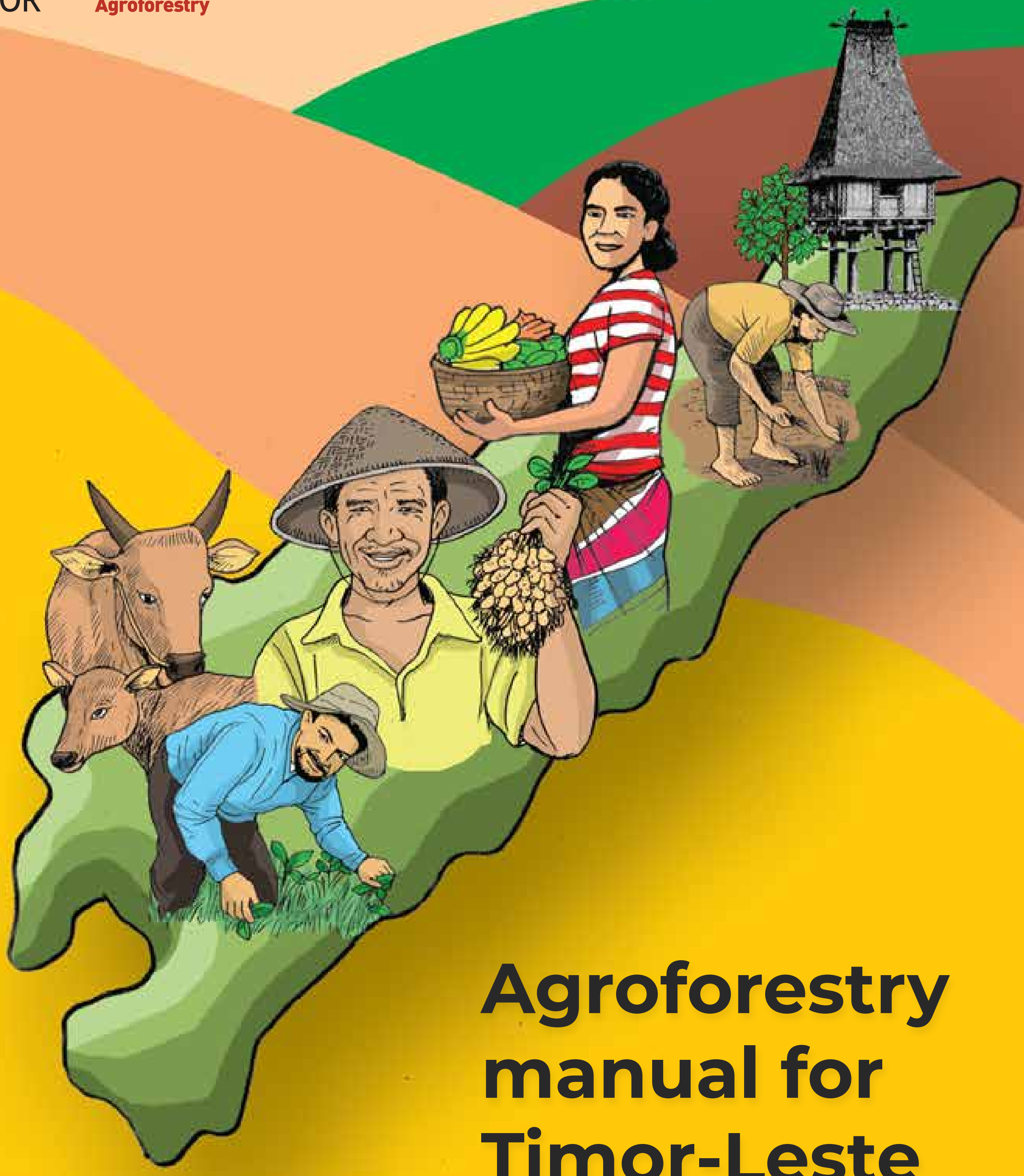

Agroforestry manual for Timor-Leste

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Foreword

Timor Leste has been facing forest and land degradation since Independence in early 2000. Over more than two decades, dense forests have been degraded, causing further environmental degradation and increased food insecurity. The Ministry of Agriculture and Fisheries (MAF) through the Directorate General of Forests, Coffee and Industrial Plants (DGFCIP) in collaboration with CIFOR-ICRAF and supported by the Asian Forestry Cooperation Organization (AFoCO) initiated development and promotion of agroforestry models in different agroecological zones in Timor-Leste for reforestation and restoration of degraded land.

