoil along the entire length of the bed. When you reach the end of the bed and have loosened the final section of subsoil, place the topsoil that you dug out from the first section to fill in the last section, then add and mix the amendments. When you've worked the entire bed in this fashion, you've double dug your bed.

The bed should be level with the ground surrounding it in areas of average rainfall, elevated in places with high rainfall, or sunken into the ground in arid places. If the beds are raised, it helps to build support around its sides with rocks, wood, bricks, etc., to prevent the soil from washing away during heavy rains.

After you have double dug and amended the beds, you can sow your seeds. Be sure to pretreat the seeds first, if needed (see seed pretreatment section below). Make small trenches with your finger or a stick about 10 cm apart, and plant the small seeds about 5 cm apart within the trenches. For seeds larger than 1 cm in diameter, space them with a distance of about 3 times their diameter. Cover the seeds lightly with soil. After sowing the seeds, cover the beds with dry grass or other light, organic material to prevent evaporation as well as to keep birds from eating the seeds. Avoid using dry grasses that have gone to seed, as they will increase your nursery's weeding requirements. Water the bed with about 5 liters of water per square meter before finishing.

Bareroot beds

Bareroot beds mean raising seedlings directly in a bed of soil. Once the seedlings are ready to transplant they are dug up and transplanted 'bareroot'. The advantage of bare-root beds is that they do not require tree sacks, which cost money, and they require less space than tree sacks. The disadvantages of bareroot seedlings is that it is labor intensive to double dig the beds, they are at greater risk of drying out during transplanting, and they are more prone to stunting or dying once planted due to greater root disturbance when removing and transplanting them.

Many agroforestry, fruit, and timber tree species can be planted in bareroot nurseries. Though tree sacks are often more successful, probably due to less root disturbance when planting. Trees with a deep taproot—as opposed to shallow, more fibrous root systems—tend to respond better to bareroot propagation since there will be less root binding in the beds, thus less disturbance when removed. Papayas, though, are notorious for responding poorly to bareroot propagation. Even trees such as citrus, which spend a long time in the nursery, may be raised in bareroot. For any tree raised in a bareroot bed, it is critical to keep the roots moist after removed from the beds or they will easily dry out and die. This is best accomplished by dumping a mud slurry over the roots immediately after removing them from the beds, then wrapping them in banana leaves to transport and plant them. Do not remove more than you will plant in a short period of time, place them in shade where possible, and take some water with you to pour over them if they start to dry out, and after planting them.

Directly seeded, bare root beds

Tree Sacks

Tree sacks (also called polybags or pots) are generally thin plastic containers that are used to grow seedlings in tree nurseries. There are many types and shapes of tree sacks. They are most often made from polyethylene, but can also be made from materials you find around your community, including used plastic bags, empty chips/snack bags, or even banana leaves formed into bags. The polyethylene sacks come in various diameters. Smaller sizes (8-10cm) are fine for most agroforestry species, where larger sacks (up to 20cm) are better for more valuable fruit or timber trees. The larger sizes are necessary for grafted seedlings, for which more time is needed in the nursery. It is cheapest to buy roles of polyethylene and cut the sacks to size (usually about 15cm), but if that is not available, you can purchase bundles of pre-made tree sacks. Fruit species like cashew, avocado, papaya, guava, pineapple, pomegranate, cola, and many timber species are usually sown in tree sacks.

Though tree sacks are more expensive, and they are heavier to transport than bareroot, they do offer an important advantage: since the roots are surrounded by soil and housed in a protective sack, the risk of roots being damaged or exposed to the elements when transporting them to the planting sites is greatly reduced.

Filling tree sacks:

The growing medium you use for filling the sacks is important to the health and development of your seedlings. Review the *Soils* section for more information on mixing the most appropriate soils. In many places, a good mix that would provide a loamy soil is 3 parts topsoil to 1 part humus, compost, or dried manure, to 1 part sand. It is important to ensure that the mixture will contain sufficient nutrients to support the development of seedlings, while having proper drainage. To mix the medium and fill the sacks you need:

- Topsoil, sand, and compost/humus/dried manure
- Buckets or a wheelbarrow to carry materials
- A screen to sift them (about .5 cm)
- A shovel to mix them
- A watering can to moisten the mixture
- Tree sacks to be filled

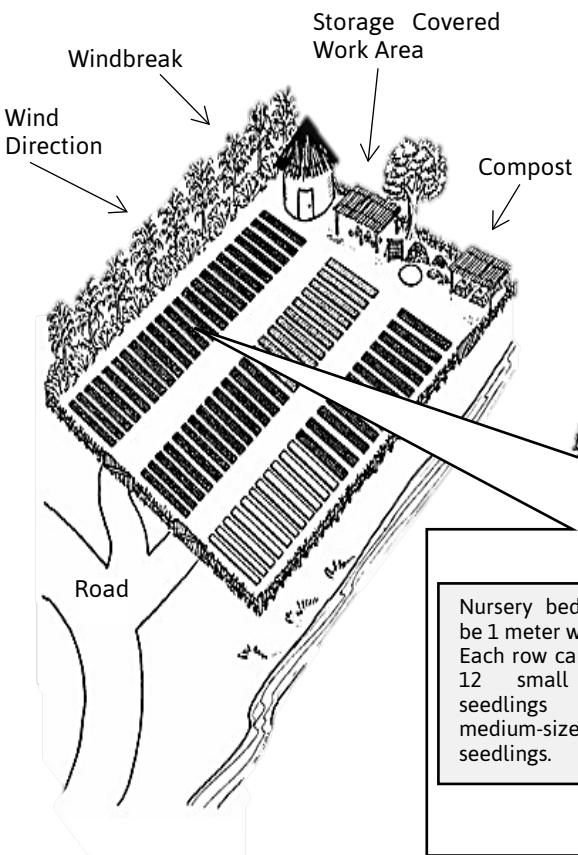
When you have the materials, follow these steps:

1. Delineate your nursery bed(s), one meter wide. You can set a stake in each of the four corners and pull tightly around them to form a rectangular barrier to keep the sacks in straight lines. Or you can pre-dig a shallow rectangular hole a few centimeters deep to place the filled sacks into.
2. Bring three wheelbarrows (or buckets) of topsoil, one of sand, and one of humus, compost, or dried manure to the site where you will mix them. You may need more or less, depending on the number of sacks you need to fill, but be sure the proportions are consistent.

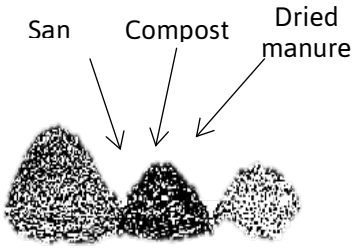
3. Sift the materials into one pile and mix them until you have a consistent blend throughout.
4. Water the mixture, and continue to mix until it is uniformly moist, but not muddy.
5. Fill one sack at a time. Make sure that you pack down each sack as you fill it up. Pinch the bottom or hold it to the ground to keep the soil in and tap it against the ground to compact the soil. You want to avoid air pockets and ensure the soil is firmly packed in, but not too tight to prevent water and air from circulating as the seedling grows. The sack should be able to stand upright without sagging over when done.
6. As you fill the sacks, place them in the prepared bed. Make sure that each sack is pressed tightly against the other, so that the nursery is as compact as possible.
7. Once the nursery is arranged properly, it is preferable to water them for one week to allow weeds to grow (and be removed) and the mixture of sand and manure to settle.

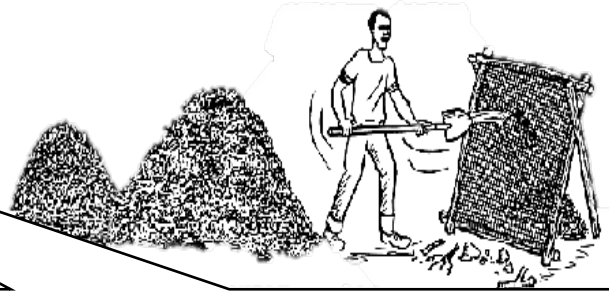
Nursery Construction

Layout of a Tree Nursery



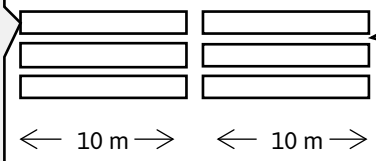
A Good Soil Recipe for





Nursery Bed Dimensions

Nursery beds should be 1 meter wide. Each row can contain 12 small potted seedlings or 16 medium-sized potted seedlings.

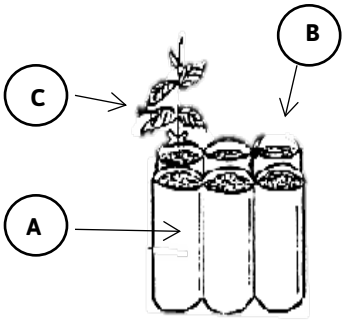


Leave 60 cm wide paths among the nursery beds

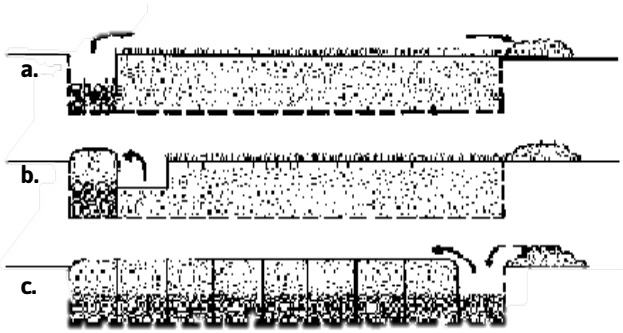
10 m — 10 m

Nursery beds can be 10 meters long.

Potted Tree Seedlings



A. Pots are filled 1 cm from the top.
B. Pots are placed in straight rows leaving space for drainage.
C. Seeds are placed in the center of the pots.



a. Dig and remove soil from nursery bed at depth of 30 cm.
b. Repeat the first step further down the bed BUT transfer soil to previous Area, mixing in compost and manure as you go.
c. Continue down bed (repeating step **b**). At the end, transfer soil from first section to last.

Building Your Shade Structures

When seedlings are very young, hot, direct sunlight over the course of the entire day is too much for them and can lead to excessive wilting or mortality. To protect them from the sun, you can easily build shade structures with some wood poles, nails or rope to fasten them, and grass or palm fronds to provide the shade. You can do this after the beds are prepared and tree sacks are filled and placed in the beds. Toward the end of their time in the nursery, you will gradually remove the shading over the seedlings—during a process called hardening off (described below)—to prepare them for harsher conditions when outplanted.

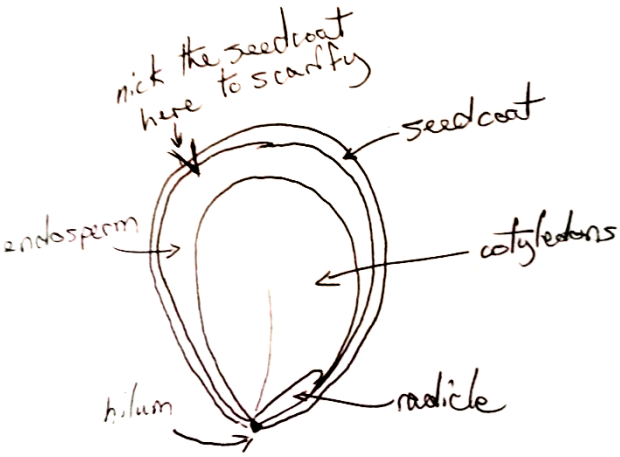
To build the shading structures you will need at least four poles (about 5cm in diameter) that frame the perimeter of each of your nursery beds, then at least four poles to support the frame. If you do not have poles long enough to run the length of your beds, you can attach additional poles together. So for instance, if you have a 3 meter x 1 meter bed, you would need two 3 meter poles and two 1 meter poles to frame the perimeter, then four 1-1.5 meter poles placed vertically at each corner of the bed to support the frame. If you have an 8 meter x 1 meter bed, you could use four 4 meter poles to run the lengths, then the two 1 meter poles for the width of the frame, and six 1-1.5 meter poles for support (1 at each corner, then 1 halfway down each length to support the longer poles).

When you have all of the poles you need, dig holes for the support poles, then stick them securely into the ground upright. After those are in place, join the frame poles to each other and to the support poles using nails or rope. When the structure is built, gather a number of small, 1 meter sticks (1-2cm in diameter is fine for these) that can be place across the width of the beds, spaced about 30 to 50 cm apart, fastened to the poles down the length with string or twine. When that is complete, place a thin layer of grass, palm fronds length-wise across the frame to provide about 60% shade, allowing about 40% of sunlight to pass through.

Seed Pretreatment

The hard seed coats of many tree species prevent water from penetrating through, allowing the seeds to remain dormant. Dormancy is a state in which seeds are prevented from germinating immediately, often giving the seed a chance to be dispersed, or waiting until environmental conditions are appropriate for them to germinate. This is advantageous in nature because it increases the chances of the seeds' dispersal and survival. In your nursery, however, you want seeds to germinate at the same time. You can encourage rapid, uniform germination by pretreating your seeds. The purpose of pretreatment is to break down or open the hard seed coat so that water can penetrate and induce germination. The seeds will generally swell when germination is induced.

In many species that grow in moist, tropical forests, dormancy is not a problem. Environmental conditions are generally suitable for germination as soon as the seeds are dispersed from the tree, so seeds will likely germinate in a matter of days or weeks and would not benefit from dormancy. In the drier tropics, on the other hand, seedcoat dormancy is common due to harsher conditions, and some form of pretreatment is necessary to obtain rapid and uniform germination.



For the species that do benefit from pretreatment, there are various methods you can use, depending on the type of seed. For seeds that have a soft coat they may only need to be soaked in water for a period of time. For harder seedcoats, it is necessary to scratch or break the seed coat to allow water to penetrate. This method, called scarification, can be accomplished by nicking the edge of the seed coat with a pair of fingernail clippers. Be sure when you scarify seeds, however, that you do not damage the hilum side, which you can see as a point, dot, or intrusion on the seed, as this is where the root (radicle) and first leaves (cotyledons) emerge from the seed (see diagram below). For species with very hard seedcoats, you may need to bring water to a boil, remove it from the heat, place the seeds in the water, and allow them to soak for a period of time. Before sowing seeds in your nursery, be sure you know which pretreatment method, if any, is applicable to the species you are sowing and pretreat them accordingly to ensure rapid, uniform germination.

Seed Sowing

Keep in mind that not every seed you sow will germinate and grow into a healthy seedling. Some seeds will simply not germinate, and others may suffer from stunting, pest attack, disease, and mortality in the nursery, and should not be outplanted. So remember to always purchase or collect more seed for sowing than the number of trees you expect to outplant from your nursery. The additional number of seeds to sow depends on the species as well as the viability, or germination rate, of the seed.

It is a good rule of thumb, however, to sow two seeds in each tree sack for smaller seeds. If they both germinate, you can transplant one of the seedlings to a seed sack where neither seed germinated. For larger seeds, particularly fruits (e.g. mango, avocado, cashew), sow only one per sack, and re-sow those that do not germinate. For bareroot beds, sow the seeds closely together, by spreading those that germinate closely together

into the spaces where seeds did not germinate. As some of the seedlings may die in the nursery after germination, it is also a good idea to sow 5 to 10% more seeds or sacks than you hope to ouplant to account for this loss.
To sow the seeds:

1. Use your finger or a stick to push two holes in each sack, or to create a shallow trenches that run straight lines across the width of bare root beds. The depth of the holes or trenches should be about twice the width of the seed you are sowing.
2. Create all the holes first, then sow the seeds in each hole without covering them up. This way you will know where you have already sown.
3. When they are all sown in sacks, or evenly down the trenches in the bareroot bed, cover the seeds with soil, to cover twice the width of the seed, and gently tamp the soil to remove any air pockets.
4. After sowing all the seeds, water them with about 5 liters of water per square meter.

Caring for Your Seedlings in the Nursery

It is impossible to overemphasize the importance of nursery care. The seedlings in your nursery require daily attention, and even twice-daily attention in the initial weeks after sowing your seeds. So be sure that you or someone in your family or group will be available every day to provide the care and attention needed. The primary care, beyond general protection, involves regular watering and weeding. As the seedlings grow, you will also need to thin them as needed, then harden them off to prepare them for outplanting.

Watering

Keep the following important considerations in mind to keep your beds watered:

- Water nursery beds with approximately 5 liters per square meter
- If a watering can is not available, be sure that all water is being poured slowly with the vessel close to the soil surface. If watering is not careful, soil will erode and seeds or roots can become exposed.
- Watering should be done in the morning before 10h00 and/or evening after 17h00.
- In the first two weeks, water the seedlings twice per day: in the morning and evening as watering in the middle of the day will lead to higher evaporation and water loss.
- It is not necessary to water immediately following a rain event where the soil has been left moist
- Sufficient watering will keep the seeds and seedlings moist at all times, but not so much that the water sits in the sacks and waterlogs the seedlings
- If the soil surface begins to show signs of a green color change (suggesting moss or algal growth), reduce the quantity of water per event
- If the leaves on the seedlings show signs of wilting (suggesting too little water) even shortly after watering, increase the amount of water given each day

Weeding

Weeds will compete with seedlings for sunlight, water, and nutrients, which can stunt their growth. Keep in mind the following to keep your beds free of weeds.

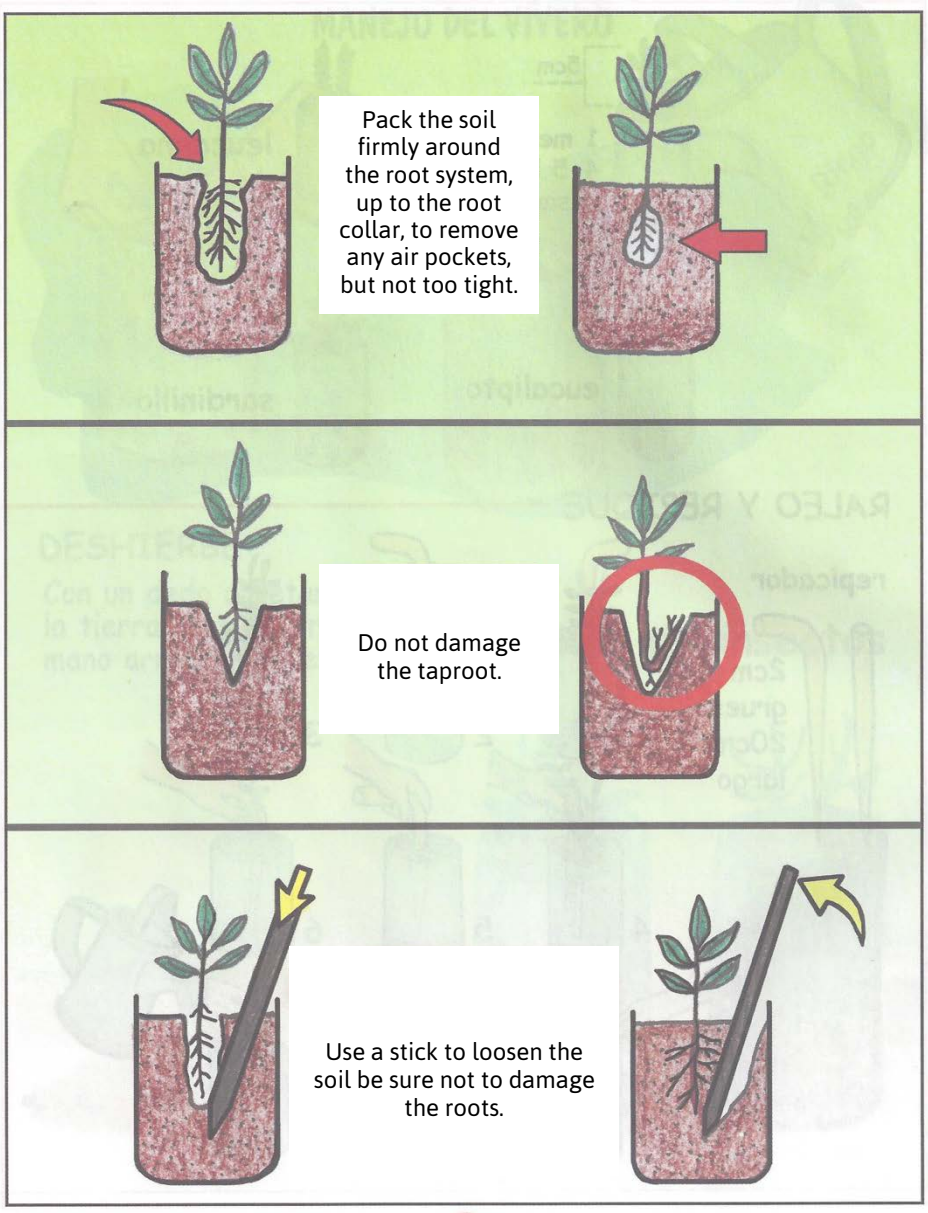
- Tree nurseries should be weeded at least once a week
- Do not weed tree nurseries in the first week after your trees have germinated – the seedlings' roots will be too weak
- Be careful not to mistake the seedlings for weeds, as they can look similar when very young
- Remove grasses and weeds from around your nursery beds, and keep them clear during the entire nursery season as their seeds can easily spread onto your beds, requiring more time to keep them weeded.

Thinning

When more than one seedling grows in a sack, seedlings should be thinned down to one seedling in each sack as they will compete for moisture, nutrients, and sunlight. Follow the steps below for thinning:

1. Thinning should be done in the shade to reduce heat stress on the seedlings.
2. Thin to one tree per sack when seedlings are 10cm tall, or about a month after seeding
3. Use a twig to prepare transplanting holes in the dirt of empty tree sacks (those where no seedlings germintated) before thinning.
4. Gently remove the weaker looking seedlings, (shorter, thinner) trying to keep the roots intact
5. It helps to insert a small twig or piece of metal wire into the soil at the base of the seedling you are removing
6. Rotate the twig or wire in a circle while grabbing the base of the seedling stem and very gently pulling it upward
7. Plant the healthiest of the removed seedlings into the prepared empty tree sacks in your nursery. Be sure that the seedling stems are pointed straight down in the sack.
8. Gently repack disturbed soil in the tree sacks to remove air pockets
9. After replanting, water the seedlings until lightly moist

For bareroot beds, thin the seedlings that are close together, transplanting them into spaces where seeds did not germinate using the same method described above.



Hardening Off

In the last month in the nursery, gradually remove shade from the seedlings and water to condition the seedlings for what will likely be harsher conditions once transplanted.

- Approximately one month from the start of the rainy season, remove the shading materials from over the nursery beds gradually, for one hour in the morning and one hour in the afternoon. After 3 or 4 days, reduce shade by another couple of hours. Keep doing this, and after 2 to 3 weeks, seedlings will tolerate full sunlight with a minimum of shock.

- The time between watering periods should also be gradually extended by 2 to 3 days. The number of waterless days is progressively extended until seedlings are capable of surviving a week or more without water.

- In water reduction, take care to avoid wilting. If it occurs, apply water until wilting stops, then begin reducing the amount of water again, but more slowly than before.

Species Pretreatment and Nursery Information

SPECIES	SEED PREPARATION	NURSERY PERIOD	DAYS TO GERMINATE	# PER POT	USES
Acacia abyssinica	Scarify	18-24 wks	6 – 30 days	2	fodder, light shade, living fence
Acacia albida	scarify	10-14 wks	6 - 30 days	2	fodder, intercropping
Acacia ataxacantha	soaked in hot water	10-14 wks	3-15 days	2	living fence, fodder
Acacia holosceria	Boil water, remove from heat, then soak	10-14 wks	7 - 25 days	2	windbreak, border planting
Acacia laeta	scarify	10-14 wks	4 - 15 days	2	living fence, fodder
Acacia mellifera	scarify	8-10 wks	4 - 15 days	2	living fence, fodder
Acacia nilotica	scarify	14-18 wks	5 - 18 days	2	living fence, fodder, fuelwood
Acacia polycantha	Boil water, remove from heat, then soak	10-14 wks	10 - 21 days	2	living fence, fodder, fuelwood
Acacia senegal	scarify	14-18 wks	7 - 21 days	2	living fence, intercropping
Acacia seyal	Boil water, remove from heat, then soak	8-10 wks	5 - 20 days	2	fuelwood, fodder
Acacia sieberiana	Boil water, remove from heat, then soak	10-14 wks	5 - 20 days	2	fuelwood, windbreak
Acacia tortillis	Boil water, remove from heat, then soak	14-18 wks	5 - 15 days	2	fodder, fuelwood
Adansonia digitata	Boil water, remove from heat, then soak	12-16 wks	14 - 28 days	2	fodder, fruit
Albizia lebbek	Boil water, remove from heat, then soak	15-18 wks	3 - 14 days	2	fuelwood, windbreak
Anacardium ocidentale	24 hr cold soak	6-8 wks	12 - 30 days	1	fruit, windbreak
Annona spp.	scarify	12 wks	21 - 45 days	2	shade, windbreak
Azadirachta indica	none	6-8 mos	7 - 21 days	2	fruit
Balanites aegyptiaca	24 hr cold soak	18-24 wks	7 - 15 days	2	fruit, living fence
Bauhinia rufescens	Boil water, remove from heat, then soak	20-24 wks	17 - 42 days	2	living fence, windbreak, fodder
Borassus aethiopium	none	direct seed	20 - 40 days	1	fruit, border planting, timber
Bougainvilla spectablis	soak cutting 24 hrs	6 mos	cuttings	1	living fence, ornamental
Cajanus cajan	none	10-14 wks	5 - 10 days	2	fodder, intercropping
Calliandra calothyrsus	Boil water, remove from heat, then soak	12 – 16 wks	12 – 24 days		
Carica papaya	24 hr cold soak	6-8 wks	15 - 21 days	2	fruit
Cassia siamea	scarify	10-12 wks	15 - 20 days	2	windbreak, shade, ornamental
Cassia sieberiana	Boil water, remove from heat, then soak	10-14 wks	7 - 20 days	2	ornamental, timber

Casuarina equisetifolia	none but ants attack	4 mos +	5 - 22 days	bareroo t	windbreak, fuelwood, timber
Citrus spp.	none	4 mos +	15 - 30 days	2	fruit
Chamaecytisus proliferus	24 hr soak	8 – 12 wks	8 – 15 days	2	fodder
Cola cordifolia	none	many mos	21 - 35 days	2	fruit
Daniella oliveri	Boil water, remove from heat, then soak	6-8 wks	10 - 26 days	1	fodder, fuelwood
Delonix regia	scarify	12-18 wks	12 - 20 days	2	ornamental
Detarium senegalense	scarify	20-24 wks	8 - 15 days	1	fruit, ornamental
Dialium guinese	Boil water, remove from heat, then soak	1 yr	15 - 24 days	1	fruit, timber
Dovyalis abyssinica	none	6 mos + or Bareroot	14 – 28 days	2	living fence, fruit
Euphorbia balsimifera	cuttings	N/A	7 - 81 days	1	living fence
Gliricidia sepium	none	8-12 wks	9 - 15 days	2	living fence, fuelwood
Gmelina arborae	24 hr soak	12-14 wks	7 - 30 days	2	ornamental, timber
Grevillea robusta	None	12 – 18 wk	12 – 24 days	2	living fence, timber
Jatropha curcas	none (plant white tip down)	10-12 wks	7 - 14 days	2	living fence, border planting
Khaya senegalensis	none	12 - 24 mo	7 - 18 days	2	shade, ornament, timber
Leucaena leucocephala	Boil water, remove from heat, then soak	12-16 wks	7 - 21 days	2	intercropping, fence, windbreak
Manguifera indica	remove hull	4-6 wks	7 - 21 days	1	fruit
Moringa oleifera	none	10-12 wks	5 - 12 days	2	food
Parkia biglobosa	Boil water, remove from heat, then soak	10-14 wks	7 - 15 days	2	fruit
Parkinsonia aculeata	Boil water, remove from heat, then soak	8-10 wks	2 - 10 days	2	windbreak, living fence, ornament
Prosopis juliflora	Boil water, remove from heat, then soak	12-14 wks	5 - 10 days	2	windbreak, livefence, fuelwood
Psidium guajava	24 hr soak	7-8 mos	7 - 16 days	2	fruit
Sesbania bispinosa	soak 24 hrs	8-10 wks	5 - 10 days	2	fodder
Sesbania sesban	soak 24 hrs	10-14 wks	3 - 7 days	2	fodder, fuelwood
Tamarindus indica	Boil water, remove from heat, then soak	20-24 hrs	7 - 10 days	2	ornamental, fruit
Ziziphus mauritiana	crack, remove, soak stone	12-18 wks	7 - 45 days	2	living fence, fruit

CHAPTER 5: REFERENCES

1. For more on these topics, see the Peace Corps Senegal Agroforestry Training Manual and the TOPS Permagarden Technical Manual.

2. This section adapted from FAO Training: Soil Texture "The dry crushing test", ftp://ftp.fao.org/fi/cdrom/fao_training/FAO_Training/General/x6706e/x6706e06.htm.

3. The Overstory ejournal, http://agroforestry.net/component/content/article?id=145:overstory-125-direct-seeding

Chapter 6: Fruit Trees

The sections above discuss everything you need to know to collect seeds, prepare your nurseries, raise seedlings, and plant them using agroforestry formations to begin protecting and revitalizing your Forest Garden site. In the second year, as your green walls and fertilizer trees are stabilizing and fertilizing your soils, it is time to start thinking about diversification. Following the Forest Garden Approach, we begin diversifying the perennials in Forest Gardens by planting fruit trees before moving on to timber trees and perennial shrubs, vine, and ground covers in year three.

Rearing Fruit Seedlings

There are endless species of fruit trees that could be planted in Forest Gardens, based on the needs and interests of the families who plant them. In TREES' Forest Garden projects, we tend to focus on those that meet market demand for families to earn income from them. As the scope of this manual is to offer general resources to guide trainers, we will focus on a handful of the more common species that families plant in their Forest Gardens.

Mango
Mangifera indica

Tree Description

Mangifera indica is a large evergreen tree to 20 m tall with a dark green, umbrella-shaped crown. Fruit an irregularly egg-shaped and slightly compressed fleshy drupe, 8-12 (max. 30) cm long, attached at the broadest end on a pendulous stalk. The skin smooth, greenish-yellow, sometimes tinged with red. The underlying yellow-orange flesh varies in quality from soft, sweet, juicy and fibre-free in high-quality selected (clonal) varieties to turpentine flavoured and fibrous in wild seedlings. The trees are drought tolerant but do not seem to suffer from occasional flooding. Mangoes are one of the most popular, widely-produced fruits in the world. However, production of local varieties with low yields and small fruit greatly reduces the profitability of mango cultivation. Specialized varieties require large amounts of start-up labor, and constant care for at least the first three years.

Bareroot Germination:

The best method to start mango seedlings is in a bareroot bed. Prior to sowing the seeds, double dig and amend the bed as we described above (see section on nursery beds). After preparing the bed, sow the seeds with 5 cm spacing between seeds, and 10 to 15 cm between rows, depending on the size of the seed. Then cover the seeds with a thin layer of soil.

Be Sure You Are Sowing Polyembryonic Mango Varieties

There are two varieties of mango seeds: monoembryonic and polyembryonic. Monoembryonic means it has one embryo inside the seed shell; Polyembryonic means there are multiple seeds inside each shell. However, polyembronic seeds generally take on the traits of the parent tree, where monoembryonic seeds do not. Whether you plan to graft your mango trees or not, it is best to select healthy fruits of polyembryonic varieties, grown near your Forest Garden. This will help to ensure they

There are a few reasons why it is beneficial to sow the seeds in a germination bed:

- To prevent seed rot, as water will drain more freely in the open soil of a bareroot bed
- The individual sprouts of polyembryonic seeds can be more easily thinned when dug up from the bed than when started in tree sacks

- Smaller or weaker seedlings can be left or replanted in the same bed (if pulled out during removal of stronger seedlings) for later use once the stronger seedlings have been moved.

Trenching Trees:
Once the healthiest seedlings from the bareroot nursery have been identified, they should be transferred to trenches. Trenching trees allows the trees to develop with more space and nutrients than are commonly available with tree sacks. Trenching also allows trees to establish a taproot that will be essential to drawing the nutrients and moisture required to survive grafting, and then allows easier removal of the root ball at outplanting. Typically, trees are trenched at the end of the rainy season. To trenchtrees:

- Dig a straight trench 50cm wide by 30cm deep.
- Carefully remove seedling clusters from the germination bed with a spade shovel, and gently separate the seedlings by hand. Select the strongest, most developed seedlings and transplant them into trenches
- Trim any kinked, rotten, or injured roots
- Return small or underdeveloped seedlings to the bed or discard them if you have the number of seedlings needed. If seedlings are diseased or pest-ridden, burn them. If they are deformed they can be composted.
- Transplant the healthy seedlings into the trenches, leaving 30cm spacing between seedlings.
- Remove all but a few of the leaves to cut down on evapotranspiration.

Trenching grants the following benefits:

- Water saving – Trenched trees require less water compared to trees out-planted in the field, this means less care while they mature to a graft-able age.
- Root care – Removing the bottom of the tree sack allows the taproot to grow without risk of damage or infections from water logging. The top part of the sack helps slow lateral roots to reduce transplanting stress.
- Grafting station – Tree trenches are the ideal place to graft, as they are protected and easily monitored.

Propagation Data

Propagation Method: From seed
Seed Collection: Seeds should come from matured fruits grown in your area. It should be free from insect damage, diseases or mechanical injuries. Avoid seeds coming from processing plants, since most of them are non-viable due to exposure from heat.
Seed Pretreatment: Dehusking or removal of the husk is recommended to facilitate fast germination. Be sure that dehusked seeds are plump and plant only those that are free from pest damage or physiological injuries. Healthy seeds should be sown with concave side down, 5 cm apart and 1 cm deep. This position prevents the development of crooked stem after germination.

Site Requirements

Preferred Soils: Mango does not have strict soil requirements, since the trees are deep-rooted and grow over a wide range of soil type and fertility levels. Planting trees in waterlogged areas should be avoided to prevent depletion from oxygen and infection due to soil-borne fungus.
Optimal Spacing: Generally at least 10 x 10m, but depends on variety

Tree Care

Pruning Period: Preferably pruning should be done during summer months after harvest. If done during the rainy season, the cut portions should be protected from fungal infection by application of fungicides, paint or coal tar.
Pruning Frequency: Pruning is done to remove undesirable and crowded branches which are of no use to the tree. This includes the removal of water sprouts, old, decaying and unproductive dried and overcrowded branches, infected and infested parts to discourage the presence and multiplication of insect pests and diseases. Pruning allowed maximum light penetration and air circulation in the canopy. This minimizes the build up of diseases inoculum and insect population particularly, mango leafhoppers.

Avocado

Persea americana

Tree Description

The Avocado is an evergreen tree reaching 10-20 meters in height. The small yellowish flowers are in clusters of thousands at the ends of new stem growth. Fruit shape ranges from pyramidal or pear-shaped to oval or spherical. The skin texture ranges from smooth to scaly with a color from dark green to violet. The flesh color varies from pale yellow to a clear green. Depending on the variety, fruit size may be 50g-2kg with up to half of that weight being the seed. Grafted trees begin producing fruit after 4-5 years, usually between May and December. Fruits mature 6-12months after flowering.

Propagation Data

Propagation Method: From seed
Seed Collection: Collect seeds still on the tree so as to lower the chances of the seeds picking up fungi
Seed Pretreatment: Soak seeds in hot water for 30 min as a treatment against the seed born fungal disease *Phytophthora cinnamoni*
Germination Rate: Allow seed to germinate by leaving it half submerged in a cup of water before being placed in a polypot, To ensure uniform germination
Time to Germination: Allow 4-6 weeks for germination
Time in Nursery: 15-18 months in the nursery
Grafting Method: Whip and tongue or T-budding are the most common
Age before fruiting: 4 to 5 years

Site Requirements

Preferred Soils: For best production, deep, fertile, well-drained soils, particularly sandy or alluvial loam soils and have a pH of neutral or slightly acid are suited for avocado.
Minimum Rainfall: Minimum annual rainfall requirement of 750 – 1,000 mm is recommended
Optimal Spacing: 8x8m spacing with 80x80x80cm hole

Tree Care

Pruning Period: Winter months
Pruning Frequency: Only those decayed or dead branches that hamper its growth should be pruned. Varieties which have a vertical growth can be pruned judiciously to encourage horizontal growth

Common Pests: Pests: Scales, thrips, and fruit flies are all pests of the trees; Root Rot (*Phytophthora cinnamomi,* fatal); Cercopsoriose
Irrigation Needs: In areas with distinct wet and dry seasons, water supply is very essential during dry months, especially during the first 2 or 3 years of the trees. Young trees are very sensitive to heat and water and should be irrigated regularly. Irrigate every two weeks.
IPM Methods: Root Rot: Avoid planting trees in soils that have poor drainage and avoid over watering; Cercopsoriose: Spray with benomyl at 10 day intervals during the rainy season and 28 day intervals during the dry season when fruit is on the tree.

Cashew

Anacardium occidentale

Tree Description

The Cashew is an evergreen tree that grows to a 10 to 12 meter height. It is easily recognizable by its spreading crown. Its leaves have rounded ends, clear veins, and are distinctively glossy. They leaves are spirally arranged and could be described as elliptical or obvate, 4 – 22 cm long and 2 – 15 cm broad, leathery in texture and a smooth margin. Cashew has a dominant taproot. The flowers are produced in a corymb of up to 26 cm long. They have five petals, and are initially pale green, eventually turning reddish.

Fruit Description

Fruit is a fleshy apple, typically 3-6 cm in size. Fruit color ranges from yellow to orange to red. The seed is attached to the bottom end of the fruit and hangs externally. The pulp is very juicy, but the skin is very fragile and extremely susceptible to consumption by insects, animals and birds alike. This makes it unsuitable for transport.

Propagation Data

Propagation Method: Cashew can be propagated by seeding in a nursery, direct seeding, and/or grafting.
Seed Pretreatment: You should remove the seeds and dry them in the sunlight. Pre-treat seeds in a 24 hour cold soak. Discard the floaters (They might germinate but won't necessarily produce good trees).
Germination Rate: Depends on the quality of seeds, but make sure to get rid of the floaters.
Time to Germination: Depends on how you plant the seed, but the seed should be planted like a desk phone, the bottom (bigger part) farther in the dirt and the top part showing a little for most rapid germination (approximately 5 days to one week with treated seeds).
Time in Nursery: Cashews should have 6 to 8 weeks in the nursery. Do not over water or the seeds will mold
Grafting Method: Whip and tongue grafting
Age before fruiting: 3 to 5 years

Site Requirements

A 20 x 20 x 20 cm transplant hole is sufficient. Be careful not to damage the taproot when transplanting. Do not wait too long to outplant seedlings as the danger of damaging the taproot increases. The planting distances for cashew varies depending on

the purpose the tree is supposed to serve. If planted in a field where crops will continue to be grown, 5 x 20 m space is generally recommended. For orchards, 12 x 12 m spacing is recommended. Cashews do well when direct seeded. Seed two per hole when the rains are regular. After a week, eliminate the weakest seedling.
Preferred Soils: Sandy well-drained soils are the best but cashew can tolerate a range of soils and climates.
Minimum Rainfall: 500 mm/yr
Optimal Spacing: 5m by 20m (recommended) in a field where crops will still be grown. 5m by 5m in orchard spacing

Tree Care

The cashew requires no special watering, cuvettes or pruning (in the early stages) in the field. Protect seedlings from animals. Seedlings and young trees should be weeded to protect them from dry season fires. It is good to inhibit fruit production until the third year, by cutting off the blossoms.
Pruning Period: You should start pruning three years after outplanting. For the period during the year, after harvesting, during the rainy season (July) is the best.
Pruning Frequency: Prune every year
Common Pests: Spiders very rarely
Irrigation Needs: None
IPM Methods: Weeding and pruning only

Citrus

Citrus spp.

Tree Description

Citrus trees are evergreen trees which will generally grow to heights of three to four meters depending on the variety. Budded or grafted citrus trees could be slightly smaller. Citrus roots reach downward to 1.5 meters. The secondary roots are between 0.15 and 0.8 meters depth. They have hard, dark colored evergreen leaves which contain oils. The fruit are all segmented. Some varieties do not contain seed. The seed may be mono- or polyembryonic.

Propagation Data

Un-grafted or un-budded citrus will flower and fruit as soon as five years after planting if in adequate conditions, whereas grafted and budded trees may flower as early as the year they are grafted.

Citrus is typically propagated in seed or germination beds. They should be composed of well-drained soils as to avoid rotting of the very sensitive citrus seeds. Water the beds often but lightly. In these beds, seeds should be sown 1 cm deep with 10-20 cm between rows. They can also be dispersed randomly in beds.

Trenching: Transplant into tree sacks when the citrus seedlings get close to being 15 cm tall. At this point a rigorous selection process should be used to eliminate any bad seedlings. Do not transplant unusually small or non-vigorous seedlings, seedlings with malformed roots, twisted, "j" rooted, or diseased seedlings. Only the best seedlings should be transplanted to the next step.

When transplanting trim the root hairs and the taproot down to 15 cm, this is to promote new growth. Rupert suggests shortening the seedling by 1/3 as well. Make a 15 - 20 cm hole in the center of the sack, plant the seedling into the hole, and press the soil around the roots trying to avoid any air pockets. Make sure the collar of the seedling is located in the same place relative to the soil surface.

Keep the sacks in the shade until the seedlings start to grow again. Make sure to weed the sacks regularly. When the rainy season is almost over dig the trench.

Propagation Method: Seeds and grafting
Seed Collection: Citrus seeds decompose quickly so only fresh seeds should be collected and used. Seeds should be dried in the shade never in the sun. When drying the seed do

not allow the seed to completely dry out but just dry out the surface for a couple of hours.
Seed Pretreatment: Mixing the dry seeds with ash may help against fungus attacks in the nursery. Store the seed in sealed plastic bags and if possible in a refrigerator making sure there is no humidity inside the bag to spoil the seeds. Seed in rows in the germination bed about 1 cm deep with 20 cm between rows. Sow seeds in the rows with 1 cm between seeds.
Germination Rate: 70%
Time to Germination: 15-30 days
Time in Nursery: One year
Grafting Method: Scions and budding
Age before fruiting: 5 years for rootsocks and as early as the first year for grafted tree

Site Requirements

The transplant hole for citrus should be 80 x 80 x 80 cm. Although citrus can be outplanted anytime of the year, transplanting in the dry season if water is not an issue, so the seedling can get established before the upcoming rainy season.

Preferred Soils: The soil needs to be well-drained. Adult trees need lots of direct sunlight to flower and fruit
Minimum Rainfall: more than 1200 mm rainfall per year
Optimal Spacing: 8 X 8

Tree Care

Citrus are very spindly and tend to branch from the base of the tree. In order to raise productive trees, pruning is a must. A citrus tree which is well pruned could be kept the size of a bush and even raised in pots without hampering its ability to produce.

Irrigation: Citrus trees will need to be irrigated for their first 3 years. In the drier areas and places with a deep water table irrigation may be needed throughout the life of the tree. Irrigation for most adult citrus trees is 20 liters 3 times a week. Once the trees are established and producing fruit, irrigation may no longer be needed but watering 2 -3 months before the rainy season can urge early blooming. If irrigated some varieties, notably the Japanese orange, will fruit all year round.

Pruning: Citrus species tend to require a lot of pruning. Most pruning should be done right after the harvest. Citrus fruit only form on new stem growth so branch ends should be pruned to urge new growth. Since it is very important for branches with fruit to have adequate sunlight, each year branches should be thinned and those "inside" the crown removed altogether to increase sunlight penetration. Other experts suggest only pruning any suckers originating from below the graft or bud site, any branches below 80 cm, and all dead branches.

Pruning Period: Citrus species require a lot of pruning. Most pruning should be done right after the harvest.

Pruning Frequency: Since it is very important for branches with fruit to have adequate sunlight, each year branches should be thinned and those "inside" the crown removed altogether to increase sunlight penetration.
Irrigation Needs: Citrus trees will need to be irrigated for their first 3 years. In the drier areas and places with a deep water table irrigation may be needed throughout the life of the tree. Irrigation for most adult citrus trees is 20 liters 3 times a week.

Banana

Musa spp.

Tree Description

Bananas are not really trees but are a large grass species. They are monocots. Bananas are also sterile; although producing both male and female flowers the banana fruit does not contain seed. Bananas will flower after they produce 30 leaves, usually in 8 to 13 months. Male flowers are purple and located at the end of the stem; female flowers are enclosed in bracts containing 6-7 "hands" each with 8-16 "fingers" or bananas. Once the plant flowers, fruit will ripen 5 months later.

Fruit Description

The ovaries contained in the first (female) flowers grow rapidly, developing by parthenocarpy (without pollination) into clusters of fruits, called hands. The number of hands varies with the species and variety. The fruit (technically a berry) turns from deep green to yellow or red, and may range from 2-1/2 to 12 inches in length and 3/4 to 2 inches in width.

Fruiting Data

The male flower always appears first from the center of the stem and the female flowers follow on the same stem. The male flower is large and usually purple in color while the female flowers look like fingers (the bananas). When the length of the stem with the male flower gets to be 20 cm long and many female flowers have appeared the male flower should be cut off where the flower meets the stem. Fruit should be kept out of the sun. Fruit are ripe when they are smooth and have no more angles.

Propagation Data

Bananas are propagated vegetatively either by planting a bulb, a bulb with a sucker, or a bayonet. Usually bulbs are planted two months before the rains because they contain a lot of stored energy and rot easily. This gives them a head start in root formation before the rains arrive. Bayonets, however, need to be planted during the rainy season. Banana plantation holes are 80 cm X 80 cm X 80 cm. The spacing in the plantation should be 2 X 2 meters. Windbreaks are very important. To plant prepare the bulb or shoot by cutting off all the roots any wounds and soaking it in a decomposed manure solution. You also want to promote new growth so cut off any existing shoots and drive a wooden stake into the center of the stem. When planting sink the collar 10 cm deeper into the soil than it was before. When the first sprouts emerge prevent all but the most vigorous from growing. Try to cut them off close as possible to the bulb or the soil surface.

Age before fruiting: Nine months after planting
Fruiting Period: Bananas produce fruit throughout the year

Site Requirements

Wind can be very harmful to bananas and should be avoided. Bananas also do best in sunny areas but cannot tolerate a lot of direct sun (ISRA). They also need shallow water tables (2 - 4 meters).
Preferred Soils: Humid, humus-rich soils
Minimum Rainfall: Optimal monthly rainfall is between 200 to 220 mm
Optimal Spacing: 2 X 2 meters

Tree Care

Mulching is very important and can be done up to 15 cm deep during the dry season. This will also help conserve water. Next generation*:* once the plant flowers the second generation shoot needs to be chosen. Choose the most vigorous shoot and cut off all the rest while the fruit are maturing - these can be sold or transplanted. When the fruit are harvested cut down the parent plant and let the second generation take its place. After three generations the plant should be replanted.
Pruning Period: N/A
Common Pests: *Cercosporiose disease*: caused by a fungus; yellow leaf spots which expand turning gray. In dry conditions we suggest only preventative measures be taken (not watering every day and planting in well-drained areas); *Nematodes*
Irrigation Needs: 20 liters every other day. Susceptible to rotting.
IPM Methods: Do not have plantations in the same place for more than 5 years. The soil in the plantation hole should also be treated.

