Sustainable Farming in Tropical Asian Landscapes

Agroecological principles and practices for cacao cultivation

A technical guide

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Objectives of the technical guide

This technical guide aims to capacitate field extensionists and farmer-leaders working with smallholder cacao growers in conducting training sessions on agroecological practices for environment-friendly and climate-resilient cacao cultivation. Specifically, this technical guide details the principles and benefits of agroecology, as well as the different agroecological practices that can be integrated into cacao cultivation, particularly in relation to soil health and fertility management, integrated pest and disease management, and shade management.

Unit 1: What is agroecological practice?

Defining agroecological practice

Agroecological practice is a farming practice that **applies ecological principles**. It aims to **address environmental degradation** caused by widespread intensive farming methods.

Agroecological practice **can be applied to any type of crop**, including cacao. With this, crop cultivation can become more **environment-friendly and climate-resilient**.

Key principles of agroecology

This section presents the key principles[1] of agroecological practices.

1. Recycle organic materials

This principle encourages using local renewable resources and enhancing resource cycling. For example, we may bury rotten cacao pods between rows of cacao, using it as additional organic inputs. This helps return lost nutrients, like potassium, to the soil. We may also use litterfall and pruned branches from cacao or shade trees for mulching and composting.

One example of recycling organic materials is placing dried coconut husks at the base of cacao trees to enhance soil fertility and help preserve soil moisture.

1 For a more detailed information, please see e.g., Wezel A, Herren BG, Kerr RB, Barrios E, Gonçalves ALR, Sinclair F. 2020. Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. *Agronomy for Sustainable Development* (2020) 40:40, pp 1-13; or Jeanneret Ph, Aviron S, Alignier A, Lavigne C, Helfenstein J, Herzog F, Kay S, Petit S. 2021. Agroecology landscapes. *Landscape Ecol.* 36: 2235–2257

Key principles of agroecology

This section presents the key principles of agroecological practices.

2. Reduce chemical inputs

It is possible to reduce the farm's dependence on chemical or synthetic inputs without compromising cacao productivity, while also promoting efficient use of local resources. For example, we can use organic inputs from plants and animals and integrate nitrogen-fixing trees like madre de cacao (*Gliricidia sepium*) or falcata (*Paraserianthes falcataria*) and cover crops like mani-mani or pinto peanut (*Arachis pintoi*). These practices enhance soil fertility while reducing the use of synthetic fertilizers.

In addition, regular and proper pruning improves shade and farm sanitation. With this, we can prevent pest and diseas outbreaks, lessening the need to buy pesticides and fungicides.

*Planting **mani-mani or pinto peanut** as cover crop helps in enhancing soil fertility while reducing the use of chemical inputs.*

Key principles of agroecology

This section presents the key principles of agroecological practices.

3. Secure and enhance soil health

Maintaining healthy soils also involves the first two principles of agroecology. For instance, adding organic matter into the soil through the use of litterfall or pruned branches helps increase soil biological activity. Also, integrating deep-rooted trees help improve soil porosity and infiltration.

In sloping areas, trees along contour lines can help stabilize the soil and reduce erosion. We may also consider using natural vegetation or grass strips along the contour lines to form natural terraces or 'green infrastructure'[2].

One of the easiest ways to conserve soil health and fertility is to use litterfall and pruned branches as mulch.

2 Do VH, La N, Bergkvist G, Dahlin S, Mulia, R, Nguyen VT, Oborn I. 2023. Agroforestry with contour planting of graces contributes to terrace formation and conservation of soil and nutrients on sloping land. Agriculture, *Ecosystems & Environment* Volume 345.

Key principles of agroecology

This section presents the key principles of agroecological practices.

4. Maintain or increase agrobiodiversity

Agrobiodiversity in time and space within the farm can be enhanced while ensuring synergy among farm components, which may also include both plants and livestock. One example is combining cacao with coconut, fruit or timber trees, and understorey crops like sweet potatoes, with appropriate spacing and management options for all to grow in synergy. Additionally, practicing integrated or multi-strata cacao agroforestry can attract insects or other animals, promoting pollination, biological control of pests and diseases, soil conservation, and nutrient cycling.

Aerial view of an integrated cacao farm

5. Synergize various components

Synergy occurs in a farming system when interaction among crop components, with or without animals, in time and space, provides multiple benefits across a range of products and services. For instance, coconut trees provide shade for cacao, while also reducing the impact of strong winds. As mentioned in the previous principles, certain fruit or timber trees may attract insects or animals that are beneficial for pollination and pest and disease control. It may also improve soil health while also providing alternative sources of income.

6. Promote economic diversification

Agrobiodiversity also diversifies sources of income. It can help farmers better cope with the economic consequences of fluctuating markets and uncertain climate conditions.

Key principles of agroecology

This section presents the key principles of agroecological practices.

7. Co-create knowledge

Agroecology and integrated farming practice naturally trigger knowledge and experience sharing among farmers or with other stakeholders. This also encourages co-creation of knowledge combining local and scientific information.

Benefits of agroecological practices

Agroecological practices make cacao cultivation more environment-friendly.

- Reduced chemical inputs and lowered risk of soil and air pollution
- Lowered risk of soil erosion in sloping lands, hence, reduced sedimentation in nearby bodies of water[3]
- Increased population of useful soil biota resulting from more abundant supply of organic matter
- More pollinators and/or natural predators, preventing pest and disease outbreaks
- Reduced greenhouse gas emissions due to minimal use of chemical inputs
- Improved soil infiltration and water retention because of integrating timber and/or fruit trees with proper spacing and shade management, especially those with deep rooting systems

3 Please see Hung, D.V., La N., Bergkvist, G., Dahlin A.S., Mulia, R., Nguyen, V.T., Oborn, I. 2023. Agroforestry with contour planting of grass contributes to terrace formation and conservation of soil and nutrients on sloping land. Agriculture, *Ecosystems, & Environment* Vol 345, 1 April 2023.

Benefits of agroecological practices

Agroecological practices make cacao bean production more sustainable.

Agroecological practices promote sustainable cacao production through the following:

Farmers can take care of their cacao trees by applying agroecological practices like regularly pruning and sanitizing their farms, while also ensuring income diversification, using resources efficiently, and enhancing soil health and other ecosystem services.

Diversifying cacao clones to facilitate successful pollination and fruit production can increase yield. Clonal diversification, coupled with appropriate capacitation of farmers, help them optimize the production of their farms, at the present and in the future.

Agroecological practices make cacao farmers more market resilient.

Crop diversification also allows for income diversification and stability, reconciling short- and long-term income sources. With this, farmers can also gain alternative sources of income, making them more resilient to market uncertainty.

Agroecological practices make cacao farmers more climate-resilient.

Agroecological practices, particularly crop diversification and integration of trees, help farmers become more resilient to various climate threats.

- Trees integrated in the farm provide shade for cacao and reduce the impact of climate threats like drought, heat, and strong winds.
- Shade trees also improve the micro-climate within cacao farms, reducing the risk of pest and disease outbreaks.
- Income diversification and stability also increase the farmer's capacity to cope with impacts of unfavorable climate on cacao.

Unit 2: Agroecological principles integrated into farm planning and design

This section presents several ways to integrate agroecological principles into planning and designing a cacao agroforestry farm.

Clonal diversification of cacao

In the Philippines, scientists and industry experts recommend having at least three to five clones per farm site. At present, there are 20 clones registered to the National Seeds Industry Council (NSIC), but only six of which are prevalently used (Table 1).

Table 1. Cacao clones approved by NSIC.

Cacao clones approved by National Seeds Industry Council (as of 2024)			
UF18	K4	ICS40	DR1
BR25	K7	P7	UIT1
PBC123	K8	USM Ch1	TSO1
K1	K9	USM Ch2	TSO2
K2	K10	S5	RSO3

Legend: *Prevalently used in the Philippines*

Clonal diversification of cacao

Multiple clones can be integrated in established farms through grafting other beneficial clones in existing cacao.

For Davao Region and neighboring provinces, UF18, PBC123 and BR25 are the highly recommended clones since these were proven to be early maturing, early fruit-bearing, high yielding, and disease-tolerant. There are also other clones like W10, PG 610 and EM 617, which have shown remarkable performance but are yet to be approved by NSIC.

Cacao is a non-self-pollinating plant. Most of its commercial clones are self-incompatible. Therefore, its productivity depends on the ability of a clone to accept or reject pollen tubes. This is also considered as a direct cause of low yields. With this, one of the solutions is to adopt clonal diversification through planting or side-grafting selected clones with neighboring rows of compatible clones. This will facilitate successful pollination, fruit production, and eventually, increased yield.

An example of suggested percentage of different clones per hectare is 60-70% of UF18, 10-20% of W10, 10% of BR25, and 10% of PBC123. It is also presented visually in the graph on the next page.