Agroforestry is known as a form of climate-smart agriculture which not only contributes to improved food security but also provides environmental goods and services, such as regulating climate, water retention and soil improvement.

Agroforestry as traditionally practised in Timor-Leste is known as *kuda haur* or mixed planting. However, agroforestry knowledge is not widely understood by decision makers, forestry staff and practitioners in the field.

This manual provides the basic concepts of agroforestry and its principles to develop agroforestry designs useful for technicians and practitioners. It also provides technical information on designing soil conservation techniques as well as on propagating trees and crops and also governance in implementing agroforestry. We hope that the manual provides insightful information for all relevant actors in expanding agroforestry practices for promoting reforestation and restoration of degraded land in Timor-Leste.

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We also would like to thank to all contributors for providing inputs that improved the manual. We thank also communities in Bobonaro, Covalima, Ermera and Liquica districts who provided valuable information on the need for technical aspects that should be included in the manual.

Finally, we thank AFoCO for its valuable contribution in supporting the project and publication of this manual.

The editors

1 What is agroforestry?

Agroforestry is a land-use practice in which woody perennials are grown within agricultural landscapes wherein both ecological and economical interactions occur between the woody and non-woody components for various social, economic and environmental benefits. Simply, agroforestry refers to the integration of trees, crops and/or animals on a single unit of land, each having their own functions and interactions among each other. Trees or woody perennials are among the most important components of agroforestry that perform productive, protective and regulatory functions. Other components of agroforestry include agricultural crops and livestock. Different components can have several influences on each other.