Papaya

Carica papaya

Tree Description

C. papaya is an arborescent herb with leaves that sprout directly from one central trunk-like stem in a spiral or nearly horizontal pattern. The stem can be from 2 to 10 meters tall and grows quickly. The stem is not woody, but a soft spongy tissue, hollow on the inside and up to 30 to 40 cm thick, and is marked with many leaf scars. The green leaves are 30 to 60 cm wide and are deeply divided into 5 to 9 segments with yellow ribs and veins. Secondary stems will frequently sprout from the main trunk. The leaves and stems contain a type of milky latex. The plant will fruit in 9 to 14 months after seeding and yearly after that.

The flowers can either be female, male, or hermaphroditic, and only one type is found on any given tree. All flowers are fleshy and waxy with 5 petals and a slight fragrance. Female flowers are formed at the base of the leaves, are ivory-white, and have only a pistallate. Male flowers are formed at the end of long stalks (1.5 – 1.8 m long) that sprout from below the leaves and have only a staminate. Hermaphroditic flowers bloom from short stalks at the base of the leaves and are ivory-white with yellow anthers.

Hermaphroditic plants are the easiest to grow for fruit production since they are self-pollinating. If completely self-pollinated the seeds will yield 67% hermaphroditic plants and the rest will be female. Lone papaya trees bearing large amounts of fruit are most likely hermaphroditic. Female plants must be planted near males plants in order to produce fruit. Fruit from a male/female cross will have 50% female and 50% male seed. Male plants will not produce fruit, and if used to pollinate hermaphroditic plants will produce 33% male, 33% female, and 33% hermaphroditic seed.

The solo (hermaphroditic) variety is usually the most desirable as it produces good quality fruit on a short tree that is easy to harvest. When working with solo varieties they must be prevented from cross-breeding with local varieties or their desirable qualities may be lost in future generations.

Propagation Data

Propagation Method: Seed in nursery either in a tree sack or bare root bed. May be direct seeded, with lower success rates

Seed Collection: Collect seeds from mature, ripe fruit. Remove gel from seeds immediately after collecting. Plant the seeds or dry seeds in the shade. Dry seeds will lose viability if not planted shortly after.
Seed Pretreatment: Cold water soak for 24 hours.
Germination Rate: Sow about 4 to 5 seeds per sack at 0.5 to 1 cm deep.
Time to Germination: 15 to 30 days to germinate. If there is a possibility of male seeds, thin the strongest plants right after germination as these are most likely to be male.
Time in Nursery: Outplant after 6 – 8 weeks in the nursery, or when 30 cm tall. Keep in partial shade until 5 – 10 cm tall. When plants are 15 cm tall thin so there is one plant per sack. Papayas can be outplanted at any time of the year since they should be watered all year round.
Grafting Method: N/A
Age before fruiting: 9 to 14 months after planting.

Site Requirements

Preferred Soils: Prefers deep, light, porous soils with a pH between 5.5 and 6.7. Grows well in soil with high organic matter but may produce low quality fruit if improperly drained. Water tables of 2-3 meters are preferred.
Minimum Rainfall: 1500-2000mm per year or heavy irrigation. Requires good drainage.
Optimal Spacing: Plant at 2 x 2.5 meter spacing. The planting hole should be 50 x 50 x 80 cm.

Tree Care

Pruning Period: Dry seasons.
Pruning Frequency: It is recommended to remove all side branches to produce larger fruit.
Common Pests: Papaya plants can attract *nematodes*, which can be a problem when papayas are planted in gardens; *Rhizoctonia* and *Phytophora* fungi; Scales can be a problem and bats are attracted to the ripe fruit.
Irrigation Needs: Nursery: Water lightly; First 2 months: 20 liters 3x week; 3 months: on water 30 – 40 liters every 2 days; Keep trunk dry to prevent rot.
IPM Methods: Nematodes: do not plant papayas in the same spot year after year; sterilize the soil before planting; Neem solution; Rot: make sure the soil is well drained, do not damage the stem; Scales can be picked off by hand or apply soapy water.

Grafting

Grafting is a method of asexual propagation in which a stem or bud (the scion or budwood material) from one variety of a plant is joined to a seedling (the rootstock) of another variety of a compatible species, and the two grow together to become one plant. It allows the characteristics of both plants to be replicated in an adult tree. Usually the scion or budwood and rootstock are chosen for their specific qualities, i.e. a certain variety of citrus rootstock may be chosen because it is resistant to drought and therefore adapted to dryer climates, while the selection of the scion of a certain variety will determine the time of harvest, quality of fruit, or size of fruit.

The Benefits of Grafting include:

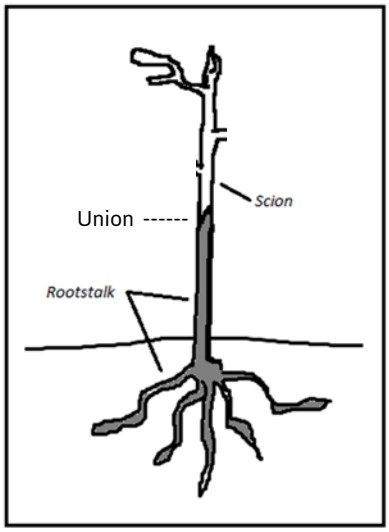
- Faster Fruit Production - grafted fruit trees produce fruit 2-4 years after grafting. Fruit trees that are not grafted typically bare fruit much later, sometimes 7-10 years after they are established.
- Control of Fruit Quality and Quantity – grafted fruit trees bare the same quality and quantity of fruit from which the cutting (scion) was taken.
- Repair of Cambium Damage – trees that have been damaged by rodents or other pests, in cases where the bark and cambium layers have been removed around the circumference of a tree, can be repaired through grafting.
- Increased Tolerance to Climatic Extremes – the root stock of some plants may be better situated for local soil conditions while the growth from a grafted scion is better suited for improved productivity. Grafting provides a means to meet the conditions of both.
- To Maintain or Secure Heirloom or Favored Varieties of Fruits – the seeds of many fruit trees will not produce the same quality of fruit as that from which the seed was taken. Grafting provides a means to reproduce or maintain a desirable variety of fruit.
- Simple Means to Replace Adult Trees with an Improved Variety- replacing one cultivar with another, through topworking, can be performed more easily through grafting efforts rather than replanting each tree.
- Resistance to Disease – it is possible to graft disease-resistant varieties to non-resistant varieties.
- Diversifying Production – through grafting, farmers can diversify their Forest Gardens with different varieties of fruit that produce different qualities and at different times, to take advantage of market conditions.

The Disadvantages to Grafting are that:

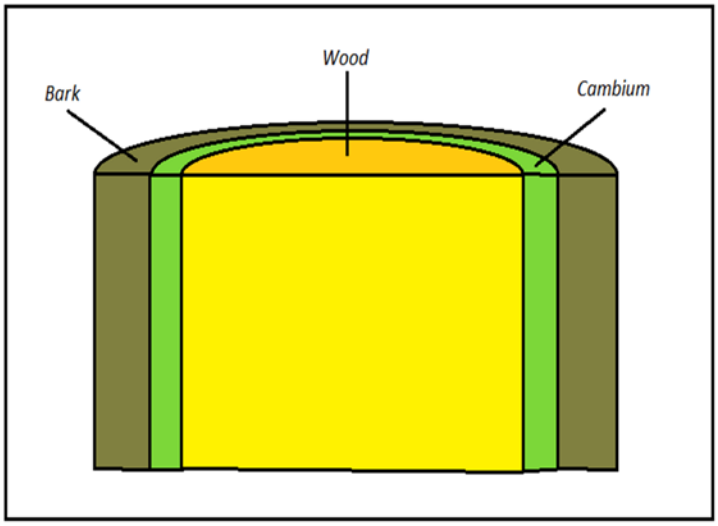
- Grafted plants require more time, care, and maintenance in the nursery than non-grafted trees.
- The life span of the grafted tree is generally shorter than un-grafted trees.

Although many tree species can be grafted, fruit trees are among the most common, since grafted fruit trees yield fruit considerably faster than non-grafted trees. The best fruit species for grafting will depend on the type of fruit you want to produce. The most profitable or desirable products will normally determine which species to graft. Grafted trees improve Forest Gardens by producing a greater quantity of high-quality fruit to consume and sell. Farmers who master grafting techniques can also sell the grafted seedlings that they do not plant in their Forest Gardens.

There are many different grafting techniques. The technique you use is often determined by the species that you are grafting, the time of year, the maturity level of the rootstock, and in some cases your comfort or skill level in one technique over another. With mangos, for example, we encourage a technique called the tongue and groove (or side) graft, and for citrus we recommend "T" budding, chip budding, or side grafting. For *Ziziphus mauritiana* and cashew trees we recommend topgrafting. There are many other grafting techniques as well. The methods discussed in this manual are relatively easy, have high success rates even for beginners, and are generally easy to teach.



Grafted Seedling



Cross Section of Woody Stem

The Principals of Grafting

How Does Grafting Work?

Grafting takes place when two previously unattached trees are connected through a binding process that involves the alignment of their cambium layers. The cambium layer is located just beneath the bark of tree and is responsible for transporting nutrients between the roots and leaves. In a successful graft, the cambium layers between the upper portion of a young tree branch (the scion) and the lower portion of a

tree (the rootstock) are aligned with each other so that nutrients can flow between them. The scion and the rootstock are then bound together to ensure the cambium layers are held intact. A successful union between the scion and rootstock will be noticeable if the scion begins sprouting new growth (shoots and leaves). Depending on the grafting technique performed, the graft can take 2-3 weeks or several months before showing signs of growth. If the graft was a success, the binding material used to tie the scion and the rootstock together can be removed.

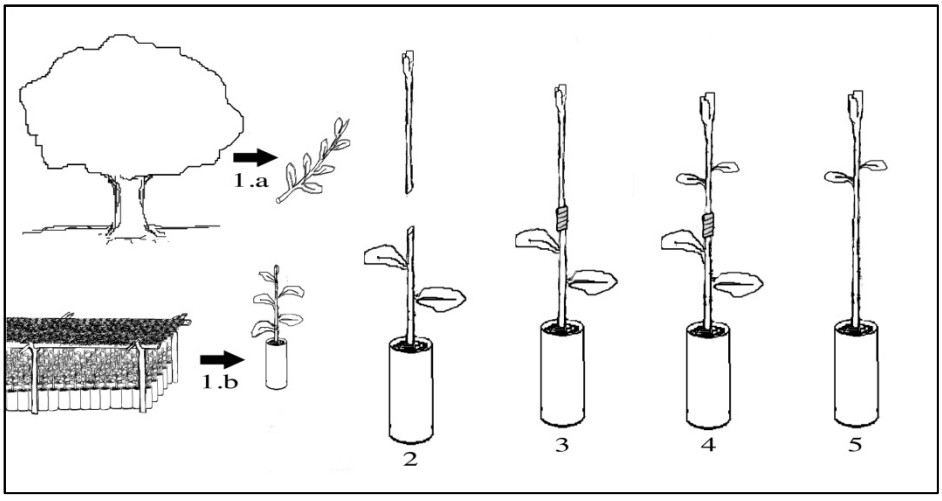
Graft Compatibility

Not every rootstock and scion are compatible with one another. The majority of trees will not form a successful graft with another tree unless they are genetically similar to one another. For example, an apple tree cannot be grafted to an orange tree because they are not closely related. However, one variety of apple tree is likely to graft to another variety of apple tree because they carry similar genes. Before grafting, be sure the rootstalk and scion from the trees you have in mind are compatible with one another. Typically, plants of the same genus and species can be grafted despite being of a different variety. In short: graft mango to mango, avocado to avocado, apple to apple, etc.

The Five Stages of Grafting

There are five basic steps for performing a graft:

1. sourcing the scion and the rootstock,
2. preparing the scion and the rootstock for grafting,
3. grafting the scion and the root stock,
4. waiting for the graft to take and for the scion sprout new growth, and
5. removing the wrapping and maintaining the grafted tree (refer to the figure below).



Scion and Rootstock Selection

The scion or budwood is the source of all of the branches and the top growth that will come after the graft union is made. Characteristics of the adult tree determined by the scion or budwood include the following: type and quality of fruit produced, time of year fruit will ripen, vigor of top growth, and the top growth's resistance to disease and insect attacks. The difference between a scion and budwood is the grafting technique for which it is selected. Grafting uses a scion which is usually a stem about 10 - 12 cm long. Budding is a form of grafting where a single bud, or eye, is attached to the rootstock seedling instead of using a whole stem.

Selecting a Source Tree

The most important aspect of the scion or budwood source tree is that it be the desired variety. The tree should also be completely disease free and should be an adult (producing fruit).

Preparing the budwood and scion selection

Look for a young vertical shoot about pencil width. One thing to look for is that often citrus tends to grow oval or "winged" branches which are more difficult to bud; look for a round branch which will be a lot easier to bud.

For budding, the lateral buds (the buds at the sides of the branch not at the end of the branch) are important. Look for lateral buds which are yellowish in color and ready to push (grow) but not yet pushing. This may be difficult to find. If your source tree is not irrigated and you come too late, during the rainy season when the trees are growing, the buds may have already pushed; likewise, if you come too early, during the dry season, the buds may be dormant. Observe the tree regularly and collect the budwood at the correct time of year when the buds are swelling naturally, usually right before the rainy season, when it first gets humid.
Budwood can usually be found at any time during the year if adequate searching is done.

Preparing the budwood: If the buds are dormant or not swollen at all the budwood should be prepared five to seven days in advance. To prepare the branch, cut off all the leaves and cut off the terminal bud. Be sure to tag the branch that you are preparing because upon return five days later it may be difficult to find. By doing this preparation you are inducing the lateral buds to swell and start to push. If the buds are swollen already the budwood should only be prepared two to three days in advance and the terminal bud should not be removed. If the buds are swollen or already pushing no preparation is needed.

Scion selection: Select a stem in which the terminal bud is swollen but not yet sprouting, particularly with mangoes. If it is already sprouting, after the graft is performed it will continue to sprout before the union of the cambium takes place. The graft point is unable to take up nutrients and will die because all the energy is going into the growth of the sprout. The scion should be somewhat lignified (green tender wood). If the scion

is not lignified, it will dry out and wilt before the union of the cambium layers takes place. The scion should be equal in diameter to the rootstock stem or smaller but never larger. Avoid scions with weakly developed terminal buds. Terminal buds should be rounded, not angular. Use scions which are already swollen naturally. After removing the scion from the tree, carefully remove any leaves and their stems from the scion. Dot collect scions when flowers on the tree are developing.

Selecting the Rootstock

The rootstock determines the bottom growth which includes the following characteristics of the adult tree: the form of root growth, the root's resistance to diseases, insect attacks, drought and other environmental conditions, and vigor of the tree.

Your rootstock should be graft-compatible with the tree you want to replicate. It is also good practice to source the rootstock from an area similar to where you want to transplant the grafted tree to be sure it is well-suited to that environment.

If you are collecting your rootstock from a tree nursery for grafting, select a healthy, vigorous seedling produced from seed collected from vigorous trees adapted to the local enviornment. Choose seedlings that have diameters of 1 cm or more halfway up of their stems. You can also dig up seedlings from a field or forest if you find the species you would like to graft, or graft directly onto a young tree that is already growing in a desirable location.

Grafting Techniques

There are many types of grafting methods. This manual will cover a handful of commonly used grafting techniques: bud grafting (including T-budding and chip budding techniques), side grafting, and topworking. Bud grafting is a type of graft where a single bud is attached to the rootstock, instead of using a full scion. The grafting method you chose will depend on your skill level, resources, and the time of year you want to graft.

Tools and Materials

The following tools and materials are needed to perform a graft. You should always use a clean, narrow, very sharp blade for making cuts to prevent wounding the tree more than needed, which will minimize exposure to pests and disease and enhance the healing process. Always clean the blade with alcohol before making cuts, to avoid the spread of pathogens that could infect your grafted trees.

- **Grafting knife:** if you do not have a sharp grafting knife, a utility knife with a sharp blade will work
- **Grafting tape:** if not available, thin plastic (about 3-5 cm in width) will work, e.g. strips of plastic cut from material used to make tree sacks
- **Grafting compound:** beeswax can be used as a grafting compound. It isn't necessary, but it does help to protect the graft union as it sets, if available

- **Alcohol:** used to clean the grafting knife before making any cuts, to prevent spread of disease
- **Scion or budwood:** see 'Selecting the scion or budwood' section above
- **Rootstock:** see 'Selecting the rootstock' section above

Bud Grafting

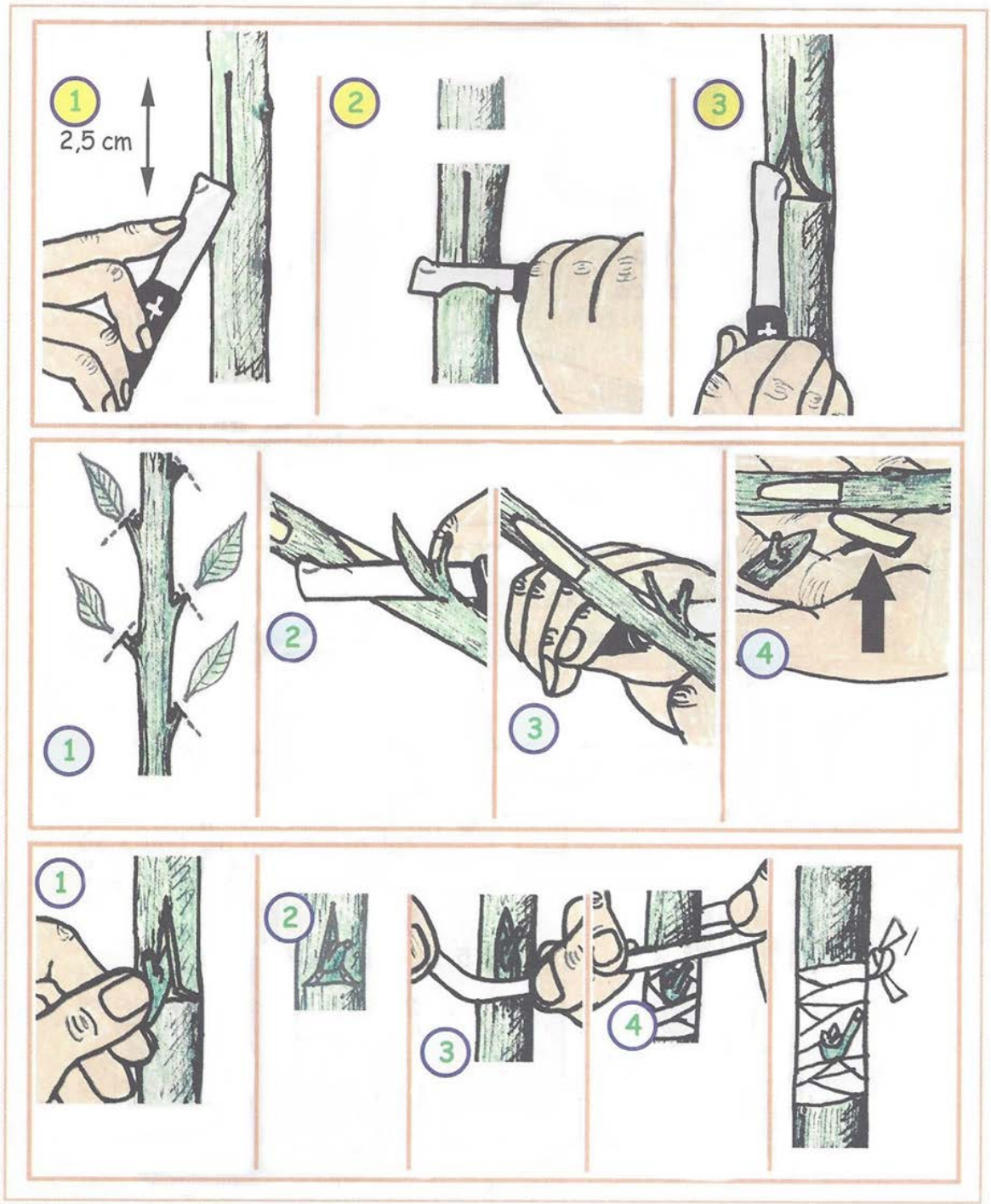
Bud grafting is the process of taking a bud from the desired scion and attaching it to a suitable rootstock. Because a bud is much smaller than a scion used for the side grafting method, the bud graft method is used for the harder wood species like citrus. However the bud method can be effectively performed on mangos as well. This method is also much faster to perform than the side grafting method but because of its size it offers less surface area to match up all the layers. Furthermore in case of bud wood, the aligning and wrapping rules for bud grafts are essentially the same as for the side graft, described below.

"T" Budding

1. Prepare the rootstock
    - Select a flat area about 30-50cm above the soil surface. After cleaning your knife, cut off all the leaves, thorns, or branches around the grafting site. Make an incision about 4-5cm long and 3-4cm across in the shape of a "T."
    - Carefully open up the "T" by spreading the bark apart with your knife. If the bark does not want to slide off the woody part, the tree needs to be better irrigated and some compost or manure should be added to the soil.
2. Prepare the budwood
    - Now collect the bud from the budwood. Starting 1-2cm below the bud, in one smooth motion cut into the budwood and upward. Cut until it is about 3-5cm above the bud. Never handle the bud by the back side – either use the leaf stem or the tail tip.
3. Form and protect the union
    - Gently insert the bud into the "T" incision. Be sure that the bud itself is in the center of the "T" part.
    - Cut off the "tail" of the bud. Make sure it is even with the horizontal incision and there is a snug fit.
    - Starting below the bud site, tie some grafting tape or thin plastic wrap. Wrap the site as tight as possible. Do not cover the bud itself. Make sure to cover the whole wound except for the bud. The bud can be left uncovered, <u>or</u> take another plastic strip and wrap loosely over the bud and tie.
4. Post-graft maintenance
    - Come back a week after grafting. Uncover the bud (if covered) but leave the "T" wrapped. If the bud is still green but not taken, bend the rootstock stem away from the direction of the bud about 10-15cm above the bud site.
    - When the bud sprouts, cut off the rootstock stem 20cm above the bud site and unwrap the rest of the plastic wrap. Tie the bud (scion) to the rootstock to encourage straight growth and to protect it from breaking. When 20-30cm of

new growth occurs, cut the rootstock off flush above the bud point.

Refer to the diagram below to see the steps in T budding:



Chip budding

1. Prepare the rootstock
   - Make a 45 degree angle incision about ¼ through the stock.
   - About 2.5 cm (1 inch) above the first cut, make a second cut going downward and inward until it connects the first cut.
2. Prepare the budwood
   - Remove the bud from the budwood similar to the cut you made on the rootstock.
   - Make the lower cut about 0.6 cm (1/4 inch) below the bud.
   - Make a second cut about 1.3 cm (1/2 inch) above the bud coming downward behind the bud and connecting with the first cut, permitting the removal of the bud piece (or chip).
3. Form and protect the union
   - Gently insert the bud piece flush with the incision in the rootstock.
   - Starting below the bud union, tie some grafting tape or thin plastic wrap. Wrap the site as tight as possible. Do not cover the bud itself. Make sure to cover the whole wound except for the bud. The bud can be left uncovered, or take another plastic strip and wrap loosely over the bud and tie.
4. Post-graft maintenance
   - Come back a week after grafting. Uncover the bud (if covered) but leave the grafted part wrapped. If the bud is still green but not taken, bend the rootstock stem away from the direction of the bud about 10-15cm above the bud site.
   - When the bud sprouts, cut off the rootstock stem 20cm above the bud site and unwrap the rest of the plastic wrap. Tie the bud (scion) to the rootstock to encourage straight growth and to protect it from breaking. When 20-30cm of new growth occurs, cut the rootstock off flush above the bud point.

Side Grafting

The side graft is a useful, relatively simple graft that is commonly used on mango seedlings and other young seedlings with thin stems. A commonly used technique for the side tongue graft is to create a whip and tongue between the rootstock and scion to increase the integrity of the union and the surface area where the cambium layer aligns.

1. First prepare the scion (see 'Scion and Rootstock Selection' section above). The scion will stay on the tree for approximately a month, allowing the buds to swell. After the scion is removed from the tree with a clean, sharp knife, it is ready to be prepared for attaching it to the rootstock.
   - Pick a flat part of the scion, between the nodes, approximately 5-10 cm below the scion apex. This is where your first cut will be made.
   - Using steady pressure, begin by making a cut 3-5 cm long from shallow to deep. Turn the scion over and make a smaller cut (approx. 1 cm) to form a wedge that will fit into the rootstock.
   - Set the scion aside.

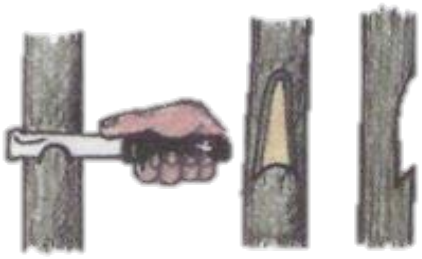
2. Prepare the rootstock:
    - Remove all leaves from the intended rootstock seedling or plant.
    - Choose a spot on the rootstock that is semi-lignified and at roughly knee height. While it isn't crucial that both the scion and the rootstock are the same diameter at the point of the graft, the closer in size they are the better chance the graft has of taking.
    - Make your first cut deep and at a 40-degree angle. This is where scion will fit into so try to make the cut identical to the shorter cut on your scion.
    - Next move your knife 3-5 cm above your 1st cut and with steady pressure make a cut, shallow to deep. The end of the 2nd cut should match up with the end of the 1st cut.
3. Attach and Align the Scion
    - Place the scion into the cuts on the rootstock, making sure to match up the cambium layers. If your rootstock is larger than your scion, the graft is still possible. Simply line up the scion to one side of the rootstock cambium. This is also your chance to make any touch up cuts to either the rootstock or the scion to make them fit together better. To ensure that the scion does take, there should be no gaps between the scion and the rootstock, so it is very important to make touch up cuts where needed.
    - When you are confident that the cambiums are matched as best as possible, you can begin wrapping the graft with clear-plastic strips. Using clear plastic is important because it allows you to look at the graft while it is still wrapped. Begin the wrap below the graft, making sure to wrap tightly, leaving no gaps. Then continue up the graft, wrapping tightly and overlapping each plastic layer. Having an airtight seal is very important because the graft is very vulnerable to pests, diseases, desiccation, as well as rotting from standing water. Once you reach the apex of the scion, wrap loosely but be sure to keep the airtight seal. As the scion takes and begins to grow, the buds on the apex will begin to grow and will need some room. After you have wrapped passed the apex, wrap tightly again and tie off the plastic.
    - Lastly, remove all but a few leaves above the graft and cut the terminal bud on the rootstock. Leaving a few leaves will allow the rootstock to pump up much-needed nutrients and water to accelerate the grafting process, while removing the terminal bud will trick the plant into sending growth hormones to open new buds. The entire stem above the graft will be removed in a few weeks when the graft has taken, but for now it's serving a purpose.
    - To make sure you did a good job, the next morning revisit your graft and check for moisture droplets inside the plastic. If you have moisture condensation within the plastic that means your seal is effective and you won't have to rewrap the scion. If there is no water however, take the plastic off and try again.
4. Post-graft Maintenance
    - The graft will require a few weeks to take so check it once every week or two. You will know if the graft took by the sprouting of buds on the apex of the scion. Healthy scions will also remain green; whereas bad scions will have

turned black and dead looking. If a graft is unsuccessful, further attempts can be made to graft the same rootstock.

- Once the buds on the apex have sprouted (4-5 weeks), remove the plastic above the apex, allowing it to continue to grow, but leave the rest of the graft wrapped. The scion is still in a weak state at this point and needs the support of the wrapping.
- When the scion is producing green leaves (not purple) the wrapping can be removed and the rootstock stem above the scion cut off. Grafting compound can be added where available.

Side Grafting

Rootstock Preparation



Front view

Side view

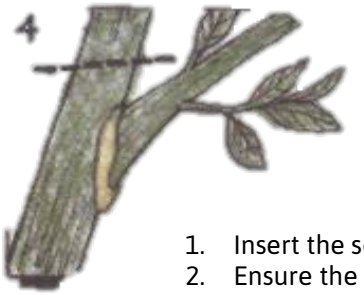
Scion Preparation

Side view

Back view

Front view

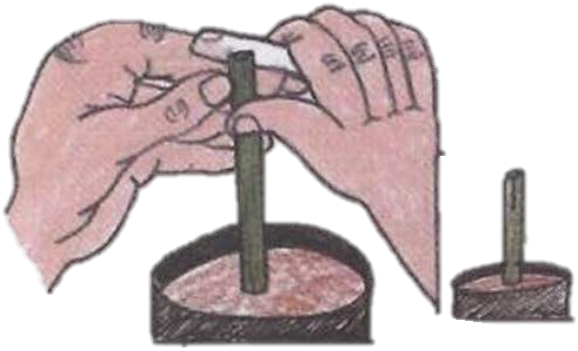
Make a downward cut 2.5-4 cm long

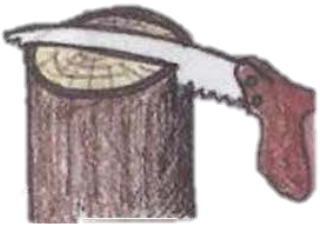


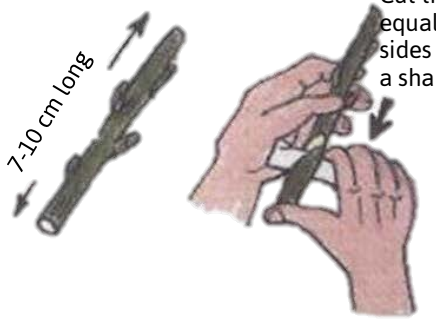
1. Insert the scion onto the rootstock.
2. Ensure the cambiums line up.
3. Wrap tightly with plastic wrapping.
4. After the scion begins to grow, cut off the rootstock above where it was grafted.

Topworking

Rootstock Preparation



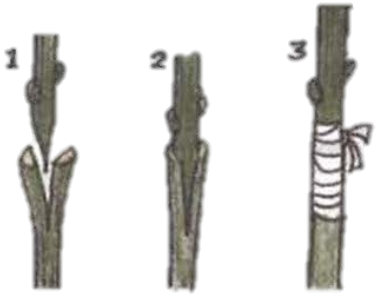




Cut the scion equally both sides to make a sharp point

Side view

Front view



1. Insert the scion in the rootstock.
2. Line up the cambium layers
3. Wrap tightly the plastic

Use wax to seal the grafts for larger trees

A successful top graft on a young seedling.

Topworking

Topworking is used on mature plants which are to be changed to a different cultivar. This method should be limited to stock branches about 2.5 to 10cm in diameter and to species with fairly straight-grained wood that will split evenly. Topworking can be done any time during the dormant season (dry season), but the chances for a good union are best if the work is done just before the active growth has initiated (just before raining season) and buds of the stock are beginning to swell. In making the graft for top working the proper placement of the scions is very important. (See figure below). The scions should be made from one year-old wood. The scion is made by cutting a long, gradually tapering wedge. Preparing the stock it is important to split the stub deeply (even split). Two scions are inserted in the stub, one at each end of the split. The scions must be carefully placed so the cambium layers match. Add grafting compound where available when the grafts are set to protect the graft unions.

CHAPTER 6: REFERENCES

1. Department of Agriculture Bureau of Plant Industry, Government of Philippines. Production Guides for Fruit Trees Avocado <http://www.bpi.da.gov.ph>.
2. Morton, J. 1987. Pineapple. P. 18-28. In: Fruits of Warm Climates. "Papaya." *Purdue.* 24 Feb. 2011. <http://www.hort.purdue.edu/newcrop/morton/papaya ars.html#Soil>.
3. Peace Corps Senegal. *Fruit Tree Manual.* Dakar: 1993.

Chapter 7: Outplanting Seedlings

Outplanting seedlings into the Forest Garden is a relatively simple procedure. To give the young seedlings the best opportunity survival however, be sure to follow the measures, techniques, and timing recommendations below.

Timing of Tree Planting

Timing is an extremely important consideration when outplanting trees into the Forest Garden, particularly when you are not able to irrigate the trees regularly after planting. To take advantage of natural irrigation, i.e. rain, plant your trees at the beginning of the true rainy season. Rainy seasons can be short and unpredictable, however. To increase the likelihood that the true rains have begun it is important to wait until two weeks of 3 or more significant rain events have passed before planting your seedlings. Do not delay planting after the true rains have begun as the seedlings will benefit from as much rain as possible to help with root establishment, increasing the likelihood that they will survive the oncoming dry season.

Timing of Tree Planting – The beginning of the true rainy season

Wait until two weeks of 3 or more significant rains events have passed before planting your seedlings.

Be sure your seedlings are ready for planting at the start of the true rainy season. Delaying further into the rainy season decreases the likelihood of survival.

Keep a close eye on your seedlings after the rains end, particularly if the rains are short. If the seedlings start to wilt excessively, and do not recover overnight, then you will need to irrigate them with 3 to 5 liters of water (depending on the size) one time per week for each seedling.

Prepare Your Planting Holes

Before removing your seedlings from the nursery for transplanting it is good practice to first dig your planting holes. It is best to do this at the time you expect the rains to begin, at least two weeks prior to actually planting the seedlings.

1. Mark out where you will plant the seedlings, using your Forest Garden design as a guide and ensuring correct spacing for the species you are planting and, where

applicable, the agroforestry technology for which you are planting.
2. Using a digging tool, dig a hole about two twice the diameter of the tree sack or root system (for bareroot trees) you are planting. For agroforestry trees in sacks that are 8cm in diameter by 15 cm deep, for instance, dig the planting pit about 16 cm in diameter by 30 cm deep. For fruit trees in sacks that are 30 cm by 30 cm, dig planting holes that are about 60 cm wide by 60 cm deep.
3. Where available, mix the topsoil you removed from the soil with well-decomposed compost or manure and line the pit with the mixture. It is important that the compost or manure be fully decomposed or the heat generated from decomposition may burn your seedling's roots. **Note:** If you do not have fully decomposed compost or manure, it is better to plant the seedling lined with topsoil, then place the compost or manure at the surface covered by mulch, so that the nutrients will slowly filter into the soil as it decomposes, mitigating the risk of the compost rotting or burning the seedlings' roots.

Extracting and Transporting your Seedlings

When you are confident the true rainy season has begun, it is time to extract your seedlings from the nursery and carefully transport them to the planting site. Be sure you have already hardened off your seedlings so that they are prepared for the harsher conditions beyond the boundaries of your nursery (see hardening off section). Follow the guidelines below for trees sacks (including agroforestry, fruit, timber, and any other seedlings raised in sacks), or bareroot seedlings.

Things to Remember Before Outplanting

1. Trees need to be tall enough to survive the shock of outplanting but not too tall that they can't be transplanted with intact roots. Before outplanting, trees grown in sacks should be 0.2-1m tall, and bare-rooted trees should be 0.5-1m tall.
2. Do not outplant trees with roots deeper than the planting holes you dug (which should be twice the depth of your tree sacks). Trim roots to this length, where needed.
3. All outplanting should be completed in the late afternoon to evening to reduce the amount of sun exposure and shock to the newly-planted tree.
4. Remember that unless you are able to thoroughly irrigate each tree every week, you should only outplant your seedlings during the rainy season when significant rain events are occurring at least twice per week. Plant early enough in the season to ensure plenty of time for root establishment for the dry season.

Tree Sacks

1. Water the seedlings thoroughly before removing them from the nursery. If the seedlings' roots have grown through into the soil below the sacks, be sure you water the seedlings well enough to soak and loosen the soil below.
2. Carefully pull up the sacks individually, using both hands for larger sacks. Try to maintain any roots that have penetrated into the soil below.

3. If the roots of the seedlings extend more than twice the depth of the sacks, carefully prune the long roots with a sharp, clean knife to twice the depth of the sacks, which should be equal to the depth of your planting holes.
4. Transport the seedlings to the planting site on flat surfaces, standing upright. If you do not have a wheelbarrow, carry what you can fit easily in your hands, or create a 'hand' barrow for two people with a wooden basket attached over two poles (see pic). Transport only the seedlings you plan to plant that day.
5. Place the seedlings upright in a shady area if you can, and plant them as soon as possible.

Bareroot Seedlings

1. Water the bareroot beds thoroughly before removing the seedlings.
2. Dig up bareroot seedlings, doing as little damage to the roots as possible. One method is to stick your spade deep into the soil close to the seedling row about 25 cm deep, move a few centimeters back, and do it again, removing a wedge of soil. Then stick the spade into the soil on the other side of the row, once again close to the seedling and "dump" the seedlings and surrounding soil into the wedge. Be sure not to let the seedlings fold over, breaking the stems.
3. Only remove enough seedlings to plant over the next few hours.
4. When dug up, cleanly trim the roots with a sharp knife if they extend beyond the planting holes you have dug.
5. Create a mud slurry with soil and water and dump it over the roots, thoroughly coating them to preserve moisture and wrap them in banana leaves or burlap sacks to prevent them from drying out. Do not store the wrapped seedling in buckets or any standing water.
6. Transport the seedling bundles to the planting site carefully and place them in shade if possible.

Outplanting your Seedlings

Tree Sacks

1. Carefully remove the seedling from the tree sack. It is helpful to use a knife or razor blade to slice vertically through the plastic.
2. After removing the plastic, gently massage the root ball to loosen it, particularly if the root system is wrapped up in a clump. If the taproots are coiled up at the bottom of closed tree sacks, carefully loosen them so that they are extended and facing downward for planting.
3. If the taproots in closed-bottom tree sacks extend deeper than the planting pit, carefully prune them with a clean, sharp knife to the depth of your planting holes.
4. Place the seedling in the planting pit that should already be dug.
5. The root collar of the seedling (the band that forms where the stem meets the root system) should be placed just the ground surface. If the planting pit is too deep, fill in some of the topsoil mixture you prepared when digging the planting holes. Be sure any extended taproots are pointing straight down in the hole.
6. Fill in the topsoil and compost mixture, compacting it firmly around the seedling,

but not too much so that it compacts the root system.
7. As the soil should be moist from the rains that recently began, there is no need to water agroforestry seedlings. If it does not rain for more than a week after planting, however, you will need to water them. For fruit, timber, and other more valuable or slower-growing seedlings, it is good practice to water each seedlings with about 3 to 5 liters of water immediately after planting them.

Bareroot Seedlings

1. Remove bareroot seedlings from the bundles one at a time, keeping the others covered.
2. Place the seedling in the planting pit, ensuring the ends of the tap roots are facing straight down in the soil. If you need to dig the pit a little deeper or prune the roots so that they face straight down, then do. If, when you plant the seedling, the tap root turns back upward in the soil, a 'J' root will form, which will lead to stunting and it may eventually die.
3. Crumble up the soil on the side of the pit and gently place it around the seedling's roots, keeping the root collar (the point where the stem met the soil in the nursery, above the roots) at ground level.
4. Pack the soil firmly around the root system, up to the root collar, to remove any air pockets, but not too tight.
5. Cleanly prune the leaves and branchlets on the stem, leaving only a few at the top of the seedling. This will encourage faster root establishment before stem and leaf growth.
6. As the soil should be moist from the rains that recently began, there is no need to water them. If it does not rain several days after planting, however, you will need to water each one.

Chapter 8: Agroforestry Technologies

Healthy soils yield healthy crops. If you do not constantly care for your soil, you will have to pay high costs for artificial fertilizers or watch your yields decline until they are too degraded to support crop production. If you do treat your soil with care, ensuring that they are constantly protected and replenished with the water and nutrients they need to produce your crops, then they will reward you with a continuous supply of nutritious, high-quality production.

Fertile soils teem with life, with more than a billion microorganisms in every handful. The organisms present in your soil—earthworms, nematodes, protozoa, fungi, bacteria, and more—are vital to crop production as they eat and excrete the organic matter in the soils, decomposing it into rich humus full of nutrients and minerals that can be absorbed by plants' roots. Through symbiotic associations between them and plants' roots, they also naturally fix critical minerals into the soil. While doing so, they burrow billions of microscopic tunnels throughout the root zones of plants, providing pathways for air and water to circulate around them.

The way we ensure soils remain fertile is by constantly amending them organic matter. Though commercial fertilizers and pesticides may provide short-term gains in fertility and pest reduction, they do much more damage in the long-term by killing off the microorganisms we depend on for sustainable fertility.

The most important mineral nutrients for plants are nitrogen, phosphorous, and potassium—the primary nutrients—but plants also require secondary nutrients and micronutrients. Though these minerals can be added through the application of commercial fertilizer, it is more sustainable and far cheaper to add it through appropriate placement of organic matter, manure, and plants (especially leguminous plants that naturally fix nitrogen into the soil, and deep rooted plants that bring these elements up through their roots, to their leaves, and back onto the soil surface through leaf fall).

Forest Gardens incorporate a variety of technologies, ideas, and innovations from various agricultural systems and concepts, including agroforestry, permaculture, conservation agriculture, climate-smart agriculture, and many more. The Forest Garden Approach takes the most relevant, low-input, sustainable agricultural technologies from all the systems TREES has used and observed over nearly three decades, and combines them into one holistic system. The following agroforestry technologies are essential to the first phase of the Forest Garden approach, which begins with protecting fields and revitalizing soils before planting more diverse and lucrative products. In addition to

creating fertile soils, the trees incorporated through agroforestry technologies also produce a variety of useful timber and non-timber forest products that families can harvest from their Forest Gardens without further contributing to deforestation and land degradation in and around their communities.

Windbreaks

In arid zones, the dry, hot climate conditions coupled with minimal water availability are often intensified by strong winds. Winds can dry out soils and damage crops, leading to stunted plants and reduced yields. Living conditions and agricultural production can be improved by planting trees and shrubs as windbreaks to reduce wind velocity and provide shade. **Windbreaks are barriers of trees or shrubs planted to slow the movement of wind at crop level and divert the force of the wind to higher altitudes.** They frequently provide direct benefits to agricultural crops, resulting in higher yields, and provide shelter to livestock, grazing lands, and farms.

Reasons for Planting a Windbreak

Primary reasons for planting windbreaks around Forest Gardens include:

- To minimize damage to vegetables and crops
- To protect vegetables and fruit trees while they are flowering (because fruits and vegetables develop from the flowers, you can increase production by protecting the flowers from heavy winds)
- To minimize soil erosion
- To minimize the amount of moisture the winds evaporate from soils

Since our aim is to maximize the use of space to provide as many benefits as possible, we can combine protection with production by choosing tree and shrub species that, apart from furnishing the desired sheltering effect, yield food, fuelwood, fodder, green fertilizer, or other tree products.

Design Considerations:

The species composition of trees and shrubs used in windbreaks vary greatly around the world, but the basic design of windbreaks stays the same. There tends to be a time of the year, often during the dry season, when strong winds cause the most damage. It is those strongest winds which must be addressed first. To reduce wind velocity, windbreaks should be planted perpendicular to the strongest winds. It may be necessary to plant windbreaks on multiple sides of fields because the wind often changes direction during the year.

Desirable characteristics of windbreak species include:

- Fast-growing

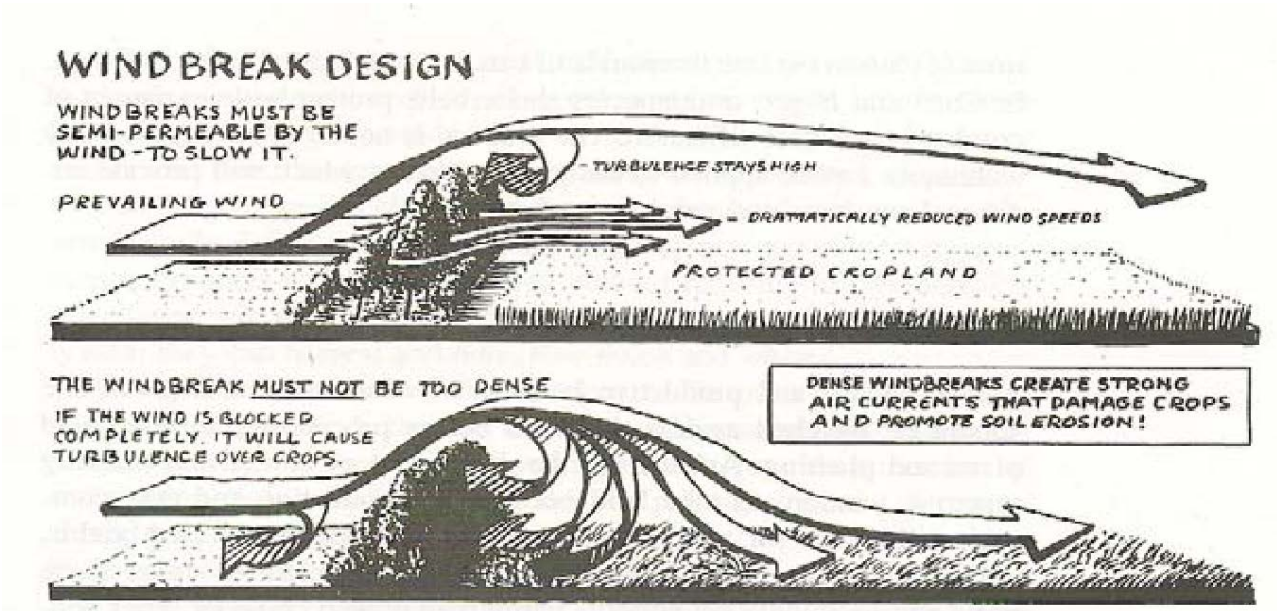
- Drought-resistant
- Ability to withstand strong winds
- Deep spreading root system to for stability
- Trees with small open crowns reducing wind speed without stopping it entirely

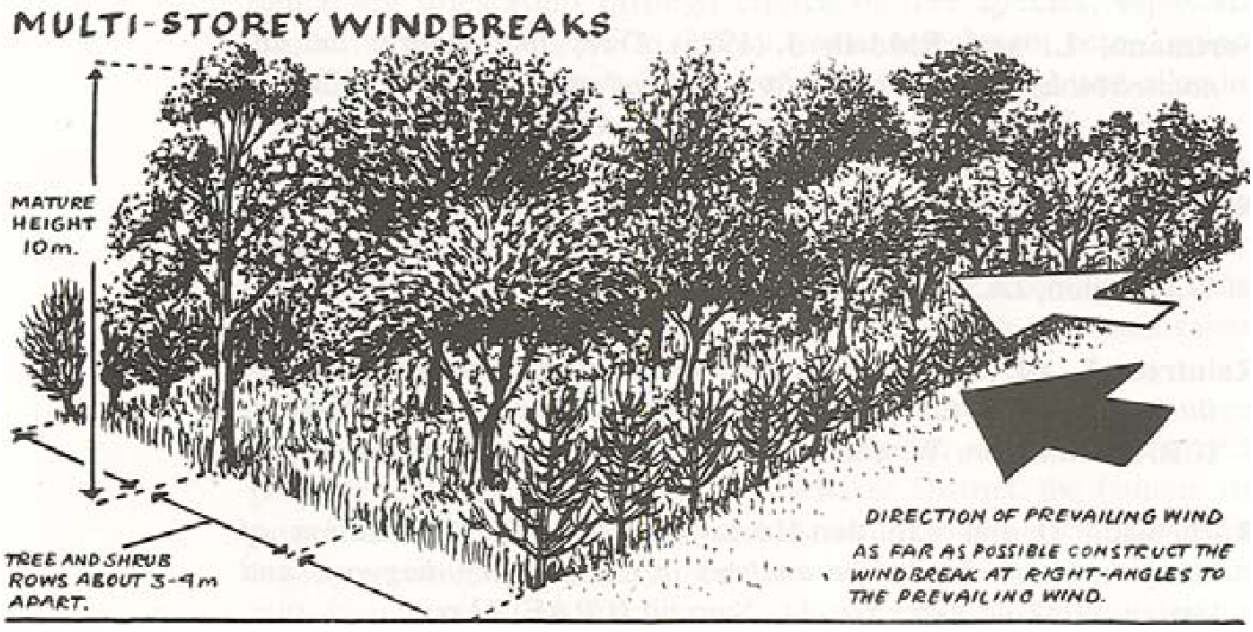
The graphics on the next page show how to orient windbreaks and the importance of keeping them from getting too dense. The goal is to slow the wind down, not to stop it. By creating a windbreak that is too dense, winds can actually create turbulence on the opposite side of windbreak, crashing into and causing damage to the field. For this reason, the windbreak should be somewhat permeable. Optimum permeability is about 50 percent, meaning the vegetation from the windbreak should fill about 50% of the space. It is also important to continuously ensure there are not any major gaps in the windbreak, as the wind will channel through those gaps, creating a destructive tunnel of high velocity winds. If gaps form, through tree die-off for example, replacement trees should be planted as soon as possible to fill them in.

