D2: AGROFORESTRY FOUNDATIONS

A TECHNICAL GUIDE FOR THE DESIGN OF COFFEE-BASED AGROFORESTRY SYSTEMS

Produced by Tirion Keatinge in partnership with PRETATERRA, This Side Up coffees, Progreso Foundation and MVO Nederland.

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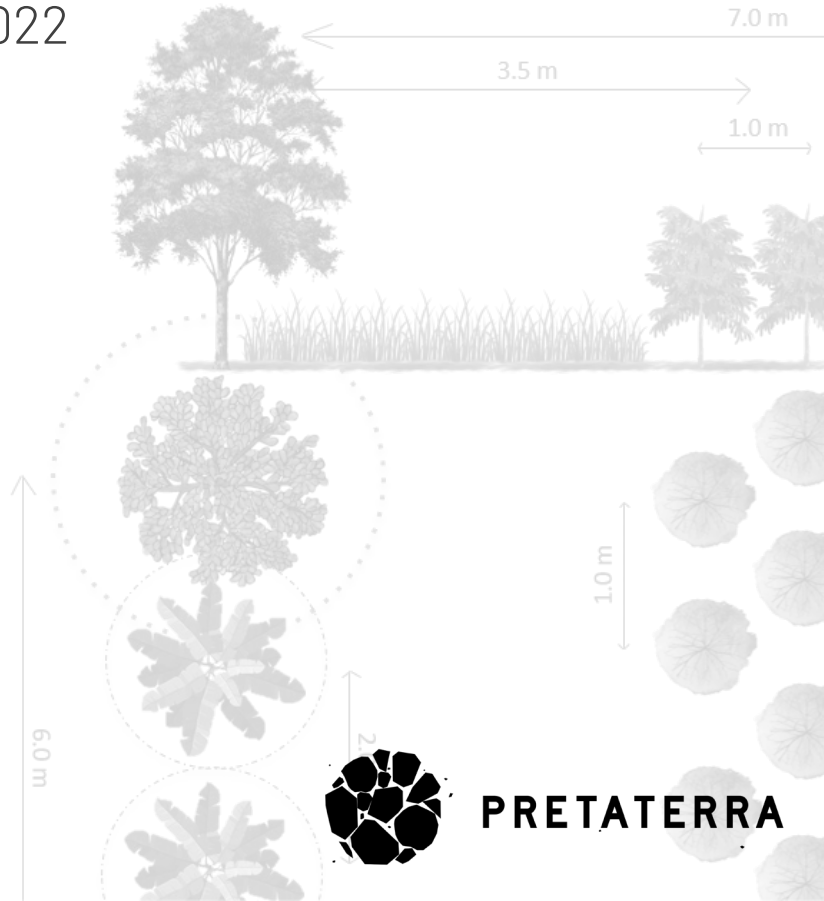

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TABLE OF CONTENTS

INTRODUCTION

TECHNICAL FOUNDATIONS

AGROFORESTRY DESIGN PROCESS

APPENDICES

EXERCISE SHEETS & TEMPLATES

INTRODUCTION

What is coffee agroforestry? Agroforestry coffee is a combination of coffee plants with one or more other tree or shrub species.

Why practice agroforestry coffee production? If designed well, a coffee agroforestry system can be more resilient, more profitable and better for communities, landscapes and the climate.

What does 'agroforestry design' involve? The main goal of design for agroforestry coffee is to understand how to maximise the positive interactions in the system and minimise the negative interactions to best meet the farm goals. This guide is designed to support with this process.

WHO THIS GUIDE IS FOR

This guide is a reference for helping farmers to design and implement agroforestry systems. It is intended to be used by those supporting farmers in this process, including:

- Coffee cooperative technical staff
- Agricultural extension officers
- Other support staff working with farmers to create or adapt coffee agroforestry systems, such as NGOs and supply chain partners

The guide provides a step-by-step process for coffee agroforestry design, including specific exercises and key technical information on coffee throughout. It is intended for use in situations where coffee is the primary crop, is one of multiple primary crops in a system, or where it is to be added as a supplementary or secondary crop.

It can be used by farmers, extension officers or other support staff working with farmers to develop or adapt context-specific agroforestry practices for coffee production.

WHAT THIS GUIDE INCLUDES

Following this introduction section, section 1 ("Technical Foundations") describes the basic principles influencing coffee in agroforestry systems. Section 2 ("Agroforestry Design Process") describes the phases of the design process. Each step is supported by technical materials and design exercises. The exercises are designed to be carried out directly with the beneficiaries of support (i.e. the coffee farmers themselves).

APPROACH TO THE DESIGN PROCESS

It is recommended to work through the design process in the order provided. However, it may also be necessary to return to different steps along the way to refine designs. For example, goals are set at the beginning, but later in the process may need to be more clearly defined in order to complete the design. Similarly, a shade species may be selected for the design, and later changed because good quality seedlings are not available at an appropriate price.

Ultimately, the design process is always ongoing: decisions should be regularly reviewed, refined and adapted.

DOCUMENT LAYOUT

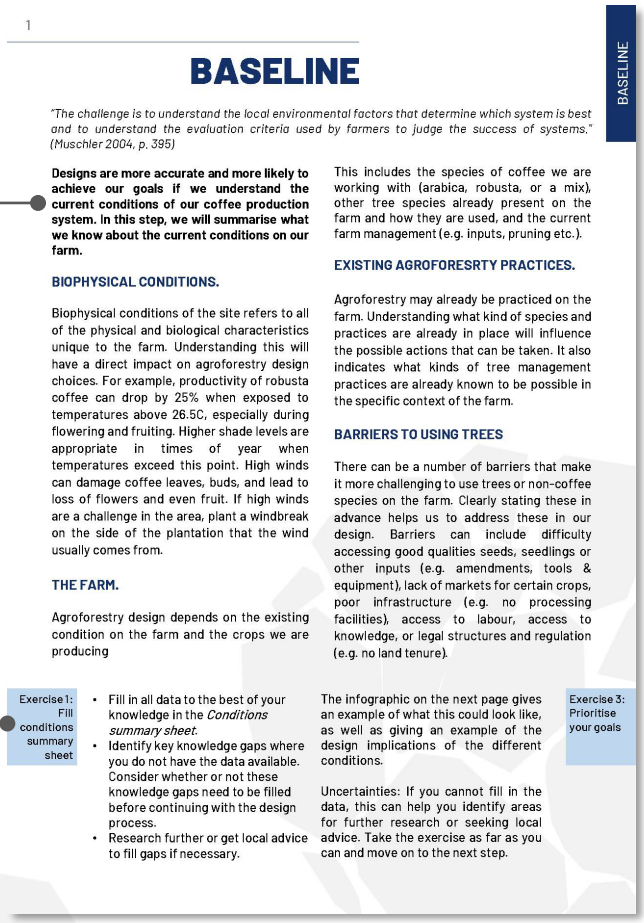
Throughout the guide you will find three key features.

1. DETAILED TECHNICAL INFORMATION & EXPLANATIONS

These sections provide more detailed discussion on the technical elements of coffee agroforestry and the design process.

2. AGROFORESTRY DESIGN EXERCISES

Each stage of the design process is accompanied by practical exercises to work through. Completion of these exercises will lead to an agroforestry design.



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BASELINE

"The challenge is to understand the local environmental factors that determine which system is best and to understand the evaluation criteria used by farmers to judge the success of systems." (Muschler 2004, p. 395)

Designs are more accurate and more likely to achieve our goals if we understand the current conditions of our coffee production system. In this step, we will summarise what we know about the current conditions on our farm.

BIOPHYSICAL CONDITIONS.

Biophysical conditions of the site refers to all of the physical and biological characteristics unique to the farm. Understanding this will have a direct impact on agroforestry design choices. For example, productivity of robusta coffee can drop by 25% when exposed to temperatures above 26.5C, especially during flowering and fruiting. Higher shade levels are appropriate in times of year when temperatures exceed this point. High winds can damage coffee leaves, buds, and lead to loss of flowers and even fruit. If high winds are a challenge in the area, plant a windbreak on the side of the plantation that the wind usually comes from.

THE FARM.

Agroforestry design depends on the existing condition on the farm and the crops we are producing

This includes the species of coffee we are working with (arabica, robusta, or a mix), other tree species already present on the farm and how they are used, and the current farm management (e.g. inputs, pruning etc.).

EXISTING AGROFORESRTY PRACTICES.

Agroforestry may already be practiced on the farm. Understanding what kind of species and practices are already in place will influence the possible actions that can be taken. It also indicates what kinds of tree management practices are already known to be possible in the specific context of the farm.

BARRIERS TO USING TREES

There can be a number of barriers that make it more challenging to use trees or non-coffee species on the farm. Clearly stating these in advance helps us to address these in our design. Barriers can include difficulty accessing good qualities seeds, seedlings or other inputs (e.g. amendments, tools & equipment), lack of markets for certain crops, poor infrastructure (e.g. no processing facilities), access to labour, access to knowledge, or legal structures and regulation (e.g. no land tenure).

Exercise 1: Fill conditions summary sheet

- Fill in all data to the best of your knowledge in the *Conditions summary sheet*.
- Identify key knowledge gaps where you do not have the data available. Consider whether or not these knowledge gaps need to be filled before continuing with the design process.
- Research further or get local advice to fill gaps if necessary.

The infographic on the next page gives an example of what this could look like, as well as giving an example of the design implications of the different conditions.

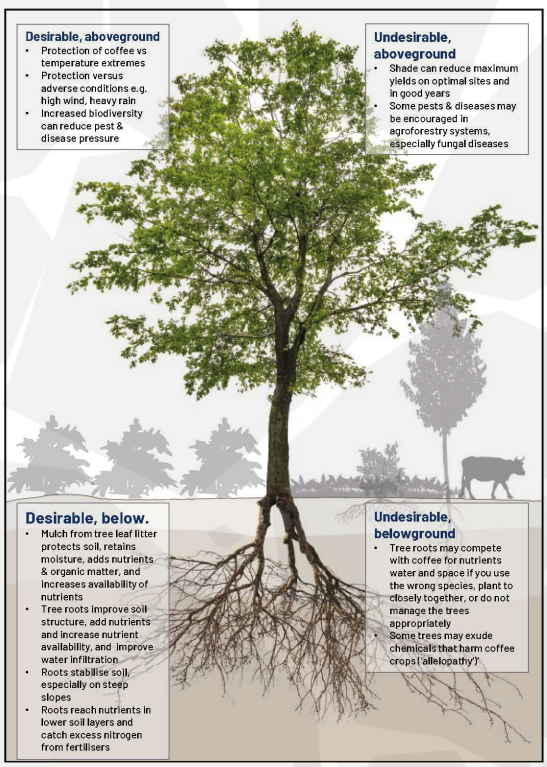
Uncertainties: If you cannot fill in the data, this can help you identify areas for further research or seeking local advice. Take the exercise as far as you can and move on to the next step.