Clonal diversification of cacao

Meanwhile, Kennemer Foods International, Inc. (KFI), one of the major cacao buyers in Davao de Oro, through several training sessions with cacao farmers in Davao de Oro, has highlighted a clone combination of 60% of C45, 15% of UF18, 10% of W10, 10% of PBC123, and 5% of BR25. KFI has also suggested a compatibility of combination among clones as shown in the table below. Higher percentages mean better compatibility of the colnes when combined.

Table 2. Compatibility of cacao clones for combination.

		Pollen donor (father)				
		C45	**W10**	**BR25**	**PBC**	**UF18**
Maternal (mother)	**C45**	0%	39.93%	45.98%	0%	0.63%
	W10	42.83%	0%	50.13%	41.38%	43.13%
	BR25	50.78%	44.19%	3.13%	26.47%	46.52%
	PBC	0.91%	44.38%	47.62%	1.88%	0%
	UF18	0%	34.82%	13.59%	0%	0%

Source: KFI

Selecting quality planting materials

One of the main factors affecting the growth and productivity of cacao trees is the quality of planting materials used. If high-quality planting materials are used, such as those of the right age and sturdiness, the seedlings have higher chance of surviving and growing faster. This ensures efficient use of resources and good growth of cacao trees even with limited inputs. The factors that need to be considered in selecting planting materials presented in the following sub-sections.

Seedling bag sizes

In propagating cacao seedlings, it is best to use 8 in x 10 in black polyethene perforated bags for cacao seedlings. However, using larger seedling bags is recommended because it supports better seedling development. Bigger bags can hold a large amount of soil mixture which has a positive effect on the growth and development of seedlings. According to cacao experts, seedlings in large polythene bags obtain the highest growth performance and sturdiness quotient value which is the indicator of best quality seedlings.

Selecting quality planting materials

Age of the seedling

A grafted cacao seedling is ready to be planted six to eight months after grafting. It can also be planted earlier, around three months after grafting, only if it has six to eight pairs of leaves which are hardened or have no new flush of leaves.

Sturdiness of the seedling

To make sure that the seedling is sturdy, we can measure its sturdiness quotient. The sturdiness quotient is the ratio of the height of the seedling to the root collar diameter, which expresses the vigor and robustness of the seedling. The ideal value for a seedling to be considered sturdy is ≤6. Anything above the said value is considered "lanky" or very tall and slender in diameter. Such seedlings are unlikely to survive in windy and dry conditions.

$$\textbf{Sturdiness quotient} = \frac{\textit{Seedling height (cm)}}{\textit{Root collar diameter (mm)}}$$

A demonstration on how to measure the sturdiness quotient.

Integrating cacao in multi-strata systems

The complexity of cacao-based farming systems can still be enhanced through integrating other crop components such as understorey species or border trees. This section details information on possible layers and combinations for multi-strata cacao-based practice.

Principles of integrating crop species in a multi-strata practice

Some key principles in integrating plant species to eventually create a multi-strata practice are presented below:

1. The first plant species to be integrated into the farm[4] are those that thrives under full sunlight.
2. Plant species that can serve as shade trees should be planted before the shade-loving species.
3. Plant species that can enrich the soil, like nitrogen-fixing trees, should be planted before those that require good soil conditions.
4. The growth rate and canopy size of planted trees once these mature should be considered in the spacing to give them sufficient space to grow and avoid over-shading. Cacao trees need more shade when young but it requires less shade during the productive stage.
5. Consider potential income from the crops, either short-term or long-term. If possible, plant species that can produce different fruits at different times to facilitate allocation of available labor.

4 Assuming a relatively 'relative' farm

Integrating cacao in multi-strata systems

Creating a multi-strata cacao-based practice optimizes the use of growth resources like light, water, soil nutrients, and space by integrating annual and perennial crop species which can complement each other. Such a system requires appropriate spacing and farm management options in order to succeed.

Possible layers and crop combinations in a multi-strata cacao-based practice

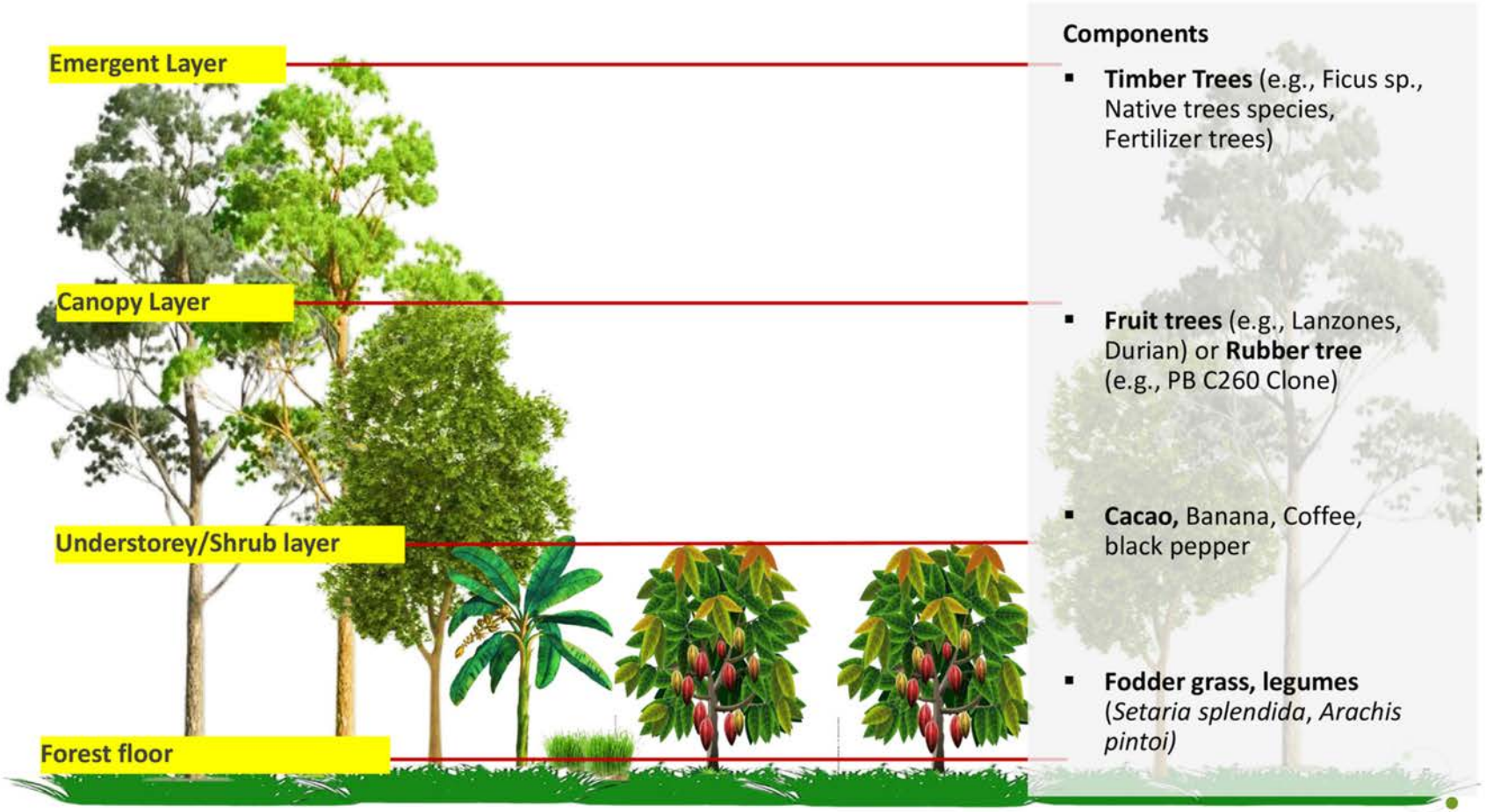

Figure 1. Layers of canopies in multi-strata cacao-based forest

Integrating cacao in multi-strata systems

Possible layers and crop combinations in a multi-strata cacao-based practice

For the emergent layer, timber trees like Musizi (*Maesopsis eminii*) can provide shade to lower canopies and produce fruits for wildlife. In the lower canopy, fruit trees like lanzones or durian, or rubber trees, can be integrated. Cacao and/or banana are in the understorey or shrub layer of the system.

Belowground, layers of root systems make water and nutrients available at different soil profiles. Deeper root systems help transfer water from deeper layers to more superficial soil layers[5]. This also allows for the plants to extract nutrients from deep soil layers. These nutrients will also return to the soil through litter fall[6]. Root decay also increases soil organic matter. In the case of sloping lands, these root systems also help reduce the risk of soil erosion.

5 Please see e.g., Alagele et al. 2021. Hydraulic lift: processes, methods, and practical implications for society. Agroforestry Systems 95 (4).