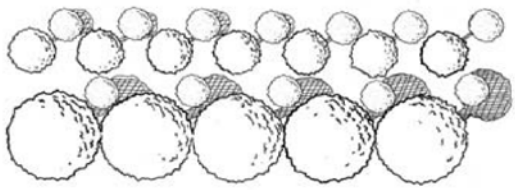
Windbreaks can protect for a distance of up to ten times the height of the tallest trees. So five-meter-tall trees protect fields for 50 meters, as long as the windbreak is uniform in height and spacing among trees. To better understand the design of a windbreak, one must look at it from the side and top.

Although windbreaks of only one row of trees may suffice, experience shows that the most effective windbreaks are those consisting of multiple rows. From a side, cross-section view, windbreaks should have a right triangle shape, with a vertical slope on the side facing the wind. If you look at the drawing below, the tall trees on the windward side (the direction from which the wind blows) of the windbreak stand beside rows of shorter shrubs or bushes. For barriers planted specifically for wind protection, taller trees on the windward side row can be spaced two meters apart. The next row, usually smaller shrubs, should be spaced about two meters from the first row, then bushes and grasses planted beyond and in between the rows to provide protection at lower levels. The lines of trees and shrubs should be staggered (figure – top view). By integrating tall trees, shrubs, bushes, and grasses into the windbreak, you can protect from winds at all levels and you can diversify the products that you can harvest from it.

Keep in mind that it is usually not recommended to plant fruit trees on the windward side of windbreaks because the stress from winds will keep them from producing much fruit. With the exception of tamarind trees, those in the genus *Averrhoa,* and those that develop fruit along their trunk - not on the ends of their branches.


WINDBREAK DESIGN
WINDBREAKS MUST BE SEMI-PERMEABLE BY THE WIND - TO SLOW IT.
PREVAILING WIND
TURBULENCE STAYS HIGH
DRAMATICALLY REDUCED WIND SPEEDS
PROTECTED CROPLAND
THE WINDBREAK MUST NOT BE TOO DENSE
IF THE WIND IS BLOCKED COMPLETELY, IT WILL CAUSE TURBULENCE OVER CROPS.
DENSE WINDBREAKS CREATE STRONG AIR CURRENTS THAT DAMAGE CROPS AND PROMOTE SOIL EROSION!


MULTI-STOREY WINDBREAKS
MATURE HEIGHT 10m.
TREE AND SHRUB ROWS ABOUT 3-4m APART.
DIRECTION OF PREVAILING WIND
AS FAR AS POSSIBLE CONSTRUCT THE WINDBREAK AT RIGHT-ANGLES TO THE PREVAILING WIND.



Top view

Poor design causes wind to funnel and damage crops.

Managing your Windbreak

The effectiveness and longevity of a windbreak depends on its maintenance, and the maintenance practices depend on the species selected for your windbreak. As the trees and shrubs mature, they change in size and shape. To maintain the composition of the windbreak—to ensure desired permeability and density—pruning, thinning, replanting of gaps, and in some cases plant removal, are generally required.

A windbreak's lifespan is generally determined by the species selected. For permanent windbreaks, rows will eventually need to be replaced, keeping in mind that shrubs often have shorter lifespans than larger trees. It will be necessary as the trees and shrubs age in a windbreak, to fell and replant rows, planting new rows parallel to the old ones. When the new row has matured, the old one should be removed.

An important thing to keep in mind when planting any trees is that livestock can and will eat them. We have seen too many tree planting initiatives end as goat feed, so be sure to **always protect your trees**! If you are not able to keep livestock from grazing near your newly planted windbreak, then be sure to protect them by creating dead fence barrier of dry, thorny tree branches. In places where open grazing is the norm, we advise creating a barrier of trees—called a *living fence* or *green wall*—around the entire Forest Garden site.

Some Useful Species for Windbreaks:

- Acacia nilotica
- Albizia lebbeck

- Casuarina equisetifolia
- Faidherbia (acacia) albida
- Grevillea robusta
- Gliricidia sepium
- Leucaena leucocephala
- Parkinsonia aculeata
- Sesbania sesban

Living Fences and Green Walls

It is extremely important to protect Forest Gardens from unwanted intruders, which most often come in the form of grazing livestock that love to make meals from the trees, shrubs, and plants you would rather keep for your family or the market. Building a 'dead' fence of wooden posts, beams, and/or barbed wire around the Forest Garden will do the trick, but the materials for these fences can be extremely costly. Also, remember that with the Forest Garden approach we are trying to maximize the utility and benefits of every bit of land. We aim for every system or technique to serve multiple functions. A dead fence can provide protection from four-legged bandits, but it does not prevent strong winds from damaging your crops, nor does it help to reduce soil erosion or provide useful secondary products. A more long-term, effective, and affordable solution that serves multiple functions is the living fence, which provides both protection and production.

A living fence is an animal-proof barrier composed of trees and shrubs that are densely planted around the perimeter of a field. Not only do living fences reduce the need (and cost) for standard fencing, but the trees and shrubs utilized in living fences can produce tangible benefits such as food, fuelwood, fodder, and other raw materials. Living fences are a commonly-used agroforestry technology, generally composed of one to two rows of trees and shrubs. Trees for the Future has developed a modification of living fences that are proving extremely effective and productive, called a green wall, which is an enhanced living fence technology consisting of three rows of trees and shrubs.

Some of the reasons why we encourage families to surround their Forest Gardens with living fences and green walls are:

- To mark boundary lines between farms or next to roads
- To separate or segment fields used for distinct purposes
- To protect and keep animals from intruding or straying
- To protect Forest Gardens from animal damage or theft
- To reduce erosion and wind damage
- To eliminate the cost of building and maintaining dead fences
- To produce useful products within border space that would otherwise be unproductive
- To mitigate damage from termites, carpenter ants and dry rot, which are a continuous headache in maintaining dead wooden fences and posts

Reasons for Planting a Living Fence

Beyond protecting the Forest Garden site, there are numerous other uses and products that living fences and green walls provide:

Fuelwood – a living fence post can be pruned periodically and the branches used for fuelwood. A convenient source of fuelwood near the farm home is especially beneficial in areas where wood is scarce. Extra fuelwood may be sold or bartered.

Fertilizer – a living fence can provides fertilizer in several ways. First, leaves that fall naturally from the tree, as well as leaves and small branches cut away when the tree is harvested for fuel, can be (1) composted, (2) mixed with the soil as green fertilizer, or (3) left on the ground as leaf litter mulch. Second, the deep roots of trees mine important mineral nutrients from deep in the soil, storing them in leaves and branches which can fall or be placed onto or mixed into soil. As these leaves and stems decompose, such minerals are released into the soil as green fertilizer, becoming available to the shallower root zones of annual crops. Third, leguminous trees (which are commonly selected for living fences) add significant amounts of nitrogen to the soil, reducing the need for costly commercial fertilizers. Finally, pruning of trees results in partial die back of roots, releasing additional nutrients directly into the soil.

Fodder – The leaves of most tree and shrub species selected for living fences provide highly nutritious fodder for livestock. The suitability of leaves as feed varies not only from species to species but also with age.

Food – Leaves, flowers, fruits and seeds of many living fence species can provide nutritious foods for people. Examples of foods that can be produced by living fences include moringa leaves, cactus flowers, mulberries, leaves and roots of cassava, pigeon peas, *Z*iziphus fruit, and kei apples.

Fiber – A few living fence plants, such as the sisal plant and some bamboo species yield branches or leaves that can be processed into useful fiber for cloth or rope, or used directly for tying.

Timber – Although families generally do not cut down their living fences to produce timber, the straight, solid branches from some common living fence species, including *casuarina* and *grevillea* can be harvested when needed for tool handles, trellises, and light construction.

Medicine – Some living fence plant species are also selected for their medicinal value. The seeds of *jatropha* produce a medicinal oil, and *gliricidia* produces a natural pesticide in the bark which makes an effective rat poison.

Windbreaks – In some areas windbreaks are extremely useful in protecting against soil and yield damage caused by winds. Where desirable, living fences can be designed to protect Forest Gardens against wind damage and livestock.

As a general rule, fuelwood or charcoal is the primary cooking fuel in developing communities. A living fence post can be trimmed periodically and the branches used as fuel. A convenient source of fuelwood near the home, such as a living fence, is especially beneficial in areas where wood is scarce. Extra fuelwood may be sold or bartered.

Families who establish living fences and green walls see a major savings in not having to purchase costly materials to construct or repair their dead fences. However, this is not to

say that establishing and maintaining a living fence is *not* labor intensive. Farmers face the greatest difficulties during the first few years when establishing a new living fence. Replanting is often necessary to fill in gaps where the previous year's seedlings did not survive. Farmers must also be sure to begin pruning the trees when the seedlings are in the nursery, and there is always pruning work to be done to maintain the fence. However, once the living fence is established, farmers can develop their Forest Gardens inside the safety and security offered by the permanent protection, and they can enjoy the many products from their living fence.

Desirable characteristics of trees used in living fences:

- Tolerant of minor "injuries" – living fences are susceptible to frequent injuries from pruning or browsing animals and should tolerate them well.
- Fast growing - to provide benefits for which they are planted as soon as possible.
- Compatible with crops – avoid species that have adverse effects on other tree species or crops they are associated with.
- Production – select trees with useful products like fodder, green manure, & fuelwood.
- Protection – they should have stiff branches, thorns, spines, nettles, or irritating latex to keep animals out.
- Vegetative propagation – ensures fast establishment while reducing the chance of spreading to pasture and cultivated areas.

Design Considerations:

Thorny species (*acacia sp., parkinsonia, ziziphus*, etc.) tend to work best in living fences, though many people also use non-thorny species. Spacing among trees in a row for thorny species should be 20-50 cm apart. Cuttings of *euphorbia, jatropha* and other non-thorny species—particularly useful for the center row of a green wall—should be planted very close together (10-20cm). For non-thorny species in the outer and inner rowsl 40 to 50 cm spacing tends to prove effective. Farmers who can afford barbed wire will often plant trees for living posts, and attach barbed wire once the trees reach the appropriate. If the trees are being planted inside a dead fence, plant the seedlings 1 meter away from the existing fence (even if it looks like you will be losing ground). Falling sticks and weeds near the dead fence can crowd and kill the seedlings, and the rotting wood can host pests that will attack your living fence when they are done with the dead one.

Though it is possible to plant a single row of trees for a living fence or green wall, experience shows that two to three rows are far more effective, as they provide additional layers of both protection and production. It is best to stagger the rows of trees for living fences and green walls, offsetting the trees in one row from those in the next. This will help to reduce root binding from the closely spaced trees, and will provide a denser barrier when branches are woven between the tree stems. A variety of species should be selected for living fences, to increase diversity and provide a greater selection of products.

TREES recommends the following composition for a three-row green wall:

OUTER ROW
The outer-most row of trees is comprised of thorny trees planted very close together to form a thick hedge that even goats cannot penetrate. We frequently use *Ziziphus mauritiana*, the jujube tree, and Dovyalis, the Kai apple, because both thorny species have a valuable vitamin-C rich fruit that can be sold at market or consumed by the family.

Suggested species: *Ziziphus, Dovyalis, Faidherbia albida, Acacia sp*.

MIDDLE ROW
The middle row tends to consist of fast-growing but sturdy trees that give the Green Wall some structural integrity. This structure is required to support the many thorny branches that are eventually woven among each other. We frequently use trees such as *Moringa oleifera* and *Jatropha curcas* to provide this line of structural support.

Suggested species: *Jatropha curcas, Euphorbia, Leucaena, Moringa oleifera*

INNER ROW
Farmers often choose a variety of trees to plant on the inner lining of the Green Wall that surrounds their field. While we recommend planting tall, fast-growing trees such as *Leucaena leucocephala, Cassia sepium* and *Gliricidia sepium* to form a multi-purpose windbreak, farmers in areas better protected from fierce winds will often opt to plant rows of protein-rich, nitrogen fixing pigeon peas so that they can harvest dozens of pounds of pigeon peas from their Green Wall twice a year.

Suggested Species: *Leucaena leucocephala*, Grevillea *spp.*, *Gliricidia sepium*, *Cassia siamea*, *Cajanus cajan*, *Calliandra*, *Sesbania*

Alley Cropping

In addition to protecting your site, the first phase of the Forest Garden Approach involves stabilizing and revitalizing soils to ensure that the more lucrative trees and crops you plant in the diversification phase will be raised in healthy, fertile soils. Particularly necessary for degraded sites that suffer from intensive and continuous planting of monoculture systems, alley cropping helps to: stabilize erosive topsoils with networks of fibrous root systems that hold soils in place; reduce the speed of runoff, encouraging water to penetrate into the soils rather than across the surface; and increase soil fertility through fixing nitrogen into the soils and providing an abundance of nutrient-rich leaves and stems as green fertilizer, which recycles soil nutrients while also improving soil aeration, and reducing soil temperature.

Alley cropping refers to the planting of multiple sets of single or double rows of trees or shrubs within which crops can be grown. Though timber and fruit trees are often selected for use in alley cropping systems, TREES encourages the use of fast-growing, multi-purpose agroforestry trees for Forest Gardens to provide for greater soil stability, water availability, and soil fertility for the diverse trees and crops that are grown within the alleys. The alley trees are pruned periodically during the growing season to provide biomass and to prevent shading of the growing crops. Many farmers in developing countries do not have access to commercial fertilizer, and if they do, the fertilizers tend to be very expensive. For them, there's good news: you can grow fertilizer on trees.

Benefits of Alley Cropping

The multiple benefits of alley cropping include:

- Reduced erosion from wind and water.
- Reduced runoff and increased groundwater recharge.
- Enhanced soil fertility through nitrogen-fixation and increased soil organic matter.
- Reduced soil moisture loss due to evaporation from wind.
- Enhanced habitat for biodiversity.
- Production of useful agroforestry tree products, e.g. fuelwood and poles.
- Protection from pests due to reducing crop visibility, diffusing pest targets due to plant diversity, interfering with pest movement, and creating habitat more favorable to beneficial insects.

Desirable characteristics of trees used in alley cropping:

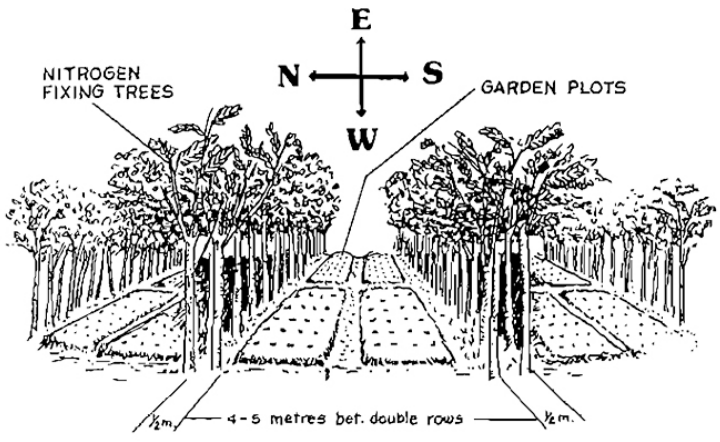
- Produces an abundance of leaf litter, preferably producing the most leaves prior to the cropping season.
- Nitrogen-fixing.
- Able to grow back quickly after pruning, coppicing, or pollarding.
- Fast growing - to provide benefits for which they are planted as soon as possible.
- Resistant to drought.
- Able to grow in degraded, nutrient-poor soils.

- Compatible with food crops – avoid species that have adverse effects on other tree species or crops with which they are associated.
- Deep taproot with minimal lateral root growth – the trees' roots should grow deep into the soil rather than horizontally to reduce competition at the root zones of crops planted in the alleys.
- Multi-purpose – select trees with useful products like fodder, green manure, & fuelwood.

Design Considerations:

On flat land, the rows of trees should be planted in the east-to-west direction, NOT north-to-south. Planting east-to-west, following the pattern of the sun as it moves across the sky, the sun is able to shine across the rows throughout the day. However, if the land is sloped, the alleys should be planted following the contours (see the Contour Planting section below), as it is more beneficial to manage erosion of topsoils than to follow the pattern of the sun. In this case, alley trees are pruned back heavily during the cropping season to minimize competition for sunlight.

In our experience we have found it highly effective to plant a double row, as close as 20 cm apart, with the trees about that same distance apart between the two rows. As with living fences, the rows are staggered to reduce root binding between the trees. However, depending on the number of trees that have been raised for planting, it is better to spread those trees across single rows with spacing between trees as much as a meter apart. In this way, farmers can begin to cover their fields with agroforestry trees. Then more trees can be raised and planted to increase the density of the rows in the following planting season.



Spacing between rows of trees is highly variable, ranging from 4 to 20 meters, depending on the farmer's preferences and the slope of the land. TREES recommends closer spacing between rows for sloping land as the alleys are also very effective in controlling erosion. Spacing of 4-5 meters between rows, though labor-intensive, will produce large quantities of wood and quickly revitalize degraded soils with the massive amount of leaf fall (Nair,1993).

Management of Alley Cropping Trees:

Throughout the growing season, on a rotational system of 3-4 weeks, the branches and branchlets of these trees are chopped and the leaves dropped around the crops growing between the tree rows (see pictures dbelow). These leaves decompose quickly, adding

large amounts of organic matter & nutrients to the soil. Particularly on degraded soils, this leads to considerable, sustainable increases in crop yields. Farmers in our program have seen their yields improved by three times only one year after the system was started.

As the growing season comes to an end farmers can allow the trees to grow tall, since they will not be competing with crops for sunlight (see pictures below). By the beginning of the next cropping season, the trees may be 3-4 meters tall and the entire tree should be cut back. The trees can be harvested at 50cm to 1m height above ground. The wood can be used for fuelwood or construction, and the leaves should be plowed back into the soil or dropped on top as green fertilizer.

Alley cropping with *Cajanus cajan.*

Chop and drop with agroforestry trees.

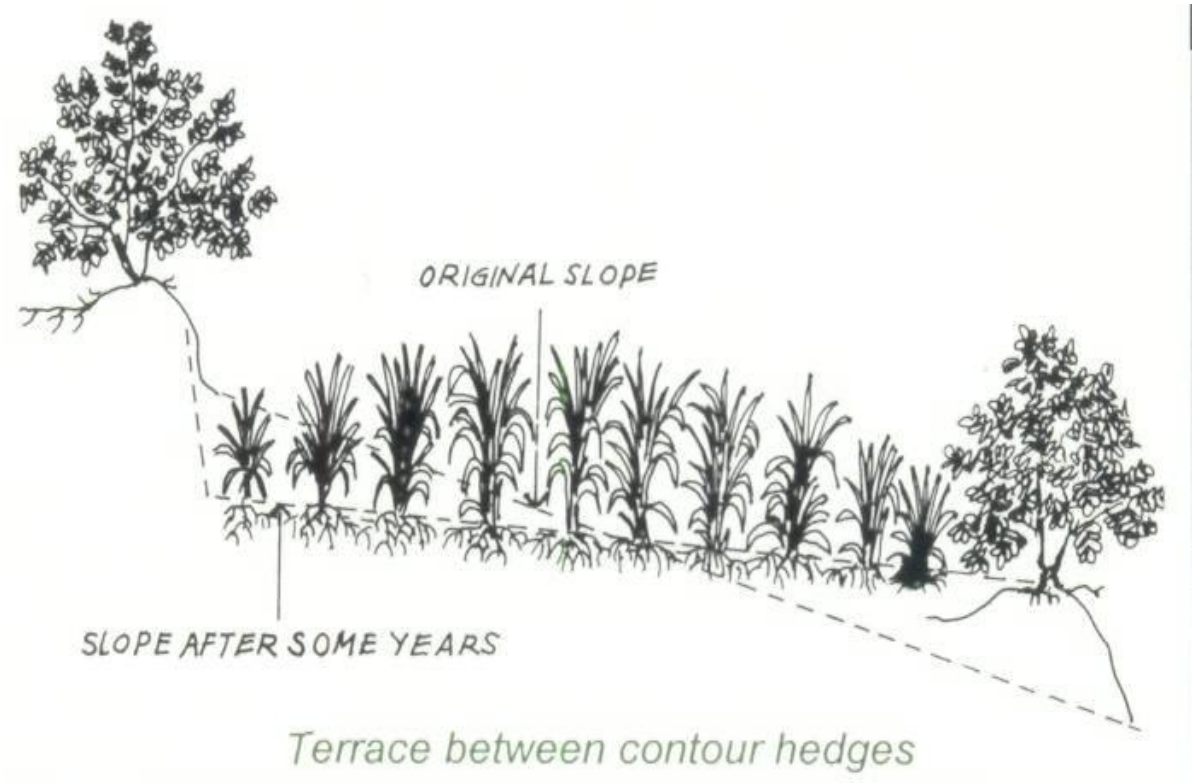
Some Useful Species for Alley Cropping

- *Cajanus cajan*
- *Calliandra calothyrsus*
- *Chamaecytisus proliferus*
- *Faidherbia albida*
- *Leucaena leucocephala*
- *Sesbania sesban*
- *Tephrosia candida*

Contour Planting

We hope we have made it clear by now that soil stability and fertility is key to sustaining agricultural productivity. Where Forest Gardens are being established on barren, degraded hillsides, particularly on slopes that exceed 5% (i.e. a one meter vertical climb or drop over 20 meters), soil erosion is a major challenge. During rains, runoff moves quickly across land if it is not slowed by vegetation or other barriers and allowed to filter into the soil. As it moves down the hillside it carries topsoil—along with any nutrients—away with it. Families can significantly reduce these problems through contour planting. **Contour planting refers to vegetative barriers planted on the contours of hillsides and slopes to stabilize soils and increase soil moisture and fertility.**

Contours are level lines that cross a slope at a constant elevation. Contours may curve from side to side to stay level, but the lines never move upslope or downslope. Once the contour lines are plotted across a hillside or slope, vegetative barriers of trees, shrubs, and grasses can be planted along the contours to control soil erosion. It is best to dig a trench along the contour lines, packing the soil from the trench firmly into a berm on the uphill slope, then planting the berm with trees, shrubs, and grasses. Once established, any runoff flowing down the slope will be slowed down by the berms, and the soil particles being carried by the water will settle behind them. The water then has a chance to seep into the soil rather than rushing further down the hill face, taking more and more topsoil with it. Over time, the soil deposits will continue to build up behind the berms while the vegetation spreads over and stabilizes them, eventually decreasing the gradient of the slope and forming a terrace.



Terrace between contour hedges

Before proceeding with contour planting it is extremely important that the family lays out contour lines accurately. If the contour lines are not level, the runoff can gather and run along the sloping vegetative barrier, potentially causing more erosion than if the barrier was never planted to begin with. If the land on a given hillside is owned by more than one family, it is best for all landowners on the hill to work collectively to develop contours across the entire hillside.

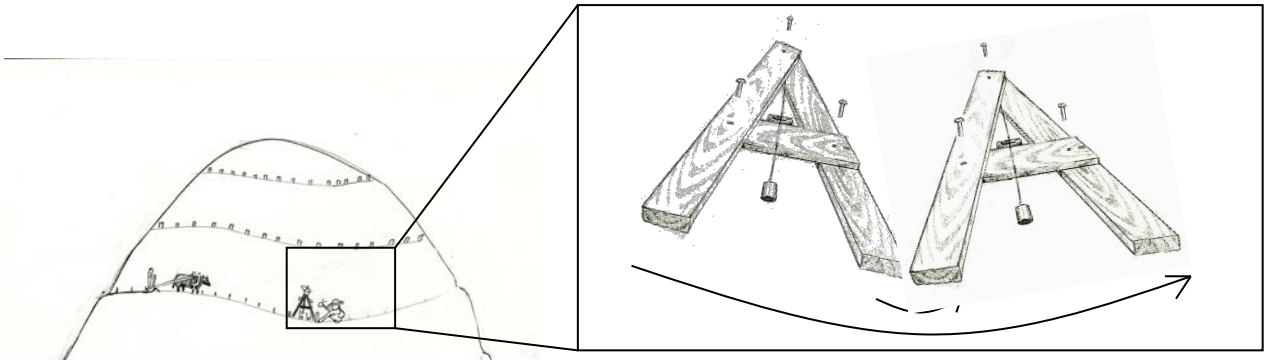
Similar to alley cropping systems, other crops can continue to be planted between the barriers. If the alleys between the contour strips are ploughed for cultivation in the early years of Forest Garden establishment, the ploughing should also be done following the contour lines (this is a good rule of thumb for all ploughing and planting on sloped land, regardless of the presence of contour vegetative strips). On any slopes greater the 60%, annual crops should not be cultivated. It is far too difficult to keep soils stable when ploughing such steep land, so stick to only planting tree crops and perennials on steep slopes, your soils will thank you (by providing increased, sustainable yields!)

Finding contour lines with an A-frame

So how do we find the contour lines using locally-available materials? We're glad you asked. The following steps will guide you through the steps of building and using an A-frame.

Materials Needed to Construct an A-frame:

- Two 1.5 to 2 meter sticks or poles about 3 to 5 cm in diameter (can be wood, bamboo, plastic, or any other light-weight, sturdy material)
- One 1 to 1.5 meter stick of the same material
- Three nails, or 2 meters of twine/string for binding the wood together
- One 1.5 meter piece of twine/string for the level
- One round rock, about 5 cm in diameter

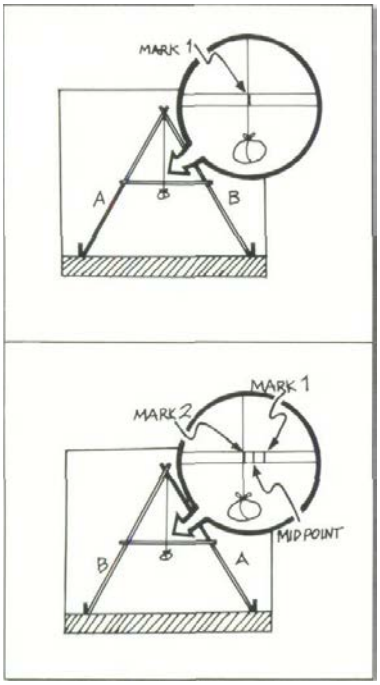


Making the A-frame – Join the three poles securely together, with the two longer poles bound together on one end with a nail or string, and the shorter pole bound across the two to form an 'A'. Tie a piece of string to the top of the A-frame, then tie the rock to the other end of the string. The rock must be heavy enough that it will not be blown by the wind. The rock should hang down about 15 to 20 cm below the crossbar.

Calibrating the A-frame – To find the center 'level' line on the A-frame crossbar, place the A-frame on nearly level ground. Mark the spots where the legs (A and B) touch the ground. Mark the crossbar where the weighted string passes it ("mark 1").

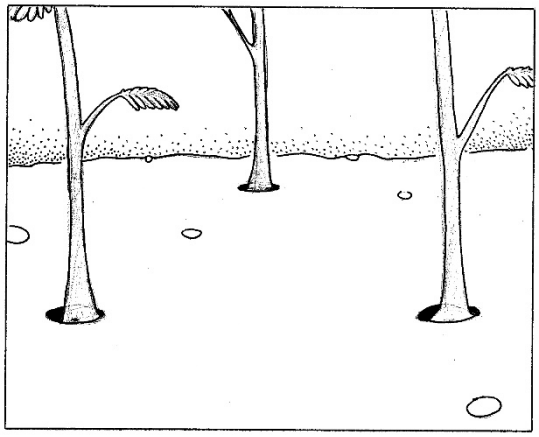
Turn the A-frame so that leg A is exactly where leg B was, and leg B is exactly where leg A was. Mark the crossbar where the string falls now ("mark 2"). If the two marks are the same, they are the midpoint. If they are different, the midpoint is halfway between them.

Check the midpoint by moving one leg until the string hangs at the midpoint. Mark the positions of legs A and B with stakes in the ground. Reverse legs A and B. If the string hangs at the midpoint again, the A-frame is level and the midpoint is accurate. Mark the midpoint clearly on the A-frame.



Step 1) Find and Mark the Contours: Find the contour using an A-frame and markers (e.g. wood stakes). Start creating contour lines at the top of the hill, using the A-frame to delineate a level line that meanders across the hillside. Placing leg A of the A-frame on the ground where you want to establish the first row, and mark the leg with a marking stake. Adjust the other leg until the string hangs across the center line, showing that it is level, then mark leg B. Next, pivot leg A around, keeping leg firmly in place at that second mark. Readjust leg until the string shows it is level and mark the third point. Continue this same process across the hillside or slope. Then follow the same steps to delineate the next line down, which should be parallel to the one you just completed. Continue this process down to the bottom of the hill.

Step 2) Prepare the Lines: Using your markers as a guide, dig one channel about 50 cm wide and 50 cm deep along the contour to create a swale. Place the soil on the uphill slope to form a berm and pack the soil firmly. Plant seeds or seedlings on the mounds at the start of the rainy season. (see earthworks section for more information on berms and swales).



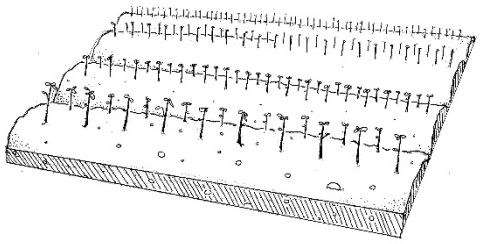
Step 3) Plant the Vegetation: Sow pretreated seeds of fast-growing, nitrogen fixing trees heavily along the mounds (plant seeds in 2 rows, with 10cm spacing within rows and 20cm between rows). Cover the seeds lightly yet firmly with soil. If planting seedlings or cuttings along the channels, spacing should be 20cm within and between rows. Grasses can also be planted to further stabilize the mounds.

Step 4) Protect the Vegetation: The first year is critical for success. Extremely heavy rains, animals, and farmers themselves can damage the structures. Be sure to keep animals from grazing on the land, and remove weeds from near the seedlings to reduce competition.

Step 5) Diversify: Beginning in the 2nd year, diversify the strips and the alleys in between with short-, medium- and long-term crops.

Distance Among Contour Rows

To provide maximum protection, the rows should be properly spaced. The **vertical drop** between contour rows (NOT the distance between rows) should be about 2 meters.
Hillsides with a gentle slope will have long distances between rows (though it is best to limit this to 10 meters between rows), while those on steeper mountainsides will be closer together.



If a family does not have the time or labor available to establish contours as directed, encourage them to establish three to begin with, and divide the field into quarters. The family can always add more contour rows over time.

Grasses commonly planted are: *Pennisetum purpureiim (napier grass),* *Pannicum* maximum (guinea grass), and *Vetivera zizanoides* (vetiver grass).

Some grasses, like napier, grow tall and fast in the wet season and might shade crops or compete for water and nutrients. Therefore plant only as much as will be cut and carried for forage.

Vegetative strip on contour

Desirable Characteristics of Trees Used for Contour Planting:

- Adapted to local climate and soils.
- Can be direct-seeded or planted from cuttings.
- Produces an abundance of leaf litter, preferably producing the most leaves prior to the cropping season.
- Nitrogen-fixing.
- Able to grow back quickly after pruning, coppicing, or pollarding.
- Fast growing - to provide benefits for which they are planted as soon as possible.
- Resistant to drought.
- Able to grow in degraded, nutrient-poor soils.
- Compatible with crops – avoid species that have adverse effects on other tree species or crops they are associated with.
- Deep taproot with minimal lateral root growth – the trees' roots should grow deep into the soil rather than horizontally to reduce competition at the root zones of crops planted in the alleys.
- Multi-purpose – select trees with useful products like fodder, green manure, & fuelwood.
- Grasses such as *Pennisetum purpureiim (napier grass), Pannicum maximum* (guinea grass), and *Vetivera zizanoides* (vetiver grass). Some grasses, like napier, grow tall and fast in the rainy season and might shade crops or compete for water and nutrients. They might also compete with trees and shrubs planted on the berms. Therefore plant only as much as will be cut and carried for forage.

Contour planting with *Calliandra calothyrsus.*

Some Useful Species for Contour Planting

- *Cajanus cajan*
- *Calliandra calothyrsus*
- *Chamaecytisus proliferus*
- *Faidherbia albida*
- *Leucaena leucocephala*
- *Sesbania sesban*
- *Tephrosia candida*

Dispersed Planting

It is common in many places for farmers to leave some of the trees on their farms when they cultivate a new area. Some very effective land-restoration techniques such as Farmer Managed Natural Regeneration (FMNR) encourage farmers to allow seedlings that germinate naturally on their farms to grow, managing them as needed. Often on the Forest Garden sites we see, there are few to no trees at the start. We encourage farmers

to leave the trees that are there, unless the benefits they provide are outweighed by other trees that can be planted to provide even more benefits.

On sites with limited existing tree cover, as we know with our goal in the protection and revitalization phase of the Forest Garden Approach, we want to increase tree cover and soil fertility. We do this by establishing living fences, windbreaks, contour plantings, and alley cropping systems. Even with all these groupings of trees, however, there are likely to still be large areas of land without trees. In these open spaces, we want to disperse the planting of trees so that these 'empty' spaces can benefit from increased nitrogen and green fertilizer that these agroforestry trees provide. Later on in the Forest Garden Approach, during the optimization phase, families will review their sites and may decide to fill in remaining open spaces with more agroforestry trees, or with timber, fruit, or other species of dispersed trees or plants.

Farmers can select many species for dispersed planting. In the first phase of the project, TREES recommends multi-purpose, fast-growing agroforestry trees with the same characteristics as alley cropping trees.

Spacing between dispersed trees varies considerably, dependant on the amount of 'open' space after alleys and living fences have been planted. A good rule of thumb is to have a dispersed tree for every 50 to 100 square meters, so spaced in a grid-like pattern about every seven to ten meters.

Management practices of dispersed trees are similar to those of the trees in alley cropping systems – the thicker branches can be coppiced at the beginning of the cropping season and used for fuelwood and poles, while the leaves, stems and branchlets can by 'chopped and dropped' as green fertilizer throughout the cropping season.

As other Forest Garden trees and plants are gradually planted and mature, families may decide to continue with the same management practices. If they are found to be competing for space, nutrients, or sunlight with other, more valuable crops, they can cut the trees out of the Forest Garden entirely. However, if the tree will produce good timber or other desirable products or services, they can be left to grow with little to no regular management. In most cases, depending on placement, surrounding vegetation, and species, families will decide how to manage each tree on an individual basis.

Firebreaks, Fuelbreaks, and Greenbreaks

Fires are a common threat, particularly in dryland regions where they can cause significant damage to trees, crops, and other vegetation, not to mention buildings, animals and humans. In fire-prone areas, it is always better to expect fires and take the steps to prevent them rather than to address them on a reactionary basis.

Fires are often human-induced. Slash-and-burn agriculture and setting pasture fires are common practice in many places, where farmers and pastoralists cut the existing vegetation on a piece of land and burn it to convert the land to agriculture or stimulate fresh fodder growth. Though ash from fires does fertilize crops or forage in the short run, it burns away much of the organic matter and nitrogen while killing seedlings and beneficial microorganisms that would otherwise provide longer-term benefits to soil. These fires are also notorious for getting out of control and burning more vegetation than anticipated. Fires are also commonly started by apiculturalists who are careless with the smoke they use for bee hives, negligent cigarette smokers flicking their butts or matches in dry areas, or herders whose campfires unintentionally spark wildfires.

The majority of fire incidents can be prevented by either refraining from or being much more diligent with such activities. Where fires are particularly problematic, we recommend educating your community about fire prevention, and encouraging community leaders to hold accountable those who carelessly start fires.

Fire prevention is not foolproof, however, and measures should also be taken to help suppress fires once they start and prevent them from burning crops and trees, particularly seedlings and wildlings. During the dry season it is good practice to regularly clear weeds and tall grasses from around young trees. This vegetation is a fuel hazard and will feed any potential fires. *Imperata cylindrica* is a common grass that proliferates where there is little other vegetation, particularly on degraded, deforested or post-fire lands. *Imperata* is a significant fuel hazard and should be cleared or pressed flat to the ground regularly around tree planting and agricultural sites to reduce the risk of fire.

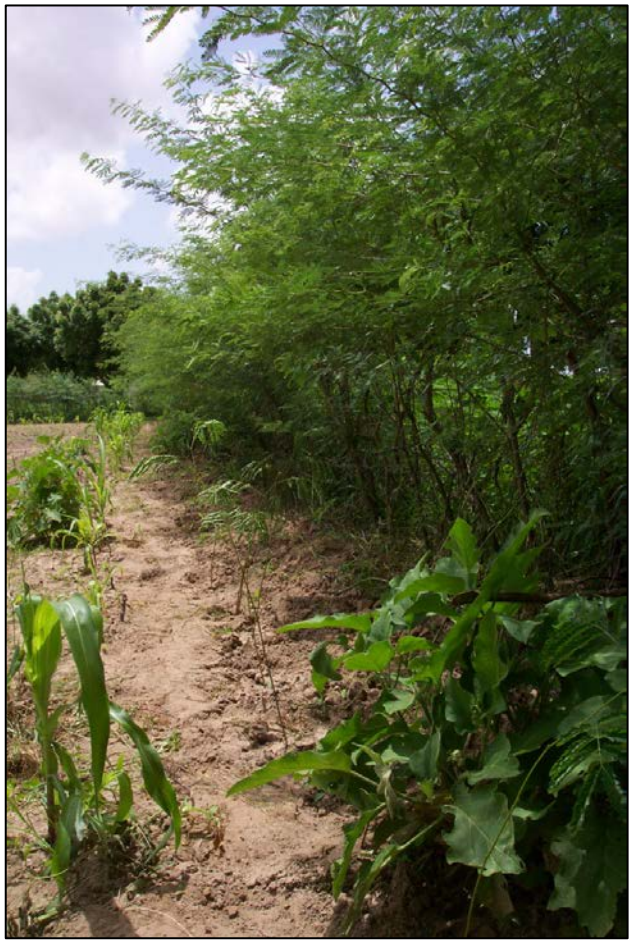
Firebreaks around larger, fire-prone planting sites should also be considered. A **firebreak** can be made by clearing a 4 meter strip of vegetation around the planting site, leaving a space of 12 meters, then clearing another 4 meter strip on the outside. The 12 meter strip in between the 4 meter clearings should then be carefully control-burned. By removing this vegetation, fires will likely subside for lack of fuel once they reach the firebreak.

In spite of the potential benefits of firebreaks for fire suppression, they are problematic as well as they require existing vegetation to be removed, taking valuable land out of productivity and exposing soils to further degradation. Where possible we recommend the use of multipurpose fuelbreaks or greenbreaks that provide fire protection as well as useful products like food, fodder, timber and fuelwood.

A **fuelbreak** is a wide strip of land around a protected area where dense, existing vegetation is thinned or replaced by other trees. When mature, fuelbreaks will minimize flammable undergrowth, thereby reducing the speed and force of fires headed into protected areas. Trees in a fuelbreak should be pruned regularly to around three meters from the ground and any dead or dry vegetation should be removed. The shade from the trees will help to suppress much of the undergrowth. Fuelbreaks are not likely to stop a fire, but should allow landowners more time to suppress it (Skinner, 2000; Imperata grasslands).

A **greenbreak** refers to a wide strip of densely-planted trees that are specifically chosen for their high moisture content and lack of flammable biomass they produce. When mature, the dense canopy of a greenbreak will help to minimize fire-prone undergrowth while the trees' fire-resistant leaves and trunks will deter fires from spreading past them. Succulent, shade-tolerant crops (e.g. banana, papaya, and root crops) can also be planted under greenbreaks to create a green barrier that will further suppress impending fires. In all cases, flammable weeds, grasses and dry vegetation should be removed regularly.

The recommended width of fuelbreaks varies broadly depending on the fire risk conditions, slope, and amount of flammable vegetation in them. Generally speaking, the width of fuelbreaks should be between 12 and 35 meters: the greater the slope and existence of flammable vegetation, the greater the width (Plana, et al). Where fire-retardant trees and crops are used in a greenbreak, three to four rows of densely planted trees should suffice. Trees selected for greenbreaks should be fire-resistant with dense, easy to establish canopies that retain succulent, green foliage throughout the year without dropping flammable leaves. See the list below for recommended fuelbreak and greenbreak species. (Imperata Grasslands)



Newly planted row of *Leucaena leucocephala* trees planted inside the protection of a thorny living fence.

Useful Species for Fuelbreaks and Greenbreaks

Recommended Fuelbreak Species:

- *Acacia auriculiformis,*
- *Acacia mangium,*
- *Albizia lebbeck*
- *Calliandra calothyrsus,*
- *Gmelina arborea,*
- *Leucaena leucocephala,*
- *Macadamia hildebrandii,*
- *Schima wallichii,*
- *Syzygium cumini*
- *Vitex pubescens.*

Recommended Greenbreak Species:

- *Anacardium occidentale*
- *Ficus elastica*
- *Mangifera indica*

Limitations to Agroforestry Technologies

Keep in mind that every system or technology selected for inclusion in Forest Gardens, as with any land-use option, has its limitations. The following are general limitations to agroforestry technologies—which can be extended to Forest Gardening as well—that families should be aware of before deciding to utilize them. They:

- Require a more intensive management system, including specialized equipment for the tree management and additional managerial skills and training to manage multiple crops on a given site.
- Remove land from annual crop production and may not provide a financial return from the trees for several years.
- Requires a marketing infrastructure if tree products are selected that are not present in the local area.
- Trees may be an obstacle to crop cultivation if not carefully planned and designed.
- Trees compete with companion crops for sun, moisture and nutrients.
- Companion crops may compete with trees for moisture and nutrients.

CHAPTER 8: REFERENCES

1. For more information on wind breaks, go to http://www.fao.org/docrep/t0122e/t0122e0a.htm

2. For more information on alley cropping, go to http://www.agroforestry.net/overstory-back-issues/337-overstory-261-alley-cropping

3. For more information on contour planting, see : http://www.worldagroforestry.org/Units/Library/Books/Book%2082/imperata%20grassland/html/4.1_soil.htm?n=20

For more information on firebreaks, fuelbreaks and greenbreaks, see:

4. Friday, Kathleen S., M. Elmo Drilling, and Dennis Garrity. (1999) *Imperata* grassland rehabilitation using Agroforestry and Assisted Natural Regeneration. International Centre for Research in Agroforestry, Southeast Asian Regional Research Programme, Bogor, Indonesia.

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Chapter 9: Popular Agroforestry Tree Species

As we've learned, trees planted using agroforestry technologies in the first phase of the Forest Garden Approach are an important step in the continuous pursuit of sustainable land management. Establishing a sustainable agroforestry system will occur over a number of years. The first year or two are extremely important as participating families must have some level of success and want to see some harvestable products or clear benefits that will keep them engaged and committed. After the initial pioneer species are established, sites are protected, and soils are revitalized through the use of a combination of the agroforestry technologies described above, diversifying the system will become much easier.

In the first phase of the Forest Garden Approach, you will start with a low number of species, perhaps just three or four. Though we do recommend native species when they host the desired characteristics required by the technology and climate, non-native, naturalized species that have been researched and used in agroforestry projects for decades often better meet the growth, production, and service needs of the system. Regardless of the species, the trees you select and plant during the first phase must include multipurpose, fast-growing (MPFG) trees that have as many of the following characteristics as possible, relevant to the purpose for which you are planting them:

- Fast-growing
- Nitrogen-fixing
- Produces an abundance of leaf litter
- Able to grow back quickly after pruning, coppicing, or pollarding
- Able to grow in degraded, erosive, nutrient-poor soils
- Compatible with crops
- Deep taproot with minimal lateral root growth
- Multi-purpose – trees that provide a variety of useful products (e.g. fodder, green fertilizer, & fuelwood) and ecosystem services (e.g. erosion control and soil improvement)

As for the exact species for your Forest Garden, it is ultimately you and your family who will make that decision. Discuss species selection with your project technicians, fellow farmers, and representatives from the local department of forestry or natural resources if you have any questions.

Below is a brief list of the most common and useful tree species or genera that TREES recommends, including a description of the tree, its products, services, and uses, growing requirements, propagation recommendations, and pictures.

Leucaena spp.

Overview: Fast growing, deciduous small tree or shrub, reaching up to 20 m tall. Native to the American tropics, improved varieties of Leucaena are now being developed on nearly every continent. It is predominantly self-pollinating and therefore gives forth offspring similar to the mother tree. Use of *L. colinsii* and *L. salvadorensis* is mostly in Central America.

Products:
Wood: Coppiceable, dense wood good for fuelwood and pole timber.
Fodder: The high percentage of crude protein and digestibility, and the copious amount of nutritious leaf litter production make Leucaena trees an excellent fodder sources. However, it contains mimosine, an irregular amino acid that can cause hair loss and stomach issues, and should be fed in limited amounts to non-ruminant, single-stomach animals (none at all to horses or mules). For ruminant animals (cattle, goats, sheep), it can be fed up to 25% of the diet.
Green Fertilizer: Leaves are high in nitrogen and are great as an organic fertilizer.

Agroforestry Uses:
Windbreaks: Good, tall filler in windbreaks because leaf density is full yet not too thick, space ~3-4 meters apart.
Living Fences: Fast growth speed makes it great for live fence posts as long as animals do not eat the seedlings before they mature.
Alley Cropping and Contour Planting: Nitrogen fixing; can be planted on flat terrain or in contour lines on slopes, Leucaena makes great hedge rows that produce organic fertilizer, pole timber, and serve as windbreaks. FUEL: Quality fuel and charcoal.
Apiculture: Leucaena is in bloom almost throughout the year, providing constant forage for honey bees.

Characteristics: Growths rates are fast, and crown shape and branch formation are all similar. Narrow canopy up to 20 meters tall, sometimes higher. Very coppiceable, growing back quickly after cutting. It is a heavy seeder, however, with the undesirable ability to colonize quickly if not managed carefully.

Site Requirements: Grows best in full sun, though can handle partial shade. Tolerant of many types of soil and terrain, but tends not to fare well in acidic soil. Can tolerate light frost though will likely be defoliated.

L. leucocephala: Altitude 0-1500 m; Rainfall 650-3,000 mm
L. collinsii: Altitude 100-900 m; Rainfall 500-1,000 mm

L. salvadorensis: Altitude 200-1000 m; Rainfall 800-2,000 mm

Propagation: *L. leucocephala*: Boil water, remove from heat, place seeds in the water and allow to soak for 2 minutes, then add cool water. Soak for 24 to 72 hours. Another option is to scarify the seed coat. Make sure not to damage the radicle/embryo (the pointed side of the seed). *L. collinsii*: Boil water, remove from heat, place seeds in the water and allow to soak for 30 seconds, then add cool water. Soak for 24 to 72 hours. Scarification is more effective. Make sure not to damage the radicle/embryo (the pointed side of the seed). *L. salvadorensis*: No pretreatment required.