Exercise 3: Prioritise your goals

11

ECOLOGICAL INTERACTIONS

ECOLOGICAL INTERACTIONS IN COFFEE AGROFORESTRY

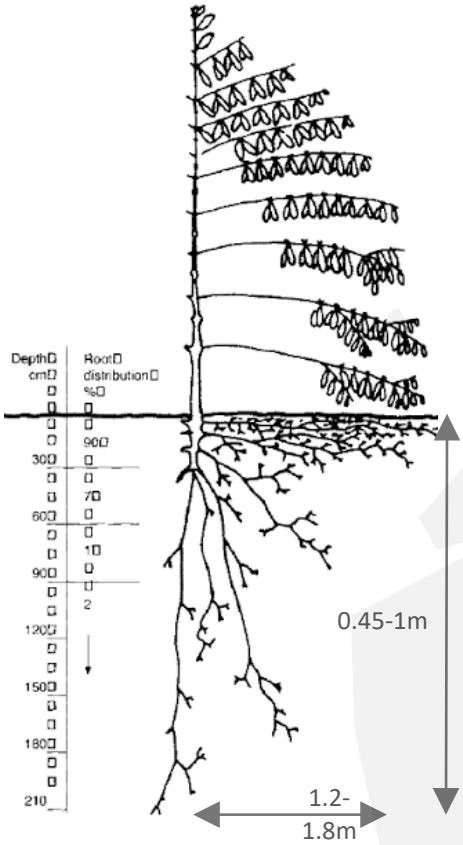


3. VISUAL SUMMARIES OF KEY PRINCIPLES

Key principles and examples are illustrated at relevant points throughout the design process.

COFFEE SPECIES PROFILE

- **Coffee is a high-value crop that benefits from being cultivated in well-designed agroforestry systems**
- **The two most widespread species - arabica (*Coffea arabica*) and robusta (*C. canephora*) - are similar, but have slightly different characteristics and requirements for optimal production**
- **Arabica coffee prefers slightly cooler temperatures than robusta, but both suffer from too much heat from direct sunlight**
- **Robusta coffee is usually more resistant to pests & diseases**



Coffee roots are concentrated in the top 30cm of soil, and typically reach 0.45-1m deep and 1.2-1.8m radius (Wintgens 2004, p.8).

PLANT SUMMARY

Plant type: Shrub or small tree
Ecology: Understory species typically growing under light to heavy shade.
Architecture:

- Arabica (*C. arabica*): 4-5m (unpruned)
- Robusta (*C. canephora*): 3.5-8.5m (unpruned)
- Pruned, both maintained to approx. 2-3m height and 2m wide

Root architecture: Approximately 90% of coffee roots are concentrated in the top 30cm of soil. A central tap root usually forms, reaching 0.45-1m deep. Lateral spread of roots is typically 1.2-1.8m from the stem (see figure, right).
Growth rate: Moderate
Typical spacing: Varied. 2.5x2.5m standard.
Density: 1000-2000plants/ha (standard); 3000-10 000plant/ha (high-density, no shade)

PRODUCTION SUMMARY

Product type: food/beverage, cash crop, own use

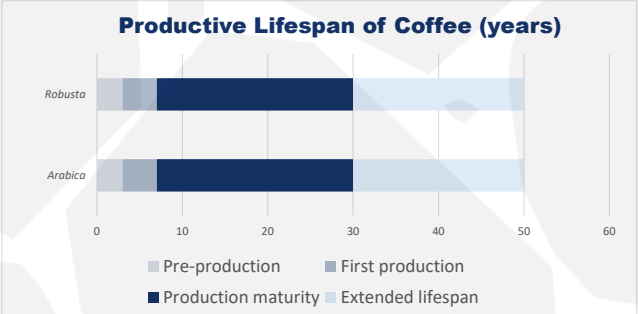
Time to harvest, arabica: 3-4 years

Time to maturity, arabica: 7 years

Time to harvest, robusta: 3-5 years

Time to maturity, robusta: 7-8 years

Coffee yield increases with age until 15 years, after which it often declines. With good management productive lifespan can be increased to at least 30 years or even up to 50 years.



Species	Ecology	Function	Altitude	Temperature	Rainfall/humidity
C. arabica	Tropical forest	Shaded understory	1600-2800masl	Optimum: 20°C annual average. Range: 15-24°C	Less tolerant of humid conditions. Rainfall 1200-1800mm, well-distributed over 8-9 months, 3-4 month dry season in coolest months.
C. Canephora	Tropical lowland forest	Shaded understory	0-1200masl	Optimum: 21°C annual average. Maximum daytime temperatures: 24-26C	Rainfall optimum 1200-1800, but tolerant of >2000mm over 9-10 months, air humidity near constant saturation

Optimum conditions for arabica and robusta coffee.

CONDITIONS

Optimum temperatures for production of arabica and robusta coffee.

Optimum annual average of 20°C for arabica and 21°C for robusta. Daytime temperatures above 24°C for arabica and 24-26°C for robusta decrease photosynthesis and cause plant stress. Temperatures below 15°C for arabica and below 16°C for robusta decrease photosynthesis and therefore productivity. Temperatures near or below 0°C lead to leaf loss, bean quality loss and death of some or all of the plant. Arabica tolerates slightly lower temperatures than robusta. Robusta has a minimum tolerance range of 1-3°C.

Optimum rainfall for production of arabica and robusta coffee.

Optimum rainfall for arabica and robusta is 1200-1800mm/year, while robusta is more tolerant of higher rainfall (>2000mm/year). Rainfall distribution is a key factor. Both require a short dry spell for regular flowering. A dry season of approximately 2-4 months is optimal. Flowering can be more irregular where there is no distinct dry season. Rainfall should be well-distributed of the other 8-10 months.

Optimum altitudes for coffee production.

Arabica thrives between 1200-1800masl. Robusta is tolerant of conditions at lower altitudes, growing between 0-1200masl.

YIELDS

Coffee yield varies greatly depending on species, variety or cultivar (clone), planting density and management practices.

Typical coffee yields in traditional lower-intensity systems: 500-1000kg/ha/year clean coffee.

Typical coffee yields in higher-intensity systems (commonly high-input, low-shade or monoculture): 1500-2800kg/ha/year

When calculating yield, it is better to calculate both per hectare yield and per plant. Plantations with higher numbers of coffee plants (i.e. plants are closer together) will often produce higher yields per hectare, but lower yields per plant.

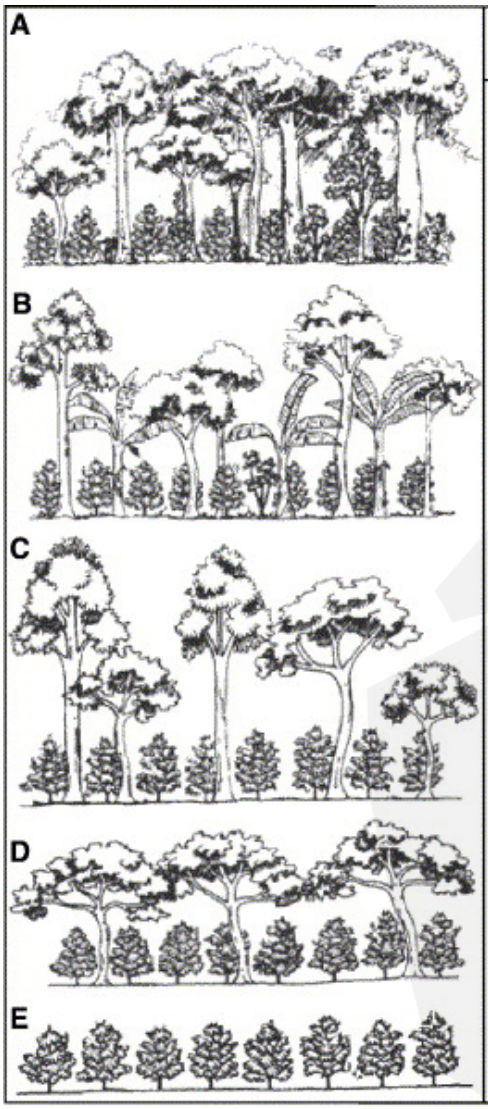
Other variables include site conditions, coffee species & variety/cultivar and agronomic practice. The example in the table below shows this variation in arabica production in Brazil.

Density/ha	Spacing	Yield kg/ha/year	Yield kg/plant/year
1250	1x4m	3941	1,576
7519	1x1.33m	7519	1,349
10000	1x1m	10369	1,036

Processed, dried coffee yield in Adamantina, State, São Paulo, Brazil, averaged across four cultivars: Catuaí Amarelo (IAC 47), Obatã (IAC 1669-20), Acaiá (IAC 474-19) and Icatu Amarelo (IAC 2944). Source: Paulo & Furlani (2010).

KEY PRINCIPLES FOR AGROFORESTRY COFFEE

- **Maintenance and improvement soil health.** Reduced competition for nutrients and water
- **Clear understanding of production conditions and key challenges.** Climate, soils, exposure, pests & disease, management methods
- **Appropriate tree species & spacing.** Light, humidity, competition, space
- **Appropriate tree management.** Light, humidity, competition, space, production
- **A contextually-appropriate design.** Meets goals, markets, end uses, knowledge, equipment, culture, legal structures



MANAGEMENT SYSTEM	%SHADE* COVER	SHADE TREE* RICHNESS
RUSTIC	71-100	> 50
TRADITIONAL POLYCULTURE	41-70	21-50
COMMERCIAL POLYCULTURE	31-40	6-20
SHADED MONOCULTURE	10-30	1-5
UNSHADED (SUN) MONOCULTURE	0	0

Agroforestry systems are highly varied across. Two key variables are the percentage of shade cover and species richness. Source: Perfecto *et al* (2005, p.438).

IMPACTS OF AGROFORESTRY ON COFFEE PRODUCTION

Agroforestry in coffee production can have different impacts depending on location & conditions, system design, management, and the goals of the farmer. There are many potential positive impacts, but there can also be negative impacts. By understanding these uncertainties, we are more likely to be successful in our agroforestry project. In all cases, impacts of agroforestry on coffee production will vary by context (e.g. different robusta varieties respond differently to shade levels, see Appendix A).

MAXIMUM COFFEE YIELD: VARIED

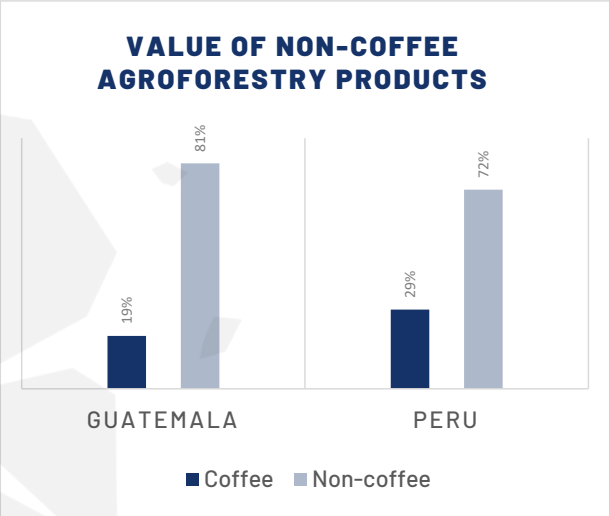
Maximum attainable coffee yields may be reduced by shading, but typically only on 'optimal' sites (i.e. ideal climatic conditions, good soil) and where use of agricultural inputs (e.g. fertilisers, pesticides) is higher. Average yields are typically better in shaded systems under sub-optimal or extreme conditions (e.g. high or low temperatures). Maximum attainable yields may be better in well-managed agroforestry systems on sub-optimal sites (e.g. low-altitude sites where heat is a production challenge, sites where soil quality is poor).

PRODUCTIVITY OVER TIME: BETTER UNDER AGROFORESTRY

Agroforestry typically helps maintain yields over time, by improving soil conditions and reducing soil degradation compared to monocultures. Coffee plants in agroforestry systems can also be less stressed, so they have a longer productive lifespan and so need to be replaced less frequently than full-sun production. Coffee plants in agroforestry systems may also 'overproduce' in one year, which leads them to produce less the next year. In shaded conditions, the coffee may produce slightly less on a 'good' year, but production is more consistent from year to year.