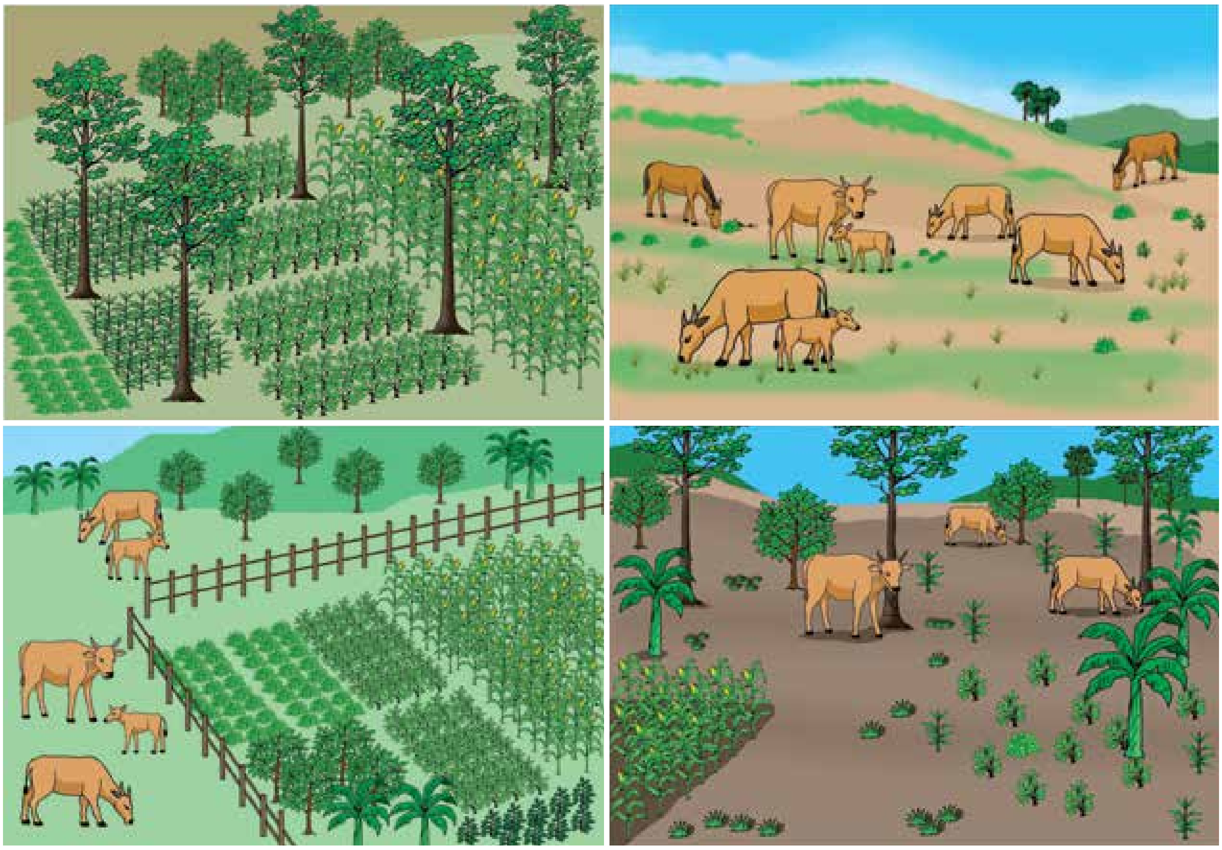

Figure 1. Various components of an agroforestry system

Based on the components, agroforestry can be classified into different systems.

1. **Agrisilvicultural systems**: Intercropping trees and crops in different spatial patterns. The species that are used depend upon biophysical and socioeconomic conditions.
2. **Silvopastoral systems**: Fodder trees and grasses are cultivated for animal use, allowing the free grazing of livestock.
3. **Agrosilvopastoral**: Trees, crops, pastures and livestock are grown on a single unit of land. This system requires intensive management and is often practised at subsistence level.
4. **Homegardens**: Usually classified as agrisilvicultural, however, the components and the interactions between the components are different in this system. Homegarden systems are characterized by the intensive cultivation of annual and perennial crops that include vegetables, cereals and fruit trees, grasses and animals.
5. **Others, including multipurpose trees, apiculture, silvofishery**: Other than the above-mentioned types, there are other types of agroforestry systems with a variety of components, such as fish, honeybees and trees, providing various functions.

2 Why agroforestry?

2.1 Food security and nutrition enrichment

In contrast to conventional agriculture, agroforestry has diverse crop varieties and tree species that produce food to enhance food security. The integration of multiple components increases farm productivity. Further, the addition of edible plants like fruits, nuts, and vegetables along with staple crops helps enhance consumers' nutrition.

2.2 Resilient livelihoods

Integrating trees with crops and livestock can reduce the vulnerability of agricultural production to climatic disasters and market shocks. It is also resilient against pest attacks, which are often devastating in the case of monocultures. Further, the use of cash crops alongside subsistence crops can create a secure environment for farmers relying on agriculture for their livelihoods. With better regulation of microclimates, agroforestry positively influences climatic impacts that can hamper the agriculture system, helping create resilient livelihoods.

2.3 Climate change mitigation and adaptation

Trees integrated with agricultural crops help in reducing the effects of climate change on agriculture. On one hand, the availability of tree products on farmland reduces the triggering factors of deforestation; on the other hand, the trees in agroforestry help in sequestering carbon that mitigates climate change. Agroforestry has a significant role in regulating microclimates that mitigate the impacts of climate change and influence the growth of crops.

2.4 Protect the environment

Agroforestry systems regulate climatic as well as environmental services. Trees help in improving air and water quality. With the use of tree litter as organic matter, the use of chemical fertilizers for agriculture can be reduced, which protects soil quality. The deep root systems of trees help in nutrient cycling. The diverse components of agroforestry support biodiversity by providing a suitable environment. Windbreak and shelterbelt functions of an agroforestry system improve air quality, protect soil from wind erosion and provide habitat for flora and fauna in an agriculture-dominated landscape.