Pests and Diseases: A myriad of insects, fungi, and animals attack Leucaena, yet few cause serious damage. Widespread leaf loss from psyllids in the mid-1980's is less of a concern for new, more resistant varieties. Adult trees have very few problems, though seed loss by seed weevils and flower loss by moth larva have been reported. Grazing animals are by far the greatest problem!

Calliandra calothyrsus

Overview: Calliandra calothyrsus is a small, thornless, often multistemmed and bushy tree. Native to Central America and introduced to Java in 1936, where it became well-established, Calliandra produces excellent fuelwood and green fertilizer, and is highly valued by apiculturalists. Leaves are high in nitrogen and are used as a fertilizer and sometimes as livestock fodder. In tropical areas it can be established at elevations above 1500 meters it develops best between about 250-1000m. Calliandra is a great pioneer species used to reclaim degraded lands.

Products:
Wood: Branches do not produce great pole timber, but as it is a very coppiceable tree that is fast-growing, multi-stemmed, and thornless, it is great for fuelwood. Calliandra should be coppiced at 20-50cm above the ground to facilitate the best resprouting and prevent fungal infections.
Fodder: Leaves and pods are rich in protein (22%) and do not contain any toxic substances, however it has does have high concentrations of tannins that can reduce digestibility.

Agroforestry Uses:
Soil Improvement and Land Reclamation: Calliandra thrives on slopes, marginal soils, and degraded agricultural land. It improves soil by fixing nitrogen and producing high amounts of leaf litter.
Alley Cropping: High leaf biomass production and high-protein leaf material, even on less fertile soils, make it ideal for use in alley cropping systems.
Living Fences: With numerous stems to weave through adjacent trees, it can form an impenetrable barrier.
Apiculture: Nectar-rich flowers produce constant, high-quality fodder for bees, allowing for year-round honey production (pic 8B).

Characteristics: Vigorous nitrogen-fixing, bushy tree. Fast growth rate to 4-6 meters tall (known to reach 12m), growth of 3-5 meters is possible in the first year. Branches tend not to develop into straight poles. Crown is moderately heavy and sheds leaves in seasonal climates. Has both superficial and deep-growing roots.

Site Requirements: Good in humid tropics, tolerates rainfall as low as 700mm, but thrives in areas with 2000-4000mm. Avoid areas with poor drainage where waterlogging occurs. Prefers light soil textures and slightly acid conditions, but can grow in a wide

array of soil types. Tolerates altitudes from 250 to 1800 m. Moderately shade tolerant. Moderately drought resistant, but during severe drought the tree will die off and come back with the rains.

Propagation:
Tree Sacks: Soak the seed in water for 24 hours. Seed 2 per sack, cover with ¼ inch of soil and keep moist. Outplant at 20-50cm height, when root collar is 0.5-1.0cm.
Bareroot: Plant pretreated seeds in nursery bed, allow to grow to 75-100cm which takes about 4 months. When ready to outplant, prune the roots at 20 cm and the top at 30cm, strip leaves. Whether propagated with sacks or bareroot, weeds should be cleared before planting and monitored during the first year.

Pests and Diseases: Calliandra tends not to suffer from major pests or diseases. Mature trees should be coppiced cleanly 50cm above ground to avoid infestations in the fissures of harvested stumps.

Faidherbia albida

Overview: Also called *Acacia albida*, *Faidherbia albida* is a large, thorny tree, reaching up to 30m in height, with spreading branches and a rounded crown. It is native to many countries across Africa, and is commonly considered one of the best agroforestry trees for intercropping in fields. The tree responds well to coppicing, but be sure to make clean cuts, as improper lopping can cause wounds, predisposing it to attacks by pathogens.

Products:
Fodder: The leaves and pods are palatable and can provide an important source of protein for livestock in the dry season.
Wood: *F. albida* is commonly used for fuelwood. It does not make a great timber due to staining and twisting, but it is easy to work by hand.

Agroforestry Uses:
Shade and Shelter: *F. albida* is often protected on farms to shade coffee as well as livestock in the dry season.
Reclamation: Its spreading root system offers excellent protection to the banks of rivers and streams.
Alley Cropping: Shedding its leaves in the rainy season, it provides nutrient-rich green fertilizer when crops need it most. Being leafless during the rainy season also reduces competition for sunlight with the crops. Repeated pruning during periods of average biomass production stimulates leaf production.
Dead and Living Fences: The thorny braches can be chopped off to form a dead fence, which is extremely important to place around a newly-planted living fence where there is risk of attack from roaming livestock. It also makes a great barrier for the outer row of a living fence.
Apiculture: It has the advantage of producing flowers at the end of the rains while most sahelian species flower before them, so can be used as a main source of bee forage at this time.

Characteristics: Due to an inverted phenology—i.e. it keeps its leaves during the dry season to provide shade, and drops them in the rainy season to fertilize crops—it is commonly considered one of the most effective intercropping trees for green fertilizer.

Site Requirements: *F. albida* grows on the banks of seasonal and perennial rivers and streams on sandy alluvial soils or on flat land where Vertisols predominate. It thrives in climates characterized by long summers, or a dry season with long days. It tolerates

seasonal waterlogging and salinity but cannot withstand heavy clayey soils. It can grow between 300-2700m, receiving 250-1000mm of rainfall.

Propagation: Propagation is most successful using tree sacks. The seed should be removed from the pods before planting, and pretreated by pouring hot water on them and allowing them to soak for 24 hours. Scarification is also an effective pretreatment method.

Pests and Diseases: Bruchid beetles attack the seeds, so collect seeds early and remove it from the pods to avoid infestations.

Sesbania spp.

Overview: Thought to be originally from Egypt, *S. sesban*, narrow-crowned, deep-rooted, single or multi stemmed shrub or small tree, 1-7 m tall.Though short-lived, one of the major advantages of sesbania over other forage trees and shrubs is its rapid early growth rate, which can be exploited by intercropping it with other slower establishing species for earlier yields. It can be difficult to establish in unprotected areas due to high favorability by livestock. *S. sesban* (pic 8D) and *S. grandiflora* (pic 8E) share many qualities, though *S. sesban* is better for drier climates.

Products:
Fodder: Sesbania leaves are high in nitrogen and is an excellent supplement to protein-poor roughage for ruminants, which readily eat leaves and young branches. The crude protein content is generally greater than 20% and often above 25%, with high digestibility. Though when grazed, the brittle tree may break too easily, exposing it to fungal attack, so it is best used in a cut-and-carry system, with stems removed cleanly from the tree.
Wood: Highly coppicable, it is a popular source for fuelwood and charcoal because it produces a high amount of woody biomass in a short time which, although soft, is relatively smokeless, quick kindling, and hot burning.

Agroforestry Uses:
Alley Cropping: Sesbania is easy to establish, it grows rapidly, and coppices readily, providing mulch of high nutrient content and making it a promising tree for alley cropping.
Soil Reclamation: It is commonly planted on fallow land for soil improvement due to its fast growth and nitrogen-fixing characteristics. Harvested leaves and stems make a rich compost or green fertilizer.
Windbreaks: Applicable as a stand-alone species around vegetable gardens, or planted with taller species for protecting large crop fields.
Living fences: Sesbania is a low-growing, bushy plant, whose fast-growth makes it ideal for quick living fence establishment. However, it must be protected from livestock or it will not survive early browsing.

Characteristics: Sesbania is a fast growing, short-lived tree that grows many branches. It tends to develop into a shrub or small tree about 4 to 15 meters tall. Flowers for either species can be yellow, pink, purplish, white or red.

Site Requirements: Tolerates saline, acidic, or waterlogged soils. Prefers between 500 and 2000 mm rainfall. *S. sesban* is able to grow at elevations between 100 and 2300 meters.

Propagation: Seed storage is orthodox, maintaining viability for 2 years, but the seeds are very susceptible to insect attack and should not be stored for more than 1 year.
S. sesban: Scarification is recommended. Make sure not to damage the radicle/embryo (the pointed side of the seed).
S. grandiflora: Scarification with nail clippers works but because of the small size of the seeds you can also easily soak them in cold water for 24 hours. Make sure not to damage the radicle/embryo (the pointed side of the seed).
Seed 2 seeds per sack 12 weeks before outplanting. Weeding around seedlings recommended in the first month after outplanting. Barestem propagation is possible as well.

Pests and Diseases: The seed is commonly attacked by insects. Leaves, stems, and branches are susceptible to attack by caterpillars, weevils, stem borers, bacteria and fungi. Burn infested plants.

Senna siamea

Overview: *Senna siamea*, also called Cassia tree, is a fast growing evergreen native to Southeast Asia. It tolerates both arid lands and tropical climates. Because of its fast growth and quick regeneration from coppicing, it is applicable to many agroforestry systems. It is very popular in arid regions, particularly West Africa.

Products:
Fodder*: S. siamea* is widely grown for fodder, but the tree is prone to browsing. Leaves are highly toxic to non-ruminants such as pigs and poultry, so these animals should be kept away from the trees.
Wood: The dense, dark wood of S. siamea makes good fuelwood, though it does produce a lot of smoke. It produces high-quality charcoal. The timber produced by the tree is very hard, resistant to termites, strong, and durable, but difficult to work. It is often used for cabinet making, handles, and poles for construction.

Agroforestry Uses:
Windbreaks: Good, tall filler in windbreaks, space at 3-4 meters.
Living Fences: Growth speed makes great living fence posts. Grown as a living fence hedge, it effectively increases water infiltration capacity of soil and combats soil erosion.
Soil Improvement: Though not nitrogen-fixing, its high biomass production does make for a green fertilizer.

Characteristics: *S. siamea* will grow in a range of climatic conditions but is particularly suited to lowland tropics with a monsoon climate. It will grow only when its roots have access to groundwater, and the maximum length of the dry period should not exceed 4-8 months. Rainfall as low as 500mm may inhibit growth from exceeding 5 meters, yet rainfall up to 1500mm can allow growth to 20m. Lateral roots have been reported to compete with crops in alley cropping, so should be kept out of gardens and crop fields (though makes a great windbreak/boundary planting). Seeds all year round. Produces large quantities of biomass, but does not fix nitrogen.

Site Requirements: Performs best on deep well-drained fertile soils, but will grow on degraded lateritic soils provided drainage is not impeded. The species is intolerant of saline soils. It grows best at an altitude between 0-1200 m with annual rainfall of 400-2,720 mm.

Propagation: Pretreatment is not required for S. siamea. Sow 4-5 seeds per sack, but not too deeply (only ~1/2 cm deep). Keep soil moist, in plenty of sunlight. Propagation by cuttings up to 2 meters in length is possible, as is direct seeding, though early seedling growth can be slow, so it is better to start S. siamea in nurseries. Weeding is necessary for the first one or two years of growth during which they require pruning to develop a straight trunk.

Pests and Diseases: Insects are quick to attack harvested or splintered wood.

Grevillea robusta

Overview: *Grevillea robusta* is a deciduous medium-sized to large tree 12-40 m tall, with a dense, conical crown. It is a fast-growing evergreen timber tree native to the Pacific Islands and Eastern Australia. It has become very popular in East Africa, often replacing eucalyptus for timber production, and growing in popularity in Central America. Grevillea grows well in tropical highlands and lowlands.

Products:
Wood: Good for medium strength poles and fuelwood, coppiceable. Plant in woodlots (2.5 m x 2.5 m) and rows (2-2.5 m between trees). Harvest branches by pruning high, leave about 1/3 of the branches after pruning to support regrowth. It also produces high-quality fuelwood and charcoal.
Mulch: High leaf litter covers the ground, making Grevillea a good source of natural mulch.

Agroforestry Uses:
Apiculture: The golden, nectar-rich flowers of *Grevillea robusta* are attractive to bees and make for great honey production.
Windbreak: Grevillea is a good tree for windbreaks, spaced at ~3 meters and combined with shorter species, though the branches may split and break under very high winds.
Intercropping: It is a good shade-species for tea and coffee. Cut roots around trunk to 30cm whenever planted next to crops to minimize competition from Grevillea's lateral root systems (Kalinganire, 1996).

Characteristics: *Grevillea robusta's* complex, shallow root system allows for efficient nutrient uptake, even in poor soils. However, it does compete with crops if roots aren't pruned. Leaves produce a chemical that inhibits growth of other plants, but no major problems regarding this issue has been reported. It is not resistant to persistent, strong winds as the wood can be brittle and break away under high pressure. In its natural range, the species is semi-deciduous, shedding most of its leaves in the dry season, and can stand up to 6 months of drought.

Site Requirements: Grevillea is found in both dry and wet climates (600-1,700mm) and can tolerate drought for up to six months. It grows from sea level up to 2300 m. It prefers neutral to highly acidic, well-drained soils (best in slightly acidic). It is not very shade-tolerant, and flowers best in open, sunny areas.

Propagation: It is best sown in tree sacks, and extreme heat may hinder germination rate. No pretreatment is required, and it germinates readily in a moist environment. Seed in sacks 1/2 cm deep and keep the soil moist. Cuttings can be easily established using shoots from seedlings or saplings, which can also be air-layered. Place cuttings 7.5-10cm long in sacks or directly into the field, about 3.5 cm deep.

Pests and Diseases: In humid regions, *G. robusta* is vulnerable to attack by fungal diseases. Attack by termites can be a problem when planted on dry sites in Africa. In the Caribbean, it has often been attacked by scale insects.

Albizia lebbeck

Overview: *Albizia lebbeck* occurs extensively throughout the India, Thailand, and Malaysia. It has been used widely for roadside planting in dry areas, and has been cultivated extensively and is now naturalized in the West Indies and Africa. *Albizia lebbeck* is very suitable for the southern sahel. It can withstand long, hot, dry periods and cold winters.

Products:
Fodder: The leaves, flowers, and pods of *A. lebbeck* make good fodder.
Wood: It has a very decorative, heavy wood of moderate strength and durability. The wood is easy to work and can be used for a variety of finishing purposes and general construction. It also provides a high-energy fuelwood.

Agroforestry Uses:
Apiculture: Its large flowers are fragrant, attracting bees. *A. lebbeck* is highly regarded by bee-keepers for the light-colored honey its nectar provides.
Soil Improvement: A nitrogen-fixing tree, produces a nutrient-rich green fertilizer/mulch.
Intercropping: It is an excellent companion plant, commonly grown as a shade tree in pastures, tea, coffee and cardamom plantations.
Windbreaks: It is a good windbreak tree, but not in areas with little to no precipitation. .

Characteristics: Medium-sized deciduous tree that most often grows to about 15-20 m tall with a diameter of 50 cm. It is fast-growing and can reach 30 meters in areas with high precipitation. It tolerates long, dry periods, and light frost.

Site Requirements: *A. lebbeck* grows best in full sun, but will tolerate partial shade. It prefers loamy soils, but can grow on sandy, weathered soils as well. It tolerates acid and alkaline soils, as well as salt spray.
A. lebbeck: Altitude 0 -1,800 m; Rainfall 500-2,500 mm

Propagation: It is best established using potted seedlings, although bare-rooted seedlings, direct seeding and cuttings have all been used successfully. Seed pretreatment involves scarification then pouring hot water over them and allowing them to soak for 24 hours. Germination improves after storage for 2-4 years, but satisfactory germination (50-60%) has been obtained from fresh seeds. Sow 2 seeds/pot, then leave them in the nursery for 15-18 weeks under partial shade before transplanting at the beginning of rainy season.

Pests and Diseases: Susceptible to damage from high winds and from attacks by insects and rodents.

Moringa oleifera

Overview: Moringa has been referred to as "Nebeday" for it's strength and tendency to "never die". It is popular in backyards throughout Asia, Africa, and Central America, and is considered by many to be a 'miracle tree' as the edible leaves are both flavorful and highly nutritious and has the ability to significantly reduce food insecurity.

Products:
Food: The leaves, young pods, flowers, and horseradish-tasting roots are all edible. The leaves are most often cooked in sauces or similarly to cabbage or spinach, and are very high in Vitamin A & C, calcium, protein, iron, potassium, magnesium, and other vitamins and minerals. Nutritious tea is made with the leaves to provide a nutrition boost, especially for pregnant women and children. Leaves, dried in the shade and pounded, can be mixed with peanut butter, chocolate spread, or any other food as a vitamin additive.
Wood: Soft, spongy wood is very coppiceable but really only used for light construction work or for fuelwood when little else is available.
Oil: Extracted from mature pods, moringa oil is a light, clean, non-drying oil that can be used as a lubricant for even very small machine parts, as well as for cosmetics and perfumes.
Other: Powder from crushed seeds can be used to coagulate and settle dirt and bacteria out of water for purification.

Oil extracted from the mature pods (oil of Ben) is yellowish, non-drying, good keeping qualities but eventually turns rancid. It is used as a lubricant, in cosmetics and perfumes,

Agroforestry Uses:
Soil Improvement: The green leaves make a useful mulch, and the press cake left after oil extraction from the seeds can be used as a soil conditioner or fertilizer.
Living Fence: Straight trunks make good living fence posts. Seeds germinate and cuttings take root easily, and are used particularly around houses and gardens to provide both protection as well as an easily-accessible food source.
Intercropping: The tree provides semi-shade, useful in Forest Gardens where intense direct sunlight can damage crops.

Characteristics: Moringa grows quickly and tends to have an open, undeveloped crown and spindly branches. Though trees can reach 8 meters, the constant breakage of branches when leaves are harvested tend to limit their growth to 3-4 meters tall.

Site Requirements: Moringa has a strong tap root and is highly drought resistant, but requires at least 500 mm of rainfall. It prefers a lot of direct sun, yet is known to survive mild frost. It prefers neutral to slightly acidic sandy soils though tolerates a wide range of conditions.
Altitude: 0-1000 m in elevation; Rainfall: <500 mm

Propagation: Moringa naturally regenerates well. Cuttings between 20cm and 4m can be used. Direct seeding does very well also, and the seeds require no pretreatment. Fresh seed will sprout in 3-5 days. Sow moringa seeds in sacks, coverd with ~1cm soil. For leaf production, seed moringa in a bareroot bed with ~10cm between seeds, do not outplant, harvest 1/2m tall seedlings by cutting them about 10cm from the ground, keep bed moist and all seedlings will regrow for continued leaf harvests.

Pests and Diseases: Root rot has been reported at times; avoid prolonged waterlogging.

Gliricidia sepium

Overview: Native to the United States and Central America, Gliricidia is a nitrogen fixing tree widely known in the Americas as "Madre de Cacao" or "Madera Negra". Because of it's high output of hard wood and nutrient-rich leaf litter, it can play a major role in agroforestry systems. After *Leucaena leucocephala, G. sepium* is believed to be the most widely cultivated multipurpose tree.

Products:
Wood: It produces a strong, durable, termite resistant wood used in heavy construction, and for tools, posts, and furniture. It also produces a good-quality fuelwood and charcoal, burning slowly without sparking, and with little to no smoke.
Fodder: Its leaves are rich in protein, low in fibre and tannin, and highly digestible. However there have been reports of non-ruminants showing signs of poisoning from it. It is not widely used for fodder because animals may dislike the taste, but palatability improves when the leaves are left to wilt overnight.
Pesticide: *G. sepium* seeds and bark can be used as a rodenticide (it has been called 'mouse killer') and general pesticide. Mix mashed seeds or boiled bark with food bait to kill rodents.

Agroforestry Uses:
Alley Cropping: Gliricidia is easy to establish and is a great species for alley cropping. It produces abundant leaf litter that has a high concentration of nitrogen making it an excellent green fertilizer.
Living Fence: Though lacking thorns, it is relatively easy to establish as living fence hedges, especially when propagated by cuttings. The straight trunks also make great living fence posts. Living fences of Gliricidia have been shown to reduce the incidence of disease in groundnut crops.
Apiculture: The flowers are very attractive to honeybees, making it a good species for supporting honey production.
Shade and Shelter: *G. sepium* is widely cultivated as shade for perennial crops (tea, coffee and cocoa). It is also used as a nurse tree for shade-loving species. Attributes contributing to its value as a shade tree include its fine, feathery foliage giving light shade, and the ability to withstand repeated pruning and to resprout vigorously.
Soil improvement: As a green fertilizer, *G. sepium* increases soil organic matter. It is a drought-resistant and valuable water-conserving species because in the dry season it sheds most of its leaves, reducing water loss through transpiration.

Characteristics: Gliricidia has a very fast growth rate, reaching as high as 4.5 meters in a few months from cuttings. However, it is known to have a strong lateral root system that can sometimes inhibit growth of surrounding vegetation.

Site Requirements: Gliricidia grows in soils ranging from pure sand to deep alluvial lake-bed deposits, a wide range of soil types. It performs well on marginally saline vertisols, but does not tolerate highly acidic soils.
Altitude: 0-1600 m in elevation; Rainfall: 600-3500 mm

Propagation: Trees are best propagated in sacks or by cuttings. For sacks, no seed pretreatment is needed, sow 2 seeds per sack 8-12 weeks before outplanting. Small cuttings may be placed in sacks or directly in the ground. They may need some water during the first dry season because root structure may not be as developed as those started from seeds. Larger cuttings, 15cm wide and 2 m long, allow for fastest growth. Scrape the base of the cutting to encourage rooting. Place 2 m cuttings ½ m in the ground a couple weeks before heavy rains begin.

Pests and Diseases: Not a target of any specific pests, though reported to be one of hundreds of plants that host the pink mealybug, a serious (sub) tropical pest around the world. Notably, it is resistant to the psyllid *Heteropsylla cubana*, which has caused serious devastation to *Leucaena leucocephala*.

Azadirachta indica

Overview: Thought to be from India and Myanmar, this broad-leaved evergreen and cousin of mahogany has been introduced and established throughout the tropics and subtropics for its highly valued hardiness, its almost year-round shade, and its multiple wood and non-wood products. It is said that it grows almost anywhere in the lowland tropics.

Products:
Wood: A. indica is a species of the mahogany family, and although it has some of the characteristics of a cabinetry wood, it is not ideal. Nevertheless it is used to make wardrobes, bookcases and closets, as well as packing cases because its insect repellent quality helps to protect the contents from insect damage. The main stem of the tree is also widely used to make posts for construction or fencing because the wood is termite resistant. It makes high quality charcoal and has long been used for fuelwood; best if coppiced at 1.5 to 2 meters.
Pesticide: Submerge leaves and crushed kernels (pic 8Z) in water overnight to make a great natural pesticide. Neem has over 20 active chemicals, the most important of which is azadirachtin, which help to repel and distort the reproduction cycles of numerous insects, nematodes, fungi, bacteria, and even viruses. The seeds contain the highest concentrations of the compound. Solution should be applied once every week on garden vegetables, field crops, and tree nurseries. Neem is not poisonous to humans.
Oil: Neem oil has been used traditionally as a topical treatment for skin symptoms in both humans and livestock, but it should not be ingested orally. Leaves can be used when making soap to give it antimicrobial and insecticidal properties. Warning: direct sunlight on leaves will destroy the pesticide ingredient.

Agroforestry Uses:
Windbreaks and Living Fences: Tolerance to most soil conditions, high survival rate, drought resistance, and resistance to grazing animals make neem a solid pioneer tree for reforesting lands, delineating field crops, or trying to establish any type of border planting (ie windbreak, living fence).
Soil Reclamation: It is drought resistant with a well-developed root system capable of extracting nutrients from the lower soil levels. Neem cake (the residue left after extracting oil from the seeds) can also be used as an organic manure and soil amendment.
Apiculture: Clusters of small white flowers attract many bees. Pesticides are not present in the honey (National Research Council, 1992).

Characteristics: Up to 30 meters tall, trunk usually not thicker than 1 meter. Very fast growth rate, up to 6 meters in a year. Very coppiceable. Neem tends not to be planted among gardens or alley-cropped with field crops because it absorbs a lot of water and may outcompete other plants. Seeds often dispersed by birds and fruit bats that eat the sweet yellow fruit around the seed kernels.

Site Requirements: It grows almost anywhere. It can withstand dry, infertile soil, as well as acid soils, and is lightly salt-tolerant. Waterlogging can kill it, and it dies in freezing temperatures. It performs better than most species on shallow, stony, sandy soils, or in places where there is hardpan not far below the surface.
Altitude: 0-1500m in elevation; Rainfall: 400-1200mm annually

Propagation: *A. indica* is easily raised in sacks, bareroot planting is possible, and fresh seeds can be direct-sown under existing vegetation. Not seed pretreatment is required. The seeds do not normally store well over 6 months, and depulping and cleaning the seeds considerably improves the germination rate. Seed in sacks 12 weeks before outplanting. Propagation by cuttings is possible, but propagation by seed is most common.

Pests and Diseases: *A. indica* has few serious pests, but several scale insects have been reported to infest it.

Ziziphus mauritiana

Overview: The genus Ziziphus belongs to the Rhamnaceae family, and has about 100 species of deciduous or evergreen trees and shrubs distributed in the tropical and subtropical regions of the world. The fleshy seed coat of several species are rich in sugars and vitamins, and this fact has made Ziziphus species important fruit trees for many centuries.

Products:
Food: Fruits of all Ziziphus species are edible. The drupes are eaten fresh, pickled, or dried and the juice can be made into a refreshing drink. Fruits are sold on local markets and consumed at household.
Fodder: Its leaves and twigs can be used as high nutritional fodder for livestock.
Wood: Ziziphus is an excellent fuel-wood tree and makes that good charcoal.
Medicine: Fruits are applied on cuts and ulcers, employed in pulmonary ailments and fevers. Sometimes mixed with salt and chili peppers to be given for indigestion. The seeds are sedative and are taken, sometimes with buttermilk, to halt nausea, vomiting, and abdominal pains in pregnancy.

Agroforestry Uses:
Living Fence: The trees are excellent for living fences. When coppiced, the branches grow laterally and can easily woven with neighboring branches. The sharp thorns deter most animals.
Soil Stabilization: Planting Ziziphus reduces the rate of desertification and soil erosion in deserts by stabilizing sandy tracts and dunes.

Characteristics: *Z. mauritania* is a vigorous grower and has a rapidly-developing taproot. Depending on the seed source and how it is managed, it can be a bushy shrub 1 to 2 m high, or a tree 10 to 30 meters, erect or wide-spreading, with gracefully drooping branches and downy, zigzag branchlets, thornless or set with short, sharp straight or hooked spines.

Site requirements: Ziziphus lives in a wide range on climates. The tree is drought resistant and can survive salinity and waterlogging. It grows best in sandy loam soils, which may be neutral or slightly alkaline, but it will grow on a wide variety of soils. It is also able to survive injury and fire damage.
Altitude: 300-1000m; Rainfall: 20 to 2200mm

Propagation: No pretreatment is needed, but storage of seed for 4 months before sowing improves germination. Will germinate in 3-4 weeks if you remove fleshy seed coat and crack hard outer shell before sowing. For fastest germination, extract the internal seed from the hard shell. This is easiest done utilizing a mortar and pestle. Be careful not to damage the fragile seeds in the process. Sow 3-4 seeds per sack. Seeds require full sunlight to germinate, and seedlings should be grown in full sunlight.

Pest and Disease: The greatest enemies of the jujube in India are fruit flies, *Carpomyia vesuviana* and *C. incompleta*. It has been found that treatment of the ground beneath the tree helps reduce the problem.

CHAPTER 9: REFERENCES

1. More information on the species listed in this chapter as well as a large variety of other useful agroforestry tree species can be found on The World Agroforestry Center's Agroforestree Database at: http://www.worldagroforestry.org/output/agroforestree-database.

Chapter 10: Tree Care

Beyond water, the most important factor affecting tree survival is protection. In the first phase of the Forest Garden Approach, when establishing your living fence around the perimeter, it may be necessary to create a dead fence about one meter beyond where you will establish the outer row of your living fence. This is necessary in places where the seedlings are at risk from grazing animals, as they can easily ruin months of work in a very short amount of time by eating your rows of newly planted seedlings. A dead fence is best made from branches of thorny trees, piled about one meter high, around the perimeter of your Forest Garden site.

After planting your seedlings, be sure that the dead fence remains intact for the first year, or until the seedlings are well established and can withstand browsing. In the Forest Garden Approach, you will not be planting higher value seedlings (e.g. fruit, nut, and timber trees) until after the living fence is established. In this case, those seedlings should be protected from grazing livestock and wind by the living fence. If this is not the case, then you should build protective barriers around each seedling (using thorny branches or sticks posted around the seedling to prevent browsing by animals.

As you will generally plant the majority of your seedlings at the beginning of the rainy season, hopefully the rains will continue for some time, allowing the trees to take root and grow strong in preparation for the upcoming dry season. At times you may plant higher value trees outside of the rainy season. In this case, you will need to water your tree once a week for the first few months, until the roots are established. About 3 liters of water per seedling should suffice if the seedling is fairly small (about 1 meter high). After a few months, you can reduce the watering to every two weeks, with slightly more water (about 5 liters). Keep a close eye on the seedlings over the first year, and if you see excessive wilting in dry soil, or if there is still wilting after watering, then increase the watering. If there are signs of wilting long after watering and the soil is still saturated with water you may be overwatering, in which case you should decrease the amount of water and continue with careful observation.

Direct-seeding

Though you generally get the best results by raising seedlings in nurseries before outplanting them into your Forest Garden, it is possible to plant them directly in your Forest Garden by direct seeding. Though this is a cheaper method, it is much more difficult to give the seedlings the care they require, which often leads to higher rates of stunting or mortality than those cultivated in nurseries.

The establishment of plants by this method is largely controlled by climatic conditions, soil type and weed competition. These factors have a significant bearing on soil moisture, which is vitally important to germination and early survival of seedlings in the field. Seedlings must be protected from grazing by vermin and livestock until they are beyond browsing height.
Other factors that play an important part in determining the success of direct seeding include:

- Correct choice of species;
- Ground preparation to provide a suitable seedbed;
- Use of good quality, viable seed;
- Correct seeding rates to ensure the required density of seedlings—too little will lead to disappointment and too much will necessitate extra work for thinning;
- Sowing when soil moisture is favorable for seedling germination and establishment—be sure to sow after the rainy season begins to be sure the seeds receive plenty of water to germinate and establish their root systems;
- Weeding, to ensure the seedlings are do not have to compete for water, sunlight, and nutrients.

Cuvettes for Fruit Trees

An aspect involved in out-planting seedling fruit trees that also carries over into the maintenance of adult trees and controlling pests is building and maintaining "cuvettes" or basins around the base of seedlings and adult trees. A "cuvette" is a flat, marked off circular area around a tree which is delimited by a small wall or ridge of soil forming a basin. A single "cuvette" is made around newly planted seedling trees while double cuvettes are made around adult trees. Some of the benefits of making and maintaining "cuvettes" are:

- To conserve and concentrate water at the root level. The walls of the "cuvettes" hold the water around the roots so that runoff is avoided.
- To help stabilize adult trees by promoting lateral root growth.
- To aid in the prevention of disease, especially fungus disease, by not concentrating water at the base of the trunk.
- Pest control, especially termite, by keeping mulch and fertilizer away from the trunk.

Young trees and newly planted seedlings
A single "cuvettes" of 0.6 meter diameter is sufficient for newly planted seedlings and 1 meter for young trees. A small mound of dirt is placed at the base of the main stem to protect it from large concentrations of standing water and also to keep mulch from touching the base of the trunk which may harbor insects or termites (Figure 1).

The dirt needed to form the wall of the “cuvettes” should always be taken from outside the 1 meter diameter surrounding the young tree. If it is taken from inside the diameter, this will remove good and rich soil, there is the potential of exposing and damaging roots growing just below the ground surface. The area within the “cuvettes” should be as flat as possible, again to avoid water from concentrating at the base of the main stem or trunk. This is very important for seedlings and young trees. Mulch should also be put in the cuvette but not right near the trunk.

Adult trees

Double “cuvettes” are recommended for adult trees. This consists of a small inner “cuvette” near the base of the trunk and a larger, outer “cuvette” which encompasses the diameter of the crown. All additions of mulch, water, manure, and fertilizers should be confined to the outer “cuvette”.

The purpose of a double “cuvette” is threefold:

- The "drinking" (capillary) roots are located farther away from the trunk. These are found in the outer “cuvette” whereas the "woody" roots are found closer to the trunk. This concentrates the water in the area where its uptake is most efficient and beneficial to the tree.
- For the same reason, all manure and fertilizer are placed in the outer “cuvette”. This also helps avoid burning the root hair of the tree.
- The “cuvette” helps to stabilize the tree.

To make a double “cuvette”, stand at the edge of the tree under the outer most branches and leaves. Mark off one step towards the trunk and one step away from the tree. This will be the distance of the outside “cuvette” and should measure approximately 0.8 to 1 meter (Figure 2). The area from the inner wall of this “cuvette” to the trunk is the inner “cuvette”.

Again, do not "dig up" the top soil to form the walls of either “cuvette”. It is better to get dirt from elsewhere to make the walls than to expose and damage the roots located just below the surface. Add hay, peanut shells or palm leaves as mulch to the outer “cuvettes” only. Absolutely nothing should be added to the inner “cuvette”.

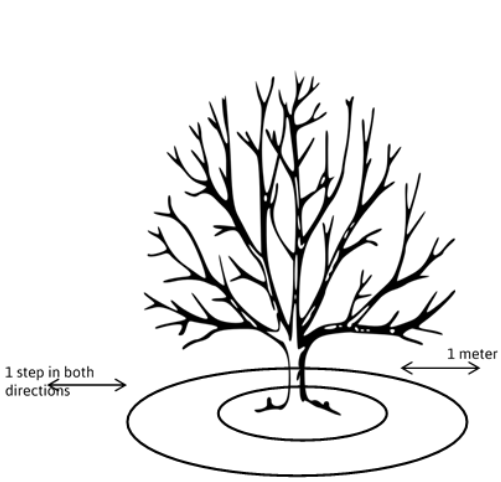


Figure 1: Procedure for making cuvettes for young trees and newly planted seedlings

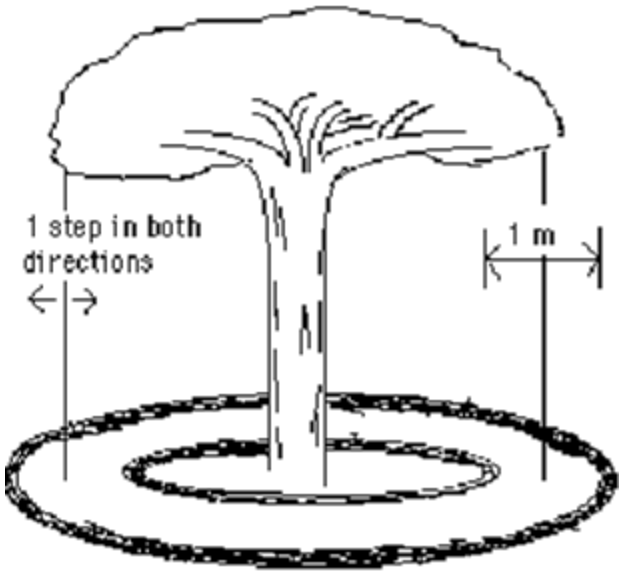


Figure 2: Procedure for making cuvettes for adult trees

Dry Season Seedling Care

There are a lot more threats to trees planted in the field than there are in the more controlled environment of your nursery. The first year after outplanting your trees is the most critical in terms of maintaining good health and protection. If they make it through the first dry season in good health, there is a good chance they will survive to maturity. Though it is important to observe the trees in your Forest Garden routinely to identify and respond to risks and potential issues. Follow the recommendations below to ensure your seedlings receive the care they need to grow healthy and productive.

- **Weeding** – Weed growth, especially during the rainy season, can easily overtake and shade out newly-outplanted seedlings in a matter of weeks. Keep weeds cleared to a distance of .5 to 1 meter around the stems of your trees.
- **Fire protection** – Fire risk is a major concern in excessively dry areas, as they can spread quickly and destroy all of your trees and any other crops on your Forest Garden site. You can reduce the risk of fire by raking a one meter fire break around the outside of your living fence, cutting down all growth (weeds, dry grasses, etc), which can be added to your compost. You should also clear dry and dead growth from the interior of your Forest Garden site.
- **Protection** – The biggest threat to your young trees is likely to be livestock. It is very important to protect outplanted seedlings from the many types of livestock that wander around open fields, as browsers and grazers can quickly defoliate and kill newly-outplanted trees. Here are several possible ways to protect your newly-outplanted trees from livestock:

- Dead fences – To protect living fences from livestock until the time that the trees can withstand browsing, create a dry fence barrier from thorny branches piled 1 meter high, and at least one meter from your newly-planted living fence.
- Anchored rice or onion sacks – Preferable for unprotected, higher-value trees, you can post 3 or 4 sticks or small posts in a triangle or rectangle around each seedling, tightly lining the sides with rice or onion sacks to form a protective barrier.

- **Watering** – In ideal situations, the rainy season that continues after you planted your trees will be sufficient for the trees to establish their root systems and survive the oncoming dry season. In reality this is often not the case, or the dry season may be longer than expected. If your trees show signs of excessive wilting in the dry season it may be necessary to irrigate them. If the rains do not extend after initially planting your seedlings it is good practice to water them about 3 times per week for the first few months so they can establish their root systems. After that, you can water them once per week.
- **Mulch and compost** – To control weeds and decrease evaporation it is important to place a layer of mulch around your trees after planting them (see mulch section). Leave about 5 cm clear of mulch around the stem of your seedlings to avoid burning the young stems as the mulch decomposes. If you did not have fully decomposed compost or manure to line the planting holes and mix with the soil, then you can add compost or manure to the surface, under the layer of mulch.

CHAPTER 10: REFERENCES

1. This section was adapted from Peace Corps Senegal's *Fruit Tree Manual.* Dakar: 1993.

Chapter 11: Pruning, Harvesting, and Tree Management

It is extremely important to manage the trees in your Forest Garden properly to promote healthy, vigorous growth. Leaving trees unmanaged weakens them, reducing production and increasing the risk of disease damage. Good tree management requires regular pruning. Pruning can be quite technical and labor-intensive, requiring different practices and considerations depending on the species, variety, and climate. However, there are a handful of general guidelines for pruning that you should follow to increase production and reduce risk of disease. The following sections describe best practices for basic pruning of agroforestry, fruit, and timber trees.

Benefits of Pruning

- Promotes healthy, vigorous growth – regular pruning strengthens trees by focusing growth on the root system and the branches you want to grow.
- Encourages production – by improving health and encouraging bud growth, pruning increases the quantity and quality of fruit and nut production.
- Prevents and controls disease – by improving tree health, trees are less susceptible to disease. Identifying and pruning diseased branches early can also prevent disease from spreading to the rest of the tree.

Pruning Fruit Trees

Pruning entails cutting off certain branches of the tree to thin the number of branches. In doing so you can increase the quality and quantity fruit yields as the tree will put more energy into growing healthy roots and fruits instead of more branches and leaves. It also protects the tree from disease. Fruit trees require periodic pruning to:

- Remove dead, damaged, and diseased branches;
- Decrease the density of the branches to promote air circulation, healthier growth, and productivity, and;
- Train the branches to grow how you want them to grow.

Stages of Pruning

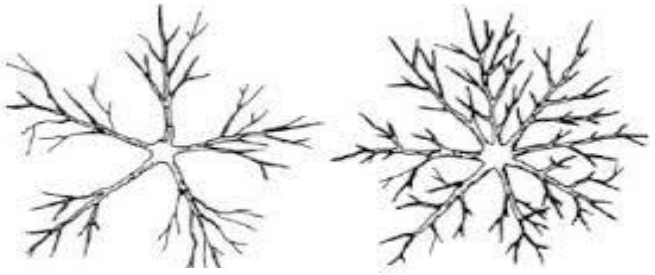
Seedlings in the nursery

You want to remove any lateral stems growing from the main stem on fruit seedlings in the nursery. You want to have one strong, straight stem on your fruit trees to promote straight and tall stem formation, which will lead to the development of a distinct trunk

and crown. If it forks into two or more main stems, the seedling may expend too much energy feeding two strong stems only to have one cut later. This type of pruning starts in the nursery and may go on after outplanting for over a year until the tree attains a height of over one meter and tree shaping can occur. The better pruned your trees are, the quicker they will grow.

Young trees
Once trees are grafted and outplanted, or simply outplanted, tree shaping is the next step. Generally any branches lower than one meter should be removed. For all grafted trees it is important to prune away any rootstock suckers that grow below the graft union, as these will maintain the genetic makeup of the rootstock and not the scion.

At this point you can begin shaping the tree's adult crown. Three to four scaffold (major) branches going in different directions and originating at different heights is the goal of shaping the tree (See left diagram).



Correc Incorrect

After the tree is shaped any new branches coming from the trunk should be removed. Also prune secondary branches shooting from too close to the trunk (30 cm) on the scaffold branches. These precautions avoid branch crowding and create a well-shaped tree. For grafted trees at any age branches sprouting from beneath the graft location should be removed.

What to Prune

Maturing and Adult trees
A good rule of thumb in pruning older trees is to periodically **remove dead, damaged, diseased, and disruptive branches**.

- **Dead** – the dead wood should be removed as it will never flower or fruit again;
- **Damaged** – branches that are wounded or damaged can leave the tree more exposed and susceptible to pests and disease;
- **Diseased** – any branches, fruit, and leaves which show signs of disease should be removed to prevent the spread of the disease pathogens.
- **Disruptive** – small, new growth branches that grow inside the crown will not be exposed to sunlight, will compete for nutrients, and may not even flower and fruit. These branches will lead to overcrowding and cross-over which will disrupt healthy tree growth and productivity.

How to prune

Be sure you always prune branches with a freshly sharpened, clean tool to ensure clean cuts and reduce damage and exposure to disease pathogens. You can use pruning shears, a knive, or machete for smaller branches. For larger branches it is best to use a saw to ensure a clean cut. You should never pull, twist, or rip branches off, even if you have already cut through the majority of the branch. This can tear the bark on the branch or stem that you are removing it from, leaving a large wound. When removing branches always cut them flush with the branch or stem from which they originate by keeping the flat side of the pruning tool flush against it as you make the cut (see Pruning Figure 2). Always start by cutting the bark on the underside of the branch to keep it from tearing off the bark below as the large branch falls. If you do not have a saw for larger branches you can use a sharp machete, following the steps outlined in Pruning Figure 3 to avoid damaging or wounding the tree.

Diseased branches should be cut 25 - 30 cm below the last diseased section. The branches then should be burned and any fruit buried far from the Forest Garden to prevent spread of the disease.

When large branches are pruned, you should protect the wound from diseases. Most importantly make straight cuts at angles so rain water will not collect on the wound. On large cuts, you can protect the wound by coating it with a mixture of wet clay and manure and letting it dry. However, this will only protect the wound in the dry season.

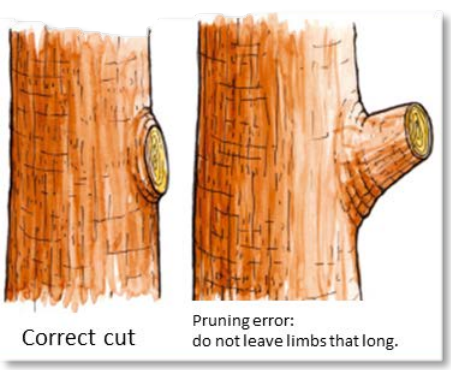
When to prune

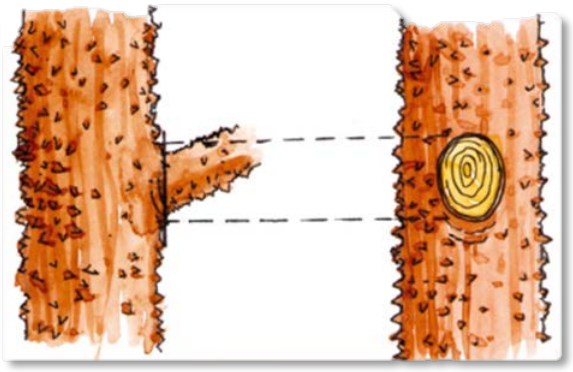
Generally, good times to prune trees at different ages are:

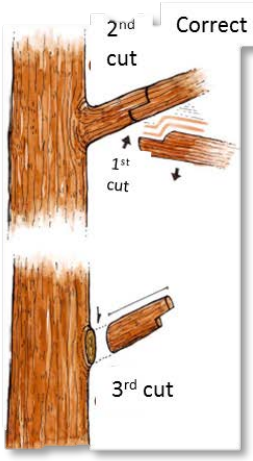
- Seedlings in the nursery – watch them closely and prune as soon as the need, or any problem, arises;
- Young trees – just before the rainy season, when the trees are dormant;
- Mature trees – after harvest

Notes about pruning

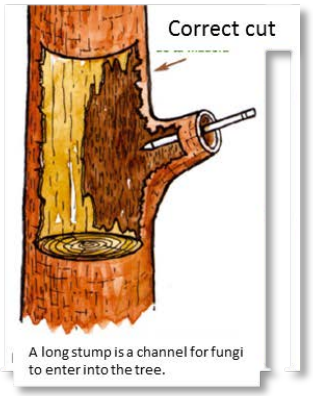
Very few trees require heavy pruning. Removing dead, damaged, and diseased branches periodically will generally suffice. Un-grafted mangos and cashews do not need heavy pruning, as some overcrowding will not affect tree health. Trees like guavas and sour sop will grow “leggy”, long spindle-like branches if not pruned but if they are in a protected field and have space there is little danger with that type of tree formation. Trees unprotected in fields should be pruned to above the reach of livestock.


Correct cut
Pruning error:
do not leave limbs that long.

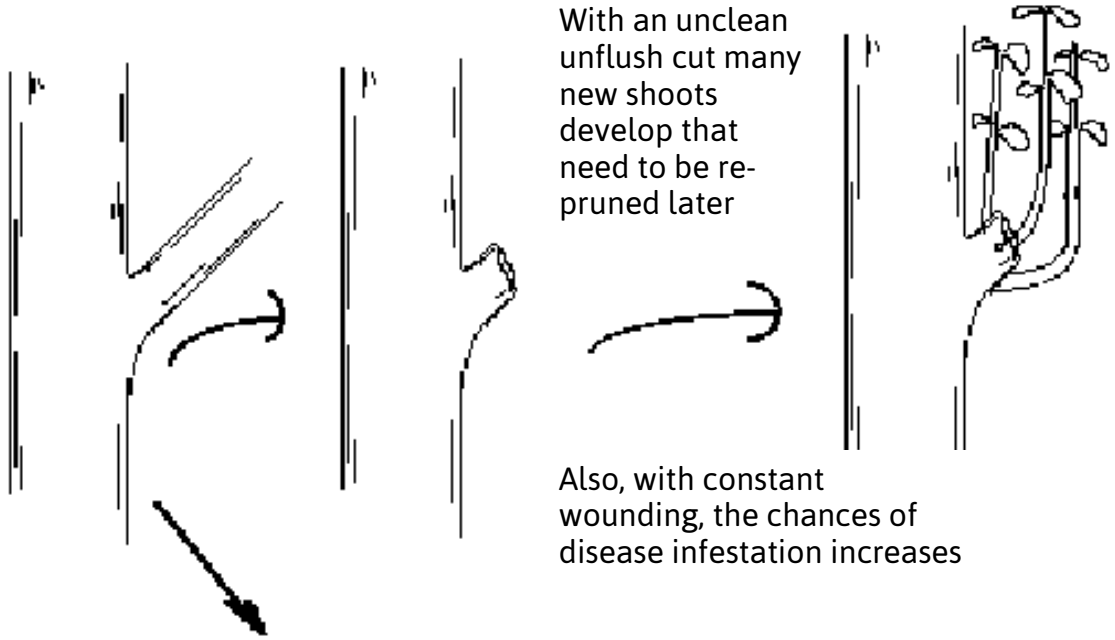



Correct cut
2nd cut
1st cut
3rd cut


The cut should not be irregular


Correct cut
A long stump is a channel for fungi to enter into the tree.