6 Please see e.g., Allen et al. Safety-net role of tree roots: evidence from a pecan (Carya illinoensis K. Koch)–cotton (Gossypium hirsutum L.) alley cropping system in the southern United States *Forest Ecology and Management* 192: 395-407.

Recommended border tree species and potential benefits

In relatively small farming areas like smallholder farms, boundary planting can help protect cacao trees from strong winds. Such trees that can be regularly pollarded can also meet the family's need for firewood and fodder. Boundary trees can also attract beneficial insects and pest predators, while sequestering carbon.

Examples of trees that can be used as farm boundaries are native trees like dap-dap (*Erythrina variegata* Linn.), bagalnga (*Melia dubia*) or tree shrubs like madre de cacao (*Gliricidia sepium*) and calliandra (*Calliandra calothyrsus*).

However, it needs to be noted that planting boundary trees requires approval from owners of adjacent farms to avoid conflicts.

Appropriate spacing and density

Ensuring the proper spacing and density of cacao-based agroforestry farms not only starts in the planting but in as early as the land preparation. Land preparation for new cacao farms should be done at least one year before seedlings are planted. The steps for preparing the land are:

1. Remove all kinds of debris in the field, without cutting existing native shrubs or trees that may also serve as nurse trees.
2. Mark the planting points using one-meter stakes according to the recommended planting distance. For cacao intercropped with other crops, the recommended spacing and density for cacao is presented in the next section. Ropes or strings are also used to mark the rows, ensuring a straight line.

Integrating cacao in multi-strata systems

Appropriate spacing and density

For sloping areas, the planting points should be aligned to the contour. Therefore, the contour lines must be established first before marking the planting points. This can be done using an A-frame or the cow's back method. The contour lines should have 0.5-meter-wide natural vegetative filter strips, laid out 10 meters apart. In between the contour strips, planting points for cacao should be established 3 meters apart, and 3.5 meters away from the strip. Permanent and some temporary shade trees should be established and well-arranged to shelter young cacao trees.

Integrating cacao in multi-strata systems

Appropriate spacing and density

The most recommended planting distance for cacao trees is 3 meters x 3 meters between hills and rows using UF18 (60-70%), W10 (10-20%), BR25 (10%) and PBC123 (10%) clones, with 1,111 trees per hectare.

When intercropped with coconut and banana as shown in Figure 2, cacao trees are planted at least 3 meters from the base of the coconut, with a 3.5-meter distance between hills and a 3.5-meter distance between rows, with 816 trees per hectare. Bananas are planted in between rows of cacao but after 3 years, the number of banana hills must be reduced.

Figure 2. An example of cacao intercropped with coconut and banana in Barangay Dumlan, Maco, Davao de Oro.

Integrating cacao in multi-strata systems

Appropriate spacing and density

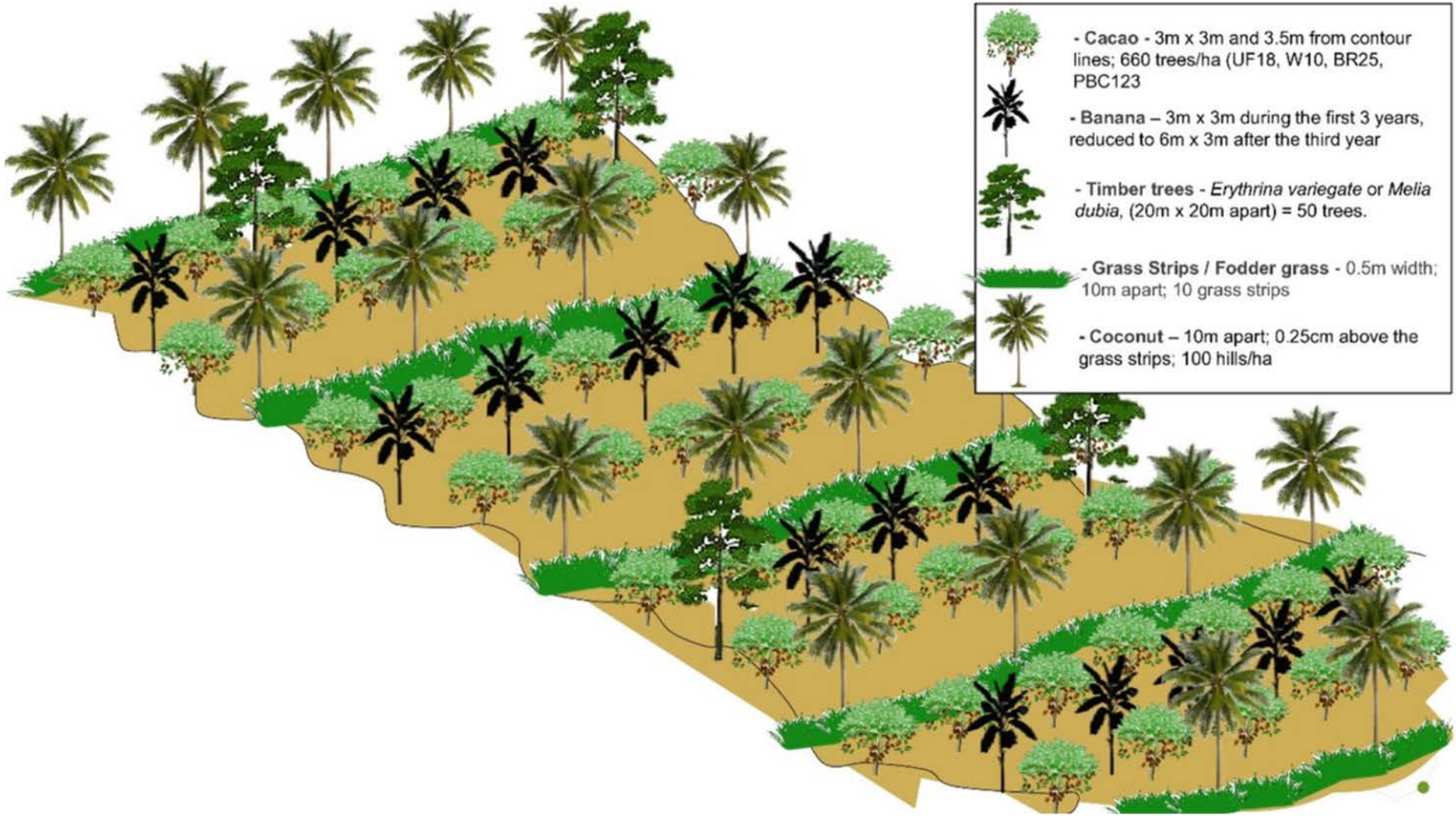

Figure 3. A sample design of a cacao-based agroforestry system in sloping land using cacao + coconut + banana + timber trees showing the suggested shade trees and intercrop species (Diagram: World Agroforestry/Erwin B. Albios)

Integrating cacao in multi-strata systems

Appropriate spacing and density

When integrated with coconut, banana and fruit trees, cacao trees are planted with a distance of 4 meters x 3 meters, with 833 trees per hectare. Bananas are planted in between rows of cacao. Coconuts are spaced 10 meters x 10 meters. Fruit trees are planted randomly, particularly 4 meters away from the cacao and in missing hills of coconut.

For sloping areas, cacao is planted in between the contour strips, with a 3-meter distance between trees and 3.5 meters away from the contour strip. As shown in Figure 3, coconut or fruit trees like lanzones (*Lansium domesticum*) can be planted 10 meters apart, around 25 centimeters away from the contour strip, eventually serving as shade tree for cacao. Banana (either Lakatan or Cardava variety) can be planted in between cacao trees to provide temporary shade to the newly planted cacao trees. Additionally, mani-mani (*Arachis pintoi*) can also be planted as ground cover.