2.5 Poverty alleviation

Agroforestry helps to diversify sources of income, e.g., cash crops, sale of timber, income from livestock. Diversification reduces the risk of economic loss. Improved and sustainable production increases farm income and also provides employment opportunities that can lead to poverty alleviation and improvement of living standards.

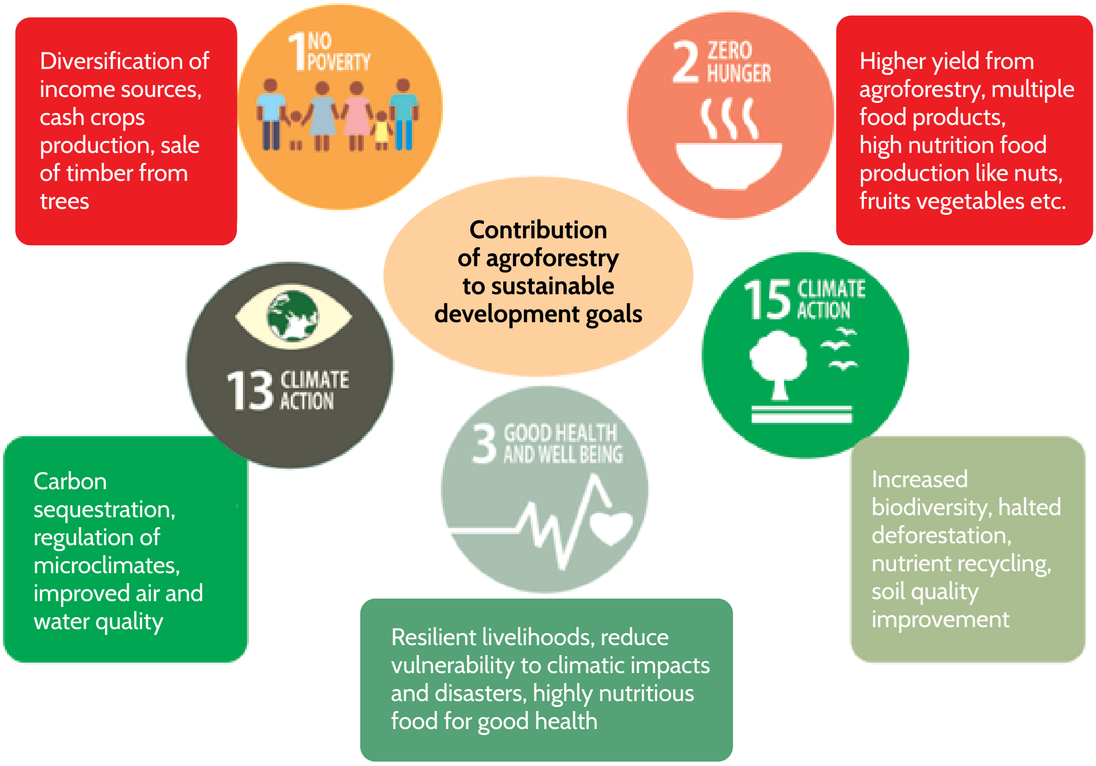

Figure 2. Contribution of agroforestry to the Sustainable Development Goals

3 Principles of agroforestry design

The principles of agroforestry design guide the realisation of outcomes and the successful accomplishment of outputs. These guiding principles cover the different aspects of the development of agroforestry from formulating action plans through to their implementation. Moreover, the principles also include the formation of viable strategies and approaches for better promotion of agroforestry on suitable land. Simply, the design of an agroforestry system involves deciding on what will be produced and selecting the components and their arrangement. Similarly, the consideration of an enabling environment for implementation of agroforestry is vital in agroforestry design. The major topics that are addressed under the guiding principles are institutional roles and arrangement, planning and sustainable financing, research, continuous learning, monitoring and evaluation and knowledge management. The guiding principles of agroforestry are listed below (adapted from Catacutan et al. 2018. *ASEAN Guidelines for Agroforestry Development*).

3.1 Institutional principles

3.1.1 Create an enabling environment

The successful implementation of agroforestry needs an enabling institutional and policy environment within which the development of agroforestry policies, programmes and investment can be facilitated.