PRODUCTION & PROFITABILITY: DIVERSIFIED IN AGROFORESTRY

Agroforestry systems can provide a greater diversity of products than coffee monocultures. Economic dependency on coffee can be reduced by growing other products for sale or own use (e.g. timber, fruit, fuel or spices). Profitability of agroforestry coffee may be higher where practices lead to reduction of agronomic inputs (e.g. because of better soil quality), or where agroforestry allows for certification of coffee production (e.g. by Fairtrade or Rainforest Alliance). Coffee berry quality may also be increased by agroforestry systems, especially in sub-optimal conditions (e.g. more even ripening in high temperatures), which can increase coffee market value.



In Peru and Guatemala, non-coffee products account for a significant amount of value from agroforestry coffee systems. Products either sold or used directly including fuelwood, fruit, lumber and livestock products. Source: Rice 2008.

PESTS & DISEASES: MIXED IMPACTS IN AGROFORESTRY

Agroforestry impacts on pests & diseases in mixed ways, the best approach depends on the pests & diseases in your area, and the conditions on your farm. For example, some fungal diseases, (e.g. American leaf spot - *Mycena tricolor*) prefer humid, shaded environments. Too much shade can increase the risk of fungal disease, especially in wet locations. Conversely, agroforestry can be beneficial in a number of ways, like reducing stress of the coffee plant, by providing habitat for predatory birds (e.g. reducing pressure from coffee stem borer - *Xylotrechus quadripes*), and by reducing the spread of disease by creating a physical barrier (e.g. coffee leaf rust - *Hemileia vastatrix*). Understanding the main pest & disease threats in your area will be essential to define which agroforestry designs and management practices are best for you. See Appendix B for further detail on different pests and diseases in agroforestry systems, and how they are affected by different conditions.

MANAGEMENT: MIXED IMPACTS IN AGROFORESTRY

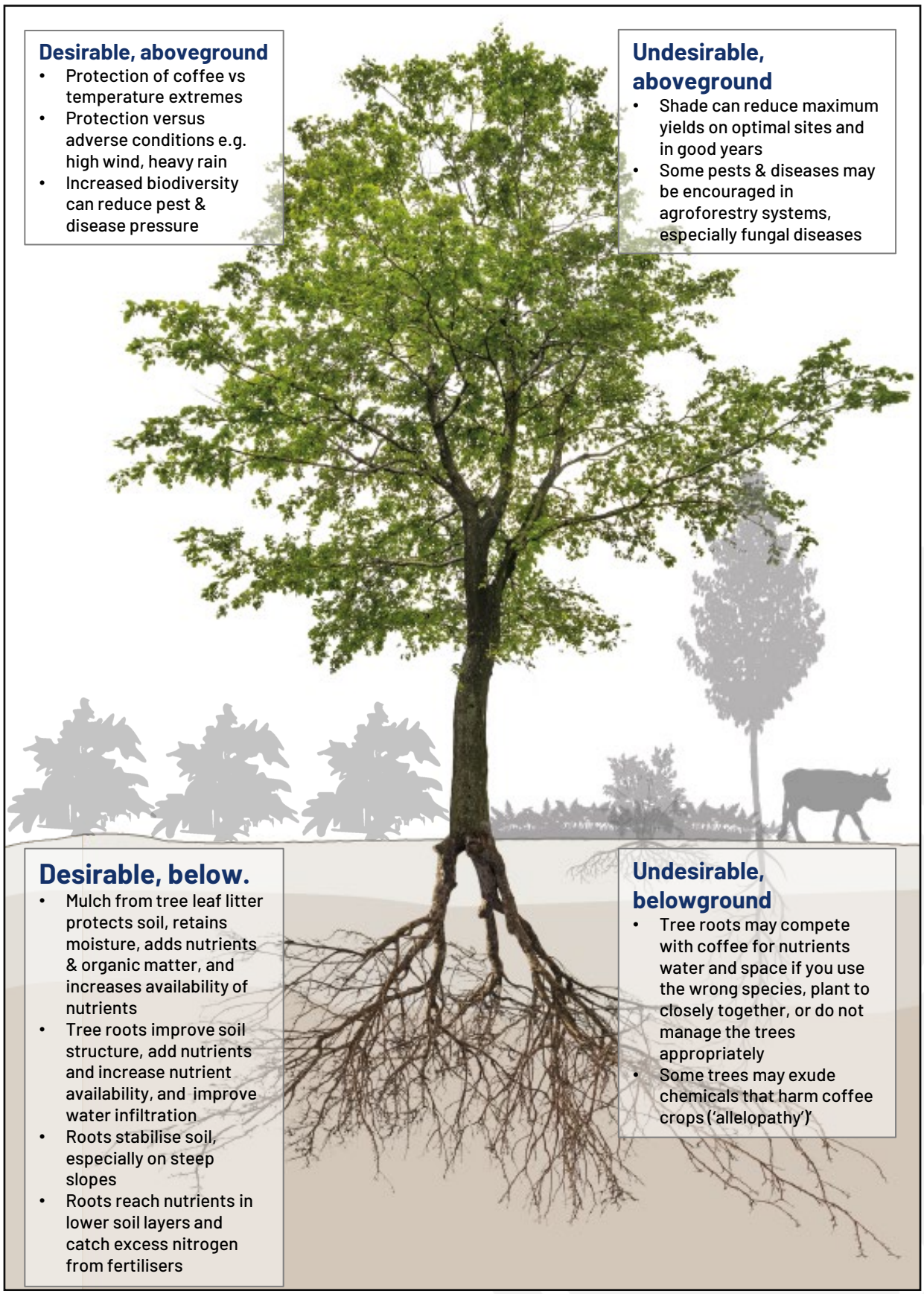
Some management tasks increase in agroforestry coffee (such as pruning of shade trees), while others may be reduced (such as weed control measures).

Good design selects tree species and practices that coincide minimally with times of year when labour time is in short supply. For example, pruning shade trees may happen at a different time of year to coffee harvest. Similarly, it should be checked whether harvesting from agroforestry species is likely to be very harmful for the coffee crops. For example, cutting down a large timber tree in the coffee plantation may damage the coffee bushes underneath. It can be informative to find out how other farmers in the area manage this challenge before planting new trees.

COMMUNITY, LANDSCAPES & ECOSYSTEM SERVICES: IMPROVED BY AGROFORESTRY

Agroforestry coffee provides more ecosystem services than full-sun coffee. This benefits both coffee production (e.g. pollination services, predation of pests & diseases) and the wider landscape and community (e.g. providing habitat for wild plant and animal species, reducing risk of flooding and landslides, connected areas of native forest, sequestering carbon, etc.). Agroforestry systems can also produce better working conditions, for example by providing shade during hot periods, and by reducing the need for use of agrochemical inputs, which can be harmful to farmers, communities and ecosystems.

ECOLOGICAL INTERACTIONS IN COFFEE AGROFORESTRY



DESIGN PROCESS OVERVIEW

1. COLLECT BASELINE DATA.

Understanding your baseline - the current situation - including site conditions on your farm, what coffee species you grow, what agroforestry species are available to you, how you already manage the farm, and market or end-use opportunities you have for either better-quality coffee or other non-coffee products. including what types of agroforestry and tree management are already practiced in your area.

2. SET YOUR GOALS.

In this essential step, you define and describe just what it is that you want to achieve with your (agroforestry) coffee production. Based on this, it is much easier to make a decision about which practices are right for you.

3. DEFINE YOUR AGROFORESTRY OPTIONS.

Understanding what agroforestry options may be available to you and which are most likely to help you meet your goals. Include especially what types of trees are used for different purposes - this is the species function.

4. DEFINE YOUR SPECIES OPTIONS.

Understanding the range of species that are available for use in your agroforestry system, what kinds of functions in the system that these species will perform, which types of agroforestry options they may work in, and

5. DEFINE THE ARRANGEMENT.

The arrangement is how the coffee and other plant/tree species are laid out on or adjacent to your coffee plantation.

Define the exact species mix. Once you know which species you have available in your area, what kind of layout you want, and what sort of function the different species should have, you can choose exactly which species to plant.

6. DEFINE THE EXACT SPACING.

Species have different characteristics - even if we know that they perform the same function in the system as another species. This will influence how closely they are planted together.

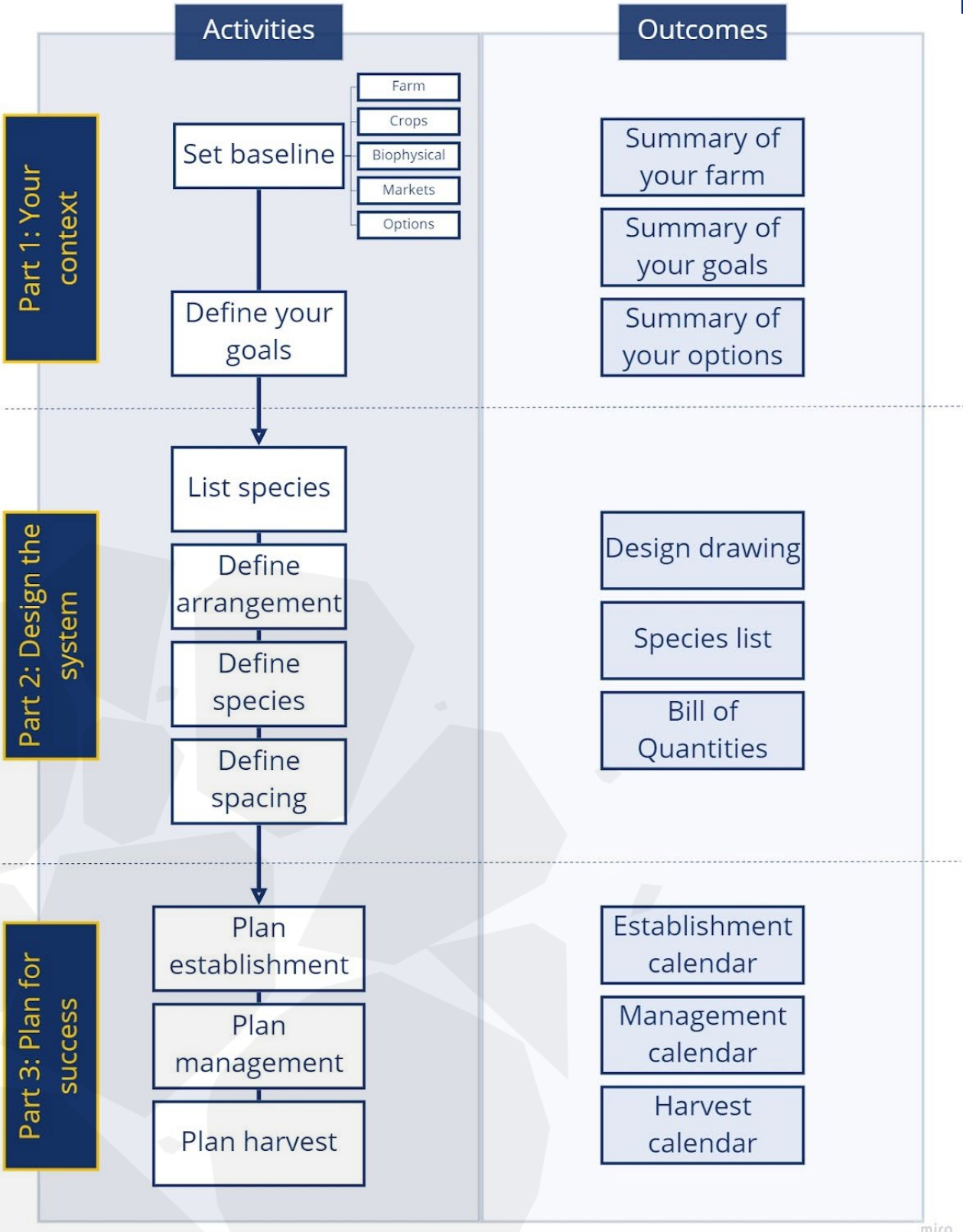
7. DEFINE BILL OF QUANTITIES.