Integrating cacao in multi-strata systems

Appropriate spacing and density

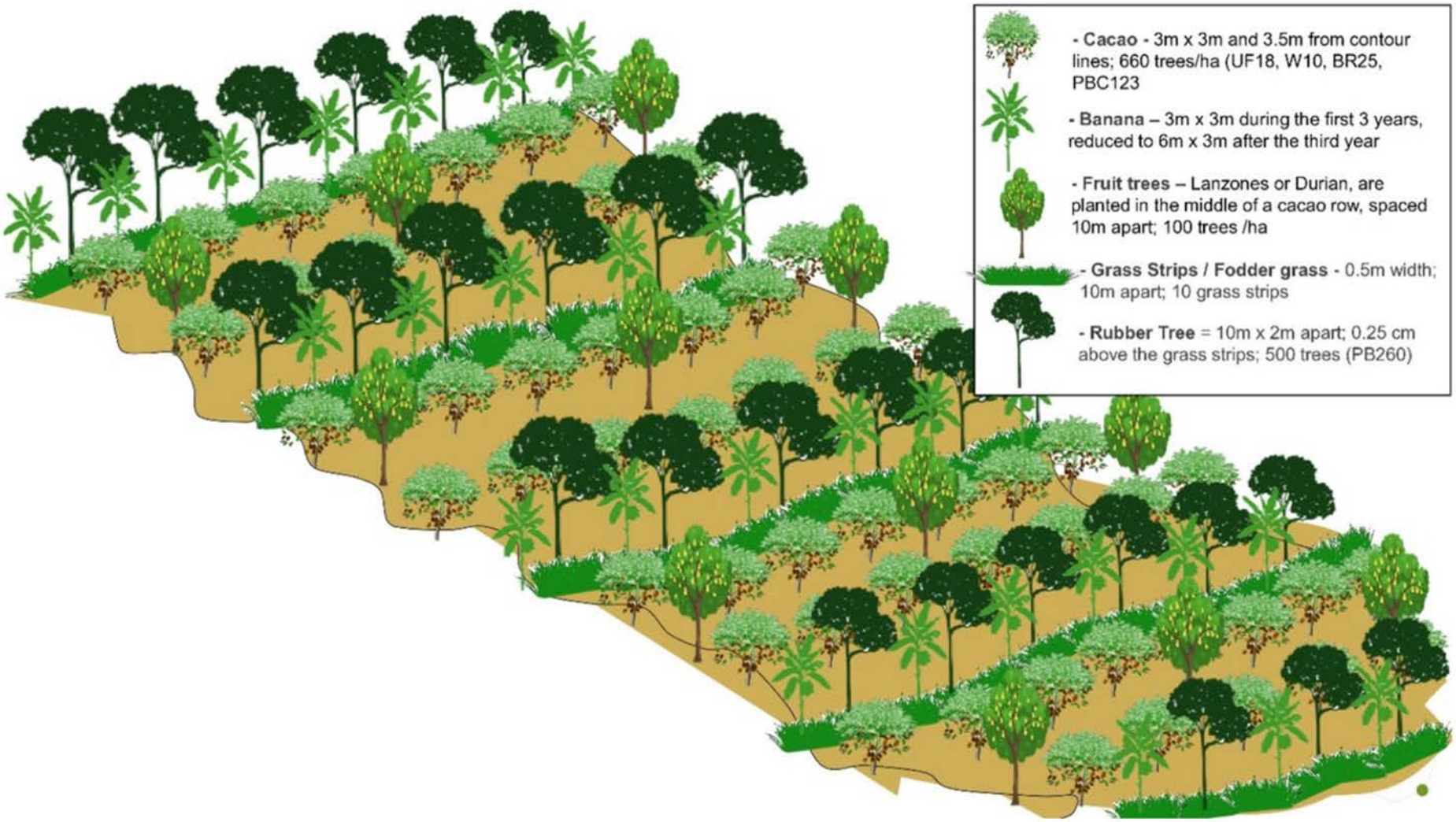

Figure 4. A sample design of cacao-based multi-strata agroforestry system in sloping land using cacao + rubber + banana + fruit trees showing the suggested spacing of intercrop species (Diagram: World Agroforestry/Erwin B. Albios)

Integrating cacao in multi-strata systems

Appropriate spacing and density

Other crops that can be integrated in between rows of cacao during the first three to five years include food crops like corn, cassava and taro, and leguminous crops like mung bean, soybean and peanut. From the sixth year onwards, the cacao will be at its peak productive stage, therefore providing too much shade for understorey crops. It is recommended to plant forage legumes like mani-mani instead to serve as live mulch for soil conservation and weed suppression.

Possible use of organic materials during basal planting

The rainy season is the best time to plant cacao. During planting, the topsoil should be put back first into the planting hole. It should be mixed with natural fertilizer, such as compost with vermicast and other organic matter. Then, a mixture of 100 to 150 grams of complete fertilizer (14-14-14) and at least 1 kilogram of dried animal manure, if available, should be placed as basal fertilizer before carefully planting the cacao seedlings.

Planting the cacao seedlings follows this procedure:

1. Carefully remove the polyethelyne bag of the cacao seedling.
2. Plant the seedling with buds or young branches facing the east.
3. Cover the base of the newly planted seedling, forming a little elevation to prevent waterlogging. Stumping or compressing the soil in the base is not advisable as it may cause compaction.
4. Coconut fronds can be placed around the planted cacao seedlings to provide temporary shade, protecting them from the sun while it is still recovering.

Unit 3: Agroecological principles in soil and water management

This section presents agroecological principles related to soil and soil and water conservation.

Soil conservation

Soil conservation follows two principles:

1. **Protect soil against erosion.** Protect the soil surface with at least 30% ground cover, reducing the rate of runoff, reducing the length and steepness of the slope, and increasing the surface roughness.
2. **Reduce soil susceptibility to water and wind erosion.** Improve soil management through incorporating crop residues, manure, and practicing crop rotation.

Approaches in soil conservation

Various approaches in soil conservation can be generally categorized into two: barrier and cover approach.

Barrier approach

This includes methods that reduce run-off and soil removal using contour-aligned barriers. Some examples are the uses of terraces, ditch and bund earth structures, grass strips, and hedgerows. Diversion channels and grassed waterways can also be used to promote water infiltration.

Cover approach

This includes methods used to minimize impact of raindrops and run-off through maintaining good soil cover. It can be formed by living or dead plant material including herbaceous plants, crop residues, tree litter, and pruned branches.

Soil water management in cacao farms

As mentioned in the previous section, the best time to plant cacao is at the onset of or during the rainy season. This is to minimize the need for watering the seedlings and the soil. If there is an impending long dry spell, watering is essential.

The soil is also an important component of the water system because of its role in infiltration, surface runoff, and groundwater recharge. Therefore, soil and water management methods must always be combined with soil conservation techniques.

Soil and water conservation options for cacao cultivation

There are various agroecological practices that can be applied in cacao farms for soil and water conservation. Some of these options are presented in this section.

Green infrastructure in sloping lands

Establishing green infrastructure is one of the most accessible and affordable soil and water conservation methods for sloping lands. One of its common examples is establishing contour lines using vegetative strips like fodder grass. The specific method of establishing contour line has been presented in Unit 2.

Figure 5. An example of barrier approach technique by installing the contours using grass strips, fodder grasses or other materials available before lay outing for cacao planting is recommended to minimize soil runoff

Soil and water conservation options for cacao cultivation

Green infrastructure in sloping lands

Figure 6. Installing the contour-aligned barriers at every two rows of cacao using discarded branches and prunings to control soil run-off as well as to promote water infiltration.

If the cacao farm has already been established in a sloping area and establishing contour lines is no longer possible, other barrier approaches can be introduced. We can use discarded branches from pruning, rocks, coconut husks, and other indigenous materials available in the farm. Such organic barriers may also serve as habitat for cacao pollinators like midges. These practices also help maximize the use of farm by-products, therefore reducing dependency on purchased inputs.

Soil and water conservation options for cacao cultivation

Integrating cover crops

Maintaining a good soil cover helps increase soil organic matter, which is an essential component of healthy soils. It also helps retain soil moisture, sequester nitrogen, conserve soil water, and serve as sinks for greenhouse gases. This can be achieved through integrating leguminous cover crops and nitrogen-fixing trees or shrubs, an example of which is shown in Figure 7.

Figure 7. Nitrogen-fixing trees like Falcata can also be integrated with cacao to help increase soil organic matter.

Soil and water conservation options for cacao cultivation

Integrating cover crops

Options for nitrogen-fixing trees

Nitrogen-fixing trees are also called 'fertilizer' trees because of their importance in soil nutrient cycling. Basically, fertilizer trees work well together with nitrogen-fixing bacteria (that is, a set of bacteria that takes nitrogen from the atmosphere and turns it into a form that plants can use) and mycorrhizae-forming fungi that allows plants to absorb water and nutrients from the soil more effectively [7]. This interaction helps improve the nutrients in the soil.

In the Philippines, the most recommended species of fertilizer trees for cacao-based systems include madre de cacao or kakawate (*Gliricidia sepium*), dap-dap (*Erythrina variegate*), bagalnga (*Melia dubia*), and Falcata (*Paraserianthes falcataria*).

Options for leguminous cover crops

When planted, leguminous cover crops serve as living mulch, providing large amounts of organic material, nitrogen, and available phosphorous in the soil which can also reduce fertilizer cost. Moreover, cover crops prevent the soil from losing too much water from evaporation. Their root system can help improve soil porosity, density, and structure. For cacao, the recommended leguminous cover crop is mani-mani (*Arachis pintoi*)[8].

7 Nygren, S.E.P., Fernández, M., Harmand, J.-M., Leblanc, H.A., 2012. Symbiotic dinitrogen fixation by trees: an underestimated resource in agroforestry systems? *Nutrient Cycling in Agroecosystems* 94, 123–160

8 Firth DJ, Jones RM, MCFayden LM, Cook BG and Whalley RDB. 2002. Selection of pasture species for groundcover suited to shade in mature macadamia orchards in subtropical Australia. *Tropical Grasslands* 36:1-12.