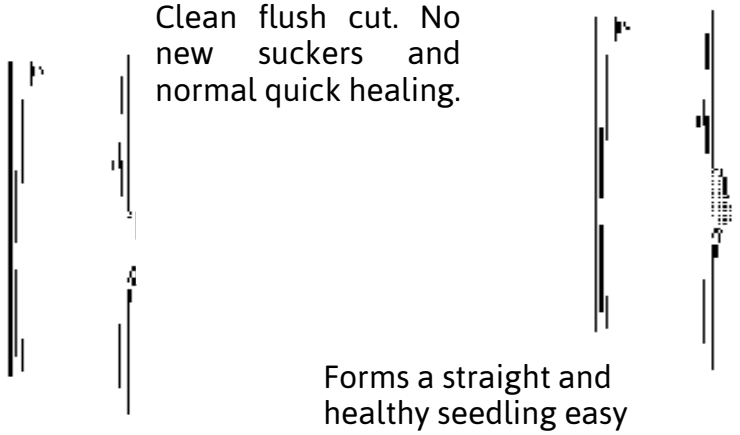
Pruning Figure 2: The importance of pruning flush with the stem



With an unclean unflush cut many new shoots develop that need to be re-pruned later

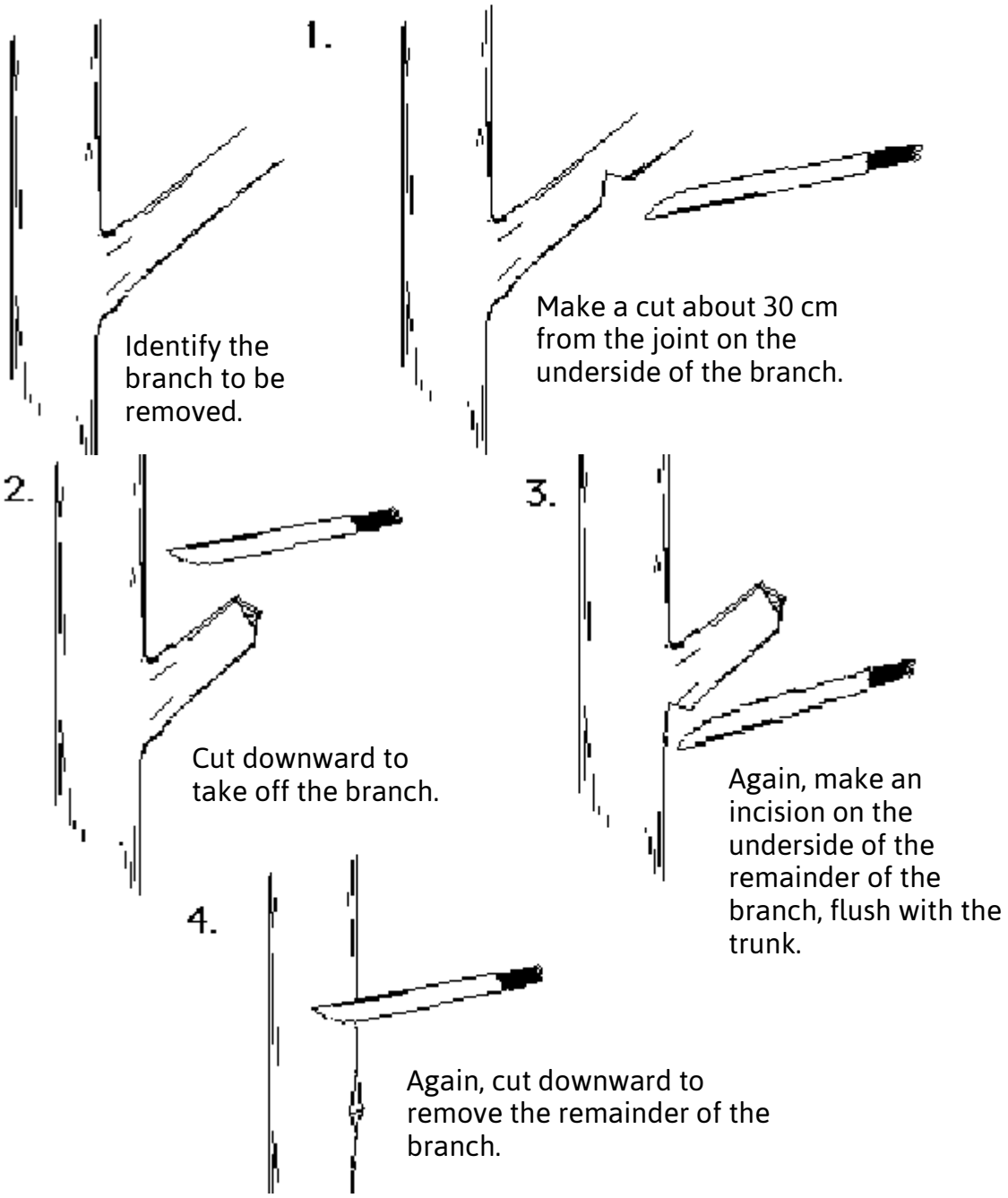
Also, with constant wounding, the chances of disease infestation increases

Clean flush cut. No new suckers and normal quick healing.



Forms a straight and healthy seedling easy to manage, outplant, and graft

Pruning Figure 3: Cutting off a larger branch with a machete



Pruning Agroforestry Trees

Most often, agroforestry trees are pruned for the products they provide, e.g. fuelwood, fodder, and poles, or to provide a service, such as protection from living fences. The agroforestry trees that we recommend for planting in Forest Gardens are selected as much for their ability to resprout quickly after pruning as for the products and services they provide. Follow the guidelines below for pruning living fences and alley cropping trees.

Pruning and Managing Living Fences and Green Walls

Regular pruning of the living fence species creates a dense, impenetrable barrier. You should prune your fence at least once per year to ensure that the trees grow bushy and thick. Pruning should begin early in the life of the tree, before the wood becomes lignified, increasing the chances of new growth low on the stem.

Stages of Pruning

In the nursery:

The key to an effective living fence is to encourage early and low lateral (sideways) branching, to prevent even smaller animals like chickens and small goats from entering. If you let the trees grow too tall before pruning them, low branching will be less likely. To encourage low, lateral branching, prune the terminal buds (see Figure 2) in the nursery stage, at about two months, and then again after they grow to 75 cm to 1 m.

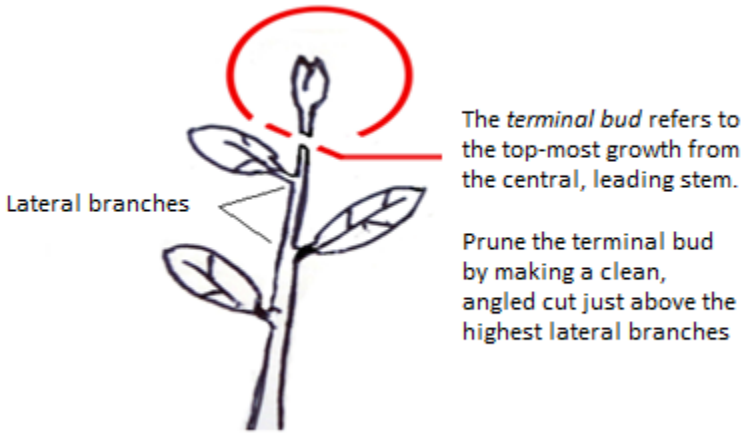


Figure 2: Terminal Bud and Lateral Branches

After planting:

After you have planted the trees in your living fence or green wall, as the branches grow long enough to reach past the stems of adjacent trees, begin weaving the branches from

each tree between the stems the trees next to them. A good time to do this is when the trees are about 50 to 75 cm high. This will train the branches into lattice patterns that produce a dense barrier as the stems and branches grow. At this time, prune the terminal buds of each tree again to further encourage lateral rather than upward growth.

Photo of pruning and weaving trees into a fence.

Mature trees

Once mature, the trees can be pruned into a hedge at 1.5 to 2 meter height every year. Major pruning is best done during the dry season while trees are still in dormant. Light pruning and shaping can be done as often as every 4 to 6 months, or as needed. When pruning, continue to weave lateral branches through the stems of adjacent trees, and prune the remaining branches and leaves for fuelwood, fodder, and green fertilizer.

Allowing some trees to grow

Particularly in green walls, you may select species for the inner row that do not need to be pruned as regularly, if at all. *Moringa, Gliricidia* or *Grevillea*, for example, may be selected for larger amounts of leaf growth, for timber, or for use as a windbreak. These trees generally do not need regular pruning, other than to remove dead, damaged, or diseased branches as needed, or for harvesting leaves for food in the case of *Moringa*.

When to prune

In general, the best time to do major yearly pruning of established plants is during dormancy, about a month or two before the rainy season, to inflict as little stress as possible. To create a thorny hedge, trees should be cut when they reach the height of about 50-75 cm, as this is when they can best withstand the stress.

How to prune

As with any pruning, be sure to use a sharp, clean tool. For agroforestry trees that are pruned regularly, the branches are never allowed to grow to thick so pruning shears, a knife, or a machete will work fine. You should never pull, twist, or rip branches off, even if you have already cut through the majority of the branch. This can tear the bark on the branch or stem that you are removing it from, leaving a large wound. When removing branches always cut them flush with the branch or stem from which they originate by keeping the flat side of the pruning tool flush against it as you make the cut.

Using the harvest

You will harvest a large amount of branches, stems, and leaves from the living fence or green wall surrounding your Forest Garden when you prune. Be sure to put this harvest to the best use possible. You can use any larger sticks and poles as stakes or trellises in your garden for example, or for fuel wood. The small stems and branches can be incorporated into the soils in your Forest Garden to increase fertility or used as a mulch around your trees, or even added to your compost as the green, nitrogen ingredient. If you prefer, the leaves and stems can also serve as nutrient-rich fodder for your livestock. Be sure you keep the harvest from different species separate, however, and follow best practice for feeding regimes and restrictions for some species (*Leucaena spp.* should be fed in varying, limited amounts to most livestock, and not at all to horses and mules) to ensure healthy diets.

Pruning and managing alley cropping, contour, and dispersed trees

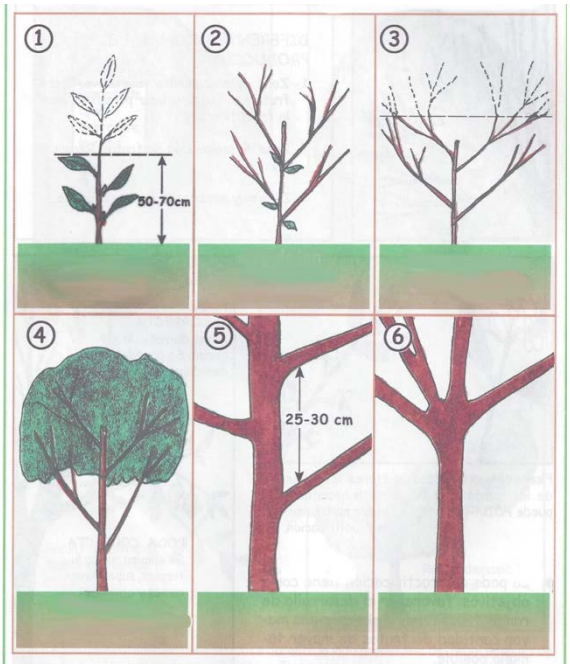
The agroforestry trees you plant using technologies other than living fences can be pruned in different ways, depending on the technology and your preference. In most cases you will coppice your trees at least once each year for their products and to limit competition for sunlight with the crops growing near them. In the case of dispersed trees, you may choose to prune them when you prune the rest of your trees or, if they are not competing for sunlight with other crops, you can allow them to grow, harvesting them when desired for timber.

When to prune

It is not necessary to prune agroforestry trees planted using alley cropping or contour technologies in the nursery. When they are planted in fields at the beginning of the rainy season, they will be too small to compete aggressively for sunlight with your crops. You can allow them to grow until the next cropping season when they can be harvested for the first time. At the beginning of the next cropping season, at the onset of the rains, the trees should be at least a couple of meters high or more. At this time you want to

coppice them to about 50 cm above ground level. You can do this at the beginning of each cropping season, allowing them to grow tall when they are not competing with other crops.

Follow the guidelines in the *How to Prune* and *Using the Harvest* sections above for pruning and use of the branches and leaves you prune. See the Diagram below explaining best times to prune trees at different stages.



Good times to prune trees at different stages are:

Seedlings in the nursery – watch them closely and prune as needed (1)

Young trees – just before the rainy season, when the trees are dormant (2, 3)

Mature trees – after harvest (4, 5, 6)

Pruning and Thinning Timber Trees

Timber trees generally do not need to be pruned as regularly as fruit and agroforestry trees but they will need to be thinned when planted closely together for intensive timber production. Thinning essentially reduces the number of trees planted in an area to allow more growing space for those remaining. The goal is to reach optimal spacing for the mature trees to produce large, straight trunks. The main concern for timber trees is that they grow into tall, straight, single-trunked trees with limited low branching. When you first plant timber trees you can plant them at closer spacing. As the trees start to grow into each other, competing for space, you can thin every other trees for smaller poles, providing the remaining trees with more space to grow taller and thicker. Timber trees do need more care in the first 1 or 2 years after the seedlings have been outplanted, though they will have been hardened off in preparation for leaving the tree nursery. As with any other trees, timber trees may be harmed by frost, drought, wind, browsing animals and poor soil.

Thinning

A good timber tree will give you long, straight logs. When you first outplant your timber seedlings, plant them close together, as close as 1 to 2 meters apart, depending on the species. This keeps branches small so that the tree's energy goes towards developing a strong, straight trunk that does not taper too much (grow thin at the top). Closely grouped trees will be less exposed to the wind, too.

As the trees grow larger, they will begin to compete with each other for water, light and soil nutrients. After 4 to 6 years or more, depending on the species, spacing, and growth, the trees will fill in the canopy. At this time you will want to thin out some of the trees to allow the remaining trees to grow without competition. Thin out trees that are weak, bent, diseased, or that have dead tops. Also cut down those with trunks that lean or have branched into two, and those with many side branches. These can be used for posts, tools, or fuelwood.

Pruning

Pruning timber trees, also called lopping, is generally done when the stand is 6 to 10 years old, depending on the species and growth rate. At this time, you will remove all lower branches to a height as high as you can reach, as well as any secondary branches. Pruning encourages straight growth and creates more clear, knot-free wood, which should add value to the timber logs when sold. It also reduces fire hazard by eliminating fuel sources close to the ground and improving access underneath the trees.

A saw is best for cutting larger timber branches. If you do not have a saw, follow the guidelines for cutting branches with a machete (Pruning Fruit Trees section, Figure 3). As with any pruning, be sure to use a clean, sharp tool, and cut branches flush with the stem. Pruning of timber trees should take place during when the trees are dormant, usually at the end of the dry season.

Note that some species may not respond well to pruning as they may require a larger percent of live crown, so be sure you know the growing characteristics of the timber trees you plant. In any case, trees that are pruned must have an adequate percentage of live crown remaining to support the tree. Lopping too much can weaken the tree, thus slowing growth and making it vulnerable to disease or insect attack.

Timber Management

The remaining trees can be left in your Forest Garden to continue growing for years, even decades. As the trees become more valuable as they age, they can serve as a savings account, harvesting (or withdrawing) trees as needed for your own use or for sale. If you (or your children, or grandchildren!) choose to harvest many at once, many years down the line, it is best to do so in sections. You can cut a section of the trees at one time, leaving the other sections to grow. After cutting a section, you can replant it with new timber seedlings and begin the process again. Since the section is cleared, there will be minimal competition for sunlight and other nutrients. These trees will then begin to grow, maturing over time as you cut and replant the other sections, one by one,

in a rotational timber management system. This will ensure you always have trees growing at different maturity levels.

Note on Spacing and Design

This section describes a timber system where trees are planted closely together for the primary purpose of timber production. In this scenario, an entire section of your Forest Garden will be set aside for timber and little else. Because timber trees require relatively little care after the first couple of years, it is best to plant your timber trees further from your home, so that other trees and crops that do require more attention are more accessible.

Depending on your Forest Garden design and interests, however, you may also choose to plant your timber seedlings further apart. This will decrease the canopy density, allowing for more sunlight to reach understory crops. It is also possible to disperse timber trees throughout your Forest Garden, among fruit trees and other crops, in a more integrated design. In these cases, thinning of your timber trees may not be necessary.

CHAPTER 11: REFERENCES

For more information, take a look at the following resources:

1. Forestry Plantation Written by Norman Jones.
   http://www.agroforestry.net/2014-03-04-10-06-24/forestry-plantation

2. Overstory #217 - Pruning Of Timber Trees
   Written by Rowan Reid. Posted in The Overstory eJournal
   http://www.agroforestry.net/overstory-back-issues/40-overstory-217-pruning-of-timber-trees

3. Overstory #182 - Remember To Touch Trees
   Written by A selection of passages by Alex L. Shigo. Posted in The Overstory eJournal
   http://www.agroforestry.net/overstory-back-issues/89-overstory-182-remember-to-touch-trees

4. World Agroforestry Centre
   http://www.worldagroforestry.org/downloads/Publications/PDFS/b15299.pdf

Chapter 12: Cut-and-Carry Livestock Management

Although alternatives to open grazing, such as rotational grazing, support both animal and pasture health, these methods are often not practical for the poorest of the poor due to investment and equipment requirements. An alternative for animal farmers in the tropics is to produce forages of higher quality in an intensive way and to bring the food to the animals instead of sending the animals to the food.

Cut-and-carry represents a smart, blended management approach that is healthier for the animals, more profitable for the farmers, and better for our planet. In a cut-and-carry system in the developing tropics, animals are penned in a specific area. Families use walls, thorny branches, poles or multi-purpose living fences to keep cows, sheep, and/or goats enclosed. This protects them from other people, pests, diseases, and the hot sun, and it keeps them from wandering. Forage must be brought to animals, since penned livestock do not roam as freely as open grazers. This gives the owner the opportunity to select the best food for the animal.

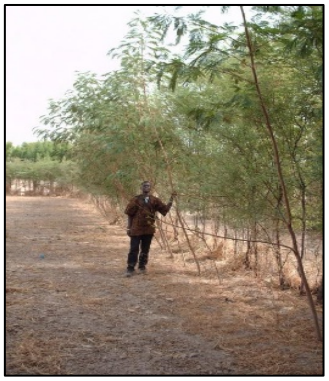
Penning animals with cut-and-carry feeding allows farmers to control diets and minimize animals' stress, but these animals are also sometimes allowed to roam free. Most farmers have ample space on fallow croplands or uncultivated communal lands where animals can stretch their legs. High quality forages can even be grown in and around the same penned areas where the animals spend most of their time.

Because the animals are restricted to specific areas, daily management is far easier. Sickness and other problems can quickly be identified and remedied before it is too late. Livestock waste far less energy than animals that spend their lives walking around in the hot sun, irritated by insects and eating grasses nutritionally equivalent to cardboard. They are comfortably housed with forage, clean water and minerals. Exposure and spread of disease are greatly reduced, and manure is more effectively collected and managed. Animals in heat can be quickly spotted and bred, or isolated and quarantined from other animals. The end result is that animals raised in these comfortable conditions have a far lower minimum daily nutritional requirement, and a higher percentage of the energy and nutrients consumed is converted into meat, milk and healthy calves. Cut and carry livestock management systems help animals avoid wasting their energy sweating in the hot sun, swatting insects and scouring fields for something to eat.

Though animals are usually penned in this system, it should not be confused with confinement rearing and animal intensification in the developed world. In the developed world confinement rearing has evolved into modern, intensive factory farming where animals are packed into small spaces. These cruel living conditions, combined with unhealthy diets meant to accelerate animals' marketability, leads many to view confinement rearing systems as unethical.

Livestock Management In Forest Gardens

In the **protection** phase, farmers learn to incorporate fodder trees into the green walls that surround each Forest Garden. The trees serve as windbreaks inside the protection of thorny living fences, and they serve as barriers around gardens and orchards to control pests. They are also planted along contours to stop erosion.



In the **diversification** phase, fodder trees help meet several needs of farmers. They are often planted in woodlots for fuelwood or in rows across the field for fertilizer. They are also planted around gardens and segments of orchards to control pests.

In the **optimization** phase. Nitrogen fixing fodder trees are planted near gardens and fruit trees. Gaps in the field are filled in with these trees, and species that are provide quality fodder in the lean season are panted.

When fodder trees are planted in rows, lines, perimeters and contour strips, they are usually spaced between 30 cm and 2 meters apart depending on species and the purpose of the agroforestry formation. When planted as living fences, fodder trees are typically planted in two staggered rows with trees spaced 30-50 cm apart. In windbreaks they are often planted at 1 meter intervals, similar to many grass forages.

The advantages of instituting cut-and-carry livestock management systems in Forest Gardens include:

- More efficient use of available land
- Improved gains and productivity
- Decreased time for marketability
- Ability to continuously improve soil productivity
- Reduced risk of damaging the ecosystem
- Increased feed efficiency
- Reduced input cost and replacement of costly animal feed
- Healthier for animals, better disease management
- Efficient manure management
- Increase quality of certain products such as meat and milk
- New market opportunities
- Able to be implemented with 100% appropriate (i.e. locally available) technology
- Social benefits such as freeing children from herding responsibilities and more time for school

Disadvantages of cultivating fodder in Forest Gardens may include:

- High labor requirements
- Difficulty determining smart, balanced rations from diverse sources
- Difficulty knowing how to maximize fodder production from different trees
- Pushback from the animal feed industry
- "Not free range" possibly perceived as less ethical
- Changes in milk taste and quality as well as lactation
- Potential need for mineral supplements
- Period of adjustment for animals
- Production constraints in the dry season
- Lack of tools for proper pruning and harvesting of fodder trees
- Processing and storage constraints in the rainy season

Selecting Forage Species

The ultimate goal of rearing animals is to provide them with living conditions that will help them stay healthy and reproduce quickly. Just like people, animals need a well-balanced diet. Grass alone is not enough. Animals need protein, macro and micronutrients, minerals, and plenty of clean water.

There is a wide range of great animal forages that farmers utilize around the world. But which species of trees are useful for forage production? Almost every country in the tropical world has many types of trees, bushes, grasses and other vegetation whose leaves and soft plant matter can be used as quality animal forage.

Picking the right fodder trees to plant requires consideration of the needs of livestock, the needs of the farm, and the needs of the family. The best fodder sources can address several needs on the farm, including fuel wood, green manure and wind and soil erosion control, protection and even food for human consumption.
Important characteristics include adaptability to specific climatic and soil conditions, growth characteristics, nitrogen fixation, versatility of usage (e.g., fuel, honey, and charcoal, etc.), protein content, digestibility and palatability. It is important to note that digestibility is often related to tannin or other secondary chemical compound content which, if high enough, can interfere with digestibility and metabolism of nutrients in certain animal species. In some cases consumption of certain amounts of fodder high in secondary chemical compounds can cause illness or even death. If no specific guidelines are provided for fodder diet percentages, one single species should provide no more than 30% of ruminants' total diet and no more than 5-10% of total diet for non-ruminants.

Grazing systems are especially difficult to maintain in tropical areas with distinct rainy and dry seasons. It is particularly important to select trees that produce leaves through long dry seasons without requiring extensive irrigation. Regions with particularly long dry seasons may require additional land to produce forage, or a greater share of the Forest Garden dedicated to fodder species.

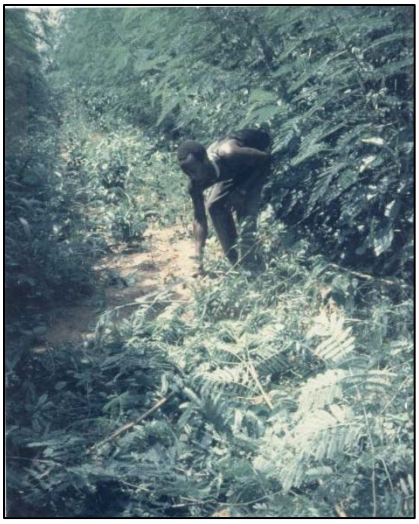
Processing and Storing Leaf Fodder

Forage trees should first be cut or coppiced when they reach 2 meters, and then again after every 0.5-1 meter in new height when re-growth is optimal. Cutting during the rainy season can be as frequent as every 2 weeks (6-8 times over the season). During the dry season, harvests may be reduced to accommodate unfavorable growing conditions.

Some farmers may choose to let the trees grow and then harvest them when the stems have reached a useful size for other purposes, such as fuel or stakes.

Processing and storing fodder takes into account many considerations such as: the time of year (dry or rainy season), animal preference and tolerance, available technology, type of final product (leaves, meal, cakes or pellets, etc.), market availability and even mode of transportation to market.

Feeding fresh forage to livestock is usually the best as it generally contains the most nutrients. However, this may not be an option all the time due to seasonal constraints, limitations in quantity and quality, and other factors. Although many tree-based fodder species produce during the dry season, they are often not as prolific as during the rainy season. Therefore, processing and storage is necessary to ensure proper supplies all year round. This also opens the door to possibilities for market options as demand for affordable, high quality feed rises during the dry season.
Options include drying forages, cutting and storing them, and/or processing them for later use either alone or mixed with other crop by-products. Other parts of the plant aside from edible leaves and petioles (herbage mass) may include seed pods, seeds, fruits and young branches.



Agroforesters around the world, and here in Ghana, have found ways to grow forage trees to feed livestock

When drying forages for storage, it is best to dry them in the shade on screens or other raised platforms that get plenty of ventilation. It may be necessary to check the material and turn it from time to time so as to prevent molding. Drying may increase the digestibility in some species by reducing the fiber content. Drying during the rainy season may be problematic due to spoilage. It should be done in accordance with weather forecasts or with improved drying methods that provide low-humidity heat. Making silage (usually fermented grasses) in bags or holes provides a more digestible product, particularly to non-ruminants, which can be easily stored.

A farmer in Kenya with a screen drying table for Calliandra processing

Forage Agribusiness Opportunities

Leaf meal can be marketed, but usually depends on equipment such as grinders and requires a binding agent (usually molasses). These types of feed supplements are more expensive to make but are very nutritious and can have a high resale value. Leaf meal is typically part of a feed ration mixed with other food. However, leaf meal may be bulky and expensive, especially during the dry season. Leaf meal and stored forages need to be compressed to increase transportation efficiency for both short and long-range transport. Typically, leaf meal is a dry season feed supplement and provides employment for producers and traders in leaf meal. This is a high-value good and has a lot of potential if processing can be made affordable and easily accessible to rural populations.

A major question is whether forage-based leaf meals can substitute for typical dairy meal in terms of not just quality and benefits, but also price and availability. Forage grown on trees can be either a supplement or a substitute.

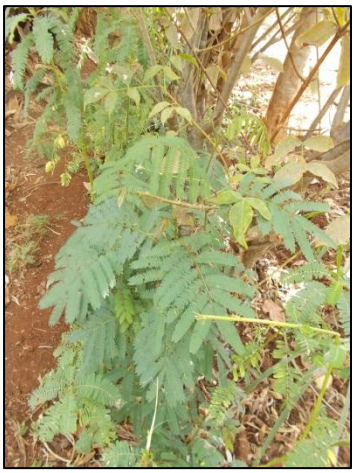
Monetary considerations that go into forage production and/or purchasing decision making include the cost of the purchase (including transportation) versus the cost to raise and manage the forages (labor, seed, less land for other crops), the difference in outputs and market options such as changes in quantity and quality of the meat or dairy products that result, and market availability and costs of feed. All of these factors determine the strategy: substitution, supplementing and/or purchasing.

Popular Highland Fodder Trees

Calliandra calothyrsus

Calliandra leaves, with 24% protein content, are wildly popular in highland communities. Calliandra does not tolerate frost yet is adaptable to various soil acidities, and it is partially shade tolerant, fixes nitrogen, and likes well-drained soil that is not waterlogged. Its forage is high in protein (17-22% crude protein), and is relatively digestible (35-40%). Trees may produce between 6 and 16.7 tons of dry material per hectare per year. However, the high tannin levels limit digestibility so one needs to limit percentage in diet. Goats love *Calliandra* while cattle need an adjustment period. Ruminants tolerate it more than non-ruminants. Rabbits and fowl should only have 5%, and in general no more than 30% of a diet should be comprised of *Callliandra*.

Leucaena trichandra



L. trichandra does not tolerate frost, it does not do well in acidic soils, and it prefers well drained soils. It fixes nitrogen. Its forage is high in protein (17-33% crude protein), and the tannin content varies as does digestibility. This species is disease resistant, adapted to cooler climates but without frost tolerance, and has multiple uses. It is written that it is not well adapted to hot tropical environments,[2] but in the Kenya highlands, where temperatures are kept at bay because of the altitude, it is popular among farmers.

Sesbania sesban/grandiflora

Sesbania tolerates light frost and a wide variety of soil conditions, it fixes Nitrogen, and it is high in protein (15-20 % crude protein) and in vitro digestibility (75-90%). Sesbania trees produce around 20 tons/ha/yr dry matter. However, it should only be harvested five or fewer times per year and it is short lived. This is a popular fodder species and used for rotational fallow and honey production. It is often combined with lower protein sources to provide a complete forage regime.

Morus alba

Mulberry can tolerate frost and prefers alkaline well-drained soils but does not fix nitrogen. It has a high protein content (15-25 % crude protein) and very high digestibility (75-80% in vitro digestibility). They produce 5.6-11.2 tons/ha/yr dry matter. This tree may compete with crops due to its need for Nitrogen and other soil nutrients, so they should be integrated with nitrogen fixing species when planted in Forest Gardens. It is valuable due to its high protein, palatability, frost tolerance, edible fruits and silk worm production.

Popular Lowland Fodder Trees

Leucaena leucocephala

Leucaena grows well under a wide range of conditions, particularly in lowlands, and it quickly grows back when cut and produces a large quantity of leaves, even during the dry season. Leaucaena leaves have the ability to greatly increase growth rate and milk

production thanks to their high levels of protein. An average herd of dual-purpose cattle needs a ration of about 11-12% protein. Local grasses have about 6% protein in the rainy season and 4% in the dry season. Leaves of the *Leucaena* tree have about 27.5% protein, high levels of vitamins A & B, and are palatable for animals.

Sesbania sesban/grandiflora

Description above.

Leucaena pallida

L. pallida tolerates light frost and prefers neutral to alkaline and well-drained soils. It does not tolerate waterlogging and is particularly at-home in very dry areas. It fixes nitrogen and, like other Leucaena species, has a very high protein content (29-35% crude protein) and very high digestibility (55-64 % in vitro digestibility). This *Leucaena* species is psyllid resistant, easy to grow and establish and tolerates more acidic and cooler sites than *L. trichandra*. However high tannin levels may limit digestibility and utilization of nutrients, so moderate amounts should be used as fodder.

Leucaena diversifolia

This *Leucaena t*olerates light frost and prefers slightly acidic and well drained soils. It fixes Nitrogen, is highly palatable, and has a high protein content (25-32% crude protein). Its high tannin levels may limit digestibility. This species of *Leucaena* has a tolerance of low temperatures and is resistant to psyllid insects. It makes good charcoal and fuelwood. It is a prolific seed producer, so it should be highly harvested and maintained to limit invasiveness. No more than 30% of total diet for ruminants and unsuitable for non-ruminants (give no more than 5-10%).

Morus alba

Description above.

Senna siamea

This is a popular fodder for goats, but secondary plant compounds are highly toxic to non-ruminant animals such as pigs and fowl. This plant also has a host of other uses such as fuel, medicine and textiles.

> Nutritionists have pointed out that *Leucaena* is in the *Mimosae* family, and the leaves contain an irregular alkaline (amino acid) called mimosine, which can reduce calving rates under certain circumstances. So these leaves should be fed to single-stomach animals in limited amounts (25% for goats and sheep, none for horses or mules) but can be fed to large ruminants as up to 30% of the total ration.

Other valuable animal fodder trees for East Africa

Chamaecytisus palmensis (Tree Lucerne)

Tree Lucerne tolerates frost and drought, a wide range of soil pH, and prefers well drained soil. It fixes Nitrogen and has a high protein content (20-30% crude protein) and is extremely palatable (77-82% in vitro digestibility). It produces10 tons/ha/yr dry matter. This species improves the soil and is good for honey production. It is easily digested and palatable, but it may take animals some time to become accustomed to it, and it can be sensitive to fungal diseases.

Gliricidia sepium

Mother of cocoa, its name translated from Spanish, does not tolerate frost or water logging, but it does tolerate a wide range of soil pH and fixes nitrogen. It offers 18-30% crude protein, 60-65 % in vitro digestibility, and 20 tons/ha/yr dry matter. It is described as having low palatability but does well when mixed with other forages. This species is especially good for ruminants and propagates easily through cuttings. It may be poisonous to non-ruminants, so do not give more than 10%. It is adapted for hot, dry sites and has a very high biomass potential. If left to grow, it offers good timber resistant to termites that is good for furniture. Its nitrogen-rich leaves are a good green manure, and it is popular among honey producers for the flowers.

Pennisetum clandestinum (Kikuyu grass)

Kikuyu grass is used for permanent pasture, grows best on fertile soils and tolerates a low pH. It may be used for hay or silage. It performs well in areas of low and high moisture regimes. A tropical plant, it does not tolerate frost. This forage need to be cut to produce quality forage and is demanding of nutrients. It provides quality forage with high protein and digestibility levels with new growth. Caution must be used when foraging on new growth after long dry spell as over-consumption can cause toxicity.

Desmodium intortum

Greenleaf desmodium grass has a moderate protein (16-24% crude protein,) and digestibility (55% in vitro digestibility). It is an annual species that does not fare well in the dry season.

A — *Leucaena* B — napier C — *Gliricidia* D — guinea grass E — *Flemingia*

An example of how smallholder farmers can mix many of the species listed above in alleys of fodder trees and grasses (Photo: New Zealand Digital Library)

CHAPTER 12: REFERENCES

1. This section was adapted from Trees for the Future's *Trees for Livestock* publication, found at: https://trees.org/post/trees-for-livestock-2/.
2. Franzel, S., Wambugu, C., Nanok, T., Kavana, P., Njau, T., Aithal, A., Muriuki, J., and Kitalyi A. 2007. The production and marketing of leaf meal from fodder shrubs in Tanga, Tanzania: A pro-poor enterprise for improving livestock productivity. ICRAF Working paper No. 50. World

Chapter 13: Permagardening

A permagarden is a *permanent bio-intensive garden* that, once established, can protect and produce an abundance of diverse, healthy foods in a relatively small area from one season to the next for as long as it is properly managed. The garden is permanent in that, once established, the barriers, paths and beds will remain there to capture, direct and store water and produce food. Bio-intensive refers to the management practices, including composting, double digging, amending, companion planting, triangular sowing, etc. that are so important to the high-yielding, long-lasting productivity of the garden. Permagardens are easily accessible, normally near the home, and can be cared for by the whole family, youth, adults, and elderly alike.

Water conservation and soil health are inherent to the permagarden, and by following simple intercropping, crop rotation and observation practices, pest problems are minimal. The pathways are permanent, providing easy access and irrigation channels to the soft-soiled beds that absorb and store water during the rainy season for use by the plants during the dry season. The berms, swales and holes bordering the garden beds control water and minimize erosion while supporting a variety of herbs, flowers and other perennial plants that provide useful products as well as pest and wind protection.

Objectives of a permagarden are to:

- Diversify and increase food production
- Provide daily nutritional needs for the family
- Provide income opportunities
- Control harmful pests
- Reduce the work needed to grow substantial amounts of food

Site Selection & Planning

As with all components of the Forest Garden, it is important to think about the design of the permagarden prior to constructing it. Things to consider include:

- Location – Does the site have easy access? It should be in a place near the home so that family members can easily check on and work in it regularly and so that the products can be easily harvested for meals each day.
- Water – Can rainwater be captured from the roof of the home or nearby slopes? Is there a nearby water source for watering your beds in the dry season?
- Sun – Garden vegetables need lots of sun. Is there an open area near the home that receives direct sunlight for a good part of the day?
- Soil – Vegetables need healthy soil to grow. Don't worry about the current state of the soil too much though as it can be amended and improved through the use of compost, manure, charcoal, wood ash, etc. Just be sure that there is no bedrock near the surface.
- Protection – Is the area (or can it be) protected from wind and intruding animals? Protection can be established by living fences and borders of perennial plants
- Space – Is there enough space to move around the garden beds? Where will the compost piles be located?

Constructing a Permagarden

Water Control

Controlling the flow of rainwater in your permagarden prevents it from washing away your beds and directs it underground where it can continue to irrigate your crops even when it is not raining. To do this, look at how water moves through your permagarden site. Where will water flow? There are two answers to this. The easy answer is 'downhill'. Water always flows downhill, until something prevents it from doing so. A more pragmatic answer should be 'water flows where we want it to flow'. Since we know that water flows downhill and always will unless something prevents it, all we need to do is decide where we want the water to go, then direct it there. We do this by following these five water control principles**: Stop, Slow, Sink, Shade and Spread**. These are achieved by constructing swales, berms, pathways and holes out of soil, in the appropriate places, to slow down the water and direct it to where we want it go, then stopping it so that it can spread underneath the garden beds and sink deep into the soils (see the *Earthworks* section for descriptions of these water control measures).

The first step in physically constructing your permagarden is to construct the outer swales, berms and holes to slow down and guide any runoff water through the garden and into the ground. A useful design for a permagarden is to construct it in a square, about 4 meters by 4 meters (see the example permagarden design below). It can be bigger, particularly if the family wants to produce vegetables for sale in addition to household consumption, but 16 square meters will produce an abundance of seasonal vegetables for a family of five. Once the footprint of the permagarden is defined, clear

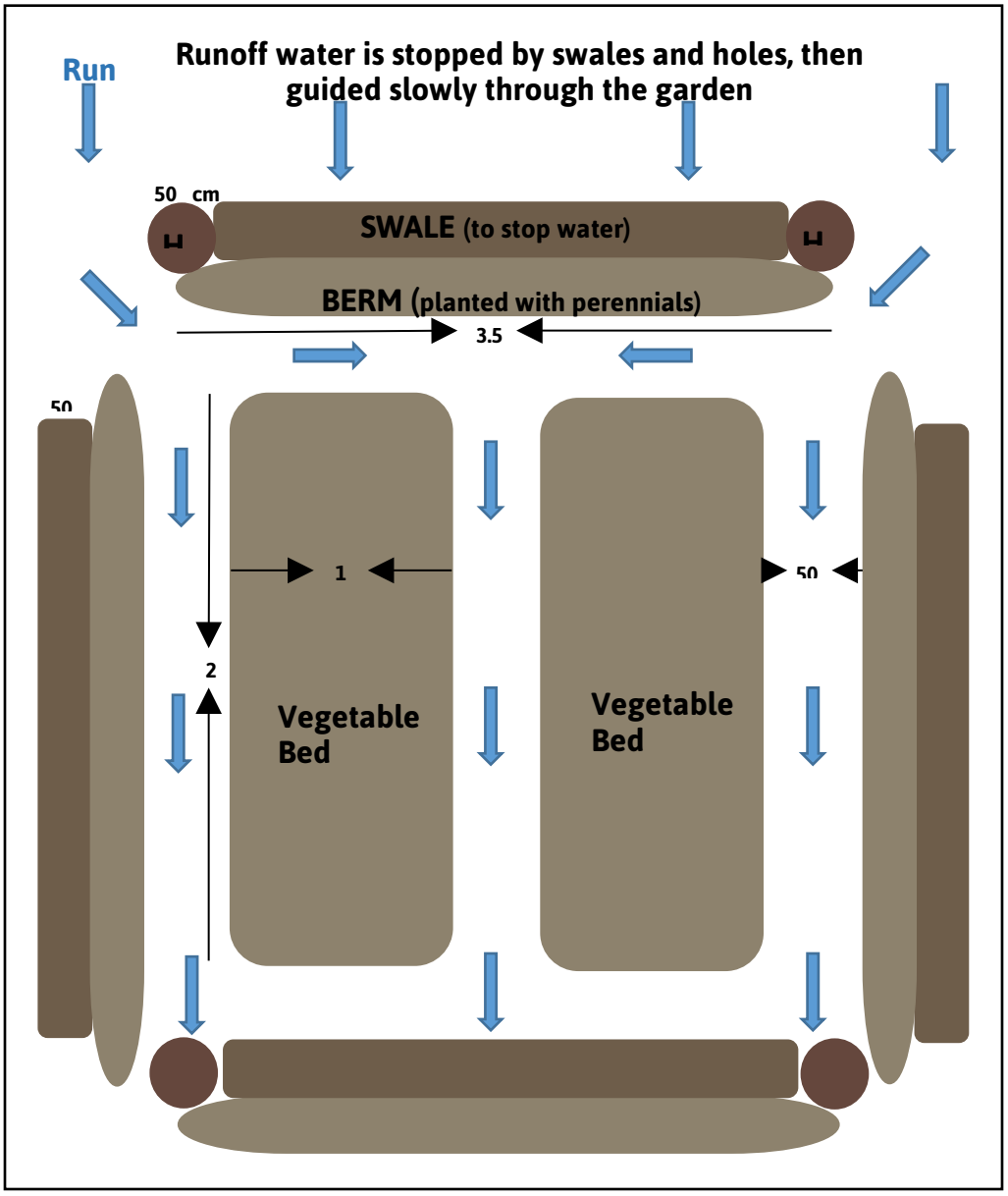
this area of vegetation and dig up the first few centimeters of grass and plant roots. You can keep the soil to build your beds and berms, and place the vegetation in your compost pile.

The top swale and berm are then built nearly perpendicular to the flow of the water, with holes on either end to stop water and allow it to sink. There should be a very slight drop from the top end of one side of the berm to the other so that water will slowly flow down, then enter through the pathway into the garden and around (and into) the beds, slowed again by the other berms and holes so as much water as possible that enters the garden area will be trapped and filtered through the beds and deep into the soil for later use by the plants in the dry season.

Double Digging & Amending the Bed

After the berms, swales and holes are dug to form the borders of the garden and direct water slowly through it and into the ground, it is time to dig the beds. Healthy vegetable crops need 4 things to thrive: sunlight, water, air, and nutrients. If sited appropriately you will have plenty of sunlight. The structures around the garden will direct water into the garden. So that leaves air and nutrients. These come from loosening up the soil deep beneath the surface of the beds to enhance aeration, then adding various amendments that will provide an abundance of organic nutrients to the soil.

Begin this process by marking out the footprint of the beds. They should be about 1 meter wide, by 2 meters long, leaving about a 50 to 60 cm path around the beds.



Example of a Permagarden design

Double digging and amending steps:
Double digging the beds is the most difficult part of constructing the permagarden, but it will ensure proper aeration and healthy root growth. It is best to complete this early in the morning when it is cool and you have plenty of energy.

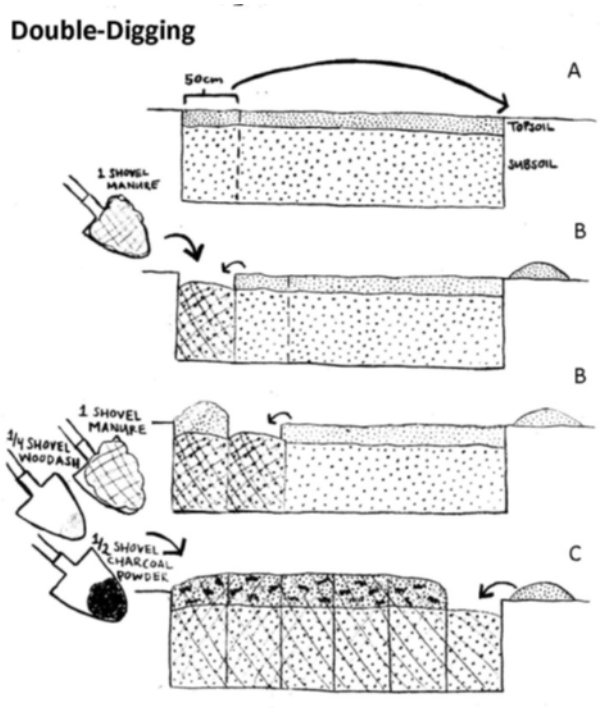
Before double digging your beds, gather the following tools and materials:

- A spade and, if available, a digging tool
- 4 shovels full of Compost or Manure per square meter

- 1 shovel full of Charcoal Powder per square meter
- 1 shovel full of plastic-free Wood Ash per square meter

When you have your tools and materials at hand, begin double digging:

1. Start by marking the corners where you want your nursery bed to lie. The bed should be one meter wide. The length depends on the size of your site but should be no more than 10 meters long so that you can move from one side of the bed to the other easily. Leave about 50 cm between beds so that you can walk around them. You do not ever want to step on the beds!
2. Remove the cover vegetation and transfer it to an area that is out of the way (alternatively, add it to your nursery's compost pile).
3. Start at one side of the bed and mark an area about 2 shovel widths (25 cm) down the length of the bed. Using a shovel, pickaxe, or digging tool, remove the topsoil from the first section you marked off, down to the depth of the hardpan (or about 25 cm where there is little to no topsoil). Place the topsoil you dig out at the end of the bed.
4. Dig the next 25 cm of subsoil below the topsoil you just removed. Do not remove this subsoil, but loosen it, breaking up the larger pieces of dirt. It makes the process much easier to have a partner with you to alternate digging out topsoil then loosening the subsoil.
5. Move down to the next 50 cm section that you marked off. This time, instead of putting the soil to the side as you remove it, shovel it to the first section that you dug out and add the topsoil to fill that hole.
6. While you fill, place two shovels of manure or compost, and a half shove each of wood ash and charcoal powder on top and mix it all in well to amend the soil.
7. Then loosen the subsoil from the second section you just dug out. Continue this process of moving the topsoil, amending it, then loosening the subsoil along the entire length of the bed. When you reach the end of the bed and have loosened the final section of subsoil, place the topsoil that you dug out from the first section to fill in the last section, then add and mix the amendments.
8. When you've worked the entire bed in this fashion, you've double dug your bed. Level off the bed with your shovel or a rake, breaking up any chunks of soil to create a smoothe, flat surface.
9. Water the beds lightly to be sure they are level, and continue watering the beds every other day for a week, removing any weeds that germinate before sowing your seeds.



Maintaining Your Double-Dug Beds
The double-digging process is a lot of work. The last thing you want to do is re-compact your soil after spending so much time and energy making it fluffy and soft. Here are a few things to keep in mind when maintaining your beds:

- Always use a watering can when watering to reduce soil disturbance and erosion.
- Mulch the garden beds when the seedlings reach about 10cm in height. Without mulch, the surface will continually drying in the sun and then remoistening when it is watered, leading to surface crusting and reduced water penetration.
- Don't step in the garden beds. Ever! This is the easiest way to compact the soil, damage existing root systems, and reduce the water-holding capacity.