A bill of quantities is a list of what you need and how much of it. This helps you to plan the establishment of your agroforestry system, and also helps you calculate how much the inputs will cost.

8. PLAN ESTABLISHMENT, MANAGEMENT & HARVEST.

Once you have designed the system, you can make a detailed plan of what needs to be done to establish the system (e.g. planting trees), managing the system (e.g. pruning coffee bushes or shade trees) and harvest products (e.g. coffee, fruit, timber etc.).

DESIGN PROCESS FLOW



BASELINE

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Exercise 3: Prioritise your goals

CASE STUDY

This example illustrates why it is important to understand conditions on the farm, and how farm practices influence the outcomes of agroforestry systems.

CASE SUMMARY

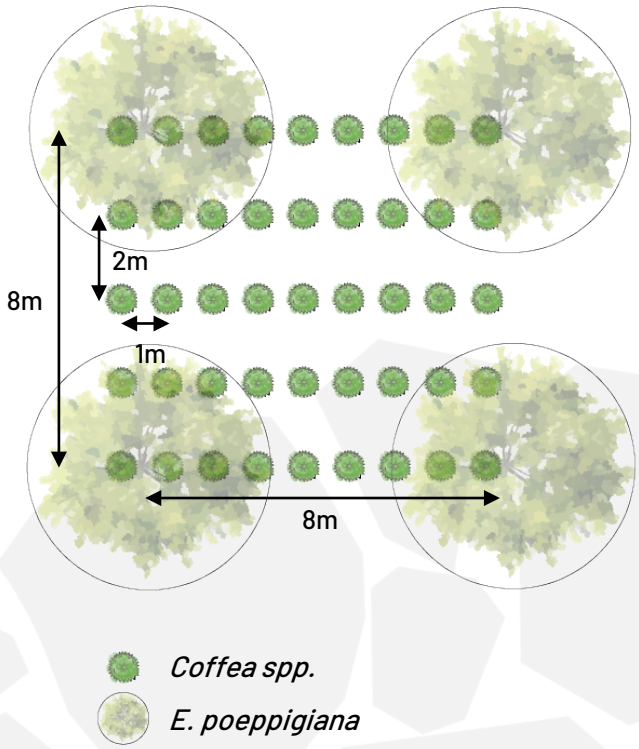
Case study source: Muschler 2001
Coffee species: arabica (*Coffea arabica* cv.s 'Catimor' and 'Caturra')
Location: Turrialba, Costa Rica
Altitude: 700masl
Temperature average: 21°C
Rainfall: 2600mm/year, without marked dry season
Slope: <5%
Soil: pH5-5.5, Typic Hapludand, medium nutrient status (low P and K)
Ecology: secondary forest and coffee plantation mosaic

DESIGN

2-species mix: *C. arabica* & *Erythrina poeppigiana*
Coffee: 5000plants/ha
Erythrina (15-20 years old): 160 trees/ha, approx. 8x8m
Functional diversity: low - 2 functional groups
Species diversity: low - 2 species

SHADE LEVELS

Dependent on pruning regime, varying from unshaded (continuously pruned shade trees), light, patchy shade (<40%) through pollarding 2x per year, open shade (40-60%) through thinning of shade tree branches and dense shade (>80%) through no shade tree management.



Condition	Dynamic	Agroforestry benefits	Further comments
Temperatures in this low-altitude area can be warmer than is optimal for arabica production.	High temperatures encourage faster and less balanced filling of coffee berries, and uneven ripening, lowering quality.	Shade levels of 40%+ promotes slower, more balanced filling and more even ripening of coffee cherries, leading to better overall quality of coffee.	Impacts of shade on quality differ between coffee cultivars/varieties. In this case, aroma scores for Catimor decreased slightly under shade, but did not decrease for Caturra.

Agroforestry practices are defined according to the local context. Strong understanding of conditions leads to improved decision-making regarding key issues such as arrangement, species mix and tree management.

SETTING GOALS

Understanding our goals - what we are trying to achieve through our agroforestry practices - is an essential part of creating systems that work for us. Integrating trees with coffee production can be done for many reasons, some examples are listed below. The more specific the goal, the more likely that appropriate systems can be designed to meet that goal.

TRANSLATING CHALLENGES & OPPORTUNITIES INTO GOALS

All farmers experience challenges in their production. It can also be possible to see opportunities even when challenges are 'under control'. Both challenges and opportunities can be expressed as explicit goals for our agroforestry systems. These goals can then be translated into desired actions which are used as guidance for the design of the agroforestry system.

Banana, *Musa* spp. Is a species commonly used to provide shade to coffee in the early stages of establishment (e.g. 1-5). It produces fruit that can be sold or consumed directly after only 1-2 years, and produces biomass to support soil health.

Exercise 2: List your goals

- Using the *Farm goals template*, list all of the challenges and opportunities you see on your farm, and the corresponding goals that you would like your coffee production system to achieve.
- Write anything that comes to mind - you will prioritise your goals in the following exercise.
- The categories provided can be used as guidance.

Exercise 3: Prioritise your goals

- Using the *Goals prioritisation template*, sort the goals that you listed in Exercise 2 into "must have" and "nice to have" categories.
- Once you have sorted your goals into two lists, you can choose to make the list more detailed by underlining or otherwise highlighting the goals that are most important.
- You should now have a list of goals with different levels of importance.

LINKING GOALS TO ACTION

Clear understanding of challenges, and clear articulation of goals can lead to clearly defined action. The table below gives some examples of how challenges/opporunities can be translated into agroforestru practices.

	Challenge/opportunity	Goal	Example action/practice
Production	Coffee yield declining due to soil degradation	To conserve and improve soil quality	Plant ground cover species and shade trees to cover soil and stabilise slopes
	Good prices for non-coffee products suitable for agroforestry production (e.g. pepper)	To increase overall production from coffee plantation	Integrate valuable products into coffee production (e.g. grow pepper on existing shade trees)
Economics	High coffee production costs reduce profitability	To increase coffee profitability	Integrate nitrogen-fixing shade trees into plantation to reduce nitrogen input cost
	Coffee with higher quality rating (e.g. 80+ points) receives higher market prices	To improve the quality of coffee produced	Reduce temperature extremes during berry ripening by planting shade trees
Provision	Family experiences poor nutrition at certain times of year	To produce nutritious food for family throughout the year	Plant diverse fruit trees within coffee plantation for year-round production
Landscape & community	Severe flooding becoming more frequent	To reduce surface water runoff by increasing water infiltration in the coffee plot	Integrate high-density lines of trees in the plantation, across the slope

DEFINING ARRANGEMENT

The way that trees are laid out in and around the coffee plantation - i.e. their 'arrangement' - is key to the impact these trees have on our coffee production. Defining the arrangement of our agroforestry plantation is one of the main tools we have to design an agroforestry system that works for us.

GET INSPIRATION FROM THE LOCAL AREA

We may already have experience with agroforestry practices or know of others who practice agroforestry in our area. Exercise 4 helps us to summarise the agroforestry practices that already exist in our area. This helps us to see what does or does not work in our area, and can provide inspiration for our own design.

Exercise 4: Describe agroforestry options

- Using the *Agroforestry & tree management template*, describe other agroforestry practices in your area or that you are familiar with.
- First, think about the arrangement of the systems, what species are used and what type of 'function' those species have
- Second, think about how those systems are established and managed, and how harvesting is done.
- Third, think about whether or not these practices usually occur in particular places on the farm or in the landscape - for example, some practices may only be used on steep slopes, or close to a river.
- Finally, consider the reasons why these practices exist and if you see any challenges for using them on your farm: why do farmers use these practices? What benefits do they provide to the farm? Could that be useful for me? What barriers or challenges would I face if I wanted to do something similar?

COMMON ARRANGEMENTS

There are many different arrangements in coffee agroforestry systems, and they are often combined. Some are dispersed arrangements: i.e. the trees are distributed throughout the coffee plantation more-or-less evenly.

These can be either randomly or unevenly distributed - commonly when coffee is planted in existing forests - or evenly distributed. This is typically from either planting trees in a regular pattern or thinning existing trees to give a regular pattern. These arrangements can provide many different benefits, depending on species, structure and management. It may be difficult to optimise the system (e.g. ideal shade level for coffee) if the arrangement is random.

DEFINING ARRANGEMENT, CONTINUED

Other designs are more linear - with trees and shrubs forming lines within or on the edge of a coffee plantation. Lines of trees at the edges may act as windbreaks, living fences, mark a boundary, or produce non-coffee crops. Lines of trees within the plantation can be used for purposes such as erosion control, breaking up monocultures (slowing spread of pests & diseases), providing shade and making management of both coffee and the trees easier than in dispersed systems. Linear systems can facilitate easier management of both coffee and trees.

Finally, some systems have trees in blocks or clumps on the farm. Even when the trees are not grown in the coffee plantation itself, blocks can provide benefits such as windbreaks, creating habitat for predators or other biodiversity, producing biomass for mulch or compost, or for other services such as slope stabilisation or protecting waterways from pollution.

Small, fast-growing leguminous tree species with light crowns – like *Gliricidia sepium*, *Leucaena leucocephala* and *Calliandra calothyrsuu* are highly-prized in coffee agroforestry sytems because they provide high inputs of biomass and nitrogen. They are also well suited to management – regrowing fast after hard pruning ('pollarding'). This means that shade levels in the coffee plantation can easily be managed depending on the season.

Exercise 5: Select possible arrangements

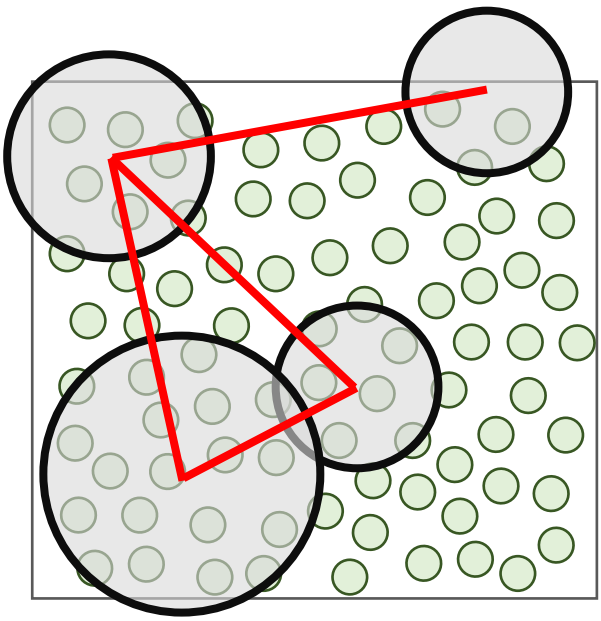
- Based on the different arrangements you have described in exercise 4, and the arrangement examples described on the next page, write up which types of arrangement may work for you.
- Link the arrangements that are interesting for you to the goals you defined in exercises 2 and 3: what are you trying to achieve? In what way could arrangement X be beneficial on your farm? Why would it work better than arrangement Y?
- For example, it may be important in our context to create even, light shading throughout the plantation, so we may select regularly dispersed trees rather than 'randomly dispersed' or 'linear boundary' arrangements.
- Use the *Agroforestry arrangements template* to help structure your thoughts.

COMMON ARRANGEMENTS

1. DISPERSED, RANDOM. SINGLE- OR MULTI-LAYERED

Trees distributed through the coffee plantation without any specific spacing.