Soil and water conservation options for cacao cultivation

Using crop residue for nutrient cycling

Soil nutrient depletion has been one of the major reasons for declining cacao yields. Chemical fertilizers are often not an option for cacao smallholders either due to lack of access or its high cost. Therefore, one recommended practice is to use crop residues. For example, composted empty cacao pods can be buried like a ring around the base of cacao trees, aligned with the boundary of its canopy. This can be done twice a year after the main fruiting season to replenish soil nutrients.

Another example is collecting empty, damaged, and rotten cacao pods and burying these along the cacao alleys in a 1-foot-deep trench. These pods should be disinfected with fungicide and covered with thin soil so it will eventually become a natural fertilizer for the soil. This practice also helps in controlling pests and diseases.

Figure 8. Rotten cacao pods can be collected in a hole, therefore, enhancing the soil's organic matter and returning some of the loss nutrients to the soil.

Soil and water conservation options for cacao cultivation

Using crop residue for nutrient cycling

Figure 9. An example of the practical application of mulching using farm leftovers (e.g., decomposed banana trunks and coconut husks) into the cacao trees to maintain soil moisture and suppress weeds.

Mulching can also be done using farm leftovers like decomposed coconut husks, banana trunks, or rice hulls. These can be placed at the base of the cacao tree to maintain soil moisture and suppress weeds. This mulch will eventually become a natural fertilizer, helping replenish soil nutrients and generally improve the productivity of the farm.

Soil and water conservation options for cacao cultivation

Rainwater harvesting

In this practice, water runoff during rainy days is collected and stored in a pond. This prevents downstream flooding while also storing water that can be used during long dry spells.

Figure 9. An example of rainwater harvesting in a cacao-based agroforestry system. The use of rainwater harvesting system is very effective and efficient as a source of irrigation water for smallholders in the Philippine upland particularly during long dry spells due to climate change.

Soil and water conservation options for cacao cultivation

Building micro-catchment systems

Micro-catchment systems are direct water harvesting methods where small structures are built across the slopes to capture surface runoff and store it in the plant zone for subsequent plant use. Such method is more beneficial than other irrigation schemes because of its simplicity and affordability. It can also be constructed quickly using local materials and manpower [9].

One way to apply this is through creating semi-circles or half-moons[10] around the trunk of the cacao using different mulching materials. This should be placed 2.5 meters away from the tree trunk, at the 'downward side' of the plant, with a width of 30 centimeters and a height of 30 centimeters.

For cacao trees not planted on sloping lands, circular bunds can also be created. Like the semi-circles, it should be placed 2.5 meters away from the trunk of the cacao, with a width of 30 centimeters and a height of 30 centimeters.

9 Boers et al. 1986. Micro-Catchment-Water-Harvesting (MCWH) for arid zone development. *Agricultural Water Management* 12 (1–2): 21-39.

10 Please also see: Partey et al. 2018. Developing climate-smart agriculture to face climate variability in West Africa: Challenges and lessons learnt. *Journal of Cleaner Production* 187: 285-295.

Soil and water conservation options for cacao cultivation

Building micro-catchment systems

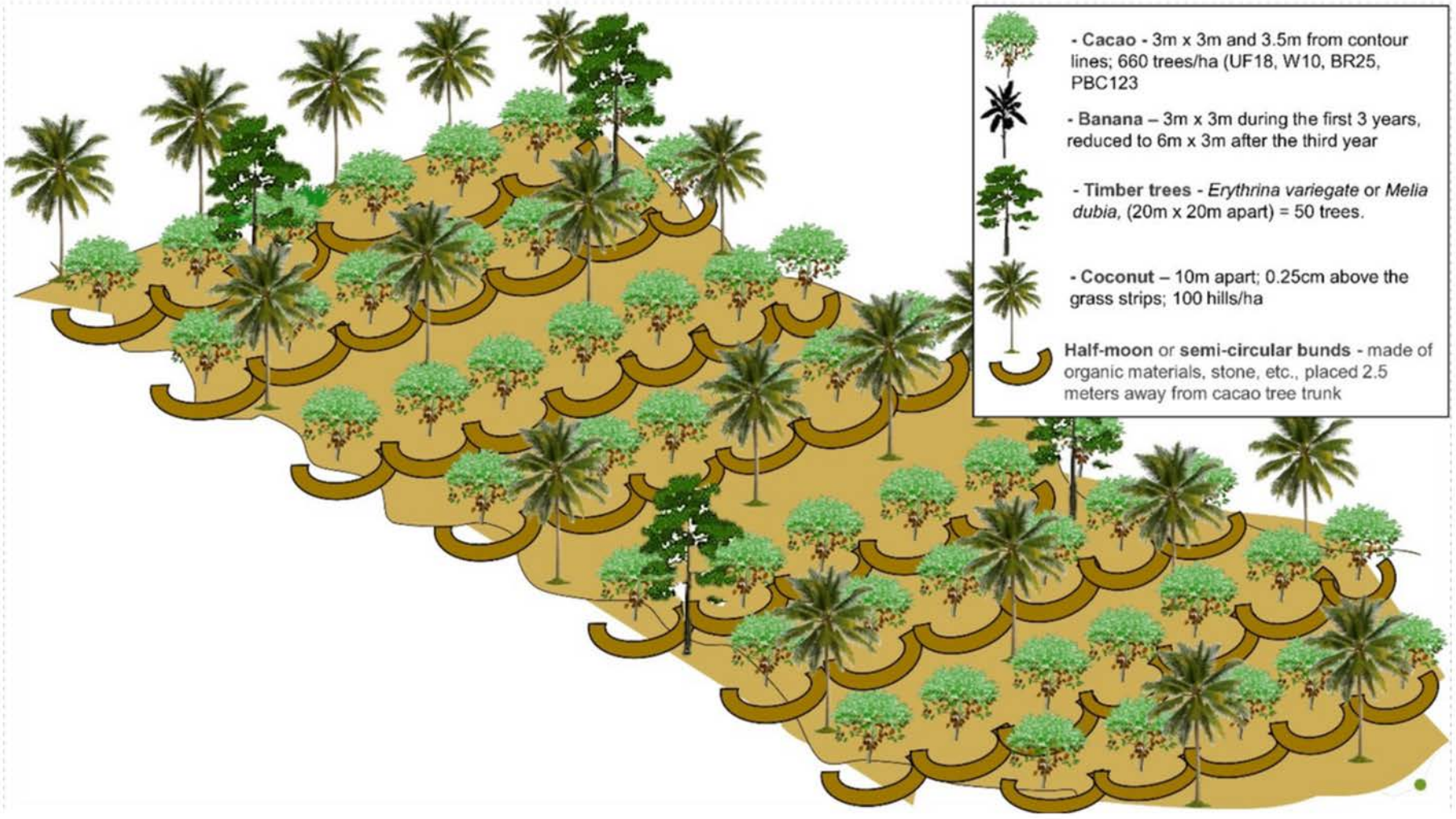

Figure 10. An example of a micro-catchment system in cacao production where half-moon or semi-circular bunds using various types of mulching materials (in blue) are created at the downstream side of the plant across the slope to capture excess surface runoff.

Unit 4: Agroecology principles in shade management for cacao

Agroecology principles in shade management for cacao

Appropriate shade can improve the micro-climate[11] and rhizosphere[12] within cacao farms. Proper arrangement and selection of shade trees positively affects yield under low input systems, as compared to full-sun cacao cultivations[13, 14, 15]. This section presents essential information related to shade management for cacao, particularly its shade requirement and the suitable shade tree species.

11 Please see for example: Famuwagun IB. 2018. Effects of shade regimes and varying seasons of irrigation on survival, developmental pattern and yield of field grown cacao (*Theobroma cacao*). *International Journal of Plant & Soil Science* 22 (3): 1-12.

12 Namely, the region of soil in the vicinity of plant roots. Please see for example: Schmidt et al. 2022. Impacts of shade trees on the adjacent cacao rhizosphere in a young diversified agroforestry system. *Agronomy* 12, 195. https://doi.org/10.3390/agronomy12010195.

13 Please see for example: Asitoakor et al. 2022. Selected shade tree species improved cocoa yields in low-input agroforestry systems in Ghana. *Agricultural Systems* 202.

14 Mensah et al. 2023. Combined effects of shade and drought on physiology, growth, and yield of mature cocoa trees. *Science of the Total Environment* (899).

15 Asare et al. 2019. On-farm cocoa yields increase with canopy cover of shade trees in two agro-ecological zones in Ghana. *Climate and Development* 11 (5).

Shade requirement for cacao

Adequate shade is essential for the health of cacao trees. Under-shaded cacao trees usually have stunted growth, scalding leaves and stems, damaged flower cushions, fewer leaves, water stress, and low yield. On the other hand, over-shaded cacao trees also have stunted growth, elongated stems and leaves, minimal flowering, fewer pods, and high incidence of pests and diseases like pod rot and pod borer.