Raised and Sunken Beds

In the double-digging example above, you will end up with a bed surface that is slightly above ground – a raised bed. The reason for this is because the compacted soil you dug up is now much looser, so it takes up more space, then you also added amendments. Depending on the climatic conditions when you are planting, however, it may be preferable to have a sunken bed rather than a raised bed. See below:

- **Raised beds** – Raised beds are elevated above the surface of the path. Generally with permagarden beds, a height of 10 to 15cm is sufficient. However, it is also

possible to raise a bed to waist height so that you do not have to stoop over to reach it. Raised beds can be created by adding enough soil amendments that the surface of the bed is heightened, or by using bricks or rocks to create and reinforce the shape of the bed and then backfilling with soil and amendments. Raised beds generally:
  - Stay less compacted than other types of beds.
  - Do not flood during the rainy season, improving the success of root crops at that time of year.
  - Are easier on your back as you do not have to bend over as far when planting and weeding.
  - Dry out more quickly than other types of beds during the dry season.
- **Sunken Beds** – Sunken beds are created by removing the layer of topsoil and setting it to the side. Then remove a 30-40cm layer of subsoil completely from the bed. The underlying subsoil is then loosened, and the topsoil is replaced and amended following double-digging practices. The surface of the finished bed should be 10-15cm below the surface of the pathway. Sunken beds generally:
  - Are ideal for areas that are hot, dry, and extremely sandy.
  - Retain moisture much better than raised beds.
  - Tend to flood in the rainy season and are not ideal for root crops.

Vegetable Propagation

Propagation refers to the controlled increase and dissemination of a given plant. For permagarden beds you will generally use two methods of vegetable propagation: germinate and transplant, and direct seed.

The Transplant Group:

- Cabbage
- Basil
- Bitter Tomato
- Eggplant
- Leek
- Lettuce
- Marigold
- Onion
- Sweet Pepper
- Hot Pepper
- Tomato
- Winter Greens

The Germinate and Transplant Method

With this method, you begin by sowing your vegetable seeds in a small area to germinate, and then transplanting them into the permagarden beds once they are large enough to make it on their own. See The Transplant Group box for some of the vegetables that prefer this method. While this system takes more time and labor than direct seeding, it is beneficial for several reasons:

Requires less water – Since you are sowing the seeds close together in the smaller germination beds, you can water them more efficiently.

Improved plant selection – Not all seeds germinate, but most transplants survive. When your seedlings are ready for transplanting, you can pick the healthiest, and strongest of them to transplant into the permagarden bed. These strong, healthy

transplants are also the best candidates for saving seeds after the plants have flowered.

Provides ideal growth space – Plants grow better when they are evenly spaced, and it is easier to evenly space transplants than plants that are direct seeded. When plants are bunched together, their roots compete for soil nutrients and water, and their leaves compete for space and light. Plants that are tightly bunched tend to be smaller, prone to disease and pest problems, and less productive.

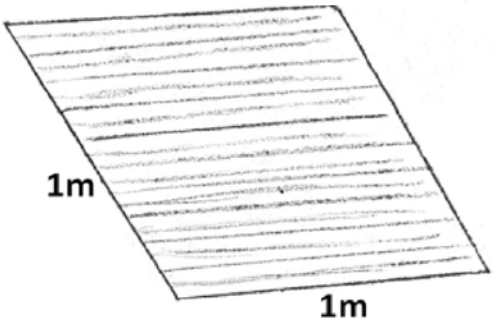
Increased root growth – Some plants benefit from increased root growth when transplanted deeper into the soil. When Solanaceae such as tomato, pepper, eggplant, and bitter tomato are planted deeper than the root collar, they actually send out roots from the portions of the stem that are in contact with the soil, greatly increasing the depth of the lateral root system.

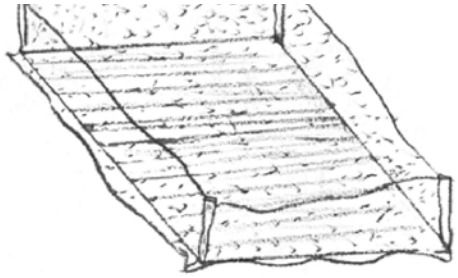
Better use of space over time – Nurseries make better use of space and time. You can have seedlings in a nursery while you still have mature crops in your garden beds. For an intensive gardening operation, you should plan to start you nursery 2-6 weeks (depending on the vegetable) before the projected harvest date of the crops in your permanent beds.

Building Your Germination Bed

1. Double-Dig and amend a 1x1 m space, following the instructions in the Double Digging section.
2. Using your finger or a stick, make shallow trenches across the width of the bed, with rows 10 cm apart.
3. Sprinkle seeds 1-2 cm apart.
4. Seed one species per row, and make not of which species you sow in each row.
5. Cover seeds and tamp lightly.
6. Water as gently as possible.
7. Place stakes in corners, about 50 cm high, and cover the bed with a mosquito net or mesh net to provide shade and protect it from insect attacks. At the very least, build a small shade structure about 50 cm from the ground to protect the germinants from direct sunlight.
8. Water daily and weed weekly.

Germination Bed





Germination bed protected with mosquito net material

Nursery Troubleshooting

Seeding a nursery is pretty straight forward, however sometimes the seeds never show. If that happens, here is a list to help you troubleshoot.

- **Seeds are planted too deeply** – If this is the case they may germinate in the soil, but the first leaves are unable to reach the surface. A good general rule is that seeds should be planted at a depth that is equal to twice their thickness. For very small seeds, including Lettuce and Basil, it can be more successful to scatter them lightly over the surface and then gently scratch them in with your fingertips or lightly spread soil over them.
- **Using old seeds** – Seeds lose their viability over time and may not germinate. If you are sure that you have planted your seeds at the proper depth, it is possible that your seed is no longer viable.
- **Planting in water-logged soil** – Seeds and young sprouts can rot if there is too much water and not enough oxygen. If a nursery is double dug properly, this should not be a problem. If you happen to be using containers, be sure to poke small holes in the sides and bottom to allow for proper drainage.
- **Using soil that has been exposed to herbicides** – Herbicides can linger in soils, reducing germination rates and slowing plant growth.
- **Planting in an area that is not protected from ants** – If there are a lot of ants in close proximity to your nursery area, they may carry off your seeds. Surrounding the edges of your nursery with a thick line of Wood Ash and watering in the seeds immediately after seeding can help deter ants from entering.

Maintaining Your Germination Beds

When your beds are prepared and you have sown your seeds, follow the practices below to raise healthy seedlings for transplanting:

- **Watering** – Water your germination beds as gently as possible to avoid damaging the tender seedlings.
- **Weeding** – Weed your germination beds weekly to ensure that your seedlings are not competing for water and nutrients
- **Thinning** – When your vegetable seedlings have two to three sets of true leaves (i.e. not the first two *cotelydons* that appear after germinating), you can start thinning. You want to have between 1 and 2cm of space between each seedling. Pull out the germinants that look small, weak, or otherwise unhealthy. When thinning, pull the undesired plants out gently so as not to disrupt the root systems of the plants you want to keep.
- Inspection – Inspect your beds daily to be sure they have enough water and that the seedlings are growing healthy. If seedlings are bent over and stuck in the soil, gently free them without pulling them out or damaging the stems.

Transplanting

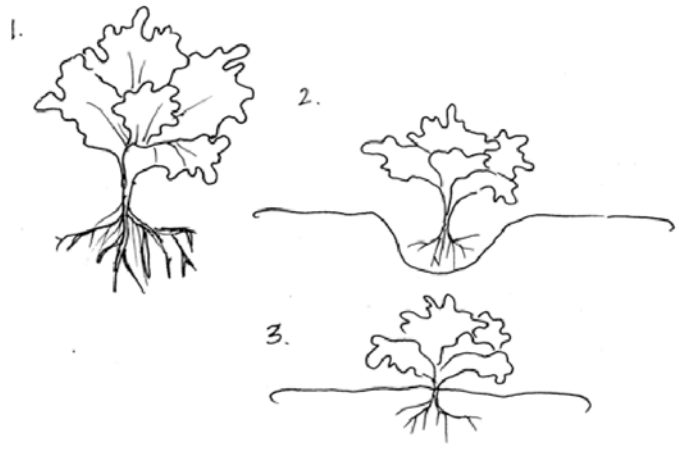
When transplanting vegetables it is important to treat them gently. Stressed or damaged transplants will take longer to re-establish in garden beds and can lead to stunting and reduced yields. Follow the steps below for transplanting:

1. Water the germination bed thoroughly, and fill a watering can for watering the transplants.
2. Dig small planting holes, spaced appropriately (see the triangular spacing section below), in the permagarden bed.
3. Gently remove the transplant from the nursery, using a stick to loosen the soil around it being careful not to damage the roots. As the stems are very delicate and can be damaged easily, hold the transplant by the leaves, carefully pulling up and further loosening the soil around it if needed.
4. Pinch off the lowest leaves, leaving the top-most 2 to 4 leaves.
5. Transplant to the depth of the root collar, or a depth that the semi-lignified or mature portion of the stem, is at the soil surface (see transplanting depth section below). Place the transplant in the hole so that the above-ground portion of the stem is as vertical as possible.
6. While holding the transplant by the leaves, carefully fill in soil over the root system. Press down gently to ensure that the root system is in contact with the soil.
7. Water the transplant.
8. Repeat steps 2 through 7 until all seedlings have been transplanted.

For general transplanting tips, keep the following in mind:

- **Never handle plants by their stems** – Stems are vital to a plant's health. The stems on transplants tend to be soft and easily damaged. When transplanting try always to hold plants either by gently cupping the root ball from the bottom, or by holding them by the leaves which are no great loss to the plant if they get damaged.
- **Water directly before and after transplanting** – Plants need water as soon as they are transplanted. Do not leave fresh transplants in the ground for longer than 15minutes

Lettuce and Cabbage Transplants



1. Gently remove the transplant from the nursery.
2. Place the transplant in the planting hole just up to the root collar. Pinch off the largest leaves.
3. Fill in the planting hole and gently press down the soil around the root zone.

before watering. If you see that transplants begin to wilt, water them immediately.

- **Transplant in the early morning or late afternoon** – The sun is hot, especially in the middle of the day. For increased transplant success, only transplant early in the morning, or late in the afternoon to give them time to establish before facing the heat.

- **Transplant on time** – Transplanting too early means young plants are not hardy enough to handle the stress of transplanting. Transplanting too late means young plants have started to outgrow the nursery and run the risk of having their roots damaged as they are removed from one another.

Transplanting Depth

Not all plants are transplanted in the same manner. Some plants prefer to be planted just up to their root collar. In general these are plants that are grown for their greens such as lettuce and cabbage. Other species, particularly those of the Solanaceae family prefer a much deeper transplanting. When transplanting members of the Solanaceae, plant them so that the semi-lignified portion of the stem is just at the soil surface. The portion of the stem that is submerged will then grow roots, greatly increasing the plant's ability to uptake nutrients.

Direct Seeding

Not all vegetables are suitable for the Germinate and Transplant method. Some vegetables, especially root crops, have much more sensitive root systems that can easily be damaged when removed from the soil. For these crops use the **direct seeding** method.

The Direct Seed Group:

- Bean
- Beet
- Carrot
- Celery
- Cilantro
- Corn
- Cucumber
- Dill
- Melon
- Moringa
- Okra
- Parsley
- Radish
- Squash
- Turnip
- Watermelon

Benefits of Direct Seeding

- **Less initial work** – All you have to do is prepare your bed, plant your seeds at the appropriate spacing, water, weed, and wait. The nursery and transplant system is more work initially.
- **Less risk of damaging plant roots and stressing plants** – Transplanting is traumatic even for those in the transplant group. If done improperly, transplanting can significantly reduce the yield of a given vegetable. Direct seeding avoids this potentially hazardous step.

Drawbacks of Direct Seeding

- **Increased water use during early stages of plant growth** – In the germinate-and-transplant system, you are watering the same number of plants in a smaller space. In a direct-seeded bed, the whole bed needs to be watered.

- **Less control over plant selection** – In the nursery and transplant system you can cull out any plants that show signs of weakness, disease, or mutation before transplanting.
- **Longer exposure of the soil surface to the sun** – Generally, you cannot mulch a directly seeded bed until after the seeds have sprouted and grown to a height of approximately 10cm. Mulching too early can damage young seedlings as they emerge from the soil and press against the underside of the mulch, or make them vulnerable to fungal attacks due to increased humidity.

Steps to Direct Seeding

1. Measure out and mark the holes or lines where you will direct seed in your bed, using the triangular spacing guidelines below.
2. Make holes or lines to the appropriate depth.
3. Place 2-3 seeds per hole.
4. Cover the seeds with soil and press down firmly enough to ensure that soil is making contact with the seeds.
5. Water the bed regularly.
6. About a week or two after the seeds have sprouted, thin them by removing any weak, sick, or mutated plants. You should leave only one plant per space.
7. Reseed any areas that did not sprout.

Triangular Spacing of Seeds and Transplants

Triangular spacing is a bio-intensive planting technique where seeds or transplants are planted at an angle from one another in a triangular pattern. This allows for a greater density of plants than traditional row or rectangular planting, leading to increased vegetable production. It also limits weed growth and moisture evaporation as the canopies will cover more of the soil surface when they are mature.

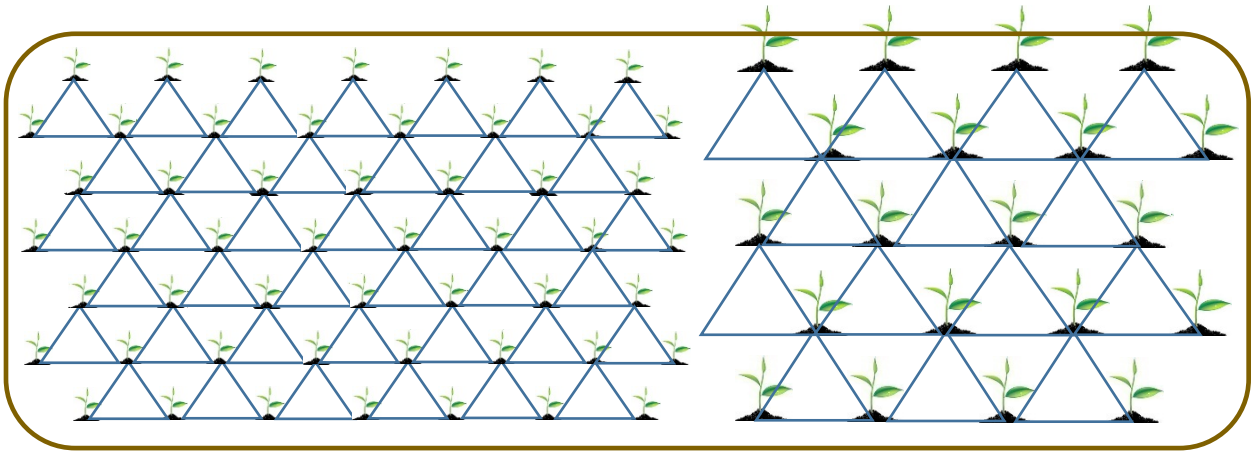
Be sure you use correct spacing for the plants you are growing however. If plants are spaced too closely together, overcrowding occurs and they begin to compete with each other for water, light, and nutrients. When this happens, weaker plants will remain small and become increasingly vulnerable to insect attack, resulting in overall reduced yields. If plants are spaced too far apart, bed space is not being used efficiently, water and nutrient resources are wasted, and yields are not maximized. The spacing information found in the Seed Spacing Table at the end of this section provides the correct spacing for many of the vegetables you may be growing**.** However, proper spacing is not an exact science and often times there is a range of functional spacing. Use the suggested spacing as a guide, but don't be afraid to make slight changes, as soil and water conditions, and desired produce size may vary with site and situation.

Follow the steps below to plant seeds or seedlings using triangular spacing:

1. Measure and cut three sticks to the appropriate spacing length for a given plant (see the Seed Spacing Table).
2. Form a triangle with the three sticks at one corner of the bed and prepare a hole – either for direct seeding or for transplants – at each corner (left, right, and top).

3. Move the triangle over to where the left corner is placed next to the right corner hole you just dug.
4. Dig holes at the top and right corners of the triangle.
5. Repeat until the first double row of holes are dug.
6. Go back to the corner and place the right corner of the triangle at the top corner of the first triangle of holes.
7. Dig holes at the left and top corners.
8. Move the triangle to the right and dig the top and right corners.
9. Repeat until the full section of the bed is prepared for the seeds or transplants of the vegetable you are planting.

The diagram below illustrates how sticks can be used to form triangles, with seeds or seedlings planted at each triangle's corners.



Triangular seedling spacing in garden bed

Comparing Figures B and C below, you can see how bio-intensive, triangular spacing allows more plants to grow in a bed than with traditional row spacing. By amending the permagarden beds with compost and other nutrients you will ensure all of the plants in the bed have enough nutrients to grow healthy and strong. The dense canopy in Figure A will also reduce evaporation and weed growth in the bed, reducing water and labor needs.

Figure B. **Vegetables Planted Using Bio-Intensive Triangular Spacing**

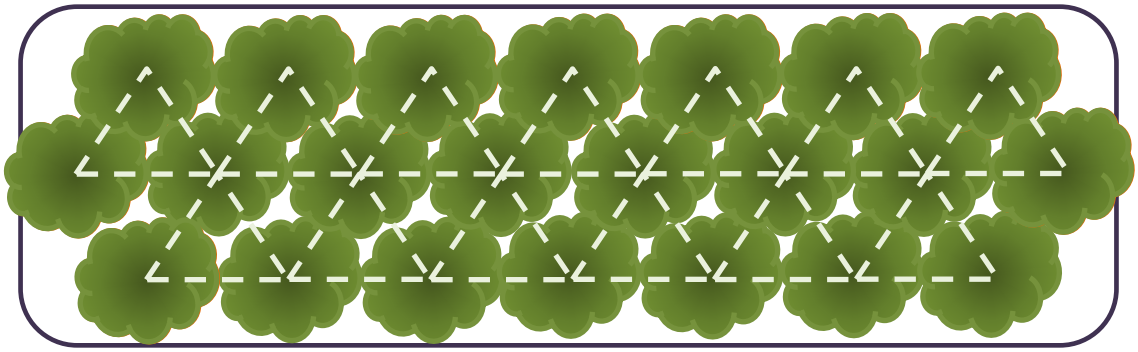
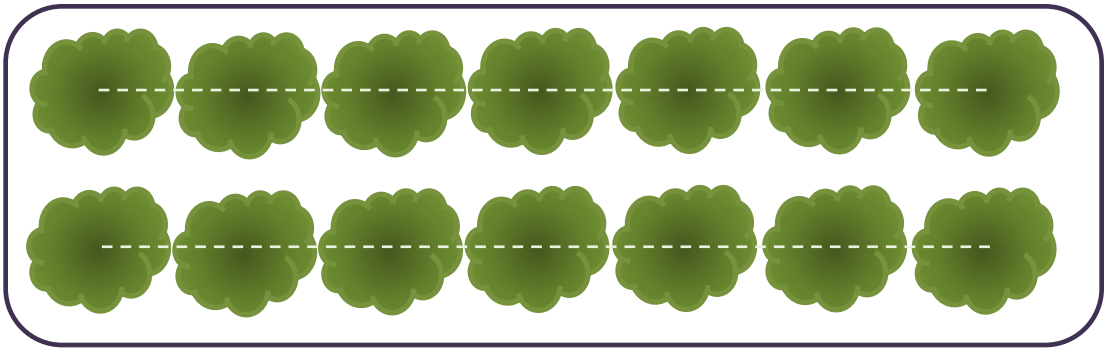
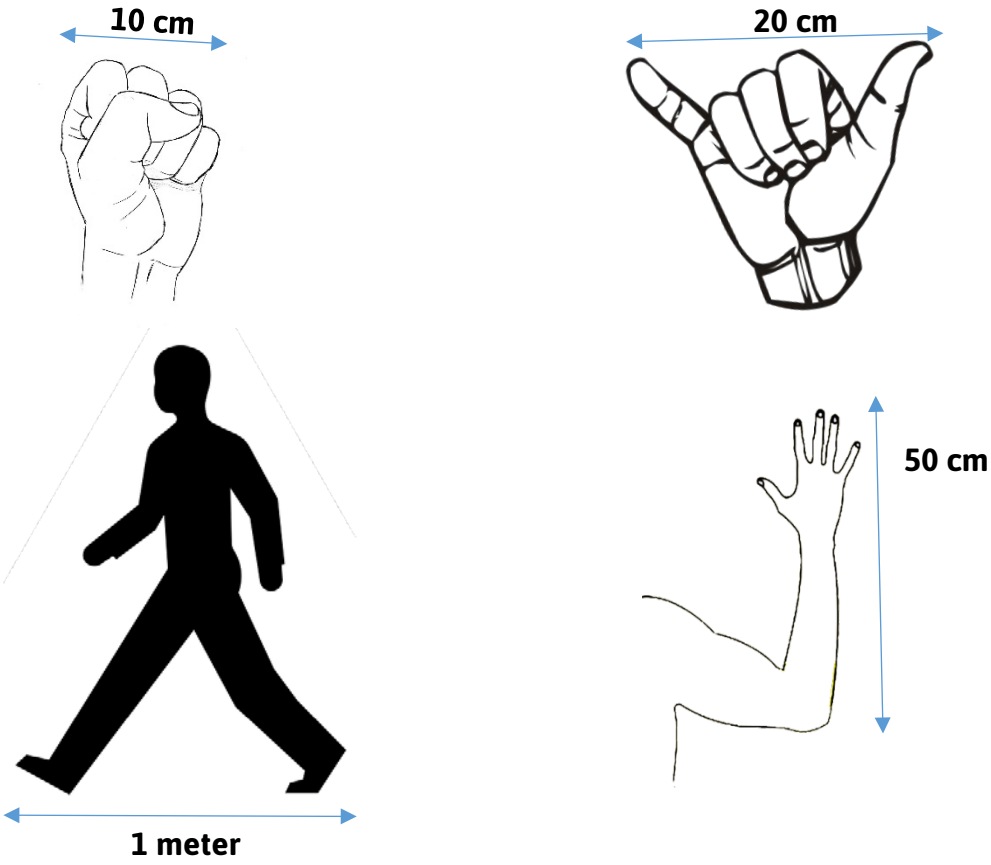


Figure C. **Vegetables Planted Using Traditional Row Spacing**



Convenient Spacing Tools

Correct spacing of the species you are planting is very important, in your Forest Garden as well as your permagarden. When a tape measure is not available, you can use parts of your body to accurately determine distances. When you are near a tape measure, use it to find out convenient body spacing tools. Some common examples are:



10cm For most people, the width of their fist is 10cm.

20cm For most people, when their little finger and thumb is stretched as far apart as possible, the distance between the tip of the little finger and the tip of the thumb is 20cm

40cm For most people, if the tips of the thumbs are placed together, the distance between the tips of both little fingers is 40cm. For those with smaller hands, the distance between the elbow and the tip of the little finger is 40cm

50cm For people whose hands span 20cm as described above, the distance between the elbow and the tip of the little finger is 50cm

1 meter is the average distance of a full step by an adult

Seed Spacing Table (in centimeters)

Crop	Spacing (in germination bed)	Spacing (in permagarden bed)
Spinach	BC*, thin to 6	12
Leaf Lettuce	BC, thin to 6	15
Kale, Swiss Chard, Collard	5	15
Tomato	5	35 (stake up with poles)
Eggplant	5	35
Carrot	-	BC, thin to 5
Radish	-	5
Turnip	-	10
Onion, Leek, Garlic	5	8
Celery	BC, thin to 5	10-15
Beets	-	12**
Cabbage	5	30
Broccoli, Cauliflower	5	30
Sweet Pepper, Hot Pepper	5	25
Squash, Zucchini, Watermelon	-	30, plant 2 per mound***
Peas	-	15
Beans	-	15
Groundnut	-	14
Pumpkin	-	100, allow to spread within bed
African Yams	-	100
Cassava	-	80-100****
Irish Potato	-	18
Sweet Potato	-	18 (from stem cuttings)
Maize	-	35 (plant 2, remove 1 at 2 weeks)
Millet	-	15

*__BC__ = Broadcast the seed lightly then cover with a thin layer of soil. Spreading straw on top will help retain moisture and prevent birds from eating the seed.
** **Beet** usually have 2 or more seeds in each seed pod. Be sure to cull (or thin) the weaker seedlings 2-3 weeks after they germinate to improve beet production.
*** **Squash, Zucchini and Watermelon** should be planted on dirt mounds, about 10-15 cm high and 50 cm in diameter. Space mounds 50 cm apart.
****__Cassava__ is planted from cuttings. Obtain the cutting material from plants at least 10 months old. Cuttings should be 3-4 cm thick and 25 cm long, with 5+ buds per cutting. Bury the cuttings half way into the ground, with at least 2 buds underground. Cut the top of the cutting at an angle to prevent rot.

Maintaining Your Permagarden

Once planted, the permagarden can provide an abundance of healthy foods and herbs for families to eat and sell. Permagarden care does not stop with sowing seeds, however. Continuous care throughout and between each growing season and from year to year are extremely important to ensure the garden remains fertile and highly productive. To ensure a healthy and sustainably productive permagarden, follow the general maintenance guidelines below:

Watering

Watering is essential, of course, for keeping crops healthy. In the rainy season watering may be needed as regularly, depending on the amount of rain. For dry season gardening, however, it is important to ensure that your garden has enough water each day. In a properly prepared permagarden, the berms, swales, and holes, in addition to the mulch and soil cover from densely planted crops, will reduce the water requirements, but you will still need to water regularly. The following guidelines provide all of the information you need to water successfully:

- **Water gently** – Whether it is homemade or purchased from the store, always use some kind of watering can that sprinkles water on your beds. Pouring or splashing water onto garden beds compacts the soil and can quickly lead to soil erosion and plant root exposure.
- **Provide adequate water** – Plants require an average of 5 liters of water per square meter per day. Depending on seasonal temperature changes, you made need more or less.
- **Water regularly** – Plants will adjust to a given watering regiment. Increasing or decreasing daily watering abruptly can stress plants, resulting in decreased yields.
- **Water uniformly** - Water the bed as uniformly as possible. It is easy to forget to water the sides of the bed, and in turn decrease the yield of the vegetables planted on the edges. If you water in straight lines across the width of the bed, this can be avoided.
- **Check soil moisture regularly** – Even if you are adhering to a regular watering schedule it is possible for soil moisture to drop below a healthy level. As climatic conditions become more arid in the dry season, water sometimes evaporates from the soil surface before it penetrates to the subsoil. If this happens frequently, a dry pan develops. A **dry pan** is a shelf of bone-dry soil beneath moist soil, and it can be detrimental to plant health as a large part of the root system has no access to water. It is good practice, once a week, to find a place in a bed that will not damage plant roots and dig down 20-30cm to ensure that there is even moisture to an acceptable depth. If not, add more water.

Thinning

Nearly all vegetables are seeded with 2-3 seeds per planting hole. This safeguards against low germination rates. However, when more than one seed germinates in a hole, the plants will soon crowd and begin to compete with each other over light, water, and

nutrients. Thinning refers to the practice of culling the weaker plants from a given planting space to allow for the most vigorous plant to have more space and resources to grow quickly and produce high yields.
A general rule is to thin seedlings when they have 1-2 sets of true leaves. Thinning too early can damage the fragile roots of the young plants you intend to keep. If too much time passes before plants are thinned, roots will entwine with each other and you may damage the roots of the plants that you are trying to keep as you cull the others. If there are spaces where no seeds germinated, you can transplant the strongest of the culled seedlings to those spaces.

Weeding

A weed is any plant that you do not want in your permagarden. Weed seeds can lay dormant in the soil for a number of seasons before conditions are right for germination. If weeds are left unchecked, they can quickly overcrowd and out-compete garden vegetables. Weed garden beds prior to planting and then thoroughly re-weed at least once every two weeks. It is easiest, as part of a daily routine, to pull out individual weeds as they sprout.
It is important not to allow weeds to go to seed around the beds, especially in the offseason, because this will add to your weeding work. If done properly each season, weeding work will become less and less over time. If even one weed is allowed to go to seed there are potentially hundreds or thousands of new weeds that will need to be pulled.

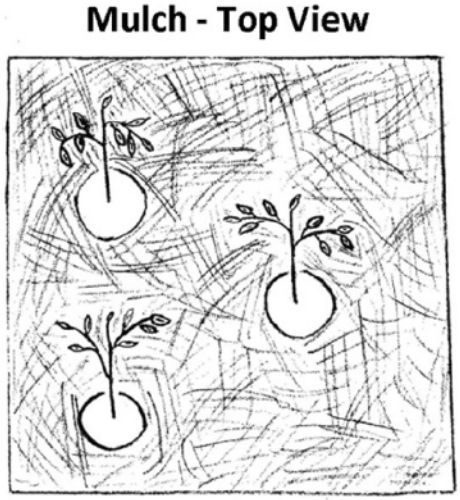
Mulching

Mulch is organic material that covers the soil to improve moisture retention, reduce erosion, minimize weeds, and improve soil structure. Mulch should be anywhere from 3 to 15cm thick depending on the material being used and what it is placed around. For permagarden beds, a 3 to 5 cm layer of mulch is sufficient and should be placed at least 3 to 5 cm from contact with plant stems to prevent fungal problems. Mulch can be made from any number of plant materials available around your home, fields, or community, including straw, crop residue, leaves, grass (including old roofing thatch), rice hulls, compost, small shredded banana leaves, bean stalks, or any other fine and easily decomposable organic material. Mulching is beneficial for a number of reasons:

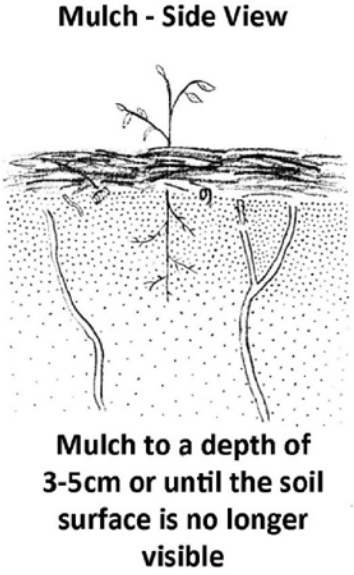
Some Options for Mulching Material

- Straw
- Crop residue (e.g. maize or sorghum stover)
- Leaves
- Grass (including old roofing thatch)
- Rice hulls
- Compost
- Shredded banana leaves
- Bean stalks

- **Protection from the sun** – When soil is exposed to the sun, microbial life deteriorates, water evaporates, and soil temperatures increase. A thick layer of mulch significantly reduces these effects, maintaining soil quality, conserving water, and keeping soil temperatures cool.
- **Moisture preservation** – Mulching is important in the dry season as well as the rainy season as it helps to preserve rainwater in the soil for as long as possible. Not only does it keep soil temperature lower, which reduces evaporation, it can also help crops thrive through dry spells during the rainy season. As it preserves a significant amount of water in the soils, even the crops following the rainy season can benefit.



- **Weed control** – If mulch is thick enough, weeds that sprout cannot make it through the physical barrier, significantly reducing the amount of weeding that is required.
- **Erosion prevention** – Mulch protects soil from the erosive effects of wind, rain, and hand-watering.
- **Prevents soil crusting** – When the soil surface is watered and then dries out repeatedly, a condition called soil crusting occurs. Soil crust is a thin, hard layer that forms over the surface of the soil. This layer prevents water from penetrating the soil and can lead to wilting. Because mulch retains moisture in the soil throughout the day, a mulched bed is unlikely to form a crust.
- **Addition of organic material** – Mulch decomposes over time, adding humus to the soil surface and improving structure and fertility.
- **Protects ground-laying fruits** – Certain fruits such as cucumber, squash, and melon may rot if left in contact with the soil surface. Placing fruits on top of a thick layer of mulch will keep them dry and safe.



- **Creation of beneficial habitat** – Mulched beds provide better habitat for beneficial earthworm and spider populations than un-mulched beds.

Mulching Tips

Mulching is not a difficult task, but there are a few things you should keep in mind. Use the following tips to ensure you get the most from your mulch:

- **Leave space between the mulch and plant stems** – If mulch is in close contact with plant stems it may promote fungal attack due to high humidity. Always leave at least 3 centimeters of space between mulch and plant stems.
- **Mulch to an appropriate thickness** – Mulch thickness will vary depending on the type of material being used. Mulch should be thick enough to protect the soil and act as a weed barrier, but not so thick that it prevents water from entering the soil. A good rule to follow is to mulch until no part of the soil surface can be seen. If using leaves, mulch more thinly than if using other materials as leaves tend to create a matt surface, preventing water penetration.
- **Chop up your mulch** – Particularly for larger plant materials it is a good idea to chop up mulch as finely as possible to ensure maximum water penetration. It will also decompose more quickly, improving your soil structure and fertility.
- **Reapply mulch as needed** – Mulch decomposes with time. Continually reapply mulch as it starts to break down.

Avoiding Soil Compaction

Plant roots need soft soil with good structure to support healthy plants. When soil becomes compacted it is difficult for roots to grow deeply and for water and oxygen to be suspended in beneficial ways. The following list provides ways to avoid soil compaction:

- **Water gently** – As stated above, watering harshly is a sure way to compact your soil. Always use some sort of watering can when watering.
- **Mulch** – Mulch slows and disrupts the impact of falling water.
- **Never step on garden beds, ever!** – Stepping in garden beds is the single easiest way to compact the soil. As plant roots spread laterally through the soil, stepping anywhere on a bed, even if not directly on a plant, can still damage plants. And even when you do not have plants growing, stepping on the beds will damage the soil structure you have worked so hard to improve. Be sure you leave unplanted pathways around the beds – at least 50cm wide – and be sure your children and anyone else who enters the permagarden area know to only use the paths.

Daily Observation

Daily observation of your permagarden is the best form of care. As it is close to the home, you or your family members can easily walk around the garden for a few minutes each morning just to see if everything is doing well. Are the plants wilting from lack of water? Is the soil drying out? Is there too much water? Are there any weeds that need to be pulled out? Are there any pests, or evidence of pests or diseases effecting the plants? Do they have enough nutrients? Note that extensive leaf damage, discoloration, mold, wilting, drying, etc. mean that additional nutrients or control methods may be needed. It is much easier (and better for the plants!) to address all of these issues as soon as you see them rather than waiting until they begin affecting plant growth and yields, or other plants. Visiting the permagarden every day to take a close look at your crops, if even for just a few minutes, will help to ensure your garden remains healthy and productive.

Caring for your Tools

Your tools are an extension of your permagarden, and they are expensive, so take care of them! If you leave your tools out in the rain or put them away covered in dirt, they will rust. Always clean, and dry tools before putting them away. Rusty tools do not last long before breaking. If tool handles are left on the ground termites will burrow into them. Tool handles break when they are full of termite holes. A strict routine of cleaning and putting your tools away after every use can extend the life of your tools by years. Dirty tools also spread disease. If you have been using your tools in an area known to have pest or disease issues, make sure you clean them (preferably with alcohol) before using them in another part of the garden. Never clean tools in water that will then be used to water your plants.

Maximizing Productivity in your Permagarden

We have already described how you can increase the productivity of your permagarden by double digging and amending your beds, and using triangular spacing to increase the number of plants per square meter. There are a number of other ways to increase the annual yields and long-term productivity of your permagarden as well. As with many of the techniques and skills that are covered in the permagarden resource section, the techniques described in this section are relevant and beneficial to apply throughout the Forest Garden, not only in the permagarden area.

Intercropping

As we have mentioned before, diversification is key to Forest Gardening, and it is the same for permagardens. Planting diverse species in the same space is called intercropping. When intercropping it is important to know the characteristics of the different plants that share the same space to be sure that they will grow well together. Groups of intercropped plants that grow well together and benefit from each other are called companion plants. Perhaps the most widely known form of intercropping, a practice used hundreds of years ago by Native Americans, is known as the “The Three Sisters”. The Three Sisters refers to an intercropping system that combines maize, pole beans, and squash within the same growing space. The Three Sisters works because it combines plants that have characteristics that are mutually beneficial to each other, companion plants. The maize provides a structure for the beans to climb on. The beans provide nitrogen to the soil that the other plants need. And the spreading squash plant create a living mulch by blocking sunlight, reducing soil temperatures and minimizing moisture loss and weed growth.

There are multiple strategies for intercropping any number of crop types so that you can harvest throughout the year:

- Planting multiple beds in your permagarden at the same time with different crops in each, then rotating in new crops as soon as the other is harvested.
- Planting multiple types of crops at their normal recommended spacing in the same bed at the same time.

- Staggering the planting of multiple crops in each bed so that different crops can be harvested at different times.

With good planning and water availability, it is even possible in some places to grow a variety of vegetables in your permagarden throughout the year so that there is always something available to harvest. However, in using an intensive intercropping system like this, it is important to remember that **not all garden vegetables are companion plants.** Plants that do not grow well together are called antagonists. It is important to know a plant's physical characteristics, nutrient needs, and growth rates and habits before intercropping them.

Advantages of Intercropping

- **Increased yield –** While there is sometimes a decrease in the yield of one type of vegetable in an intercropping system, the total yield of the bed is often significantly higher than a bed grown with a single species.
- **Decreased labor –** While the time and energy it takes to maintain a single growing space may remain the same or increase slightly with an intercropping scheme, the total labor for the same yield decreases.
- **Decreased water requirements –** Using space more efficiently to maximize production means that all available soil space is being taken up by root systems. This means that the vast majority of water entering the soil is being used by the vegetables.
- **Pest control –** Different plants can be used to either deter pests from them, or attract beneficial, predator insects that will eat pests. Planting aromatic plants next to non-aromatic plants can confuse and deter pests from both. Insectary plants that provide pollen or nectar for beneficial insects can control pest populations as well.
- **Reduced vulnerability –** As we have learned, growing only one crop increases vulnerability. If an unmanageable pest or disease comes through an area it has the potential to decimate an entire crop. If you do not have anything else planted, then you will lose your entire crop. Intercropping ensures that multiple vegetables (often unaffected by the same insect pests) are grown in the same space. If one vegetable type is destroyed by pests or disease, you and your family will still benefit from the other vegetables you grow.
- **Increased micro-climates –** By planting two vegetables with different physical characteristics next to each other, you are creating micro-climates of sun and shade. These diverse temperature margins are ideal for shade/cool loving plants, or beneficial insects flying through your garden looking for pest prey.

Keep in mind, however, that intercropping is more complicated and requires greater planning than planting only one crop. Plant combinations, nursery timing for transplants, germination time for direct seeds, growth rates, and harvest times must all be taken into account for a successful intercrop. If anything is too far off it is possible for overcrowding, competition, and decreased yields to occur.

General Rules for Intercropping

- **Use appropriate spacing –** Be sure to use correct spacing when intercropping plants. Plants should be no closer together than the smallest spacing of the vegetables being planted. For example, when intercropping eggplant at 40cm spacing with lettuce at 10cm spacing, a given head of lettuce should be no closer than 10cm from the base of the eggplant.
- **Take advantage of plants' differences –** One of the largest benefits of intercropping is that plants that have different physical characteristics can be worked into the same bed like puzzle pieces.
    - Place plants with low leaf cover and compact or shallow root systems next to plants with larger leaf cover and deeper root systems.
    - Mix slow-growing plants with fast-growing plants so they don't compete
    - Grow plants that require lots of nutrients (heavy feeders) with those that require little (light feeders).
    - Plant aromatic plants that deter pests to protect non-aromatic plants.
    - Plant flowering plants with pollen and nectar that attract beneficial insects to feed on pests.
    - Grow plants that attract and trap pests near your other higher-value crops
    - Plant crops that grow in different ways (e.g. climbers and stalks or bushes) so that one can be supported by the other.
- **Work with plants from different families –** In general, plants from different vegetable families are susceptible to different pests and diseases than those of other families. By diversifying vegetable families being grown in the garden, the potential for devastating insect loss is even further reduced.
- **Keep transplanting and seeding issues in mind –** If a bed is direct seeded it is difficult to intercrop with transplants before the seedlings sprout without disturbing seeds that are in the process of germinating. Always transplant before direct seeding OR direct seed first and then wait until the seedlings have broken the soil surface before transplanting. Your decision will rely on the growth cycles of the particular plants being intercropped.

Crop Rotation

Each crop that you plant requires specific nutrients to grow. These nutrients are not always the same as those that other crops require. Some crops even fix nutrients (e.g. nitrogen) into the soil that can be used by other plants. If you plant the same crops repeatedly in the same bed without replacing the nutrients that crop needs to thrive, yields will quickly decrease. If you rotate your crops from one season to the next, however, the new crops can use the nutrients that the last crop may not have needed as much of. This practice is called crop rotation, which you can do by recording what has been planted in a given space each season and placing a different crop in that same space the following season. Crop rotation is important for maintaining soil health for field crops as well as for your permagarden beds.

As pests and diseases tend to be species- or family- specific, when planting the same crop season after season in the same bed it will allow pests and disease populations

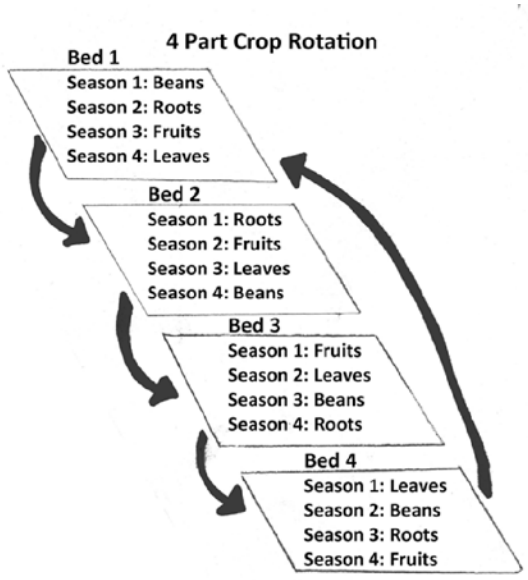
that live off of that crop to multiply. If allowed to do so, they will populate to the point that they can decimate your crop. By rotating families of crops from one season to the next you can break the life cycles of the pest and disease populations that live off of that host crop, preventing them from becoming problematic.

Crop Rotation by Type:

The simplest rule of thumb is to plant crops in a rotational cycle based on the part of the plant you eat, from leafy greens to fruiting vegetables to root crops to legumes (beans). As each of these families of plants generally require different types or amounts of nutrients, it allows you to reduce nutrient depletion by balancing fertility losses and gains. Good crop rotation practices and the addition of organic matter to the soil between growing seasons will ensure the soil always has the nutrient load it needs to keep plants healthy.

Types:

- **Leaf** (needs more Nitrogen) – lettuce, spinach, kale, chard, mustard greens
- **Fruit** (needs less nitrogen, more phosphorous) – tomato, pepper, eggplant, okra
- **Root** (needs little nitrogen, more potassium, some phosphorous) – carrot, potato, beet, radish
- **Legume** (returns nitrogen to soil) – beans, cowpea, pigeon pea, peanut

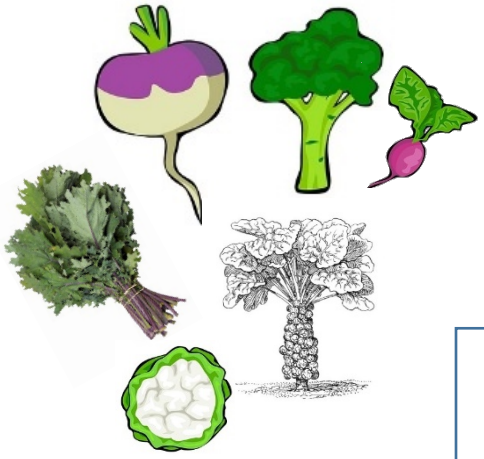


Crop Rotation by Family:

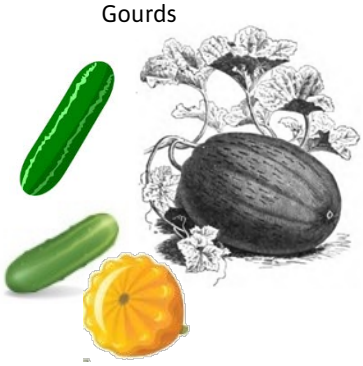
Another option for rotating crops is by always planting a different family. There are numerous families that different vegetables belong to, with many of them seemingly very different from others in their family. Use the figure below to identify the families of some commonly planted vegetables.

Genetic Families of Vegetables for Rotation Planning (Pest Management)

Cruciferaea
"cabbage family"
Kale, Cauliflower, Cabbage, Broccoli, Brussels, Sprouts, Radish, Turnip

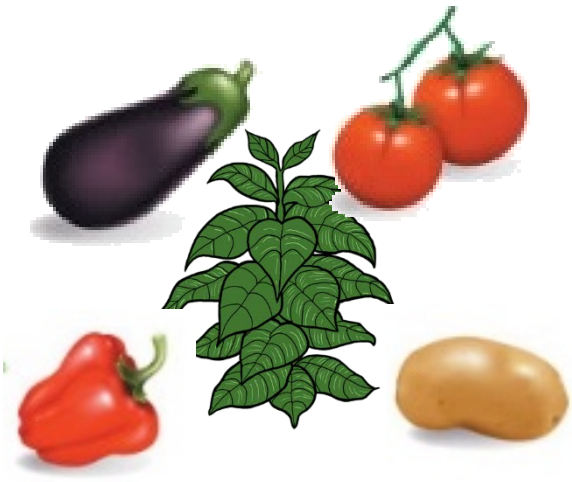


Curcurbitaceae
"vines" Cucumber
Melons, Pumpkin, Squash, Zucchini, Gourds

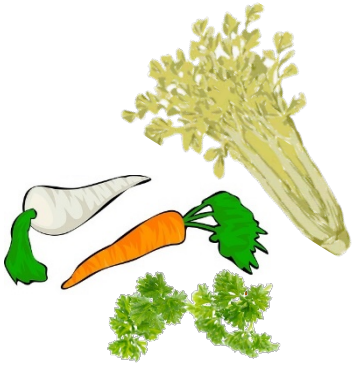


Malvaceae
Kale, Hibiscus, Okra, Cotton

Solanaceae
"popular standing plants"
Potatoes, Tomatoes, Eggplant, Peppers, Tobacco



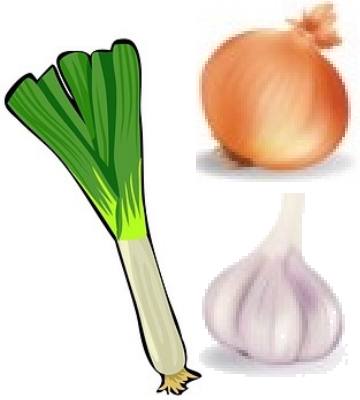
Apiaceae
"parsley-top"
Carrots, Celery, Parsley, Parsnip



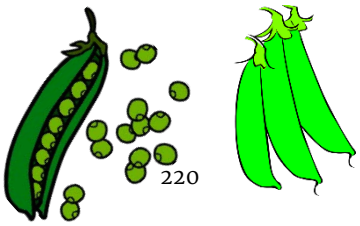
Chenapodiaceae
Beets, Spinach

Compositeae
Artichoke, Lettuce

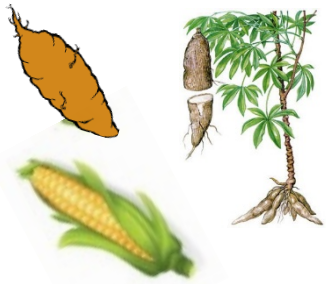
Amaryllidaceae
"onion looking things"
Chives, Garlic, Leek, Onion, Spring onion, Shallots



Leguminoseae
"peas & beans"
Black-eyed peas, Beans, Cow peas, Pigeon peas, Sugar snap peas

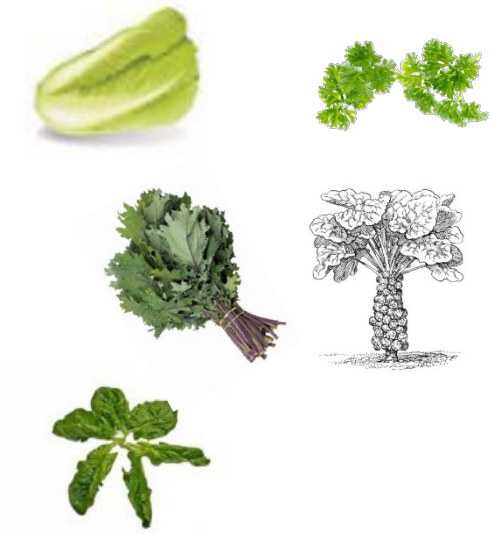


Others:
Corn, manioc, sweat potato



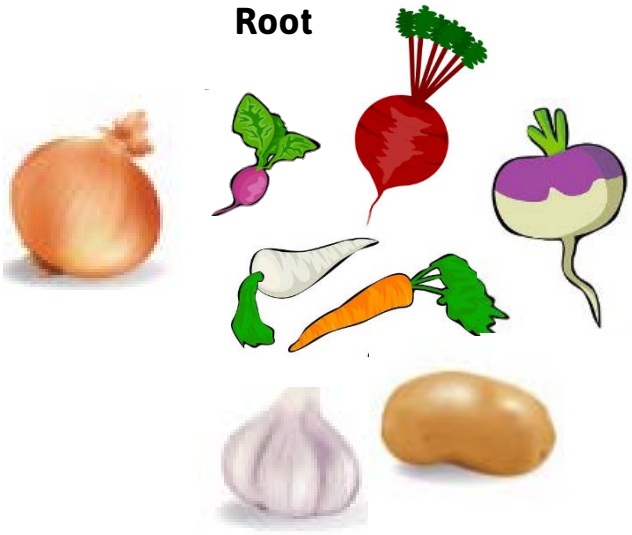
Simple Families of Vegetables for Rotation Planning (Nutrition Management)

Leaf

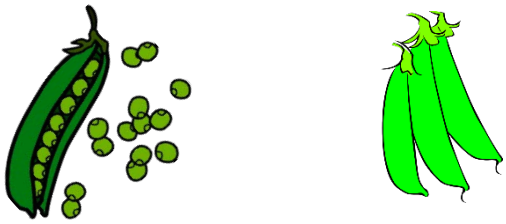


Fruit

Root



Legume



Cover Cropping and Green Manure

Cover cropping is a system in which expendable plants are seeded with the purpose of protecting the soil from the sun after the main crop has been harvested. Any cover crop that is turned back into the soil without going through a composting process is called a green fertilizer. Plants that make excellent cover crops include cowpea, sweet potato, lablab bean, and velvet bean. Cover cropping and green manure are techniques that are more commonly used in field crop production; however, there are some uses in the garden.