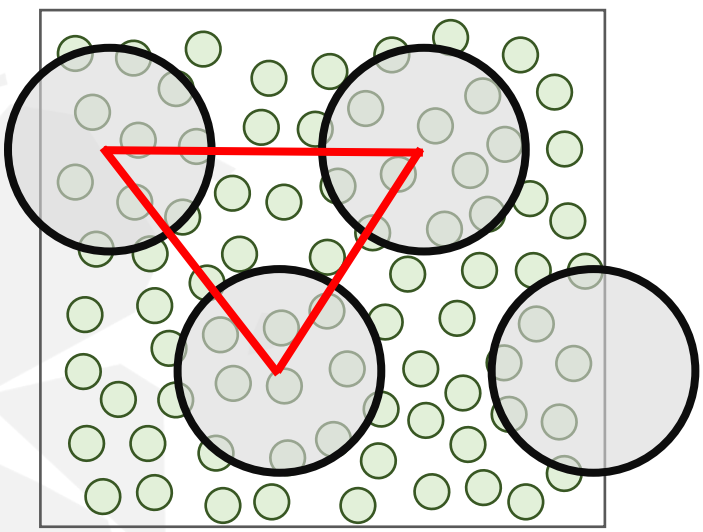
Common applications:
Often complex, multi-layered systems enriched with a range of useful species providing both products (e.g. food, spices, timber, honey, resin) and services (e.g. shade, soil cover, nitrogen fixation, biodiversity etc.). Can also be simplified systems created by thinning existing forests. Coffee productivity is unlikely to be optimised.



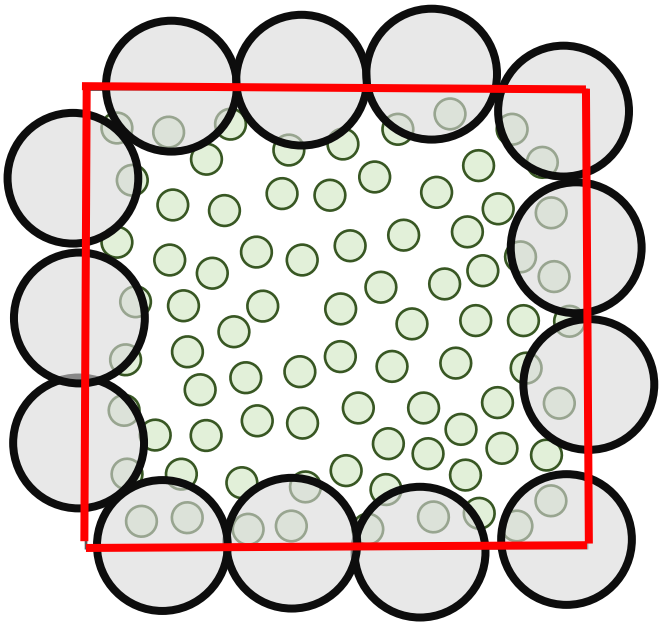
2. DISPERSED, REGULAR. SINGLE- OR MULTI-LAYERED

Trees planted evenly throughout the coffee plantation, or thinned to create even structure.

Common applications:
Often simple, single-layered agroforestry systems to provide even shade, benefits to soil (e.g. nutrients, erosion control) and 1 additional product (e.g. timber, fruit).



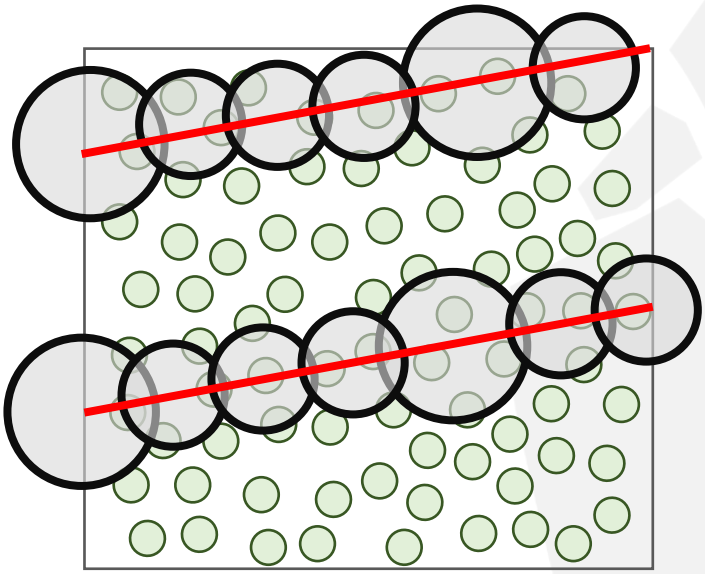
COMMON ARRANGEMENTS CONT.



3. LINEAR, BOUNDARY.

Trees are planted in a row on some or all sides of the coffee plantation.

Common applications:
Often used as windbreaks, living fences, fodder banks, or as boundary marking. Commonly using species that do not grow very tall and may create a dense barrier from near ground level.



4. LINEAR, INTEGRATED.

Trees are planted in lines within the same row as coffee plants.

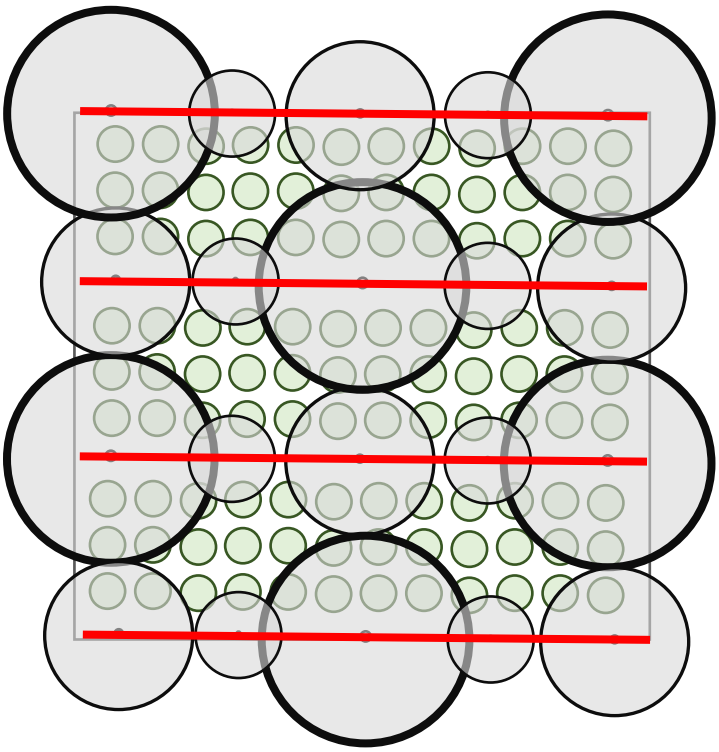
Common applications:
Similar to 2, sometimes more complex (higher diversity of non-coffee species). Often provide shade, benefits to soil (e.g. nutrients, erosion control), and additional products. Can be better for mechanisation than 1 & 2.

COMMON ARRANGEMENTS

5. LINEAR, ALLEY.

Trees are planted in lines through the coffee plantation, in a separate line to the coffee plants.

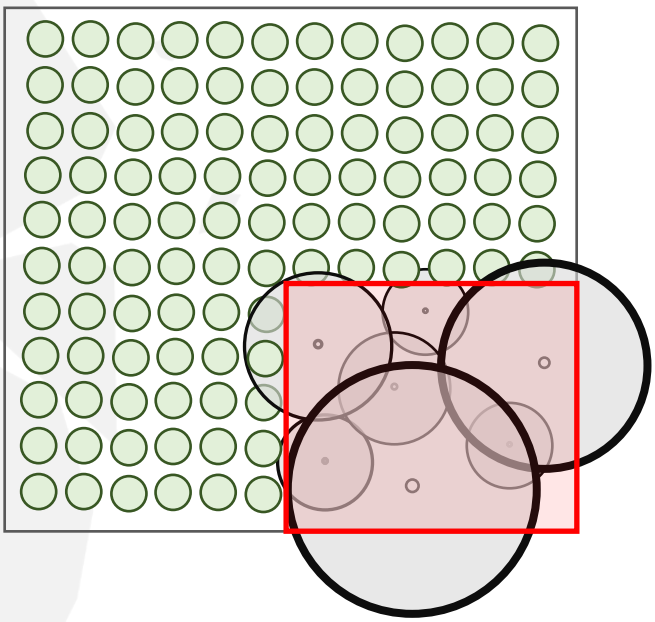
Common applications:
More or less diverse systems, from 1 non-coffee species to 20+. Often to provide similar benefits to complex versions of arrangement 1 (diverse production, diverse services), but more easy to optimise and manage 'rationally'. Growing trees in separate lines can facilitate easier management of both coffee and non-coffee plants. Typically better for mechanisation than 1 & 2.



6. BLOCKS.

Trees are planted in blocks on the farm, near or adjacent to coffee plantations.

Common applications:
Usually bringing diversity to the farm landscape, providing benefits such as increased biodiversity (pollination for coffee, predators etc.), windbreaks, slope stabilisation, producing products for use in the coffee plantation (such as biomass for mulch) or protecting landscape features (e.g. reducing nutrient runoff into waterways).



SPECIES LONG LIST

The first steps in defining which species may be used in our agroforestry system are to A) understand which species are available and B) what kind of function we want trees to play in the system. Some tree species may be perfect for the design, but are impossible to find in a particular location, are too expensive, or of poor quality.

FUNCTIONAL GROUPS: MORE DESIGN FLEXIBILITY

Within an arrangement, certain types of trees are placed in specific locations. Each of these trees play a role in the system - they have a 'function'. In other words the function of the tree is what the tree does in the system.

The table below is an example of a species long list for an agroforestry system in Indonesia, organised by functional group and describing the main characteristics of each species.

The function of the tree usually is connected to the tree's natural characteristics (e.g. shape, size, how long it lives, ecological interactions like nitrogen fixation, and the products that it provides). It is also linked to how the tree is managed. For example, some coffee farms may have leucaena (*Leucaena leucocephala*) evenly spaced throughout the plantation, which are kept small by regular pruning or 'pollarding'. Their function is to provide the desired amount of shade to the coffee throughout the season, and to fix nitrogen.

Other coffee farms may include mahogany (*Swietania macrophylla*) - a large tree used to create a high canopy to shade the coffee, provide habitat for birds, and produce timber after 15+ years. The two species have different characteristics, management practices and products - therefore they have different 'functions'.