The required shade for cacao trees highly depends on their age and the soil fertility conditions in the area. The actual shade requirements are presented in the table below.

Table 3. Shade requirement for cacao depending on soil fertility and tree age.

Cacao age (year)	Shade requirement in fertile soils	Shade requirement in less fertile soils
1	30% - 70%	30% - 70 %
2	30% - 50 %	30% - 70 %
3	20% - 40 %	20% - 50 %
4	20% - 30 %	20% - 40 %
5	10% - 25 %	20% - 30 %
>5	10% - 25 %	20% - 30 %

Shade requirement for cacao

Aside from soil fertility, elevation, temperature and seasons also influence shade management. While cacao can thrive in elevations of 50 to 1200 meters above sea level (masl), the optimum elevation is 400 to 800 masl. At above 500 masl, cacao trees require less shade as opposed to lower elevation, hence the need for more shade trees.

Additionally, elevation affects the surrounding temperature in the farm. When the temperature is high, cacao trees require more shade. Therefore, cacao trees require more shade in lower elevation and during dry seasons. This also means that shade trees need to be pruned at the onset of the rainy season, so that these will grow during the dry season to provide the required shade for cacao.

Moreover, cloudiness affects shade management. During a long dry spell when the sky is usually clear, cacao trees need more shade. But during prolonged rainy periods, less shade is needed. With this, more pruning of the shade trees and cacao trees need to be done to prevent self-shading.

Selecting appropriate shade tree species

In selecting the proper shade trees to combine with cacao, it is important to consider the shade tree's growth and physical characteristics. This includes growth rate, height, and canopy shape, as well as planting densities.

Tree height. Trees with lower canopy height give more shade. However, such trees compete more with cacao trees for space and light as compared with taller shade trees. Additionally, trees or shrubs that can reach more than 4 meters in height are recommended to be used as permanent shade for cacao. On the other hand, those that are 1-2 meters high are appropriate shade trees while the cacao is still young.

Crown shape and density. The trees and shrubs that can be used to provide shade for cacao are those with the following crown shapes: conical, flat-topped spreading light crowns, tall bole with small dense crowns, and narrow columnar crown shapes[16]. Example of these are timber trees like dap-dap *(Erythrina variegate)* and bagalnga *(Melia dubia)*, and fruit trees like lanzones.

Those with rounded dense, wide conical, canopy conical in layers, and wide columnar crown shapes are not suitable for cacao. Examples of trees having such shape are mango (*Mangifera indica*) and rambutan (*Nephelium lappaceum*)[17].

16 As a note, certain species can have different canopy shapes depending on the variety. For example, for rubber, RRIM 600 and PB330 produce more shades than PB260 and GT1. PB260 is more suitable for cacao. The appropriate crown shapes and density for cacao are presented in Figure 11.

17 Mango and rambutan are also susceptible to disease.

Selecting appropriate shade tree species

Figure 11. Crown shapes of shade trees which are suitable and not suitable for cacao.

Other considerations. Functional characteristics like the ability to fix nitrogen, attract biodiversity, and improve soil porosity due to deep root systems and income benefits of trees should be considered in selecting shade trees.

Pruning

Pruning is an essential activity in the management of a cacao farm. It involves cutting and removing undesirable and excessive parts of the plant such as branches, twigs, and leaves into its desired productive shape and form. Additionally, an appropriate pruning regime considers seasonal changes in temperature and precipitation to protect the understorey.

Benefits of pruning[18,19]

Pruning brings several benefits to the smallholder farms and farmers. Specifically, it:

1. Increases cacao pod production by:
    - Stimulating flowering and enhancing fruiting
    - Increasing the capacity of trees to produce plants, and
    - Enhancing quality of cacao beans
2. Controls the shape and height of the tree to ensure easy access for harvesting and other farm management practices
3. Reduces pest and disease infestation in the farm.

18 Please also see for example: Esche et al. 2023. The role of shade tree pruning in cocoa agroforestry systems: agronomic and economic benefits. *Agroforest Syst* 97:175–185.

19 Tosto et al. 2022. The effect of pruning on yield of cocoa trees is mediated by tree size and tree competition. *Scientia Horticulturae* (304).

Pruning

Key principles of pruning

In conducting regular and appropriate pruning, the following principles must be kept in mind:

1. Ensure that there is an adequate amount of water available on the farm or through irrigation methods.
2. Avoid pruning during the dry season.
3. Use standard sharp tools when pruning to prevent unnecessary damage to cacao trees.
4. Avoid over-exposing the crown of the cacao to sunlight.
5. Do not over-prune the cacao to ensure that at most 30% sunlight can enter.
6. Do not climb the cacao tree while pruning.
7. It should provide good air circulation within the farm, with a sight space up to 50 meters.
8. Prune shade trees first before pruning cacao trees.

Pruning

Types of pruning and intensity

There are three types of pruning:

Formative pruning

Formative pruning is done to make the tree look balanced and to help the cacao to form a more symmetrical canopy, allowing only upright and healthy branches to carry the pods that will develop later. The types of formative pruning include: tip pruning and shape pruning.

1. **Tip pruning** should be done around three months after planting and three months thereafter within the first two years.
2. **Shape pruning** is done 15 months after planting, once the cacao starts flowering.

Pruning
Types of pruning and intensity

Maintenance pruning

Maintenance pruning is done to maintain the cacao plant by removing dead, diseased or sick, and broken branches, inward-growing shoots, worm branches, chupon and water shoot. This lessens competition of nutrients, sunlight and other factors among parts of tree.

The various types of maintenance pruning are:

1. **Production pruning** is done when the peak fruiting period ends. This should be minimized during long dry spells.
2. **Access pruning** is usually done upon flowering (May to June) and before high peak harvesting (September to October).
3. **Sanitary pruning** should be conducted at bi-monthly or six-week intervals.

Photo Source: DTI Davao de Oro

Pruning
Types of pruning and intensity

Productive pruning

The purpose of doing productive pruning is to give the cacao tree a structure that will help maximize its production capacity and facilitate the entry of sunlight, which is essential for the pollination, enhances pod growth and strengthens the formation of new leaves that will help increase tree's productivity level.

It can be categorized into two, depending on the intensity of the trim:

1. **Light pruning** involves cutting back water shoots, orthotropic shoots, and unhealthy or unproductive branches, including those that are hanging. This should be done once a year, before the peak flowering season, which typically occurs between April and June, depending on the local climate.
2. **Heavy pruning** entails reducing the plant's canopy height to between 3 and 3.5 meters and removing overlapping branches that interfere with neighboring plants, as well as other unproductive branches. This pruning should also be performed once a year, ideally between mid-October and December, depending on local weather conditions. This timing occurs after the peak fruiting period and before the flowering season reaches its height.

Pruning
Types of pruning and intensity

Cacao pruning requires careful decision-making and skill. Only undesirable branches and sprouts should be removed. Removing between 40% to 100% of cacao branches at once, which leads to excessive sunlight exposure of the crown, is considered over-pruning.

Pruning tools and materials

Tools used in pruning cacao trees

To prune cacao trees, we need the following tools:

1. Pruning shear
2. Pruning saw
3. Expandable pole saw pruner

Pruning

Pruning tools and materials

Tools used in cacao rehabilitation

Cacao rehabilitation is usually recommended for cacao trees from 21 years old and above. Below are the tools that we may use in rehabilitating old cacao trees:

1. Pruning saw
2. Expandable pole saw pruner
3. Small Chainsaw - this is used for bigger cacao trunks and branches
4. Grafting knife
5. Grafting tape
6. Plastic cellophane cover
7. Plastic straw rope
8. Ice candy wrapper or a small plastic as covering for grafted scions

We also need high quality cacao seedlings if we want to replace the existing cacao with a new one. However, if we decide to do side-grafting or top-grafting instead, we will need good and healthy scions with at least three active bud eyes.

Unit 5: Agroecological principles in pest and disease control

This section presents the most common pests and diseases affecting cacao, and the agroecological practices that may help prevent or address these problems.

Common pests and diseases in cacao[20]

The most common insects and pests affecting cacao, as well as their respective mode of action and control measures, are listed in Tables 3 and 4.