Rainy season soil protection – Many gardeners do not grow vegetables during the rainy season because they are focusing on field crop production. Typically gardens are left to over grow with weeds and grasses and then cleared and burned before the cold season vegetable production begins. The act of clearing and burning greatly reduces the fertility of garden soil over time. Planting a cover crop in the garden area after the first few rains can help suppress persistent weeds and grasses, and can be used for composting material or turned into the soil as green manure.

Cold season crop rotation – If the garden is large enough and not every bed needs to be used for production, it is a good idea to use the giver phase of the crop rotation cycle for cover cropping and green manure. Maintain cover crops through the growing season in the selected beds and let them die when halting production before the hot season. Leave the dry organic matter on the soil surface through the hot season, and then compost it or work it directly into the soil at the beginning of the rainy season.

Intercropping and Companion Planting

There are countless types and varieties of vegetables that families can grow in permagardens. The list below provides some basic information for some of the most common vegetables and their companions, antagonists, and recommended intercropping combinations and schemes. Below that is a table with even more common vegetables, with their companions and antagonists.

Cabbage

Family: *Brassicaceae*
Other members include: cauliflower, kale, collards, broccoli, Brussels sprouts, kohlrabi, horseradish, mustard greens, rutabaga, turnip, Chinese cabbage, radish, watercress
Companions: Beet, onion, bean, potato, garlic, carrot, peppermint
Antagonists: Tomato, pole bean
Intercropping Suggestions:

Cabbage and Onions – Cabbage and onions grow well together

1. Start cabbage and onions in nursery on the same date.
2. 20-30 days later transplant cabbage at 40cm triangular spacing
3. 10-25 days later (40-55 days from seeding) transplant onions in diagonal lines between cabbage at 10cm spacing.
4. NOTE: Traditional onion cultivation requires stopping watering cycles to allow onions to dry in the soil before harvest. Cabbage heads must be harvested before

onions are fully mature to allow for this process. Alternatively you can encourage out-of-ground drying for a quicker harvest, and to free up growing space.

Carrot

Family: *Apiceae*
Other Members Include: celery, dill, chervil, coriander (cilantro), fennel, parsnip, parsley
Companions: pea, lettuce, onions, tomatoes, beans, cauliflower, cabbage, turnips
Antagonists: dill
Intercropping Suggestions:

Standard Intercropping Scheme – Carrots can be intercropped with a variety of vegetables with non-competitive root and leaf structures. Planting 2-3 lines of carrot between pepper, eggplant, okra, or hibiscus planted at 40cm triangular spacing is a common way to intercrop with carrot.

Eggplant

Family: *Solanaceae*
Other Members Include: Pepper, tomato, tomatillo, nightshade, potato, and tobacco.
Companions: bean, onion, potato
Intercropping Suggestions:

Standard Intercropping Scheme – When planting eggplant at 40cm triangular spacing, it is possible to intercrop with a wide variety of other non-competitive root crops and low-level vegetables such as carrots, radishes, turnips, beets, and lettuce.

Lettuce

Family: *Asteraceae*
Other Members Include: Endive, chicory, artichoke, sunflower, Jerusalem artichoke
Companions: Carrot, radish, cucumber, onion, garlic, strawberry
Planting Suggestions:

- **Tight Spacing** – Planting lettuce at 10cm triangular spacing will yield small heads. The benefit of this spacing system is that the heads are harvested before the leaves have a chance to turn bitter. This system can be particularly useful if growing lettuce during the hot season when lettuce tends to turn bitter and bolt before a head forms.
- **Medium Spacing** – Planting lettuce at 20cm triangular spacing will yield medium sized heads. This spacing offers a nice balance between the benefits of the tight and wide spacing.
- **Wide Spacing** – Planting lettuce at 30cm triangular spacing will yield large heads. If growing lettuce in the hot season it tends to turn bitter and bolt before reaching a mature size. This system also does not maximize use of garden space while the lettuce is maturing.
- **The Triple Harvest Scheme** – It's possible to find a profitable balance between the tight spacing and medium spacing by transplanting lettuce on 10cm row spacing.

Once the lettuce has grown to the point that it is beginning to overcrowd, harvest the lettuce by pulling out every other head of lettuce in staggered rows. The lettuce remaining in the bed should now be at 20cm triangular spacing. Leave these heads in the bed until they are beginning to overcrowd and then harvest them by cutting the head of lettuce at the base, leaving 3-4 of the lower leaves remaining. A second head will grow back. Leaves from these heads need to be tasted daily to monitor for leaf bitterness. As soon as the leaves show signs of bitterness, harvest the entire bed by removing the plants.

Intercropping Suggestions:

Standard Intercropping Scheme – Lettuce works well when intercropped with any taller growing vegetables that will provide shade. For any vegetables that are planted at standard 40cm spacing, 2-3 lines of lettuce can be planted between diagonal rows at 10-20cm triangular spacing.

Lettuce and Cucumber – Place a cucumber trellis (see section on vegetable support) in the center of the garden bed. Transplant lettuce at 10cm line spacing throughout the entire bed. Direct seed cucumber in two rows at 50cm spacing. As the cucumber starts to grow, make sure that it begins to climb the trellis, freeing space for the lettuce. As the lettuce starts to crowd into each other, pull out every other head in staggered rows. The end result should be lettuce planted at 20cm triangular spacing. When those heads are mature, cut them at the base instead of pulling the whole head out. Wait for heads to reform and then pull them for a third harvest. At this point the cucumber should be covering the trellis and producing fruit.

Okra

Family: *Malvacea*
Other Members Include: cacao
Companions: Pepper, cucumber
Intercropping Suggestions

Standard Intercropping Scheme – When planting okra at 40cm triangular spacing, it is possible to intercrop with a wide variety of other non-competitive root crops and low level vegetables such as carrots, radishes, turnips, beets, lettuce, and cabbage.

Okra as a wind break and shade provider – When growing vegetables that require small amounts of shade and are susceptible to wind damage (such as lettuce and carrot), okra (like corn) can be grown in 1 row at 40cm spacing along the edge of the bed to provide shade and function as a wind break.

Bulb Onion

Family: *Amaryllidaceae*
Other Members Include: Leek, shallot, green onion (bunching onion), Egyptian walking onion, garlic, chives, and garlic chives
Companions: Beet, strawberry, tomato, lettuce, leek, cabbage, eggplant
Antagonists: Pea, bean

Intercropping Suggestions:

Intercropping for small-scale production – Onion has a compact bulb and a narrow profile leaf structure that makes it ideal for intercropping with a wide variety of crops. Typical intercrops with onions include lettuce and onion: lettuce, carrot, and onion; onion and cabbage; and onion and tomato or onion and eggplant. However, when onions are of proper size to harvest, they are typically left in the ground as watering is slowly reduced to nothing to allow them to dry and cure before harvest. Because of this practice it can be extremely difficult to intercrop onions with any long cycle plants. Only lettuce has a short enough cycle to ensure there will be no harvesting conflicts at the end of the season.

Onion and Lettuce – Onion and lettuce work extremely well as an intercrop. There are a variety of patterns that can be followed. One that works is planting lettuce in rows at 10cm within-row and 15cm between-row spacing, and then planting a row of onions between each row of lettuce at 10cm within-row spacing. The lettuce is on a short enough cycle that it can be harvested before the onions are mature. Often times there will be enough time for a second round of lettuce to be transplanted and harvested before the onions are mature.

Sweet Pepper

Family: Solanaceae
Other Members Include: Eggplant, tomato, tomatillo, nightshade, potato, and tobacco.
Companions: Basil, okra.
Intercropping Suggestions:

Standard Intercropping Scheme: When planting green pepper at 40cm triangular spacing, it is possible to intercrop with a wide variety of other non-competitive root crops and low level vegetables such as carrots, radishes, turnips, beets, and lettuce.

Hot Pepper

Family: Solanaceae
Other Members Include: Eggplant, tomato, tomatillo, nightshade, potato, and tobacco.
Companions: Basil, okra.
Intercropping Suggestions:

Standard Intercropping Scheme – When planting hot pepper at 40cm triangular spacing, it is possible to intercrop with a wide variety of other non-competitive root crops and low-level vegetables such as carrots, radishes, turnips, beets, and lettuce.

Tomato

Family: Solanaceae
Other Members Include: Eggplant, pepper, tomatillo, nightshade, potato, and tobacco.
Companions: Chive, onion, carrot, garlic, parsley, marigold
Antagonists: Kohlrabi, potato, fennel, cabbage
Intercropping Suggestions:

Tomato and lettuce – Because tomato tends to vine in irregular patterns and needs to be staked, caged, or trellised, it can be a difficult crop to fit into an intercropping scheme. However, lettuce can be intercropped with tomato because the growth time of lettuce is short enough to harvest before it becomes overcrowded by the tomato. Transplant tomato at 40cm triangular spacing. Transplant lettuce in rows between the rows of tomato at 10cm spacing. When the lettuce starts crowding, harvest every other head in staggered rows leaving the lettuce in a 20cm triangular pattern. Harvest lettuce a second time when they begin to re-crowd. At this point the tomato should be reaching full height. Do not re-transplant lettuce.

List of Companion & Antagonist Crops

Crop	Companions	Antagonists	Remarks
Spinach	Beans, Lettuce, Peas, Strawberries	Potato	Beans and Peas provide shade for spinach
Leaf Lettuce	Mint, Beans, Beets, Carrots, Maize, Marigold, Onions, Peas, Radish, Strawberries	Parsley	Mint repels slugs, which feed on lettuce
Kale, Swiss Chard, Collard	Beets, Carrots, Marigold, Radish, Turnips	-	
Tomato	Beans, Basil, Carrots, Spinach, Broccoli, Cauliflower, Celery, Marigold, Peppers, Melons	Cabbage, Kale, Maize, Peas, Potatoes, Rosemary, Broccoli, Cauliflower, Dill	Growing basil 25 cm from tomatoes increases tomato yields. Marigolds repel hornworms and nematodes.
Eggplant	Beans, Peppers, Potato		
Carrot	Beans, Garlic, Lettuce, Onion, Parsley, Peas, Rosemary, Dill, Tomato	Dill, Parsnip	
Radish	Cabbage, Maize, Cucumber, Eggplant, Lettuce		Radish can be used as a trap crop against some beetles and aphids
Turnip	Peas		

Onion, Leek, Garlic	Beets, Cabbage, Carrots, Lettuce, Rosemary, Strawberry, Tomato, and each other	Beans, Peas	Repels aphids, carrot fly, and other pests
Celery	Bush beans, Cabbage, Dill, Leeks, Tomatoes	Potato, Parsnip	
Beets	Broccoli, Cabbage, Cauliflower, Collards, Garlic, Onion, Lettuce, Sage	Pole and Runner Beans	Beans and beets compete with each other. Beet leaves add magnesium when composted.
Cabbage	Beets, Bush beans, Celery, Mint, Onion, Potato, Oregano, Rosemary, Dill, Sage	Pole and Runner beans, Peppers, Strawberry, Tomato	Celery, onion and herbs keep pests away. Rosemary repels cabbage fly.
Broccoli, Cauliflower	Basil, Bush beans, Cucumber, Garlic, Lettuce, Marigold, Mint, Onion, Potato, Radish, Rosemary, Dill, Sage, Thyme	Mustard, Oregano, Strawberry, Tomato	Rosemary repels cabbage fly. Dill attracts wasps for pest control
Sweet Pepper, Hot Pepper	Basil, Onions, Spinach, Tomato	Beans, Cabbage, Kale	
Squash, Zucchini, Watermelon	Flowering plants (for pollination)	Sweet Potato	
Peas	Beans, Cabbage, Carrots, Celery, Corn, Cucumber, Lettuce, Potato, Sage	Onions, Leeks, Garlic	
Beans	Beets, Cabbage, Cauliflower, Kale, Cucumber, Celery, Swiss chard, Spinach, Maize, Eggplant, Peas, Potatoes	Onion, Leeks, Garlic, Peppers	Maize is a natural trellis and/or shelter beans and beans provide nitrogen for the maize.
Groundnut	Beets, Cabbage, Carrots, Celery,	Basil, Onion	

	Maize, Cucumber, Eggplant, Lettuce, Marigold, Pea, Potato, Radish, Rosemary, Strawberry		
Pumpkin	Beans, Maize, Radish	Potato	Maize, Beans and Pumpkin are an age-old companion group, called *The 3 Sisters*
African Yams	Beans, Oregano, Basil, Dill, Marigolds		
Cassava	Beans		
Irish Potato	Beans, Cabbage, Corn, Eggplant	Celery, Cucumber, Pumpkin, Rosemary, Strawberries, Tomato	Cucumber and tomato attract pests that can attack potatoes
Sweet Potato	Beets, Okra, Dill, Thyme	Squash, Zucchini, Watermelon	
Maize	Beans, Cucumbers, Peas, Potatoes, Pumpkin, Squash, Zucchini	Tomato	Tomato worm and corn earworm are attracted by both plants.

http://www.vegetablegardeninglife.com/companion-planting-charts.html#sthash.hf620aAn.dpuf

CHAPTER 13: REFERENCES

Some information in this chapter was adapted from two resources:

1. The United States Peace Corps Senegal Agroforestry Training Manual

2. The Technical and Operational Performance Support (TOPS) Program. 2015. TOPS Permagarden Technical Manual. Washington, DC: The TOPS Program.

Chapter 14: Compost

Compost is an essential part of any healthy garden. The many benefits it provides makes it one of the most important and essential components of your permagarden as well as your Forest Garden. Compost drastically improves soil structure and fertility, helping you to produce sustainable yields of highly nutritious and lucrative crops. It can help sandy soils hold nutrients and water better and can improve drainage of clayey soils. Over time, compost can restore vitality and productivity to even the most degraded soils. Billions of microorganisms live in a single handful of compost. These microorganisms are constantly working for your garden by breaking down organic matter into nutrients that plants can readily absorb, and by burrowing massive networks of tunnels around your plants' roots and deep into the soil to improve air and water circulation.

Benefits of Composting

Compost is fairly easy to make, using materials that are available in, on and around the household, garden, fields and neighborhood. Some of the many benefits include:

I**mproved structure:** Compost feeds the immense number of beneficial insects and microbes in the soil. These organisms burrow networks of tunnels around the root systems of the plants, improving aeration and water infiltration. This allows for better root growth, enhances water drainage in clayey soils, and improves water and nutrient retention in sandy soils.

Aeration: The vast majority of the nutrients plants need to thrive is obtained from *air, sun, and water*. Compost loosens the soil, allowing air and moisture into it and enhancing the exchange of nutrients. Carbon dioxide released by the decomposition of the organic matter diffuses out of the soil and is absorbed by the canopy of closely spaced plant leaves above.

Fertilization: Compost contains some important macronutrients like nitrogen, phosphorous, potassium, magnesium, and sulfur, and it is especially important for trace elements such as molybdenum, zinc, and iodide.

Nutrient release: Organic acids from decomposing organic matter dissolve soil minerals, making them available to plants. As organic matter continues to break down it slowly releases key nutrients for plant uptake and to ensure a healthy soil microbe population.

Nitrogen storage: Nitrogen, one of the most important of plant nutrients, is also the most volatile. If added to soils low in organic matter, much of it converts to gas and is lost to

the air. Organic compounds bond to the nitrogen and allow it to be released slowly and steadily as the plant needs it.

Soil acidity and toxin buffer: Plants have specific tolerances in terms of soil acidity and toxins. Organic matter allows plants to have a greater tolerance to these elements that are common in poor soils.

Germination and early seedling growth: Once seeds are planted and the seed coats break down, compost in the soil will act like a sponge, absorbing the water and keeping it moist around the seed for a much longer time. This increases the speed of germination and the likelihood of the young seedling growing through periods of dry weather that would otherwise destroy the tender stems, roots and leaves.

Turning waste into food: Compost can easily be made from the waste from your crops, animals, kitchen scraps, and other organic matter that often goes unused. Your compost piles will convert this waste into food for your plants, which in turn will provide more, healthier food for your family.

Composting Ingredients

Composting is an aerobic process, meaning it requires air circulation to promote decomposition. The process relies on soil microbes to decompose the organic materials that make up your compost pile. The decomposition process will heat up the soil to 120°F to 140°F (49°C to 60°C) after a couple of days. The pile will cool off after a few more days, and when you turn the pile to aerate it, it will heat up again. Five elements work together to form compost:

- Carbon
- Nitrogen
- Air
- Water
- Bacteria

The key to efficiently making high quality compost is to ensure a good ratio of the compost elements. This will promote good aeration and moisture content, which leads to efficient decomposition of the organic materials.

By adding manure and topsoil to your compost piles you will provide the bacteria (and other microorganisms and insects) you need to decompose the materials. These bacteria need moist conditions and plenty of air to survive and break down the materials, so you need add water and turn the piles regularly to ensure they have the air and water needed. The bulk of the materials needed to make compost are composed of carbon and nitrogen. Carbon-rich materials come from dry, brown, organic materials, and nitrogen-rich materials generally come from green plant materials. Use the lists below to identify carbon and nitrogen sources that are available around your home.

Carbon Rich Materials (browns)	**Nitrogen Rich Materials (greens)**
Dry Leaves	Green Leaves
Dry Grass	Green Grass
Peanut Shells	Green Weeds (pest free)
Rice Hulls	Manure
Millet Stalks/ Chaff	Food Scraps
Old Roofing Thatch	Old Fish
Cardboard	
Newspaper	

Compost Enhancement Materials

It is also good practice to add other materials to your compost to enhance the quality or the nutrient load. For the purposes of making compost these materials are not considered carbon-rich or nitrogen rich and should not be used in the same quantities as the standard materials. These optional composting materials can include:

- **Charcoal powder** – which increases water holding capacity and habitat for microbial life.
- **Wood ash** – stabilizes pH levels, and adds phosphorous and potassium to the compost. NOTE: When using wood ash, make sure that no plastic was burned along with the wood.
- **Egg shells** – rich in calcium, egg shells provide an additional boost of this trace element that your plants will appreciate.
- **Sugar and vinegar or lime juice** – increases the decomposition rate by encouraging microbial activity. The cost of these materials generally prohibit the purchase of them for adding to compost, but any wastes from the use of these ingredients, including used limes, are beneficial.
- **Urine** – adds large quantities of nitrogen. The use of human urine may be culturally inappropriate in some sites. Human urine should only be added to the first compost pile to prevent the spread of human pathogens.
- **Coffee grounds** – if your family drinks coffee, then add the grinds to your compost pile will add an abundance of organic nitrogen. Coffee grounds can also be added to your amendment materials when amending permagarden beds or mulching around trees.

Materials to Avoid Using in Your Compost Piles:

- **Meat** – meat can rot and produce harmful pathogens that can lead to illness and disease. If it does not decompose fully it can spread these pathogens to your garden.
- **Diseased or pest-infested plant materials** – to avoid the risk of diseases or pests infecting your permagarden, you should remove and burn infected plant materials when you see them rather than adding them to your compost pile.

- **Plants that are toxic to microbial life** – Some plants can have a negative effect on the microbial life in your compost piles. Some toxic plants include hemlock, juniper, bamboo, gmelina, onion, citrus, castor bean, and eucalyptus
- **Acidic plant materials** – pine needles and other plants that have high acidity levels will negatively impact the pH level of your compost.
- **Perennial invasive weeks** – plants such as wild morning glory, kuch, Bermuda, striga, or kikuyu may not fully decompose in your compost and could be problematic. Avoid using materials, including their root systems, in your composting materials.

Making Compost

There are many different ways to create and maintain a compost pile. One example that we find very useful is, after finding an appropriate site, to arrange your compost into three piles that will each be built, allowed to decompose, and then rotated on a continuous basis. This will ensure a regular supply of humus-rich compost throughout the year.

Identifying a Compost Site

Appropriate placement of your compost piles is important to ensure optimum decomposition and access. Too much sun or too much water will kill the bacteria in it. If you place the piles too far away, you may not maintain them as needed, and you will have to carry the materials and finished compost longer distances. Ideally you should locate the piles on bare ground in a shaded area near the garden. Each pile will cover about one square meter of ground. Leave enough space around each pile to easily access and turn them as needed. You do not want water to collect around and under the piles, so be sure runoff will drain around and away from the compost area.

Building and Maintaining your Compost Piles

Once an appropriate site is found, follow the steps below to build and maintain your compost:

1. Gather the materials below to start your compost pile. Use a machete or hoe chop down the materials to small pieces – the smaller the pieces, the faster they will decompose.

Materials to start you compost pile:

- 6 large sacks of dry, brown (carbon) materials
- 3 large sacks of green (nitrogen) materials (you want to add about 1 part nitrogen for every 4 parts of carbon materials)
- 1 20 liter bucket of manure and/or, fertile topsoil, or finished compost as your source for bacteria
- Compost enhancement materials, if available (e.g. charcoal powder, wood ash, egg shells, etc)
- 3 or 4 - 20 liter buckets of water
- 1 - 3m x 3m plastic sheet, if available

2. Place a 10 cm layer of brown carbon material on the ground, forming a 1m x 1m square.
3. Add a 5 cm layer of green nitrogen material.
4. Add about 5 large handfuls of bacteria mix.
5. Blend these layers together with your hands, mixing 5 liters of water into it; form the pile back into a 1m x 1m square.
6. Repeat steps 2 through 5 until the pile is 1m x 1m x 1m. Try to keep this shape as much as possible.
7. If you have one available, cover the pile with a sheet of plastic to help hold the moisture and heat in the pile. The plastic will speed up the process but it is not necessary; you can also cover the pile with grass or soil to hold in moisture. This is all you need to do to start the pile.

   Note: After 2 days the pile will become very hot – this a good thing! It means the bacteria are working to break down the materials. You can place a stick in the middle of the pile, removing it periodically to check that the pile is still hot and moist.
8. WAIT ONE WEEK, then add 20 liters of water over the top to keep the pile moist then cover it again. Gather more materials for the second pile.
9. WAIT ANOTHER WEEK, then mix and flip the entire pile to a space next to where it was to aerate the compost. Form it back into a 1m x 1m x 1m shape, add 20 liters of water, and re-cover it.
10. Make another pile where the first one was, following steps 2 through 6.
11. WAIT TWO WEEKS, then repeat steps 8 and 9. Add water as needed in between to ensure that the piles stay moist. Mix, flip and reform the piles again and begin the third pile where the first one was.
12. WAIT TWO WEEKS, then repeat steps 7 and 8. Continue to mix and flip the piles every two weeks, soaking them in water as needed to ensure they stay moist.
13. When the first pile is brown, crumbly and cool to the touch (usually after 2 to 3 months) the compost is ready to be used in the garden. Spread this compost where needed in your permagarden or Forest Garden and start a new pile.

You will know when the compost is ready when it is dark brown, crumbly and cool to the touch, similar to the soil found just below the bed of a forest. It is perfectly fine, even

preferable, to have insects (e.g. spiders, centipedes, worms, etc) in the compost and garden. Just like the microorganisms, they help to decompose the organic matter into usable nutrients, and many of them eat the pests that attack your plants. After removing the previous crop from a bed, apply about 10 liters of finished compost to each square meter of garden bed, prior to sowing the next crop.

Influencing the Speed of Decomposition

If you do not provide the bacteria in your compost with suitable living conditions it may take much longer to decompose, if it does at all. You can decrease the amount of time by which your compost will reach completion by keeping the following factors in mind:

- **Size of the material** – Though it may take some additional work to chop up all of the materials you add to your compost, the smaller they are the faster they will decompose.
- **Adequate carbon: nitrogen ratio** – If there is too much carbon, the pile will not heat up and will take longer to break down. If there is too much nitrogen, the nitrogen in the pile is released as a gas in the form of ammonia. Ammonia not only smells bad, but it is an indicator that the nitrogen that could otherwise be used as plant nutrient is being lost to the air.
- **Adequate aeration** – High oxygen levels help feed beneficial bacteria, increasing the heat of the pile and speeding the decomposition process. Turning the pile every two weeks will ensure an adequate oxygen level.
- **Adequate moisture levels** – A dry compost pile will decompose very slowly and a sopping wet pile runs the risk of rotting. A pile should be damp, but not soggy.

Troubleshooting for your Compost Pile

You can place a stick straight down in the middle of your compost pile to act as a diagnostic tool. You should pull it out every few days to check it for the following three signs:

1. **Moisture level** – The stick should be damp and moist. Use the following to diagnose moisture content:
    - If it is dry the decomposition process will be very slow - add a 20 liter bucket of water.
    - If it is wet and slimy the pile is too moist, and runs the risk of rotting – turn the pile to aerate it and release some of the moisture.

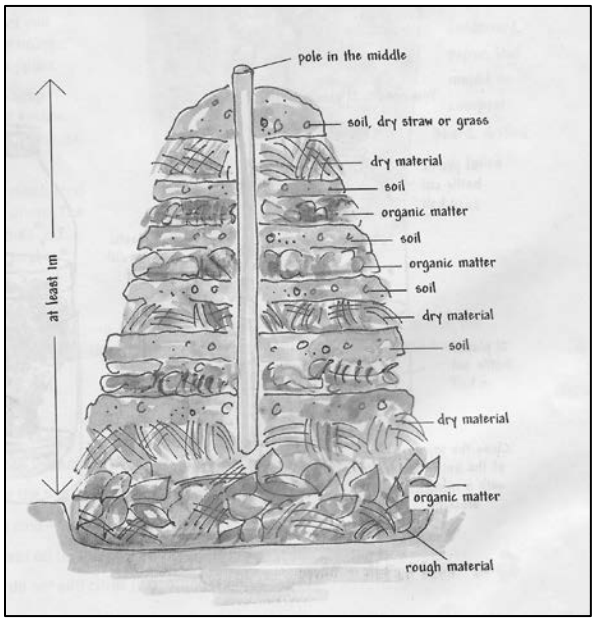
2. **Heat** – The compost pile should start to heat up after about 2 to 4 days if it is properly built. When you touch the stick immediately after it has been taken out of an active pile, it should be uncomfortably hot. If the stick never gets hot, the pile is not functioning. This could mean one of 3 things:
    - Not enough moisture. If the stick is dry and the pile is cool, add water and give the pile time to heat up.
    - Too much moisture. If the stick is wet and slimy and the pile is cool, turn the pile and aerate it to release some of the moisture.

- Not enough nitrogen materials or bacteria. If the stick shows the proper moisture level, but the pile is still cool, there is not enough nitrogen – or potentially bacteria – for the desired chemical processes to take place. Turn the pile while adding nitrogen materials and manure. Water the pile until it is properly moist.

3. **Smell –** If the compost pile is decomposing properly, the smell will change over time. At first, it will smell sour and unpleasant. After about two weeks the pile will start to smell less sour but still not pleasant. After four weeks the pile will start to smell sweeter and by the six week mark it will have a pleasant, earthy smell like a forest after a rain. The compost pile should never *stink*. If the compost pile begins to smell so bad that you can't be near it then one of the following might be wrong:

- If the stick is wet and slimy and smells terrible, then there is too much moisture and the pile is rotting. Aerate the pile by turning it thoroughly.
- If the stick is at the proper moisture level and smells terrible, then there is too much nitrogen. Turn the pile while adding carbon materials and water as necessary.

See example photos below.



Finished compost piles in the shade. Healthy compost is dark, black, and moist

CHAPTER 14: REFERENCES

Some information in this chapter was adapted from two resources:

1. The United States Peace Corps Senegal Agroforestry Training Manual

2. The Technical and Operational Performance Support (TOPS) Program. 2015. TOPS Permagarden Technical Manual. Washington, DC: The TOPS Program.

Chapter 15: Optimizing The Understory

The understory of your Forest Garden refers to the various plants that fill in the space beneath the canopy trees. As your Forest Garden mature, the canopy will be made up of the timber trees as well as some of the larger fruit trees you plant. The understory includes all the shorter trees and shrubs, herbaceous plants, vines, and ground covers that, when carefully selected, can provide a wide variety of products while also helping to maintain soil fertility, reduce moisture loss, and protect against pests. By integrating understory plants into your Forest Garden you are continuing to diversify the timing of harvests to provide for more frequent returns while further increasing the total productivity and sustainability of your site.

After you have protected your Forest Garden site, revitalized the soils, and began diversifying your production with fruit trees, timber trees, permagardens and more, it is time to begin optimizing your production. At this point you will take a close look at the layout of your Forest Garden, with an aim of maximizing the use of: space (horizontally and vertically), time, sunlight (or shade), and water. Are there any gaps where other plants can be added to fill the niche? What companion plants can be added that would benefit from or provide benefits to the trees and other plants that are already growing? What plants grow best with full sun? What can grow in partial or dense shade? How can you conserve or better utilize rainwater?

The understory plants that fill in these spaces will help you to make more efficient use of land, labor, and resources. However, it does require careful planning to ensure that you have the right mix of plants in an increasingly complex system. It is important to have an understanding of the needs of the various species, and how they affect other species near them. The most obvious consideration for understory plants is that they will need to tolerate shade. How much shade depends on the spacing and density of the canopy trees above them. The shade also influences more than just the amount of sunlight that reaches below. It also influences air temperature and humidity, soil temperature and moisture, wind movement, and more, which all have an impact on your understory plants. The understory environment provides a number of benefits for plants, including:

- Reduced evaporation of water through the leaves and branches of the plants, which conserves moisture in the plants and reduces water use
- Protection from temperature extremes and fluctuations
- Shielding from winds
- Suppression of invasive weeds, which tend to prefer open conditions and full sun
- Support for a range of beneficial soil microbes that do not thrive in the open.

The Understory is Dependent on the Overstory

The canopy layer, or overstory, plays a critical role in creating the understory environment and thus largely determines which understory plants you will be able to grow effectively. The most influential factors of succession that affect the understory are the canopy tree shape, canopy foliage type, tree spacing, and rooting patterns.

- **Canopy shape –** The canopies of trees can take a variety of shapes. They can have a wide, spreading canopy, a narrow, more conical form, or anything in between. The canopies can be tall and dense, or a thin layer. The shape and form of the overstory trees is an important consideration in planning which plants you can best intercrop into your Forest Garden's understory. The form and canopy shape of the overstory trees will help determine appropriate spacing for the trees and understory crops. In some cases you can alter the shape and form of the overstory trees by training and pruning the branches.
- **Canopy foliage type –** Some types of tree foliage create dappled sunlight or light shade (e.g. *Acacia abyssinica* or coconut) while others develop a thick canopy with dense, heavy shade beneath (e.g. mango). Although you will select understory crops that tolerate some degree of shade, some light must be available for most crops to be productive. The type of foliage should be considered along with canopy shape, to determine the spacing needed to create an optimal understory environment for the selected understory plants.
- **Tree Spacing –** Increased spacing of the overstory trees is important if you want to create a lush understory environment. If you opt for standard, close spaced trees in a monocultural orchard or forestry system, you would need to phase out your understory crops as they would be out-competed for light and space. We do not recommend this as the lack diversity will diminish the resilience and sustainability of your system. Forest Garden systems generally involve a reduced number of trees per acre (anywhere from 25% to 75% less) compared to monocultural plantings for timber or fruit trees. This wider spacing can be in a uniform pattern or in a more random pattern of dispersed trees. What you lose in production of the canopy trees, however, can be more than made up with a diverse and well-planned selection of understory crops. Plan your spacing to optimize the environment for the understory, and minimize competition for space, light, and nutrients.
- **Rooting Patterns –** As the various trees and plants fill in your Forest Garden aboveground, their root systems will likewise fill in belowground space. As such, the root systems of all the plants will also be competing for resources, so you want to be sure you are planting crops and other plants that access different root zones and nutrients in the same vicinity. Around each deep rooted tree, you can plant shrubs, bushes, vines, root crops and others in the same area that will access different layers in the soil horizon. Through careful planning, the integration of various plants with different rooting patterns will allow you to increase the overall

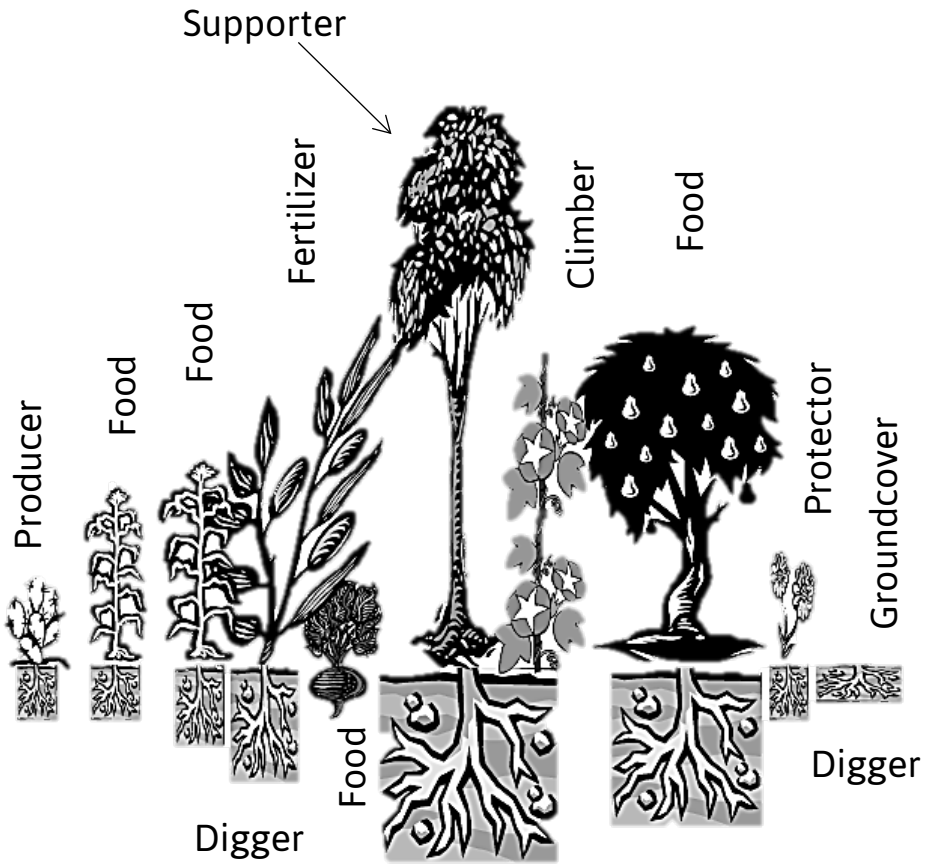
productivity of your Forest Garden considerably while minimizing competition for water, air, and nutrients among them.

Guild Building in Your Forest Garden

Planning your Forest Garden establishment strategy requires a good understanding of the growing requirements and characteristics of the plants you select, and their relationships with other plants near them. When you group different plants together in a system that maximizes the service or production potential of each plant, you are creating a **guild**. A guild is a permaculture concept that seeks to mimic the way plants grow in healthy, natural environment. In the process of optimizing your Forest Garden understory, you are identifying companion plants that exhibit complementary growth and rooting patterns to minimize competition. In doing so you are creating guilds. The list below defines some of the many different functions that you can try to include in the guilds you create:

- **Providers –** plants that provide food and money, e.g. fruits, vegetables, grains, and timber.
- **Fertilizers –** legumes that fix nitrogen into the soil.
- **Miners –** deep rooted plants or tubers that open the soil and bring up nutrients from the deep in the subsoil, releasing them as organic matter in the leaf litter.
- **Climbers –** to take advantage of vertical space.
- **Supporters –** plants that provide support for the climbers.
- **Cover crops –** shallow-rooted, surface-level plants that cover the ground and shade and protect the soil, hold moisture, and retain weeds.
- **Protectors –** plants that protect your site and the crops within, e.g. insectary plants, aromatic pest confusers, and green walls.

See Figure below for an example of a guild.



Succession of the Understory

One of the important considerations in designing guilds and optimizing your understory system is the rate at which the understory environment changes, in a process called succession. Following the Forest Garden Approach, you will begin planting understory plants to create guilds while your canopy trees are still maturing and the overstory is relatively open. The understory environment will continue to change, becoming shadier, cooler, and more humid, as the overstory trees fill in the canopy. Because of this, the composition of your understory plants will need to change over time as well. Earlier on you can grow plants that benefit from more sunshine. As the canopy fills, you will need to transition in plants that are tolerant of shade and a cooler, more humid environment. The understory succession will influence decisions in overstory and understory plant selections and plant spacing.

Understanding how the tree cover and understory conditions will change will allow you to optimize your understory planting schedule. For example, if understory crops cannot tolerate full sun, then you should not plant those shade-loving plants until the overstory trees have grown enough to provide a sufficient canopy. The amount of time that

appropriate conditions for your understory will last influences your decisions for optimum output from understory crops, thus influencing crop selection, spacing, and scheduling. In the Forest Garden Approach, we begin introducing more shade tolerant crops in the third year. Until that time, you can continue planting the annual crops you previously planted, leaving space around the trees you have incorporated into the site to avoid competition. As your overstory trees continue to grow and spread, you can initially maintain the optimum understory conditions by pruning or thinning the overstory trees.

However, if you do not wish to restrict the growth of the overstory too much, you will likely choose to replace some of the early annual understory crops with other perennial crops that are better adapted to a denser overstory. This method of succession planting optimizes the productivity of the understory as the environmental conditions change.

Selecting your understory crops

Whether your understory crops are integrated for continuous yields or in a succession intercropping system, species selection is an important consideration. When selecting species, be sure you understand the compatibility of the growth and rooting habits to ensure the plants are compatible and not overly competitive for nutrients and space. Integrate your companion understory plants in a way that maximizes available light, space, and nutrients, while minimizing competition. In relation to the overstory trees, understory crops should:

- Tolerate partial shade.
- Exploit different soil horizons than the overstory trees as much as possible.
- Be shorter than the overstory trees when mature unless explicitly planned to utilize the shade when growing, but eventually overtaking and creating a higher canopy layer.
- Be less susceptible than the overstory trees to diseases they may have in common.
- Not involve damage to the overstory trees during cultivation or harvest of understory crops.

Avoid competition between the under- and overstory

Understanding the rooting habits, potential allelopathic effects (where plants produce biochemicals that influence the germination, growth, survival, or reproduction of other plants), and growth rates of the overstory species will help you to ensure that the trees you incorporate into your Forest Garden will create a beneficial environment for the understory crops. Some tree species may be too fast-growing or have negative allelopathic effects on crops, making them inappropriate for this kind of system. For example, *Eucalyptus* and *Casuarina* species exhibit allelopathic effects that prohibit the growth of other plants near them. Other trees may simply have aggressive root systems or growth rates that are incompatible with most understory crops. Similarly, be sure to select understory crops that are not overly competitive with your overstory trees.

Selecting and testing local varieties for understory crops

The vast majority of modern agricultural research has, at the expense of sustainability, focused on growing crops in monocutural systems that are fully exposed to the sun. Many new varieties have been bred specifically to tolerate high light intensity. Where possible, it may be beneficial to experiment with traditional, native varieties of understory crops that may be better adapted to the understory environment than modern varieties.

Limitations of understory planting

As with any agricultural practice, it is important to understand the potential limitations of understory intercropping. These include a:

- Shortage of scientific study and information about tree and understory crop interactions
- Risk of unforeseen competition or allelopathic effects
- Greater complexity in management of multiple species and multiple products
- Potential damage to overstory from harvest of the understory, or vice-versa
- Increased challenges of marketing diversified products.

However, with adequate knowledge and good planning, you can overcome them to effectively integrate understory crops with tree crops in your Forest Garden. In doing so you can significantly increase and sustain the overall productivity of your land.

Cover Crops

Cover crops are usually creeping legumes which cover the ground surface between widely spaced perennial crops such as fruit trees and coffee, or between rows of grain crops such as maize. They are most applicable in earlier stages of Forest Garden establishment when the overstory is more open to give them better access to sunlight. Often cover crops are combined with mulching. They are grown to protect the soil from erosion and to improve soil fertility. Cover crops protect the soil from splashing raindrops and too much heat from the sun. They slow down the movement of water on sloped land, and their roots break up the soil and increase water infiltration.

Most of the plants used as ground cover are legumes, such as different varieties of beans and peas. Pigeon peas and other crops with strong tap roots and a longer growing season than maize and beans make a good mix and can be used to break up hard-pans in semi-arid areas. For the cover crop to compete with the main crop as little as possible the cover crop should be of a low yielding variety. Cover crops should be planted as soon as possible after tillage to be fully beneficial. This can be done at the same time as sowing the main crop, or after the main crop has established, to avoid competition at crop nutrition level. Cover crops are not very suitable for dry areas, with annual rainfall of less than 500 mm as they might compete for water with the main crop. Under such conditions it might be better to keep the weeds and natural vegetation as cover.

Advantages of Cover Crops

- Improved soil structure and soil fertility.
- Reduced soil erosion and runoff.
- Suppression of weeds.
- Production of food and animal forage.
- Improved soil moisture and reduced surface crusting.
- Reduced fluctuations in soil temperatures.
- Some cover crops can provide good cash income.
- Cover crops can be a good alternative source of mulch, especially useful in semi-arid lands where crop residues are important animal feed.

Limitations to Cover Crops

- Compete for water and nutrients with the main crop.
- The dense cover crop foliage might serve as a refuge for rodents.
- Involves additional farm labor and inputs.
- Legumes can be sensitive to diseases.

Earthworks

Earthworks (also called soil and water conservation techniques) are physical barriers that you can construct from soil and stones within your Forest Garden site to control and slow the movement of water and soil. It is best to begin building earthworks in your Forest Garden at the start of establishment. Depending on the type of earthworks you build, and the extent to which they cover the site, they can take a considerable amount of time and labor. They are most relevant on sloped sites prone to heavy erosion, but are applicable even on gently sloping sites as even on these you can lose a considerable amount of topsoil over time. In the Forest Garden Approach we encourage those of you with sloping land to begin establishing earthworks in the protection phase through digging channels along the contours of your slopes and planting trees, shrubs, and grasses on the uphill side to stabilize the mounds (see Contour Planting section). As you proceed through the Forest Garden program, you will learn to establish earthworks around your permagardens and higher-value trees to direct water deep into your soils where your crops can access it well into the dry season. The benefits of constructing earthworks are to:

- **Maximize water absorption on a landscape** – Even on land that appears to have no slope, there will be water flow when it rains. Earthworks help you to stop, slow, sink, and spread flowing water so that it can be of use to surrounding vegetation.
- **Control and direct the flow of water** – Rains can be torrential. Sometimes there is simply too much water for your soils to absorb and hold. Earthworks can be used to direct the flow of water to places that need it more without running the risk of creating erosion channels that will damage an agricultural space.
- **Capture topsoil and organic material** – Along with capturing water, earthworks also capture topsoils that wash away, as well as leaf litter and other windblown organic

material. As these materials break down they create a rich layer of topsoil that feeds surrounding vegetation.
- **Stabilize sloped land** – Significantly sloped land is more vulnerable to erosion and topsoil loss than relatively flat land. Earthworks can decrease the slope of your land by creating steps so that it can be better used for agricultural purposes.

There are a number of types of earthworks that you can construct in the process of establishing your Forest Garden to help you to conserve soils and water, and increase tree and crop health and productivity:

Berms and Swales

Berms and swales are the most common types of earthworks you will likely use in your Forest Garden. A swale is a long trench dug out across the ground, along the contour, to catch runoff water, soil, and organic matter. The soil you dig out to form your swale is generally used to create a berm of earth on the up- or down-slope side of your swale. Berms and swales allow water to enter and remain in the landscape more evenly. There are three commonly used types of berms and swales.

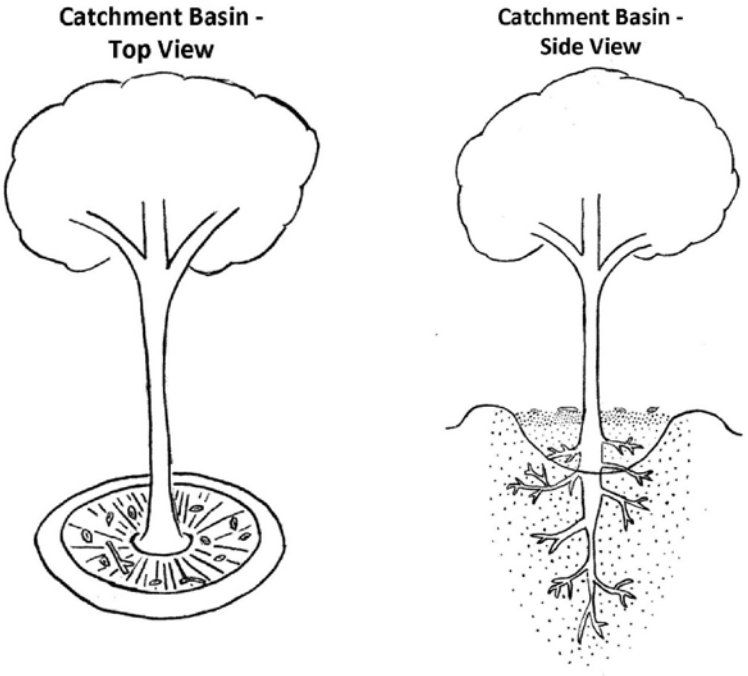
Standard berm and swale – A long, low berm and swale combination that snakes across the contour of your Forest Garden site or surrounds your permagarden, protecting the uphill side from fast-moving runoff, and catching excess runoff on the downside. Standard berms and swales allow for the most uniform collection of organic material across your Forest Garden site, and are commonly used in fields in combination with alley cropping. Standard berms and swales are perfect for slowing down the movement of runoff leading into your permagarden, and for creating a guiding contour line that you can follow for ploughing your site in early years of Forest Garden establishment. It is best to plant perennial vegetation (trees, shrubs, grasses, herbs, etc) along your berms to stabilize them.