SPECIES AND GROUPING			ECOLOGICAL DATA							
Functional group	English name	Latin name	Plant type	Succession	Strata	Ecological versatility	Requirement level	Nutritional deposition	Aggregate value	Crown permeability
Long Cycle Timber	Mahogany tree	*Swietenia macrophylla*	Tree	Late secondary	Upper-high	Low	High	Low	High	Medium
	Tabebuya	*Tabebuia rosea*	Tree	Late secondary	Upper-high	Low	High	Low	High	Medium
Large Fruits and Palms	King of fruit	*Durio zibethinus*	Tree	Initial secondary	High	Medium	Medium	High	Medium	Low
	Mango	*Mangifera indica*	Tree	Initial secondary	High	Medium	Medium	High	Medium	Low
	Avocado	*Persea americana*	Tree	Initial secondary	High	Medium	Medium	High	Medium	Low
	Jackfruit	*Artocarpus heterophyllus*	Tree	Initial secondary	High	Medium	Medium	High	Medium	Low
	Magosteen	*Garcinia mangostana*	Tree	Initial secondary	High	Medium	Medium	High	Medium	Low
	Coconut	*Cocos nucifera*	Palm	Initial secondary	High	Medium	Medium	Medium	Medium	Medium
	Palm tree	*Elaeis guineensis*	Palm	Initial secondary	High	Medium	Medium	Medium	Medium	Medium
Medium fruits	Rambutans	*Nephelium lappaceum*	Shrub	Pioneer	Medium-high	Medium	Medium	Medium	Medium	High
	Cashew nut	*Anacardium occidentale*	Shrub	Pioneer	Medium-high	High	Low	High	Medium	High
	Guava	*Psidium guajava*	Shrub	Pioneer	Medium-high	High	Low	Medium	Medium	High
	Soursop	*Annona muricata*	Shrub	Pioneer	Medium-high	Medium	Medium	Medium	Medium	High
Short-term service trees	Rain tree saman	*Albizia saman*	Tree	Initial secondary	High	High	Low	High	Low	Medium
	Inga	*Inga edulis*	Tree	Pioneer	High	High	Low	High	Low	Medium
	Bixa	*Bixa orellana*	Tree	Pioneer	High	High	Low	High	Low	Medium
	Moringa	*Moringa oleifera*	Tree	Pioneer	High	High	Low	High	Low	High
	Pigeon pea	*Cajanus cajan*	Shrub	Pioneer	High	High	Low	High	Low	High
Fruit/Service	Banana	*Musa sp.*	Herb	Initial secondary	Medium-high	High	Medium	High	Medium	Medium

SPECIES LONG LIST

Once we have understood the function of the tree, it is possible to be more flexible with designs. We can choose other species that play a similar function, but suit the context better. For example, leucaena is a coppiced, nitrogen-fixing shade species, but in some areas it can become invasive. In these cases, gliricidia (*Gliricidia sepium*) can play a similar role and may be preferred by farmers to reduce risk.

CREATING A 'SPECIES LONG LIST'

A species 'long list' is simply a list of all the different species that could be available to us for use in our agroforestry system. Ideally, this list is organised into groups of species which can play a similar role or 'function' within the system. As described above, this can make us more flexible in our designs. The graphic on the next page gives an example of different species and their possible 'functional group'.

Exercise 6: Create species long list

- Using the *Species long list* template, write down all of the species that you know are used in agroforestry in your area, or that you know of that could be used in your coffee plantation
- For each species, note down what you know about the characteristics (size, shape, growth rate, canopy width, canopy type - i.e. does it cast heavy or light shade? - etc.), services (e.g. and products (e.g. food, medicine, timber, spices etc.) it provides.
- If helpful, use inspiration from the agroforestry systems & practices you described in exercise 4. Which species do you usually find in different kinds of systems? Can you describe the characteristics of these species? Why are they useful? What products do they provide? Are there risks or challenges involved with planting them with coffee?
- Based on this, create categories of different types of species - these will be your 'functional groups'. Decide which species are similar and label with a name that feels appropriate for your context. For example, both pink cedar (*Acrocarpus fraxinifolius*) and mahogany (*Swietenia macrophylla*) are timber-producing large trees used for coffee shade, usually as the tallest trees in a system. We may choose to call these 'large timber shade trees'.

SPECIES SELECTION

Species selection involves a more detailed analysis of the available species to match our goals. All species will have advantages and disadvantages. These must be assessed in the context in which they will be planted.

UNDERSTAND DESIRABLE AND UNDESIRABLE CHARACTERISTICS OF SPECIES

Species selection should be directly connected to (A) the agroforestry goals of the farm, and (B) the types of arrangement that has been chosen. Some key questions include:

What size and shape is appropriate for the chosen arrangement? For example, a living fence for boundary demarcation and soil erosion control requires a species that grows densely near ground level (e.g. <2.5m), such as *Dracaena fragrans* (Costa Rica) or *Commiphora zimmermannii* (Kenya).

How fast does it grow and begin to produce? For example, slow growth may be acceptable for a long-term investment, such as clove (*Syzygium aromaticum*), but faster growth may be desired where production is required quickly, such as banana (*Musa spp.*).

What kind of shade does it create? For example, dense shade from species such as mango (*Mangifera indica*) may decrease the yields of coffee plants directly beneath, so use should be considered carefully before planting. Other species such as *Grevillea robusta* have lighter canopies that may cast a more appropriate type of shade.

What kinds of leaf litter does it create? For example, smaller, softer leaves from species such as *Erythrina subumbrans* decompose more quickly than those with larger, tougher leaves, providing nutrients to the soil more quickly. Larger, harder leaves from species such as mango (*Mangifera indica*) or avocado (*Persea americana*) may stay on the soil surface longer, providing nutrients more slowly but protecting the soil for longer.

Does it provide other services that the system requires? For example, only some species fix nitrogen - typically leguminous species such as *Gliricidia sepium* and *Leucaena leucocephala*.

Does it host other organisms (e.g. animals, pathogens) that we either do or do not want? For example, some trees such as citrus (*Citrus spp.*), inga (*Inga spp.*) or mango (*Mangifera indica*) can host the pathogen responsible for brown eyespot (*Cercospora coffeicola*).

What is its nutrient and water demand? For example, eucalyptus species (*Eucalyptus spp.*) can be very water demanding - in areas prone to drought this can compete significantly with coffee. By contrast, grevillea (*Grevillea robusta*) is a deep-rooting species, which can reduce competition for water in the shallow rooting zone of coffee roots.

What kind of management does it require or tolerate? For example, if a shade tree needs to be pruned heavily twice per year, it needs to tolerate this kind of pruning regime. Common examples include *Erythrina poeppigiana*, *Calliandra calothyrsus* and *Grevillea robusta*.

SPECIES SELECTION

LINK SPECIES SELECTION TO AGROFORESTRY GOALS

Species selection should be directly connected to (A) the agroforestry goals of the farm, and (B) the types of arrangement that has been chosen. Certain goals and arrangements will define what kinds of species are suitable.

MATCH SPECIES CHOICES TO SPECIES THAT ARE LOCALLY AVAILABLE

Species should also be chosen based on availability. Key considerations here include: **(A) Access and timing.** Is the species available in this location and at the time that it is needed? **(B) Quality.** Are the propagules (e.g. tree seedlings) of a good enough quality? **(C) Price.** Are the propagules an acceptable price?

MARKETS & END USES: CHOOSE CROPS BASED ON WHAT IS FEASIBLE

If the aim is to make production more diverse, it is important to know that those products can either be sold or used once they are produced.

This can depend on a number of factors including: **(A) Harvest.** Is it possible to harvest in the right way or at the right time? **(B) Processing & storage.** Is it feasible to process the product for use or sale and/or store them appropriately before they are sold? **(C) Available markets.** Are there markets for the product in the area, and is it possible to get the products to those markets in good condition? **(D) Use value.** Is the product something that is actually of use to the farm family or community?

Exercise 7: Define species traits

- List the different types of tree that you want in your system (i.e. the functional groups) - using the questions on the previous page to prompt you.
- For each of these types of tree, write what kind of characteristics are most important to you
- Link these choices back to your goals and to the types of arrangement you defined in exercise 5. For example, if you prefer a regularly dispersed pattern for even shading and a key goal for you is to produce food for your family, a species description could be "medium to large trees that produce fruit".
- The result should be a short list of the types of trees you want to see in your system.

Exercise 8: Choose your species

- Identify the species that most closely meet your criteria, based on the criteria you have developed in exercise 7.
- Use the species list developed in exercise 6 to find which appropriate species are available to you.
- List the species you want in the *Species short list template* provided. This list shows the main species that you will use in your system.
- If you are still unsure which species to choose after this process, you can further refine your ideas by either listing the expected positives and negatives of each species (use the *Species review table*), and/or by completing the "pairwise" exercise described on the next page.

SHADE TREE CHARACTERISTICS

'Good' shade/agroforestry tree characteristics will depend on the system goals. But there are some characteristics that are commonly seen as desirable. Table adapted from Beer (1987).

Ecological compatibility with coffee	Minimum competition for water, nutrients, space, e.g. with a deep root system that overlaps minimally with crop roots.
Strong rooting system	Shade trees are often more exposed than in forest contexts, so are more likely to fall over in high winds. Species example: Durian (*Durio* spp.) has a shallow root system, so planting tall trees in open locations creates a risk of windfall.
Roots easily from stake	Shade can rapidly be established by vegetative propagation. Species example: Gliricidia (*Gliricidia sepium*) establishes readily as fresh cuttings as large as 10cm diameter.
Captures nutrients not captured by crop	E.g. deep root systems can use nitrogen in lower parts of the soil and cycle them back to the crop via the leaf litter.
Fixes nitrogen	Brings more nitrogen into the system, making it available to coffee and other crops via roots and leaf litter.
Light crown with regular shade pattern	This ensures that shade is more evenly distributed in the coffee plantation and that the quality of light coming through the canopy is better.

Exercise 9: Pairwise exercise

- This exercise can be used whenever a choice needs to be made between a number of different options.
- Using the *Pairwise table*, list the species that you are choosing between in both the top row and left hand column, in the same order.
- Each cell represents a choice between two different options. In each cell, write which of the two species you would prefer, if you had to choose only one.
- Once you have filled in the table, each cell will have a species name in it. The species whose name occurs the most times is the 'most preferred'. The species which occurs the second highest number of times is the second most preferred and so on. This should give you a list of species in order of preference.

SHADE TREE CHARACTERISTICS CONT.

Tolerance of repeated heavy pruning	Species example: *Grevillea robusta* can be pollarded multiple times per year, growing back rapidly.
Non-brittle branches & stem	This reduces the risk of branches and whole trees snapping and damaging the crop beneath.
Thornless stems & branches	Makes management easier.
If deciduous, rapidly regains leaves in summer	Quickly re-establishes shade cover when needed.
Not likely to suddenly lose leaves due to pest/disease attack	More likely to maintain the desired level of shade.
Small leaves	Avoids large amounts of rainwater collecting on leaves, reducing the risk of drip damage (e.g. which can increase the rate of soil erosion).
Provides valuable wood, fruit or other product	Increases production and income from the coffee plot.
Not allelopathic	I.e. does not give off substances that can harm the crop (e.g. from roots).
Does not host pests & diseases that are a serious threat to coffee	Different tree species can often share the same pests & diseases. For example, *Inga* spp., oranges (*Citrus* spp.) and mango (*Mangifera* spp.) all host american leaf spot (*Mycena citricolor*).
Is not likely to become a weed	Some planted species may become difficult to control, e.g. castor bean (*Ricinus communis*), Sunn hemp (*Crotalaria juncea*) and Leucaena (*Leucaena leucocephala*), in some areas.
For timber: small diameter, light crown	This reduces risk of wind throw, allows for higher density of shade trees without negatively impacting coffee production and reduces damage to coffee when trees are harvested.
For timber: rapid growth of central stem	This is also called rapid “apical growth”, where the central stem of the tree grows rapidly.
For timber: self-pruning and produces as clean, straight stem	Some trees naturally lose lower branches, especially under conditions such as shade, forming a branch-free straight stem which is more valuable for timber.

SPACING & BILL OF QUANTITIES

Spacing - i.e. how far apart we plant our chosen species - along with arrangement and species, is the final planning method available for influencing the dynamics on the coffee farm. Spacing will influence all key dynamics in the coffee agroforestry system, including light, temperature, humidity, soil water nutrients and space. It will also influence how the system is managed (for example, must be far enough apart to allow machinery access if needed, or high-density tree spacing may call for more intensive management of shade).

FACTORS INFLUENCING SPACING

Exact levels of desired shade depend very much on the local conditions and the goals of the coffee agroforestry plantation. In very general terms, light-moderate to moderate-heavy (between 20-70% shade) have greater benefits than either little/no shade (e.g. 20%) or heavy shade (70%+).