Table 4. Common insects affecting cacao

Insect pest	Causal organism	Mode of action	Control measures
Cacao Pod Borer 	*Conopomorpha cramerella*	The larva feeds on the tissue surrounding the cacao beans and on the placenta.	• Use of resistant cacao clones (side grafting or replanting) and proper pruning • Pod sleeving every two weeks or less once the pod is as big as D-sized battery • Regular and complete harvesting every 2 weeks or less • Removal and burying infected pods • Use of natural enemies like small 'sugar' ants (*Iridomyrmex* spp.), large black ant (*Dolichoderus* sp.) and weaver ant (*Oecophylla smaragdina*) • Chemical spraying when the pest attack has been very serious; specifically, spraying insecticide every 7-10 days and alternate the use of different chemical brands (e.g., Pyrethrin and Chlorpyrifos)

20 Please also see: https://car.da.gov.ph/wp-content/uploads/2023/05/Peast-and-Diseases-of-Cacaco.pdf

Common pests and diseases in cacao[20]

Table 4. Common insects affecting cacao

Insect pest	Causal organism	Mode of action	Control measures
Mealybug  Photo source: CABI/E. Hidalgo	*Planococcus lilacinus*	Feeding causes distorted shood, stunted growth, and wilted young cacao pods	• Pod sleeving every two weeks or less once the pod is as big as a D-sized battery • Mixing detergent powder and oil (around 30-60 mL) with 10 liters of water and spraying it every after 7 to 10 days • Use of natural enemies: *Scymnus* sp., Lacewing
Stem borer or twig borer  Photo source: Cocoa Research Institute of Ghana	*Zeuzera sp.*	The caterpillars of this pest bore into the bark of the stem and make a tunnel inside it, which can extend to the roots. Once this happens, the leaves of the affected stem ultimately die.	• Cutting or pruning the branch affected by the stem borer • Use of plant extracts of botanicals

20 Please also see: https://car.da.gov.ph/wp-content/uploads/2023/05/Peast-and-Diseases-of-Cacaco.pdf

Common pests and diseases in cacao[20]

The most common diseases affecting cacao are presented in the table below.

Table 5. Common diseases affecting cacao

Disease	Causal organism	Mode of action	Control measures
Cacao pod rot 	*Phytophthora palmivora*	Symptom begins as a tiny black spot on the infected part then gradually enlarges until the pod becomes blackened. In extreme damp weather, which is favorable to pathogen development, a mass of mycelium with conidia can be produced on the surface of the diseased pod. Diseased pods can fall or remain on the tree, drying up and becoming mummified.	• Application of sanitary pruning and regular management of shade to allow sunlight penetration • Ensuring a good drainage practice to avoid the spreading of spores in the puddles of water • Removing and burying infected pods • Cutting and destroying trees that died due to canker • Use of resistant clones • Use of fungicides
Stem canker 	*Lasiodiplodia theobromae*	Stem cankers are produced following the infection of wounds on the trunk or branch. With this, the infected plant can have pod rot, wilting of young cacao pods, and chupon blight.	• Use of fungal antagonists like Trichoderma Rubbing plant extracts or botanical slike kamantigue (*Impatiens balsamina*) extract on the infected area • Spraying copper-based fungicides on the infected area

20 Please also see: https://car.da.gov.ph/wp-content/uploads/2023/05/Peast-and-Diseases-of-Cacaco.pdf

Common pests and diseases in cacao[20]

Table 5. Common diseases affecting cacao

Disease	Causal organism	Mode of action	Control measures
Vascular Streak Disease 	*Oncobasidium theobromae*	Yellowing of leaves characterized by interveinal chlorosis, roughened bark on infected branches, vascular streaking or brown stain in the wood when splitting open, and black vascular traces in leaf scar.	• Regular pruning • Sun drying of infected parts • Sanitation • Use of resistant clones like PBC 123

20 Please also see: https://car.da.gov.ph/wp-content/uploads/2023/05/Peast-and-Diseases-of-Cacaco.pdf

Key steps of integrated pest and disease management

Integrated pest and disease management (IPDM) involves prevention, identification, diagnosis, and treatment of pests and diseases.

Prevention activities

Preventing pests and disease outbreaks require the following activities:

1. Selecting disease-resistant clones
2. Conducting field sanitation
3. Proper pruning
4. Application of balanced nutrients to have healthy plants

Disease identification and treatment application

To identify the disease, diagnose its severity and apply appropriate treatments, the following activities are necessary:

1. Identifying the causes of the disease
2. Assessment of the severity of the disease
3. Application of control methods appropriate to the severity of the disease
4. Removing the pathogen sources like the diseased plat parts and pods
5. Pruning the cacao trees
6. Irrigating and paying attention to soil fertility to improve plant health and disease resistance
7. Applying fungicide in appropriate concentrations when diseases begin to cause unacceptable financial losses

Reducing chemical inputs using biological approaches

Studies have shown that bio-control agents and biopesticides could be effective in protecting cacao pods from specific pests and diseases.

Although chemical spraying is discouraged, spraying pesticides or fungicides every 7-10 days is advisable once the infestation reaches 30-50% of the farm. The recommended time for spraying is at 8:00 to 10:30 in the morning to avoid killing cacao pollinators. Spraying on the trash alley or contour-aligned barriers made of discarded branches and prunings should also be avoided as pollinators live in these barriers.

Bio-control agents for cacao

Using bio-control agents is also an option. According to the Davao Regional Crop Protection Center, some of the bio-control agents that can be used to address pests and diseases in cacao are *Trichogramma chilonis*, *Beauveria bassiana* or white muscardine fungus, and *Trichoderma* spp[21].

- *Trichogramma chilonis* is used to prevent cacao pod borer, by stopping the development of its causal organism which is the *Conopomorhpha cramerella*. The Philippine Government produces this in the form of Trichogramma cards which as hung in the branches of cacao trees. These are applied late in the afternoon, with three to five cards per week starting from flower initiation.
- The white muscardine fungus helps prevent the growth of cacao pod borers. It is commonly produced in cracked corn medium. It is then suspended in water, with a little amount of non-bleach detergent. The suspension is then sprayed onto the cacao trees.
- *Trichoderma* spp. is a free-living fungus found to be effective in managing soil-borne diseases like the cacao pod rot or black pod. It is produced using either cracked corn or agar as media and can be applied through drenching and spraying.

21 Davao RCPC. Sept 2024. *Biological Control Agents against Insect Pests and Diseases of Cacao*. Training of trainers on biologically based approaches to manage soil fertility and pests and diseases in cacao, September 2025. [Slide Presentation]

Plant-based pesticides

There are also indigenous materials that can be used as pesticides. Some of these plant-based pesticides are presented in the table below.

Table 5. Application of plant-based pesticides

Plant-based pesticide	Function	Pests and diseases targeted	Production	Application
Citronella oil	*Insecticide, Fungicide*	Cacao pod borer, Helopeltis, Cacao pod rot, and Vascular streak disease	Mix 30 mL of the oil with 1L of water and 30 mL of detergent. Let the mixture soak for at least 12 hours.	It can be sprayed in the afternoon, once a week.
Neem seeds	*Insecticide, Fungicide, Viruscide, Nematicide, Bactericide*	Caterpillars, Leaf miners, Aphids	Mix 25-50 g of powdered neem seeds with 1L of water and 1mL of alcohol. Let the mixture soak for at least 12 hours.	It can be sprayed in the afternoon, once a week.
Garlic	*Insecticide, Fungicide, Nematicide*	Caterpillar, Leaf miners, Apids, Fungi	Grind 10 garlic cloves, then mix it with 1L of water. Let the mixture soak for at least 6 hours.	It can be sprayed in the afternoon, once a week.

Source: Martini, E. September 2024. *Plant-based pesticides for cacao agroforestry pests and diseases handling*. Training of trainers on biologically-based approaches for managing soil fertility and pests and diseases in cacao, September 2024. [Slide Presentation].

Plant-based pesticides

Table 5. Application of plant-based pesticides

Plant-based pesticide	Function	Pests and diseases targeted	Production	Application
Dioscorea roots (or yam)	*Insecticide*	Helopeltis	Grind 1 kg of Dioscorea roots and get the extract of its water. Mix the extract with 10L of water. Let the mixture soak for 24 hours.	It can be sprayed in the morning or in the afternoon, once a week.
Philippine tung	*Insecticide*	Cacao pod borer, Helopeltis	Extract the oil from the tung seeds. Mix 5 tablespoons of the oil with 1L of water and 1 teaspoon of detergent powder.	It can be sprayed in the morning or in the afternoon, once a week.
Billy goat weed (or bulak-manok)	*Insecticide*	Cacao pod borer, Helopeltis	Grind 1 kg of the leaves and mix it with 1L of water and 1 teaspoon of detergent powder. Let the mixture soak for 24 hours.	It can be sprayed in the morning or in the afternoon, once a week.
Clove	*Fungicide, Insecticide*	Cacao pod rot	Grind 2 kg of dried clove leaves with 1L of water and 1 teaspoon of detergent powder. Let the mixture soak for two days.	It can be sprayed in the morning or in the afternoon, once a week or every two weeks.

Source: Martini, E. September 2024. *Plant-based pesticides for cacao agroforestry pests and diseases handling*. Training of trainers on biologically-based approaches for managing soil fertility and pests and diseases in cacao, September 2024. [Slide Presentation].