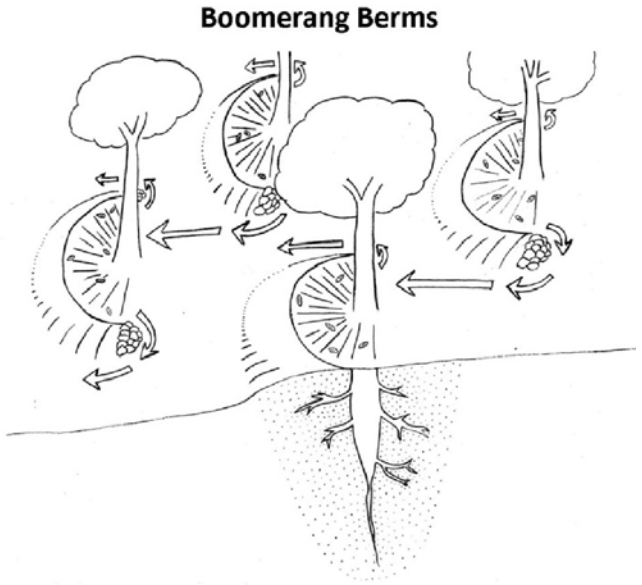
Boomerang berm – A semi-circle or half-moon shaped berm that is placed around an established tree to capture water specifically within the tree's root zone. You can establish a series of boomerang berms so that the overflow from one berm descends into the catchment area of a downsloping berm.

Diversion swales – A berm and swale laid out slightly off contour, designed to slow the flow of water and channel it to a more desirable location. Diversion swales are useful in mitigating flood waters and directing excess water to areas that can hold it better or need it more.

Holes – A deep depression or bowl in the soil that catches any runoff water. Holes are often dug at points along swales when the expected runoff is too much to be stopped and absorbed by the more shallow swales. You can dig holes on the uphill slope of boomerang berms to sink and store more water for the trees planted within them.

Catchment basins – Also known as a *cuvette,* is a shallow depression in a level landscape completely surrounded by a berm. Catchment basins are designed both to hold human delivered irrigation and to prevent excess rain water from drowning a flood sensitive planting.





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Chapter 16: Integrated Pest Management

Pests are a constant concern for all farmers. As all farmers know, they can easily destroy entire crops in very little time. Pests tend to prefer specific crops, however. One of the many important benefits of Forest Gardens is that their innate diversity means that a given pest will only affect a one of the many crops that are producing at a given time. So even if you have a pest infestation, you will still have other crops to provide food and income opportunities.

That said, it is in your interest to control any pests as much as possible. Modern, intensive agricultural practices often rely on expensive, synthetic pesticides to kill pests, which often lead to negative environmental affects, not to mention the health threats to those who mishandle the toxic chemicals. Furthermore, pesticides generally kill all insects, including beneficial insects that naturally protect your crops, as well as all the beneficial organisms that live in and around your soils—those that are so critical in maintaining your soil fertility.

In the Forest Garden Approach we encourage natural, organic measures to control pests, using an approach known as Integrated Pest Management (IPM). IPM is an approach that involves managing pest populations instead of controlling or eradicating them. It requires a greater knowledge of the pest, crop, and the environment. Therefore, its strategy focuses on harnessing inherent strengths within ecosystems and directing the pest populations into acceptable bounds rather than eliminating them entirely. It focuses on *pest* management rather than *pesticide* management. This strategy avoids undesirable short term and long term environmental impact and will helps to ensure sustainable productivity of your Forest Garden.

Integrated pest management is a comprehensive long term pest management program based on knowledge of an ecosystem that weighs economic, environmental, and social consequences of interventions. It requires a complex understanding of the crops you are growing, the soils in which you grow them, the pests in your area and their natural enemies, and the interactions between and among all of them. Thus it is impossible to describe IPM approaches applicable to all Forest Gardens. However, we will describe the general philosophy and process for developing an IPM approach in your Forest Garden, a basic overview of many of the common pests farmers are likely to encounter, and recommended approaches for managing them.

The use of pesticides and other approaches that treat the symptoms rather than the root causes are unsustainable and should be the last option rather than the first line of defense. An integrated pest management strategy should always start with the question

'Why is the pest a pest?'. It should also seek to address underlying weaknesses in ecosystems and/or agronomic practice(s) that have allowed organisms to reach pest status.

An integrated process
Integration or compatibility among pest management tactics is central to Integrated Pest Management. Simply mixing different management tactics does not constitute IPM. Mixing the tactics arbitrarily may actually aggravate pest problems or produce other unintended effects.

IPM recognizes there is no "cure-all" in pest control as pests are too diverse to control with any one measure. Reliance on a single tactic will favor pests that are resistant to that practice. In IPM, integrated control seeks to identify the best mix of pest controls for a given insect pest. The determination of the correct cause of pest problem (understanding pest biology) and ecology is essential in manipulating the environment to the crop's advantage and to the detriment of the pest.

Acceptable pest levels
IPM recognizes that eradication of a pest is seldom necessary or even desirable, and generally not possible. The primary objective in pest management is not to eliminate a pest organism but to control all pests to an acceptable level that will have little impact on the productivity of the overall Forest Garden system. The emphasis is on control, not eradication. IPM holds that wiping out an entire pest population is often impossible, and the attempt can be expensive and environmentally risky and unsustainable. An IPM program's initial task is to establish acceptable pest levels, or thresholds, and apply controls where the thresholds are crossed. These thresholds are pest and site specific, meaning that the impact of certain weeds or pests on one site may be negligible, but at another site it may be significant. By allowing a pest population to survive at a reasonable threshold, selection pressure is reduced. This stops the pest gaining resistance to chemicals produced by the plant or applied to the crops. If many of the pests are killed, then any that have resistance to the chemical will form the genetic basis of the future, more resistant, population. By not killing all the pests there will some un-resistant pests left that will likely dilute resistant genes that appear.

IPM process

IPM is applicable to Forest Gardens of all types and species arrangements, and in all climates and agroecological conditions. There are some basic IPM measures, including crop rotation, and soil fertility management and protection, that can go a long way toward preventing pests from populating your Forest Garden. These by no means will control all pests, however. It is extremely important that you carefully monitor the plants in your Forest Garden regularly, identify any issues with pests as early as possible, and determine the best approach to control them. This process includes:

Proper identification of pest damage and responsible pests

Correct pest identification must be the first objective. You must know the pest you are dealing with before you can determine the best approach for controlling it. Cases of mistaken
identity may result in ineffective actions. If plant damage is due to over-watering, for instance, it could be mistaken for fungal infection as many fungal and viral infections arise under moist conditions. This could lead to laborious or costly control methods that would have no effect on the health of the plants you are trying to protect.

Pest and host life cycles biology

Understanding crop growth and development is an underlying principle of IPM. We cannot
just focus on the pest. The interactions between crop and pest (as well as the environment) are very important. It is important to carefully monitor your Forest Garden regularly to identify and respond to pests before they become a serious problem. In some cases, however, by the time you see a pest it may be too late to do much about it beyond spraying it with pesticides and having to accept the costs and impact on the greater health of your Forest Garden. Often, however, there is another stage of the life cycle that is susceptible to preventative actions. For example, weeds reproducing from last year's seed can often be prevented with mulches. In other cases, knowing what a pest requires to survive – feeding off of a certain type of plant, for instance – may allow you to remove that element from your Forest Garden.

Evaluate and record results

Evaluation is often one of the most important steps in Integrated Pest Management. It is the process of reviewing an IPM approach and the results it has generated. Asking the following questions is useful: Did the steps you took effectively control the population? Was this method safe enough? Were there any unexpected side effects? What is the next step? Understanding the effectiveness of the IPM approach allows you to make modifications to the IPM plan prior to pests reaching the threshold and requiring action again.

Pest management tactics

There are different pest management tactics to suppress pests. They include host resistance, biological, cultural, mechanical, sanitary, mechanical and, when all else fails, chemical controls. The primary pest management tactic involves maximization of built-in pest reduction features of an ecosystem. Molecular or genetic mechanisms are potentially manifested in a number of these more specific tactics. Each category, discussed below, employs a different set of mechanisms for suppressing populations.

Biological control

This involves the use of other living things that are enemies of a pest to control it. The planting of insectary and nectary plants and aromatic pest confusers, for instance, can

repel pests or attract their natural predators. IPM is mainly aimed at developing systems based on biological and non-chemical methods as much as possible.

Host plant resistance

This involves the use of plant varieties with desirable economic traits, but less attractive for pests or for their reproduction and subsequent development. It also involves withstanding the infestation or infection, or the reduction of pests to a limited level during the plant growth and production period.

Cultural measures

This involves practices that suppress pest problems by minimizing the conditions that favor their existence (water, shelter, and food). Some of these factors are intrinsic to crop production, making the environment less favorable for survival, growth and reproduction of pest species. The appropriate placement of specific crops within your Forest Garden can reduce infestation from insect pests. If followed in an appropriate manner, cultural practices can provide significant relief from pests.

Mechanical control

This is the use of tools to manually control pests. It involves agricultural practices like tilling, manual pest removal, and weeding. The pruning of infested parts of fruit and timber trees, and defoliation in certain crops help reduce pest populations. Chaffing of sorghum and maize stalks and burning of stubbles kills maize borer.

Sanitary control

Preventive practices are important part of an IPM program. These include cleaning field equipment (i.e., tillage equipment, haying equipment, pruning tools, etc.), planting certified seeds where possible, and quarantine or burning of infested crops or vegetation. These are methods used to prevent the introduction or reintroduction of a pest into the field.

Natural control

Natural control involves the enhancement of naturally occurring pest management methods to combat pests like crop rotation, and intercropping of plants that harbor beneficial insects or deter pests.

Chemical control

The therapeutic approach of killing pest organisms with toxic chemicals has been the prevailing pest control strategy for many decades. Safety problems and ecological damage continue to ensue from them, and there are renewed appeals for effective, safe, and economically acceptable alternatives. Synthetic chemical pesticides are the most widely used method of pest control, but they are also generally the most costly, and pose the greatest risk to the sustainability of your Forest Garden system and general environment. The four major problems encountered with conventional pesticides are toxic residues, pest resistance, secondary pests, and pest resurgence. We encourage the

use of natural pesticides—often made from locally available, organic materials—that are more environmentally friendly where possible. We strongly recommend only using synthetic pesticides as a last resort, or only used as required and often only in limited amounts and at specific times in a pest's life cycle.

Benefits of Integrated Pest Management

The benefits of Integrated Pest Management are immense, directly impacting Forest Gardens and the families who adopt them, and indirectly benefitting society.

- **It protects environment** – through elimination of unnecessary pesticide applications, IPM is an environmentally friendly approach to pest control. In IPM, pesticides are only used when other methods of pest control have failed, and even then in very small doses. IPM measures are used in bringing a pest organism to acceptable bounds with as little ecological disruption as possible.
- **IPM improves profitability** – since IPM approaches aim to apply the most economical pest management tactics, potential profitability is higher for the families who practice IPM.
- **It reduces risk of crop loss by a pest** – applying pest management and monitoring tactics can ensure the reduction of crop loss or damage by effectively controlling pests.
- **It can lead to long term sociological benefits** – long term benefits to society can also emerge from IPM in areas of employment, public health, and well-being of farmers, their families, and surrounding communities.

Disadvantages of Integrated Pest Management

In spite of the numerous benefits of IPM stated, there are also some drawbacks to it:

- **An IPM program requires a higher degree of knowledge and management** – making the decision not to use pesticides on a routine or regular basis requires advanced planning and a higher degree of knowledge and management. This planning includes attention to field histories to anticipate what the pest problems might be, selecting crop varieties which are resistant or tolerant to pest damage, and choosing tillage systems that will suppress anticipated pest damage while giving the crop the greatest yield potential.
- **IPM can be more labor intensive** – consistent, timely and accurate field scouting takes time. However, this information is the corner stone of IPM programs. Without this information you cannot make intelligent management decision.

Pest Prevention Measures

In all cases, it is preferable to prevent pests from attacking your crops rather than trying to control them once they do. The sections below describe the prevention measures you should take to decrease the risk of pests colonizing in your Forest Garden.

Diseases and Pests Common to Agroforestry and Fruit Trees

In this section we will discuss characteristics and controls of certain general categories of pests and diseases which attack tree nurseries and fruit trees. Use the following sections to identify the problem encountered and determine a control method.

Diseases

Disease control starts with prevention. When establishing fruit trees that grow slowly and may be producing for over 50 years, it is important to start preventative measures even before seeding in the nursery. Be especially careful at this stage because preventative measures taken at the time of planting may prevent a disease that could attack an orchard 5 to10 years in the future. Also, because diseases are not a onetime phenomenon and may take years to develop, preventative measures, especially sanitation, should be practiced routinely, not just applied at one time. There are three types of pathogens that attack plants and cause diseases: fungi, bacteria, and viruses. Fungi are the most abundant. They cannot manufacture their own food and are reliant on the host plants for survival. Fungi travel in the spore stage of their life cycle on animals, wind, water, and insects (vectors or carriers). Fungus diseases can be controlled by fungicides but often come back quickly, necessitating multiple applications.

Diseases caused by bacteria are also very common. Bacteria also travel in a spore state on hosts to infect new plants. Like fungi they also do not manufacture their own food. Bacteria are harder and more expensive to control. Spraying trees with antibiotic is possible but not generally accessible to most farmers in the developing world. Most commonly the infected trees should destroyed.

Viruses are the most serious type of disease. There is no chemical means for controlling them and infected trees should be destroyed. They are transmitted by sucking insects, especially scales and aphids, and by unclean tools such as knives, machetes, and other pruning tools. Resistant varieties are the only real control method for virus diseases.

Here are a few simple preventative methods that you can use to prevent diseases before they infect your Forest Garden or nursery:

Physical preventative methods

Both fungi and bacteria live and thrive in humid conditions. One of the easiest ways to avoid fungus and bacteria caused diseases are to keep the Forest Garden dry. Build cuvettes (see section on cuvettes) so that the bases of the trunks of your trees remain dry. Pruning can also help. A well-pruned tree with air circulating throughout the branches will be much less likely to be attacked by these diseases. Avoid over-watering! If the trees are planted in clay soils that retain water, water much less than trees in well-drained soils. Try to plant only in well-drained soils.

Resistant varieties
Perhaps most importantly, try to find varieties that are resistant. If disease does attack, take advantage of this and identify trees which are unaffected for future seed sources. Never take seeds or vegetative planting material from diseased sources.

Sanitation
Most disease vectors can be washed off with soap and water. All tools, including baskets for harvesting fruit, should be washed with soap and water before each use. Household bleach or rubbing alcohol should be used on tools to kill viruses. If there is disease in the region you should collect your own fruit and take it to market yourself rather than having collectors from other sites harvest fruit from your own.

If you are examining a disease in another farmer's site, before to wash well before returning to your own or others! Wash yourself, wash your tools, change or wash your clothes. Diseases pass from orchard to orchard very slowly. Fifteen kilometers between two orchards may hold off a disease for years, but you can easily distribute it to your site or to others in one visit.

Sterilizing Soil
When propagating trees in areas where diseases are a problem, it is good practice to first sterilize the potting soil you will use for raising your seedlings and lining planting holes. Soil for nurseries and plantation holes can be sterilized using a simple 50 gallon drum method:

- Remove the top of a metal, 50 gallon drum, and poke numerous holes through it;
- Replace the top inside the drum on supports about 15 cm from the bottom;
- Place the drum on three stones, at a height sufficient to light a small fire underneath;
- Fill the drum with 10 cm of water, and fill your potting soil mix on the top placed inside the drum, to about 3 cm from the top of the drum;
- Bury a potato about 15 cm deep into the potting soil in the drum;
- Spread a thick layer of large leaves or sacks over the soil for insulation;
- Start a wood fire under the drum and keep it stoked;
- When the potato is completely cooked, the soil should be vector free.

Diversify and Rotate!
Monocultures are particularly susceptible to diseases which can quickly spread across an entire field. This is not as much of a threat in a Forest Garden, however it is best practice to diversify the varieties of fruits and other trees you plant in your Forest Garden. If you are planting a lot of mango trees, for example, mix up the varieties and mix up the rootstock seed sources. For citrus however, resistance to diseases comes only from using proper rootstock which is disease resistant, but you can still diversify the varieties grafted on the rootstock. Plant certain varieties in rows with other types of trees between the rows. This way harvesting is still easy yet variation is kept high. One easy thing to do is to put large thick windbreaks with dense trees such as cashews throughout the orchard to segment the field.

If planting short lived fruits (e.g. papayas, bananas, and pineapples) do not plant them in the same spot after removing the previous crop. Instead, rotate in different trees or other crops. It is also a good idea to rotate nurseries. In an area where there was a mango nursery the previous year, this year raise citrus or let it go fallow.

Pest control
As mentioned above, diseases, especially viruses, have no way to move between host plants on their own. As these pathogens spend some of their life cycle in vectors (carriers of the disease), a good way to control diseases is to control the vectors. Scale insects and thrips are perhaps the most infected insects we deal with, but general sucking insects, nematodes, flies, and even the beneficial bees may be carriers of disease.

Keep your trees healthy
Trees have natural defenses against diseases. Weak, sick, or damaged trees may quickly succumb to normally harmless diseases. Lack of water or nutrients, failure to prune dead, damaged, diseased, and disruptive branches, and damage caused by careless pruning, can severely weaken a tree and make it susceptible to diseases. Read the pest sections below to find out how to control these.

Pests
Because pests are such a diverse and unpredictable problem, only so much can be done in advance to prevent infestation. With some pest types, though, preventative measures do exist and should be employed when the pest is known to be in the region:

Sanitation
As in diseases, pests thrive in unclean or unkept areas. Any dead or diseased plants or parts of plants should be removed from the plantation. Dead plant material is a breeding ground for pests and a feeding ground for termites.

When traveling from sites with pest problems, take care not to transport any pests or eggs. Any vegetative matter or soil which is exchanged between sites should be completely cleaned before arriving to another site. Fruit which may contain scales or fly eggs should not be brought to non-infested sites.

When pests are a problem, sterilize soil as described above to destroy all eggs, nematodes, and larvae living there.

Plant resistant species
This is much more difficult with pests than it is with diseases. Some species may be found which are resistant to pests such as nematodes or taste bad to pests such as caterpillars.

Weeding
Keep weeds cleared from in and around your cropping areas and permagarden. Weeds can host pests that will attack your crops.

Termites
Termites are a big problem in the dry tropics. Preventative measures should be taken early on in tree development to control these pests. Despite local rumors, few termite species live off living tissues. They mostly only attack dead wood. The species that do attack living trees, however, are present in some parts of Africa. These species rarely kill adult trees and actually do little harm to healthy trees. When a tree is being attacked and killed by termites it is usually a sign that something else is wrong. Termites can do severe damage, however, and may even kill many seedlings or young trees. A couple of preventative measures can be taken to help alleviate the termite problem:

- **Wood ash** – mix wood ash in with the soil in the nursery and the transplant hole. Wood ash is very abrasive and termites do not like to crawl through it.
- **Neem leaves** – add neem leaves or neem seed cake to soil mixtures in the nursery, and periodically at the outplanting site.
- **Removal of dead wood** – because termites feed mainly on dead matter it is important to keep large amounts of dead wood clear from your Forest Garden and nursery site. After pruning a tree gather up all the cut branches and use them for fuelwood them or take them away, to harbor termites elsehwhere. If you have a dead fence to protect your growing living fence or nursery, keep it a suitable distance from the trees and keep the area between the two clean.
- **Mulch** – keep the soil rich in organic matter and covered with mulch. The termites that do remain will feed on this dead plant material and not your trees.
- **Build cuvettes** – Fruit trees love mulch and love periodic additions of manure. Yet these two substances attract termites. By building a cuvette, and adding mulch and manure to the cuvette instead of at the base of the tree - thus keeping the area at the base of the tree clean - the tree trunk will avoid direct exposure to termites.

Nematodes
Nematodes, another very common pest problem, can also be controlled or avoided completely by preventative measures listed here:

- **Sanitation** – soil sterilization should be done in nurseries if nematodes have been a problem in the past (see *soil sterilization* section above). Burn any infected plants.
- **Plant resistant varieties** – some varieties have built up natural defenses to nematode attack. Plant resistant varieties wherever possible.
- **Intercrop with marigolds** – marigold roots repel nematodes and can be easily planted at the beginning of the rains with very little effort. Plant them on the bunds surrounding your permagardens and disperse them in beds and other parts of your Forest Garden among plants susceptible to nematode attack. Most marigolds are prolific seeders, so the seeds collected from dead flowers can easily be replanted.
- **Crop rotation** – one of the best ways to avoid continuous nematode infection is rotate crops susceptible to nematodes, never planting them in the same place continuously (see crop rotation in the intercropping section). Bananas and papayas,

which are short lived but especially sensitive to nematodes, should never be planted in the same location after removing, nor in a location where there were other nematode-attracting vegetables or fruit trees.
- **Enrich your soil** – Natural enemies of nematodes are present anywhere nematodes exist. These natural enemies are generally present in health soils enriched with organic matter. Add mulch and manure to cuvettes and keep the soil around trees healthy and full. This will also help the tree stay healthy so that its own defenses can protect it against nematode attack.

Pest Control Measures

Using preventative measures when establishing trees in your Forest Garden, you will avoid many of the common and more serious pest and disease risks. Unfortunately they can still attack your crops even when all precautions are taken, and oftentimes farmers already have some existing trees on the Forest Garden site, some of which may already host some type of pest. It is understandable when problems arise that you may prefer treating these pests with proven chemical treatment rather than experimenting with natural treatments, and we do discuss chemical options for managing pests and disease below. As chemical treatment can diminish the overall integrity and health of your Forest Garden, however, we strongly recommend using chemical treatment only as a last resort.

There has been an emphasis in research on natural and organic pest control methods over the past decade, but unfortunately little has been suggested about organic or biological control of diseases. This is because, as mentioned above, there are few organic methods to destroy disease pathogens other than simply destroying the infected tree. At the same time, even if cures are available, the diseases or pests need to be correctly identified first in order to use the correct treatment, which may not be easy. Figuring out what pathogen, pest, or combination thereof is causing certain symptoms often requires experts that are typically not present or accessible in most places. Although tricky, disease and pest identification is possible to an extent that can be adequate for most cases.

The first step of the IPM process, when an undesired or unnatural symptom exists and is persistent or spreading on or between trees, is to look for and identify a pest. Pests, because of their physical presence, are much easier to diagnose and treat than diseases. Sometimes a pest will be too small to see or will not be present (leaf borers are located inside stems, cut worms only come out at night) so the absence of a visible pest does not immediately mean a disease is present. If the pest is not present ask the following questions about the symptoms of the disease or pest:

- Are the symptoms general all over the plant or localized in one area?
- What parts of the plant are affected? What part of the plant was first infected? Is the disease spreading?

- What are the characteristics of the symptoms? Wilting? Large brown spots? Discoloration? Rotting? Death of part of the plant? Cancers? Perforations? Cuts? Dropping of young fruit? Presence of gum or resin?
- What time of year do the symptoms appear? and
- Is the damage serious enough to require treatment?

After you answer these questions, try to use the following general descriptions to try to identify the problem. If the symptoms do not match up or you still do not feel confident, try to get an expert or extension agent knowledgeable on pests and diseases in your area to help you identify the cause.

Diseases

Although chemical controls may be available, as we have said time and again, we do not encourage their use unless the disease is accurately identified and all other forms of control have been exhausted. Remember that the best way to combat disease is by taking precautions in disease prevention from seed selection to nursery care to outplanting and managing of trees. Keep your trees healthy and control pests which carry disease. However, when symptoms of disease do arise, use this section that describes some of the most common diseases as a reference and foundation from which further investigation can be done.

Fungus Diseases

Fungi can live on the surface or inside the host plant. Powdery mildews and root rots are caused by fungi which live on the surface of a host plant. Fungi can also live inside the host and erupt in the form of downy mildews, leaf spots, blight, rusts, anthracnose, and scabs. Fungi can also remain completely inside the host causing "wilts".

Preventative Measures: Avoid creating humid situations in the nursery and orchard. Build and maintain cuvettes around high-value trees to avoid water-logging roots and trunk. Avoid over-watering. Plant trees only in well-drained soils. Do not water every day in soils which do not drain well. Adhere to spacing requirements to allow aeration between trees. Use resistant varieties when applicable.

Organic control: Prune and burn all infected areas.

Chemical Control: Spray fungicides.

Anthracnose is probably the most commonly found fungus disease. It plagues the mango although it may also attack citrus, avocado, annona spp, and other species. Generally anthracnose is spread by fungi. The symptoms appear to be very similar for all species. It seems to attack branches, leaves, fruit, and sometimes young roots, and eventually leads to death of the tree. When it attacks mangos the extremities turn brown and the roots may dry up. Leaves

have small, round spots dark brown to black in color or holes which may appear in leaves in place of the spots. Leaves will also fall off the tree. Fruit will have small dark spots, especially young fruit. The disease can also manifest itself as cankers on leaves, roots, and fruit of citrus, annona spp., papaya, and avocado.

Possible Control Measures: For all species, prune and burn all infected branches, leaves, and fruit. Spray infected areas with fungicides.

Damping off occurs in the nursery when fungus disease attacks germinating seeds. This is often a problem with citrus.

Preventative Measures: Avoid excessive watering in the germination bed or after seeding tree sacks. Be sure the germination bed or sacks are well-draining. Treat the seeds with ash before sowing.

Possible Chemical Controls Fungicides.

Cercospora appears as cankers on leaves and spots on fruit. Like anthracnose, its pathogen is usually fungi. The treatment is generally the same as with anthracnose.

Possible Control Measures: For all species, prune and burn all infected branches, leaves, and fruit.

Root rotting caused by *Phytophtora* spp. is common in many places. It attacks many species, although it is most commonly found on citrus, pineapple, papaya, and avocado. Fruit becomes discolored, leaves dry out and fall off tree, and roots are destroyed.

Possible Chemical Controls: Spray with fungicides.

Bacterial Diseases

Bacteria spores are transported by wind, water, animals, insects, and humans. Bacteria can feed off of living or dead tissue. They multiply in the host plant by rapid cell division.

Gummosis is the most common and most serious bacterium spread disease of citrus. It attacks the roots and trunks of trees. Leaves turn yellow, become brittle, and fall off. The most obvious symptom is the gum being excreted from the tree, usually along the lower trunk and roots. It will lead to the eventual death of the tree.

Preventive Measures: Using resistant rootstock, planting in well-drained soils, and making cuvettes are especially important to combating gummosis.

Possible Control Measures: Cut off infected areas and paint with flint coat

Viral Diseases

These diseases cannot be prevented nor controlled by spraying. They are transmitted by sucking insects. By controlling these insects you are indirectly controlling the disease (see "sucking insects" below). Viruses are not visible to the naked eye and can only be seen through an electron microscope, therefore they are known by the symptoms they manifest.

Preventative Measures: For citrus, use resistant rootstocks.

Tristezia is a disease which attacks citrus grafted on non-resistant rootstock. The disease causes "die back" from the twigs inward and results in death of the tree. Early prevention in anticipation is good planning for citrus growers.

Preventative Measures: Grafting onto resistant rootstock and controlling sucking insects are the most important ways to avoid this disease.

Possible Control Measures: The only way to control tristezia is to destroy the infected trees.

Exocortis stunts the growth of the tree by causing slow growth and incompatibility between the budwood and rootstock.

Preventative Measures: Use resistant rootstock.

Possible Control Measures: Destroy infected trees.

Pests

There are basically three types of insects which attack plants: sucking insects, chewing insects, and borers.

Sucking Insects

Sucking insects have modified mouth parts which include a long straw-like appendage that they insert into plants to suck out juices. They can attack the leaves, bark, or fruit of the plant. Large amounts of these insects can weaken a plant or lower a plant's yield. They are also the principal carriers of plant diseases. The first and most obvious symptom of sucking insects are the insects themselves. Sucking insects are usually controlled by contact poisons, which can be made organically from locally available ingredients.

Types of Sucking Insects

Scales or mealy bugs will be the most obvious because they do not move or move very slowly. They appear as either black or white spots or bumps on the plant surface. They usually appear on the stems or branches, but are also found on leaves, buds, and fruit. They have either a hard, or cotton-like appearance,

almost resembling tiny oysters or seashells in some cases. Scales live in colonies. Once one is spotted others you can be certain that others are nearby. Sometimes scales live in symbiosis with ants (scales suck the juices out of the plants and the ants feed on undigested sugar excrement from the scales in return for protection from possible carnivores). Scales attack almost all fruit trees commonly planted in Forest Gardens, especially citrus and mango species. Scales are considered the dirtiest pest because they are well known to be carriers of viral diseases. They can weaken plants and lower the quality of the fruit.

Organic Control: Because there may be so many of them, scale insects are difficult to control. Physically removing them is possible but can be laborious. Try using a cotton swab dipped in alcohol to touch each insect. Spot spraying the trees with a mixture of peanut soap and water will also kill scales. Since scales often live closely with ants, a method for controlling scales is to control the ants. The ant species which live with scale insects live on the ground and are forced to use the trunk of the tree as transport to and from the scales. Applications of anti-ant compounds around the trunk can be useful.

Aphids can be too small to see with the naked eye. Aphids reproduce very quickly and live in colonies. Although one of these pests may not be able to do much damage, a colony can severely damage a plant. They often discolor plants at the site of attack. If leaves are turning gray because of many tiny holes on their surface (silvering) aphids may be the cause. They also cause distorted growth like bent or twisted branches and leaves. They can also attack and lower the quality of fruit. As with scales, aphids ants will often be observed alongside aphids. They secrete honey dew which they process from the plant's juices, and the ants eat the honeydew in exchange for protection. Aphids may carry diseases. They usually are active during the plant's growth phase.

Organic Control: Spot spray with a clay/water solution or annona spray. Control the ants (see scales above).

*** Note on scales and aphids - natural enemies can be used to keep these insects under control in your Forest Garden. Often when orchards are treated with insecticides, the enemies are killed rather than the scales and aphids, resulting in a sudden increase in their numbers. For this reason among many others, pesticides should only be used as a last resort and then should be spot sprayed. Another way to control aphids and scales is to control the ants by applying anti-and compounds at the base of the tree.*

Thrips are the third economically important sucking insect. Thrips are generally too small to see with the naked eye. They may also cause silvering of the leaves and fruit; sometimes infected leaves may roll up. They also are carriers of virus vectors.

Organic Control: Neem oil can be used to spot treat heavily infected areas. Smothering a solution of soap and water on the leaves and stems of heavily infected areas may be enough to dehydrate and kill them.

Chewing Insects
Chewing insects actually eat the plant parts, usually attacking the leaves of the plant. These are usually not a problem for mature plants unless there are a huge number of these insects, as in the case of locust swarms. Chewing insects are a problem in nurseries and germination beds, however. They can completely defoliate seedlings quickly. A seedling that loses all its leaves will be weakened considerably and will take a long time to heal. Often seedlings in fields (cashews, for example) after being attacked by defoliating chewing insects are very susceptible to termites and are destroyed by a combination of these two pests. Most caterpillars and grasshoppers are chewing insects.

Caterpillars are young butterflies or moths. They are easily visible on plants; their primary symptom is leaf damage. Look for the small white eggs often found on the underside of leaves singly or in clusters.

Organic Control: Touch the caterpillars with a rag soaked in kerosene or hand pick them off by looking for damaged plants. Bring a chicken along for a free meal!

Cutworms is a common name given to a group of chewing insects that come out at night. One type of cutworm cuts off seedlings right at the collar, killing the whole seedling. Another type will climb the trees and eat the leaves; they eat irregular holes into the leaves starting with the edge.

Organic Control: Identify the infected plants during the day, then go out at night with your flashlight and hand pick the insects. Try cutting the top and bottom off a large can of tomato paste and putting it around the base of the seedling. You may also dig around the soil of plants showing symptoms to find the cutworm sleeping.

Leaf miners can be identified by clear lines on the leaves of the plant. They are rarely an economically important pest.

Organic Control: Prune and destroy affected leaves or dust the leaves with wood ash.

Boring Insects
Borers are insects that bore inside the plant stem, root, or trunk. Borers can destroy seedlings, plants, and young trees by completely cutting off their stem. If their populations grow uncontrolled they could be a problem for Forest Gardens and permagardens. Symptoms of a borer insect are spot wilting of the infected

branch or plant, and a small hole where the insect entered the stem. Boring insects can cause a lot of damage for annona species.

Control: Prune infected tree branchs about 25 cm above the borer's hole. If the branch at the prune site is hollow, prune further up. Destroy the borer.

Flies

There are some species of flies that lay eggs in fruit, thus destroying the fruit, and some that have maggots that eat plant tissue. Fruit flies are the most economically important as they may be able to attack fruiting trees in your Forest Garden in great numbers and destroy that fruit's harvest. Small yellow stains with a black spot in the middle on a fruit is a sign eggs were laid. Later the fruit will have localized rotting, cavities where the maggot eats on the inside, and may drop off early.

Organic Control: Make poisonous bait traps to catch the flies. Mix two teaspoons full of household ammonia and 1/4 teaspoon of soap powder in a quart of water. Fill a jar with the mixture and put the jar right next to the sunny side of the plant. This bait should be changed once a week. Also destroy any affected fruit.

Physical Control: Collection and disposal of fallen infested fruits and the infested soil should be removed. Undersized fruits left on the tree should be picked and destroyed. If the trees are few in number, bagging the fruit with cloth or paper bags can be resorted.

Ants

Ants may use the plants in your Forest Garden as homes (the red ant on mangos and oranges, for example), or cause indirect harm to the plant by protecting other insects such as scales or aphids. Red ants may not cause any direct damage to the tree except for damage to the leaves at the nest site but can cause discomfort when the tree is worked on or harvested. These need to be controlled because if left unchecked the ant will reproduce until the trees are completely overtaken. Control is simply finding, cutting down, and burning the nests.

Non-insect pests

Mites are tiny animals, often invisible to the eye, which suck the juices from plants much like aphids and scales do. Mites are related to spiders and thus are not technically insects. They cause silvering of the leaves and fruit by the millions of tiny "bites" they leave. They can weaken trees and lower the quality of the fruit. One species, which attacks citrus, appears as tiny red dots on the underside of leaves. Look for leaves on citrus which have small light spots on the top; turn the leaf over and look for the mites.

Organic Control: Try spot spraying with a soap and water solution.

Nematodes are microscopic worm-like parasites that stick their heads into roots and suck out plant juices or live entirely inside plant roots. They can cause general tree wilting, small production of fruit, small sized fruit, and stunted growth. To confirm the presence of nematodes dig up the roots of the infected plant and look for the “nodes” (small bumpy swellings).

Organic Control: Crop rotation. Sterilize the soil. See *Nematodes* section under *Pest Prevention Measures* above

Snails can be a problem during the rainy season in nurseries. They eat the leaves of young plants and can completely destroy them.

Organic Control: Use sunken bowls filled with beer as traps. Trenches a few centimeters deep made around the nursery and filled with wood ash will prevent snails from entering. Adding salt in trenches, or put directly on the snails will kill them.

Diseases and Pests Common to Permagardening Crops

This section lists some common pests that you may encounter in your permagardens, along with some recommended control measures.

White Fly

- Indication of Presence: fly around when disturbed, make honey dew
- Plants Affected: beans, brassicas, cucurbits, okra, , Solanaceae
- Habit: underside of leaves
- Damage: Sap-feeding weakens plants, transmits viruses
- Controls: remove infested plants/leaves, sticky traps, insecticidal soaps, neem oil, hillbilly breath

Mealy Bugs

- Indication of Presence: Mealy bug colonies
- Plants Affected: Sweet potato, water spinach, papaya
- Damage: Deformation of new growth, reduced yield, death of plant
- Habit: Underside of leaves, new growth
- Controls: Good cultural practices for plant vigor, beneficial insects, physical removal

Leaf Miners

- Indication of Presence: White tracks in leaves
- Plants Affected: Cucurbits, okra, , Solanaceae
- Damage: Reduced photosynthesis, reduced yield
- Controls: Remove infested parts

Fruit Flies

- Indication of Presence: Holes in exterior fruits, maggots in interior, deformation or rotting around the portion of the fruit infected
- Plants Affected: Cucurbits Solanacea, beans, Papaya
- Habit: Vegetable Fruits
- Controls. Remove dead fruit, Hillbilly breath

Pepper Maggots

- Indication of Presence: Peppers begin to form translucent brown patches
- Plants Affected: Hot pepper, green pepper
- Habitat: Maggots – peppers, Flies - leaves
- Controls: Destroy fallen fruit, crop rotation, Hillbilly breath

CHAPTER 16: REFERENCES

1. The information found in this chapter is largely taken from C.O. Ehi_Eromosele, O.C. Nwinyi and O.O. Ajani. INTECH. Chapter 5: Integrated Pest Management. 2013. http://cdn.intechopen.com/pdfs-wm/42758.pdf

Glossary

A-frame: Three poles lashed together in the form of an "A", which is used to mark the contours on a hillside for terrace farming.

Agroforestry: The combination of forestry technologies with agriculture and livestock to create more integrated, diverse, productive, profitable, healthy and sustainable land-use systems.

Agroforestry tree: A tree that is purposefully grown to provide more than one significant contribution to the environment or people's livelihoods. Also called a 'multipurpose tree'.

Allelopathic effects: The retarding, growth-suppressing, or reproduction-suppressing effects of substances or chemicals naturally-occuring or secreted by plants or trees.

Alley cropping: An agroforestry technique in which trees are planted in rows to form alleys of crops within agricultural fields. The trees provide numerous benefits inclucing soil conservation, organic (green) fertilizer, and water conservation to the agricultural system. Also known as hedgerow intercropping.

Antagonists: In the context of Forest Gardens, any plant or substance that could diminish, retard, or reduce plant growth, yield, or production.

Berm: A long, low mound of earth or stone laid out level on the up- or down-slope of a swale, usually built with the soil dug out to from the swale.

Biophysical characteristics: The biotic and abiotic surroundings of an organism that influence its growth and survival. For a plant this includes factors such as elevation, sunlight, soil, and rainfall.

Budding: A common form of propagation in which the bud of one tree is fused to a rootstock to develop into a new tree. Also called 'bud grafting'.

Budwood: A portion of a stem or branch with vegetative buds, used for budding. The buds along the stem of the cutting should be yellowish in color and ready to push (grow) but not yet pushing.

Cambium: The living layer of a woody plant species along its stem and branches, located between the bark and the wood. The cambium transfers water and nutrients from the

roots to the rest of the tree, and must be closely aligned between the rootstock and scion for a graft to be successful.

Canopy: The cover (above the understory) formed by the leafy upper branches of the trees in a forest or agroforestry system.

Carbon sequestration: The removal and storage of carbon from the atmosphere.

Clayey soils: a soil composed of tiny, hard, and easily-compacted particles.

Companion plants: Plants that grow more successfully or with greater yields when cultivated in the same location than separately.

Compost: Organic fertilizer or soil amendment that is produced when bacteria in soil breaks down organic matter through decomposition.

Conservation: The preservation and protection of trees and forests for the benefit of the environment and the health of the community.

Contour planting: The planting of trees along the natural slope of land to decrease soil erosion and to increase water infiltration and groundwater supply.

Coppice: A method of encouraging regrowth in certain tree species by cutting the stem close to the ground.

Crop rotation: Alternating the types of crops grown on a piece of land over time, usually to reduce specialist pest prevalence or environmental footprint.

Cutting: An easy and popular form of propagating trees in which the branch, stem, or leaf of a tree is planted directly into the ground to grow into a new tree.

Deforestation: The loss of forests due to extensive cutting of trees.

Double digging: The process of separately digging-up the topsoil and subsoil layers of a cultivated space to add and mix soil amendments at what will be the root level, followed by re-burying the space with the removed top soil and then subsoil. The process improves soil fertility and aeration.

Earthworks: Physical barriers that you can construct from soil and stones within your Forest Garden site to control, slow, and/or stop the movement of water and soil.

Environmental services: The benefits that trees and other plants bring to the local and global environment. They include services such asc erosion control, water and air filtration and purification, carbon sequestration, habitat for biodiversity, and pest and disease control.

Erosion: The loss of precious topsoil as a result of wind, moving water or ice, and by such processes as landslides or slow movement of soil over time.

Exotic: Commonly used to refer to a plant or other organism introduced from a foreign country or region. For example, Grevillea robusta, which comes from Australia, is an exotic tree species in Ethiopia.

Firebreak: Wide strips of land where all vegetation has been removed, to prevent fires from damaging fields and homes.

Fodder: Leaves, flowers or pods that are used as food by livestock.

Forest Garden: A multi-layered, integrated agricultural system, designed to resemble a forest ecosystem, which combines diverse plants and animals into one area to sustainably produce a variety of products and environmental services.

Fuelbreak: A wide strip of land around a protected area where dense, existing vegetation is thinned or replaced by other trees.

Grafting: A common method of tree propagation in which a scion from a desirable species is fused to the rootstock of another species.

Graft union: The portion of a grafted tree where the rootstock and the scion bind together through the fusion and healing processes of the two.

Grafting compound: Material that protects graft unions and open cuts from water, air, and pests. Tar and beeswax are commonly used, effective grafting compounds.

Greenbreak: A fire suppression measure formed from a wide strip of densely-planted trees that are specifically chosen for their high moisture content and lack of flammable biomass they produce.

Green fertilizer: The incorporation of nutrient-rich leaves into the soil to improve soil structure and fertility. Green fertilizers perform multiple functions that include soil improvement, moisture retention, and soil protection. Also called ‘green manure’.

Green wall: A enhanced living fence technology formed by three layers of trees or shrubs.

Guild: A permaculture concept that seeks to mimic the way plants grow in healthy, natural environment by maximizing the various functions that different plants provide.

Hardpan: A hardened, impervious layer of soil, typically of clay, occurring in or below the soil and impairing drainage and plant growth.

Humus: the organic component of soil, formed by the decomposition of leaves and other plant material by soil microorganisms.

Indigenous: A plant or animal species that originates naturally from a given country or region. Also called 'native'.

Integrated Pest Management (IPM): A process of managing and reducing the prevalence of pests through integrating physical, biological, natural, and chemical control methods in tandem.

Intercropping: The cultivation of two or more plants in the same space to increase the growth or yield of both plants.

Invasive: A non-indigenous species (e.g. plant or animal) that adversely affect the habitats they invade economically, environmentally or ecologically.

Living fence: An animal-proof barrier composed of trees and shrubs that are densely planted around the perimeter of a field. Living fences protect the land and soil, reduce the need (and cost) for standard fencing, and produce tangible benefits such as food, fuelwood, fodder, and other raw materials. Also called a 'live fence'.

Loamy soil: a soil made up of a mixture of sand, silt, and clay. Loamy soil is especially able to retain nutrients and water and is ideal for most agricultural purposes.

Lopping: Cutting all lower and secondary branches to encourage a tree to grow straighter.

MPFG: Multi-Purpose, Fast-Growing trees which, in addition to growing quickly, provide numerous environmental services including carbon sequestration, soil improvement, and erosion control as well as tangible products including fuelwood, food, fodder, and medicine.

Naturalized: A plant that is not originally native to an area, but has been introduced and planted to such an extent that it occurs plentifully on a grand scale.

Nitrogen fixing: The process by which plants convert nitrogen in the atmosphere into nitrogen compounds in the soil that can be consumed by other plants to promote healthy growth.

Outplanting: The process of removing seedlings from a nursery and planting them in the field.

Permaculture: A contraction of 'permanent' and 'agriculture', it refers to the development of agricultural ecosystems intended to be sustainable and self-sufficient.

Permagarden: A garden that is built and maintained using permaculture practices and concepts to increase sustainability and self-sufficiency.

Perennial: A plant that lives for more than two years, often differentiated from an annual plant, which are shorter-lived.

Pioneer trees: Hardy species of trees that are either planted or colonize naturally on previously disrupted or damaged ecosystems. Pioneer trees improve growing conditions to allow for the succession of other trees and plants.

Pollarding: Cutting the branches at the top of the tree to prevent the tree from growing beyond a certain height.

Pruning: The removal of branches or sections of plants or trees.

Reforestation: Planting trees to create new forests on lands where trees are depleted or have been deforested.

Root collar: The zone of a plant where the root system ends and the shoot system or stem begins.

Rootstock: The lower portion of a tree used for grafting, including the stem and root system, which is selected for adaptability to the local environment.

Sandy soil: Granular soils containing small rock and mineral particles, usually gritty and course.

Scarification: A method of seed pretreatment that nicks the protective seed coat to promote faster seed germination.

Scion: The branch of a tree which is selected for its flowers, fruits, leaves or stems. It is grafted to the rootstock to develop into a new tree.

Seed germination: The first stage of growth for a seed, which happens under the right environmental conditions and the protective seed coat breaks.

Seed pretreatment: Action taken prior to planting a seed, for instance by scarification, soaking in water, or acid treatment, to terminate the seed's dormancy and encourage faster germination.

Silty soil: a soil mixture with coarse grains and fine grains.

Slash-and-burn agriculture: A kind of shifting cultivation in which existing vegetation is cut, stacked and burned to provide some nutrients to the soil and clear fields for future farming; also called 'swidden cultivation' and 'shifting cultivation'.

Soil amendment: A material or substance added to the soil with the end goal of improving agricultural yields.

Soil crust: A thin, hard layer that forms over the surface of the soil when the soil surface is watered and then dries out repeatedly.

Soil pH: The acidity or alkalinity of soil, expressed on a scale of 1-6.9 for acids (1 being the most acidic), and 7.1-14 for bases (14 being the most basic), and 7 being absolute neutral.

Sustainable land use: Land use that achieves production to meet the needs of present and future populations while conserving or enhancing the land resources on which that production depends.

Swale: A long, shallow trench laid out level along the contour of land to trap and slow moving water and debris.

Symbiotic relationships: A relationship or arrangement between two organisms where each has a process or byproduct that benefits the other.

Taproot: The largest, most central, and most dominant root of a primary root system, growing vertically downward.

Terminal bud: The growth apex of a plant or tree where new wood, shoots, or stems emanate.

Terrace: A broad, natural or man-made surface running along the contour of sloped land. Terraces reduce soil erosion, conserve moisture, and improve agricultural conditions and sustainability on sloped land and mountainsides.

Thinning: The removal of a plant or tree, or of branches of a plant or tree, to allow for the healthier growth of fewer plants, trees, or branches.

Transplanting: The process of removing or thinning a germinant or young seedling from a germination bed and replanting it in another bed, space, or tree sack.

Understory: The various plants that fill in the space beneath the canopy trees in a Forest Garden.

Windbreak: In agroforestry this refers to a long line of tall and short trees and shrubs planted in multiple rows along a field or garden to block the wind from disturbing crops and eroding topsoil and moisture.

Zero-grazing: A method of raising animals that involves bringing fodder to them rather than letting the animals graze freely.

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