There are a number of variables to consider, including:

Local conditions. Conditions listed in the "Baseline" section such as temperature, rainfall, soil condition, slope, all influence potential spacing. For example, where temperatures rarely exceed optimum range, or average temperatures are cool, lower levels of shade may be needed to optimise coffee productivity. Where temperatures are consistently too high, more shade may be appropriate, leading to a higher density of shade trees.

Coffee species. Different coffee species have different responses to shade. Generally, robusta is more tolerant of more open conditions (e.g. 20-40% canopy cover) than arabica (e.g. 30-55% canopy cover).

Desired outcome/goals. The goals of the system directly impact choice of spacing. For example, a high density of valuable trees - for example, durian (*Durio zibethinus*) - may be desirable if the goal is to produce high volumes of fruit, and some reductions in coffee production are acceptable. If maintenance of coffee production is essential, spacing may be wider.

FACTORS INFLUENCING SPACING CONT.

Tree architecture (size, shape). Trees that have larger, spreading canopies will typically be spaced further apart than trees with narrow canopies.

Tree canopy density. Trees with dense canopies will cast more shade beneath the canopy than those with less dense canopies. To reduce the impact on coffee crops, these may be spaced further apart than those with light canopies. For example, *Grevillea robusta* casts a lighter shade, so spacings of 4x4m are not uncommon.

Number of strata/layers. More layers of canopy in an agroforestry system - 'strata' - will have a stronger impact on coffee production. Where there are multiple layers, it may be necessary to space trees of the same species further apart to avoid excessive shading.

THINNING

In some cases, it is possible to plant trees closer together than their final spacing will allow. This can have the advantage of filling spaces between trees before they reach full size, as well as providing additional benefits such as increasing the volume of production, improving crop quality, conserving soil etc..

For example, teak (*Tectona grandis*) may be planted at initial spacings of 4x4m and thinned to 8x8m as the tree grows and matures (e.g. at 10-15 years old), providing wood products and while reducing shade pressure. Avocado, similarly, may often be planted at high densities (e.g. 8x8m) and thinned to lower densities (e.g. 16x16m) after 8-10 years. These methods depend on ongoing management of the tree.

Exercise 10: Draw agroforestry design

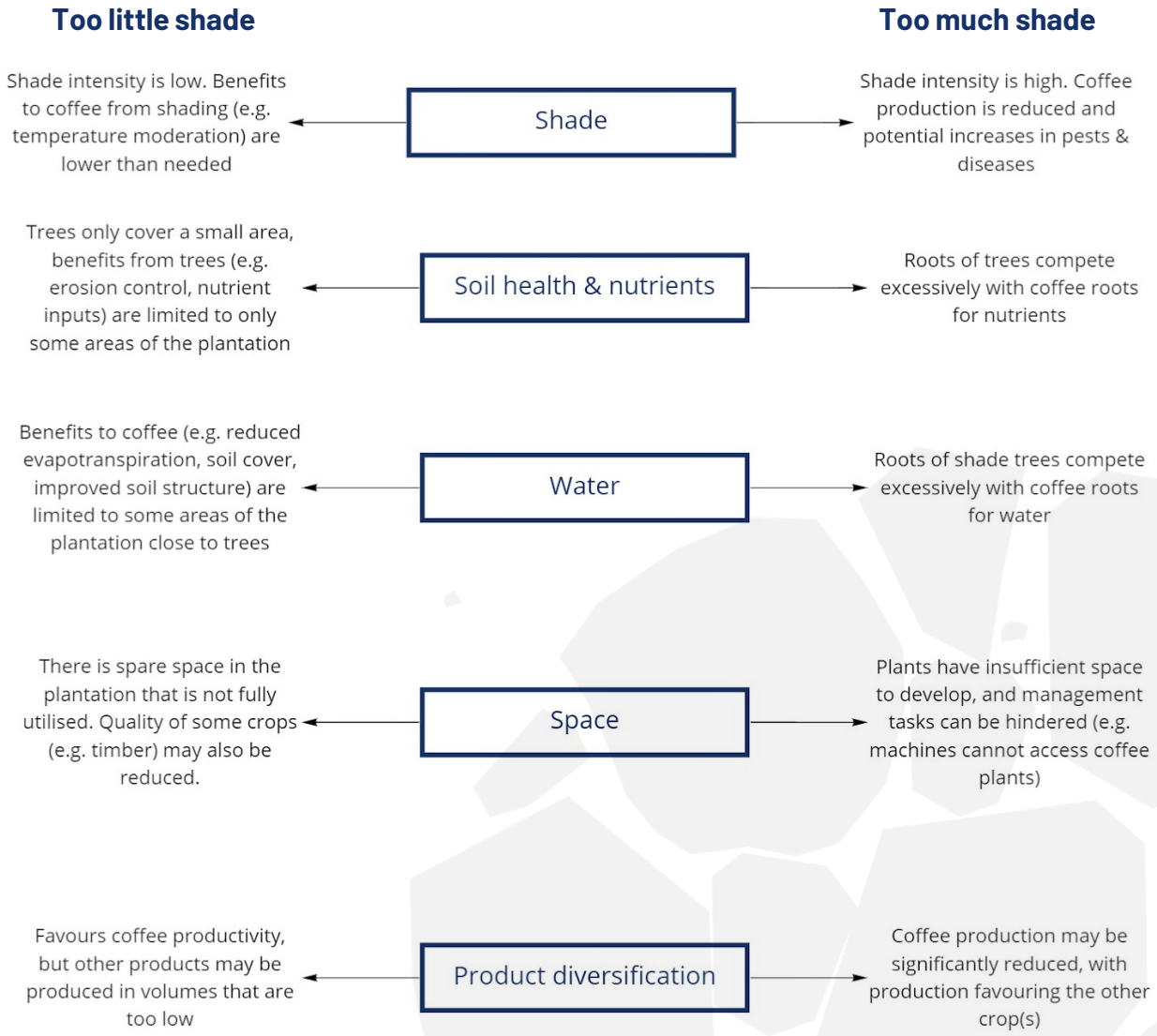
- Draw your proposed agroforestry design on paper.
- This can be done in a number of ways, but a common "top-down" or "plan view" method.
- Some key elements to include are: species, arrangement and the space between species

- Using the *Bill of Quantities template* for support, define the exact number of each species required for your agroforestry system.
- This can be calculated per unit area (e.g. per hectare), and multiplied by the size of your plot to give an accurate indication of how many of each species you need to procure.

Exercise 11: Write up bill of quantities

CHOOSING SPACING

The graphic below shows generic impacts of spacing on interactions in agroforestry coffee plantations.



CASE STUDY

Study source: Baggio *et al* (1997)

The table below shows the results of intercropping grevillea (*G. robusta*) with arabica coffee in Paraná state. It illustrates the trade-offs involved in deciding on tree spacing. In this case, higher tree densities provided much greater crop protection against frost damage than lower densities or open-grown coffee.

At the highest densities of grevillea (199 trees/ha), coffee yield was reduced. Here, the optimum density (highlighted in green) was 48 trees/ha (spacing 12x17.5m), improving coffee productivity, improving the overall economic output of the plot, and providing significant protection from frost damage.

Density (trees/ha)	Spacing (m)	Impact on coffee productivity over 8 years	Total economic output	Protection of coffee from frost
119	8x10.5	Significantly less (85%) than open-grown control	Slightly reduced compared to open-grown (97%)	5 times greater protection than open-grown
71	10x14	Similar (101%) to open-grown control	Significantly increased compared to open-grown (108%)	5 times greater protection than open-grown
48	12x17.5	Significantly higher (109%) than open-grown control	Significantly increased compared to open-grown (114%)	2 times greater protection than open-grown
34	14x21	Slightly higher (106%) than open-grown control	Significantly increased compared to open-grown (110%)	2 times greater protection than open-grown
26	16x24.5	Similar (97%) to open-grown control	Similar to open-grown (100%)	2 times greater protection than open-grown

ESTABLISHMENT

The main steps involved in establishment are:

- **Source good quality seedlings or planting material (e.g. seeds, cuttings)**
- **Care for seedlings if storing before planting**
- **Prepare the ground (e.g. weed control)**
- **Plant the tree/seedling**
- **Feed & protect the tree (if necessary)**
- **Prune and form the tree (if necessary)**

Two key questions should guide decision-making about establishment:

What methods for establishment are appropriate in this context?

This will depend on a number of factors including: the species being planted (e.g. what is the nutrient requirement?), the type of plant material (e.g. is it being planted from seed, as a seedling, a large hardwood cutting etc.?), the site conditions (e.g. are there a lot of weeds or is the ground clear?), tools and equipment available, the amount of labour available, and availability of other materials (e.g. is there a good local source of compost, manure or organic material for mulch?).

When do specific activities need to be carried out in order to be successful?

Sequence - some activities need to happen first - for example, a living support pole for pepper (Piper nigrum) must be planted before planting the pepper itself. Seedlings may need to be ordered from nurseries a number of weeks or months in advance. Seasons - what time of year is most appropriate for the species to maximise establishment success? For example, in many areas, trees will be planted at the beginning of the rainy season to give them maximum time to establish before the dry season starts, increasing chances of survival.

Exercise 12: Define preferred establishment practices

- Using the Establishment practices table, list different potential establishment practices.
- List what is needed to successfully use this practice, and when it needs to be done.
- Assess the potential positives and negatives of each practice in your context. For example, some practices may be more labour-intensive than others, some may cost more or less money, and the materials for some may be readily available, but not for others.
- Based on this assessment, write down whether or not you think you are likely to use this method when establishing your own system or new system elements.

ESTABLISHMENT CONT.

The table below shows an example establishment calendar for pepper (*Piper nigrum*) on a live support of gliricidia (*G sepium*) in Indonesia.

Activity	Year 0.												Year 1.											
	Jan	Feb	Mar	Apr	Mei	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Mei	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Clear ground clearance & remove weeds							●	●	●															
Plant gliricidia live pole									●	●														
Plant pepper										●	●	●	●											
Tie pepper to live pole														●	●	●	●	●						
Occasional weeding around pepper														●	●	●	●	●	●	●	●	●	●	●
First pepper pruning																●	●	●						

Exercise 13: Fill in establishment calendar

- Based on the preferred practices you listed in exercise 12, fill in the *Establishment calendar template* to plan the establishment process for your agroforestry system.

- 'Establishment' may be very fast, occurring in only a few days, weeks or months, or may last multiple years - as in many cases where trees, shrubs and other species benefit from special pruning and treatment in the early stages of their life, before they reach production maturity.

REFLECTION & CONCLUSION

Before implementing a new system, it is useful to review your plans and critically evaluate whether or not they really meet our goals. Intercrops may have positive, negative or no significant impact on the coffee crop. Our job in agroforestry design is to maximise the positive and minimise the negative. What is 'acceptable' will depend on your goals for the system.

OPTIONS FOR REFINING OUR DESIGN

Arrangement.
- Different arrangement
- Add another arrangement in combination to the one we have chosen

Species.
- Different species
- Fewer species
- More species

Spacing.
- Closer together
- Further apart

Establishment.
- Plant sooner
- Plant later
- Plant in a different order
- Different propagation material (seeds vs seedlings vs cuttings etc.)
- Different establishment methods (e.g. different tools, different materials, different land clearance method etc.)

Management.
- Different management practice
- Different tools
- Different timing

Harvest.
- Select different varieties (e.g. change harvest time)
- Different tools
- Different timing

SHADE SUITABILITY OF SOME ROBUSTA CULTIVARS

Different types of robusta clones interact differently with shade. The impact is not known for all clones. The table below derived from Piato *et al* (2020) gives an indication of the growth and productivity response of different clones to shade in terms of growth and productivity.

Even where this response is negative, shade trees may still provide other benefits such as pest & disease control and soil improvement.