Natural farming technologies

Natural farming technologies help farmers reduce their dependency on chemical-based inputs, minimizing production costs. This must be coupled with essential management practices such as improving soil fertility, judicious application of appropriate shade management, pruning regime, and farm sanitation.

Cacao pod husk composting

This is done by mixing two parts of chopped empty cacao pods with one part of green manure such as madre de cacao, mani-mani or tithonia/Mexican sunflower and dried animal manure. A mixture of liquid Indigenous microorganisms (IMO) needs to be sprayed on it before covering it with banana leaves and plastic sheets to reduce heat and moisture loss and to protect from being soaked in rainwater.

The compost heap should be turned every 14 days, especially during the first 8 weeks. It can be used as natural fertilizer after 12 weeks.

Composting is a great way to recycle waste and return nutrients to the soil. Dried and decomposed cacao pods provide the soil with nutrients like phosphate, nitrogen, and potash, making it a great topsoil to use orto combine with other decomposed crop residue materials and applied around the cacao trees.

Photo source: Cacao de Betulia

Natural farming technologies

Benefits of cacao pod husk compost

1. Promotes nutrient-rich soil and increases water-holding capacity
2. Supports healthy crop growth
3. Reduces pollution and other negative environmental impacts associated with chemical fertilizers and fungicides
4. Improves soil nutrient cycle
5. Help to prevent disease-causing bacteria, viruses, and *Phytophthora palmivora* that causes cacao pod rot disease

Natural farming technologies

Indigenous microorganisms (IMO)

The use of Indigenous microorganisms (IMO) is one of the options to improve the soil fertility condition of the farm, prevent the spread of bad microbes in the soil, contribute to the required nitrogen for cacao trees, and multiply and strengthen the flowers and young cacao pods by mixing 300 ml or 2 sardine can-full of IMO mixed with 16 liters of water and spraying it at cacao trees and around its base.

Oriental Herbal Nutrients (OHN)

The use of oriental herbal nutrients (OHN), which is made of chopped garlic, onion, ginger, chili, and coconut wine, mixed with muscovado sugar, is a natural way of repelling insects and preventing the spread of harmful fungi that may damage cacao pods and trees. This can be done by spraying a mixture of 2 tablespoons of OHN per 1 liter of water ideally in the early morning and late afternoon.

Unit 6: Agroecological principles in harvesting activities

Agroecological principles in harvesting activities

Cacao takes five to six weeks to mature from the time of pollination. Cacao pods change color as it matures: the green pods turn yellow; reddish or purple pods turn orange to light yellow. These are ready for harvest once the pod surface changes its color by approximately 75% or more from its immature pod color.

For sanitation, it is important to clean and wash our hands before and after handling the cacao.

Agroecological principles in harvesting activities

Pods can be harvested regularly at least every two weeks. In doing so, a pruning shear should be used to harvest the pods that can be reached by hand. For pods at a higher position, a harvester with a pole can be used. The harvester should be aimed at the pedicel of the pod to avoid damaging the flower cushions.

After harvesting, the cacao pods must be stored in a shaded area for three to five days before pod breaking. The pods should not touch the ground. In breaking the pod, a pod splitter should be used to prevent bean damage. The beans are then removed from the pods using a wood and bamboo scoop. The good beans are separated from the placenta and pet-infested beans. After this, the wet beans should be drained 8 to 12 hours before fermentation.

Glossary

A-frame. A tool made from local materials (e.g., bamboo poles or wooden branches, strings, rocks or plastic bottles) used to ensure equal spacing of contour lines.

Agrobiodiversity[1]. The combination and interaction between animals, plants, and micro-organisms of diverse genetic resources in a cultivation system, that works together productively.

Agroecological practice. A farming practice that applies ecological principles, with the objective of addressing the environmental degradation caused by intensive farming practices.

Agroecology. Science and practice of making food systems sustainable through applying ecological practices in cultivation.

Agroforestry. A land use that integrates trees with crops and/or livestock, providing beneficial interactions (e.g., soil and water conservation, micro-climate improvement, shade management, etc) across the agroforestry system.

Biological control. Methods of controlling and/or preventing pests and diseases using biological approaches such as natural fertilizers and control agents such as certain fungi species.

Canopy. The area of ground covered by the crown of the tree.

Carbon sequestration. The process in which trees absorb carbon from the atmosphere.

1 Based on the definition of FAO. 2006. *Building on Gender, Agrobiodiversity, and Local Knowledge: A Training Manual.* Retrieved from https://www.fao.org/4/y5956e/Y5956E00.htm

Glossary

Climate-resilient practices. Farming practices that help in mitigating or adapting to the effects of climate change on crops; Farming practices that help crops withstand negative effects of climate change.

Contour. Strips of vegetation (e.g., natural vegetative strips) or concrete structures (e.g., rock walls) used as buffers in sloping lands.

Cow's back method. A method of marking the contour lines involves letting the cow or carabao walk along the contour to ensure its proper spacing.

Economic diversification. The variation in sources of income for farmers brought by integrating various crops and other components into their land.

Ecosystem services. The benefits that people get from a healthy ecosystem or environment (e.g., clean air, soil erosion prevention, water supply).

Micro-catchment systems. Methods of harvesting water directly from the soil surface and storing it for plant use especially during drought. These systems usually involve building small structures using local materials to capture water.

Market resilient. Cacao farmers are considered market resilient if they can manage the negative impacts in the fluctuation of prices in the cacao market and mitigate its effects to their livelihood and family's welfare. Market resilience is achieved through exploring other sources of income.

Glossary

Micro-climate[2]. The climatic condition, including temperature, light, wind speed and moisture, in localized areas.

Multi-strata system. An agroforestry system in which components' crowns form distinct layers or strata.

Nutrient cycling. The process in which nutrients are transferred across the system, from the atmosphere and/or the soil, to the plants through its roots.

Organic materials. Dead or decomposing materials coming from living organisms like plants and animals (e.g., rotten cacao pods, dried coconut husks, rice hulls, chicken manure)
Planting density. The number of plants per unit area.

Planting density. The number of plants per unit area.

Pollarding. A shade management technique where the top branches of the tree are pruned to promote growth.

Pruning. The practice of removing the branches of a tree to avoid crowding and/or overshading other components of the agroforestry system[3]. For the case of cacao-based cultivations, it is also an important practice to manage pests and diseases and to improve productivity.

2 Based on the definition from Naiman RJ, Decamps H, McClain ME, Likens GE. 2005. 5 – Biotic Functions of Riparia. *Riparia: Ecology, Conservation, and Management of Streamside Communities* pp. 125-158. https://doi.org/10.1016/B978-012663315-3/50006-X

3 Based on the definition from Gassner A, Mercado A, Miccolis A, Mukaralinda A, Okia CA, Somarrimba E. 2022. Management of trees in agroforestry systems. In Gassner A, Dobbie P (eds). *Agroforestry: A Primer*.

Glossary

Rhizosphere[4]. Composed of soil particles, organic matter, plant roots or rhizomes and other organisms in the soil that supports the processing of nutrients and perpetuating a symbiotic balance in the soil.

Sedimentation. The process in which eroded soil particles are washed off from the topsoil and are accumulated in bodies of water like rivers and oceans.

Self-incompatibility. A biochemical process that prevents genetically identical cacao plants from self-fertilization, therefore causing minimal fruiting[5]. Since cacao is self-incompatible, clones in a farm should be diversified.

Soil biota[6]. Composed of the various micro-organisms and soil animals living in the soil (e.g., bacteria, fungi, algae).

Sturdiness quotient. Measures the sturdiness of the seedling based on the ratio of the height of the seedling and the root collar diameter. The higher the sturdiness quotient, the better.

Synergy. The interaction of the different components of a cacao-based cultivation system to produce an effect greater than the sum of its individual results.

4 Based on the definition from Naiman RJ, Decamps H, McClain ME, Likens GE. 2005. 5 – Biotic Functions of Riparia. *Riparia: Ecology, Conservation, and Management of Streamside Communities* pp. 125-158. https://doi.org/10.1016/B978-012663315-3/50006-X

5 Based on the definition from Gassner A, Mercado A, Miccolis A, Mukaralinda A, Okia CA, Somarrimba E. 2022. Management of trees in agroforestry systems. In Gassner A, Dobbie P (eds). *Agroforestry: A Primer*.

6 Based on the definition from Gassner A, Mercado A, Miccolis A, Mukaralinda A, Okia CA, Somarrimba E. 2022. Management of trees in agroforestry systems. In Gassner A, Dobbie P (eds). *Agroforestry: A Primer. Design and management principles for the people and the environment.* Bogor, Indonesia: Center for International Forestry Research (CIFOR) and Nairobi: World Agroforestry.

World Agroforestry MARS RAINFOREST ALLIANCE IFAD Investing in rural people