Clone	Impact of more shade on growth and productivity	Recommendation
C153	Positive	Preferred as understory crop.
LB1	Positive	Preferred as understory crop.
GG229	Positive	Preferred as understory crop.
JM2	Positive	Preferred as understory crop.
03V	Negative	Less preferred as understory crop.
06V	Negative	Less preferred as understory crop.
12V	Negative	Less preferred as understory crop.

PESTS & DISEASES

An overview of key pests & diseases, and the influence of agroforestry in occurrence and management.

Pest/disease	Favourable conditions	Impact of shade & intercropping	Ways to increase positive interactions and reduce negative
Mycena citricolor - American leaf spot	High humidity environments.	Increased risk under excessive shade, especially on moist sites.	Lower shade levels on moist sites. Shade management during wet periods (e.g. pruning/pollarding)
Cercospora coffeicola - Brown eyespot / iron spot	High-humidity environments. Weakened coffee plants (e.g. nitrogen- and potassium-deficient).	No-shade conditions may weaken coffee plants through nutrient and water stress. Risk may be increased by greater vegetation density in high-humidity environments. May be hosted by shade species e.g. *Inga* spp., orange (*Citrus* spp.) and mango (*Mangifera* spp.).	Cultivate coffee under well-managed shade. Consider hard-pruning shade trees at humid times of year. Do not use shade species that host the pathogen. Maintain good soil health.
Hemileia vastatrix - Coffee leaf rust	High-humidity. Excessive temperatures. Monoculture.	Interplanting with other crops can reduce spread of disease. Increased humidity agroforestry systems can promote the disease, especially in wet locations.	Manage shade levels during wet seasons of the year. Plant 'barriers' of other crops within the coffee plantation.
Colletotrichum coffeanum	Plants weakened by nutritional stress or overproduction.	Shade typically reduces plant stress and overproduction. Response to shade and humidity not very pronounced.	Avoid little or no-shade conditions. Avoid abrupt changes in shade levels (e.g. hard pruning). Maintain good soil health.
Colletotrichum gloeosporioides	Plants weakened by nutritional stress or overproduction.	Shade typically reduces plant stress and overproduction. Response to shade and humidity not very pronounced.	Avoid little or no-shade conditions. Avoid abrupt changes in shade levels (e.g. hard pruning). Maintain good soil health.
Xylotrechus quadripes - Coffee stem borer	More active under higher light conditions.	Some shade reduces stem borer activity. Provision of habitat for parasites & predators (e.g. birds) may decrease incidence.	Maintain healthy coffee plants by the use of healthy seedlings, maintaining good soil health, avoiding the planting of alternative hosts.
Hypothenemus hampei - Coffee berry borer	Mixed, typically increased by shade.	Excessive shade can promote pest. Diversity of trees can provide habitat for predators such as birds, parasites and ants.	Reduce heavy shade. Prune coffee bushes to maintain open structure. Remove fallen and infected berries. Pick berries regularly during harvest season. Select resistant varieties & cultivars (e.g. *C. arabica* 'Goiaba'). Favour diverse types of agroforestry species.
Weed plants	Greater sunlight, especially for aggressive weeds.	Shade can decrease or eliminate the presence of aggressive weeds (e.g. grasses - '*Poaceae*').	Increase shade levels to reduce incidence of aggressive weeds.

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1. CONDITIONS SUMMARY SHEET

Category	Data type	Answer	Possible design implications
Biophysical	Climate (temperature, rainfall, wind)		
	Soil (texture, pH, nurient status, organic matter)		
	Landform (slope, aspect)		
	Ecology		
	Land use		
	Other comments		
My coffee production	Coffee species		
	Plot size		
	Management (coffee & tree management, fertility, harvest)		
	Inputs into coffee plot		
	Key coffee production challenges		
Existing agroforestry	Are trees present in my coffee plantation or on my farm?		
	Are there other non-tree species present in my coffee plantation?		
	Type of plant (function) & species		
	Role/function of each species		
	Arrangement of species		
	Spacing of species		
	Density (total number per hectare)		
	Products		
	Markets currently accessed		
	Management of agroforestry species		
	Inputs into agroforestry plot		
Constraints to including trees on farm	Resources (e.g. seeds, seedlings, inputs, tools)		
	Markets		
	Infrastructure		
	Labour		
	Knowledge		
	Legal structures & regulation		

2. FARM GOALS TEMPLATE

Challenge/opportunity	Goal

3. GOALS PRIORITISATION TEMPLATE

Must have	Nice to have

4. AGROFORERSTRY AND TREE MANAGEMENT OPTIONS TEMPLATE

Practice name	Arrangement, functional groups & species, spacing	Esatblishment, management, harvest	Landscape / farm niche	Rationale & outcomes	Challenges / barriers
Practice 1:					
Practice 2:					
Practice 3:					
Practice 4:					

5. AGROFORESTRY ARRANGEMENTS TEMPLATE

Practice name	Advantages of this arrangement on my farm	Potential challenges of this arrangement on my farm	Likelihood of using this arrangement
Arrangement			
Arrangement			
Arrangement			
Arrangement			

6. SPECIES LONG LIST TEMPLATE

Species name (local)	Species name (Latin)	Description (size, shape, growth rate, other traits)	Products produced	Services provided	Main function(s)

7. PAIRWISE TABLE

	Species 1	Species 2	Species 3	Species 4	Species 5
Species 1					
Species 2					
Species 3					
Species 4					
Species 5					

7. PAIRWISE EXAMPLE

The table below gives an example of a filled in pairwise table. In this case, 5 species options were compared. Based on the number of times each species appears in the table, the species preference list would be (from highest to lowest):

1. Durian (4 appearances)
2. Avocado (3 appearances)
3. Banana (2 appearances)
4. Pepper (1 appearance)
5. Gliricidia (0 appearances).

	Pepper	Banana	Gliricidia	Avocado	Durian
Pepper					
Banana	Banana				
Gliricidia	Pepper	Banana			
Avocado	Avocado	Avocado	Avocado		
Durian	Durian	Durian	Durian	Durian	

8. BILL OF QUANTITIES TEMPLATE

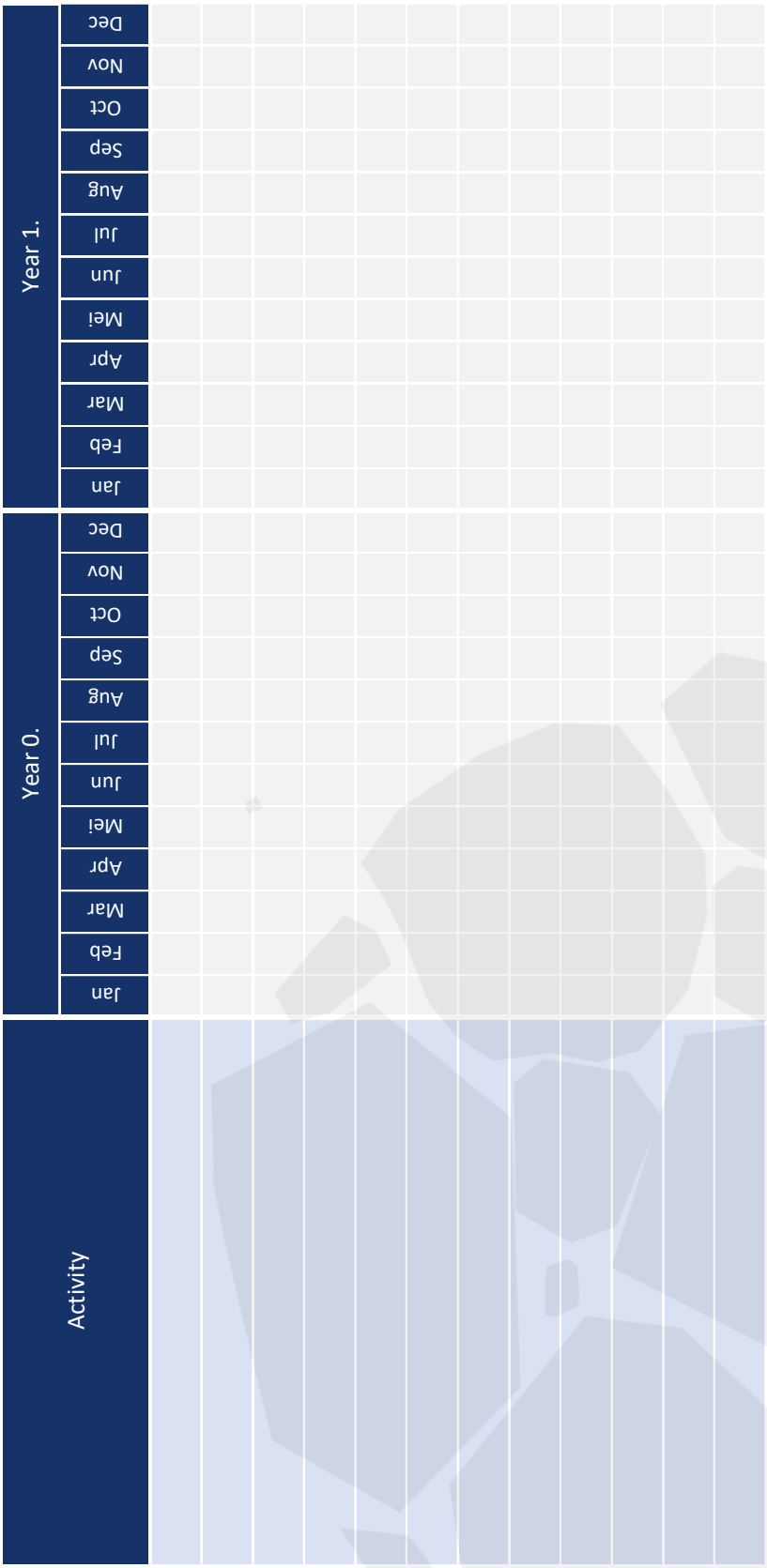
Species			Spacing				Quantity				
Functional group	Common name	Latin name	Spacing (m)	In-row (m)	Between -row (m)	Space per plant (m2)	Number / hectare, mono	Number / ha, mixed	Contingency multiplier	Total required / ha	Total required / plot
									105%		
									105%		
									105%		
									105%		
									105%		
									105%		
									105%		
									105%		
									105%		

Size of plot (ha)	
m2 per hectare	10000

9. ESTABLISHMENT PRACTICES TEMPLATE

Method / practice	What is needed (materials, equipment etc.)?	When should it be done? (E.g. Season, or in relation to other tasks)	Advantages	Disadvantages	Likely to use?

11. ESTABLISHMENT CALENDAR TEMPLATE



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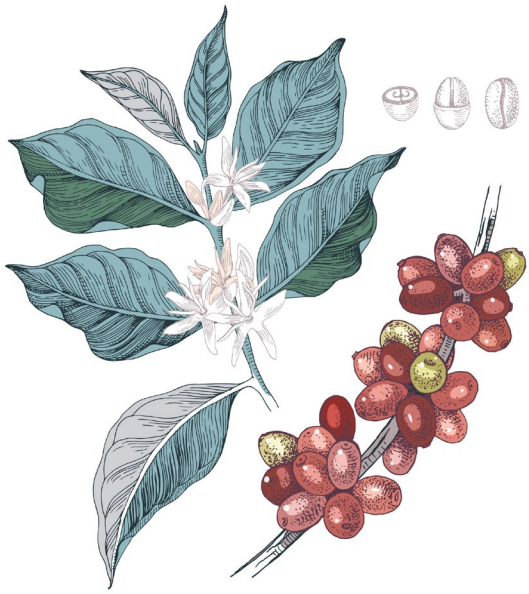

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