- Ensuring agroforestry has clear policy and legal support
- Developing national agroforestry programmes and strategies
- Providing enabling conditions, such as security of land tenure, market conditions and infrastructure for better adoption
- Assuring appropriate and continuous funding to support agroforestry

3.1.2 Ensure effective organizational capacity

Building the capacity of the designated institution and relevant stakeholders of the agroforestry programme should be ensured for effective implementation, knowledge sharing and conducting research.

- Strengthening the capacity of institutions related to agroforestry at national and sub-national levels
- Enhancing national capacity to conduct participatory agroforestry research
- Strengthening collaboration between national organizations and international research and development organizations
- Encouraging agroforestry education at school and university levels by developing curricula

3.1.3 Support effective cooperation and participatory decision-making

The landscape approach to planning agroforestry interventions, intersectoral cooperation and integrated decision-making should be employed because of the multifaceted nature of agroforestry and its interconnection with agriculture, forestry and other land use and sectors, such as livestock, energy, aquaculture, and rural livelihoods development.

- Promoting a participatory approach that includes all stakeholders in planning, decision-making, and implementation of agroforestry interventions
- Incorporating agroforestry interventions in sectoral strategies
- Designing agroforestry interventions in the context of landscapes and in relation to future shifts in climate as well as economic conditions
- Including the various goals, interests and accountabilities of relevant stakeholders in the landscape targeted for agroforestry

3.2 Economic principles

3.2.1 Recognize the value of goods and ecosystem services

The different benefits provided by agroforestry in the form of goods and ecosystem services should be recognized and farmers should be rewarded or compensated for their contribution.

- Promoting all types of agroforestry goods by branding, certification and strengthening agroforestry value chains
- Recognizing local knowledge in the use of agroforestry products and ensuring equitable benefits among stakeholders
- Providing long-term benefits to farmers through the PES (Payment for ecosystem services) scheme.

3.2.2 Enable environments for agroforestry and investment markets

An enabling environment that encourages long-term investment by corporate and smallholder investors in agroforestry should be created for the better proliferation of agroforestry.

- Developing financing schemes with lower interest rates to support agroforestry business models for micro-, small- and medium-sized enterprises
- Supporting long-term and flexible financing through policy-level interventions
- Ensuring technical and trade promotional support to develop agroforestry value chains
- Providing transparent and simple procedures for processing and marketing agroforestry products

3.3 Environmental principles

3.3.1 Maintain and enhance ecosystem services at farm and landscape levels

The careful planning and proper management of agroforestry should be promoted to ensure the conservation and restoration of ecosystem services without undermining economic and other benefits.

- Planning of agroforestry interventions to achieve multiple economic, environmental, and social benefits
- Recognizing and assessing the positive impacts of agroforestry in the provisioning of ecosystem services, including forest restoration, abatement of soil erosion and climate change mitigation
- Conducting environmental impact assessments before implementing large-scale agroforestry interventions to ensure complementarity of ecosystem services
- Developing and implementing standard operational field practices in the establishment and maintenance of agroforestry interventions

3.3.2 Understand and manage trade-offs

The understanding and management of trade-offs is vital when introducing agroforestry wherein trees, agriculture crops and livestock are integrated on the same unit of land.

- Employing participatory methods to understand the decision-making of smallholders and medium- and large-scale corporate farmers regarding short- and long-term production
- Projecting the magnitude of potential trade-offs and decision-making by quantifying the economic and environmental costs and benefits
- Reducing and managing trade-offs through long-term credit, lower interest rates, insurance, and payment for ecosystem services' schemes

3.4 Socio-cultural principles

3.4.1 Recognize and respect local knowledge, traditions, and choices

Local and traditional knowledge, cultural values and social norms should be taken into consideration when planning, designing and implementing agroforestry interventions.

- Identifying and respecting local practices and knowledge of agroforestry development
- Considering local knowledge and choices in agroforestry options (e.g., tree and crop species, livestock breeds) and practices during planning and decision-making
- Identifying and addressing the local need for training, technology, infrastructure, and land-use rights.

3.4.2 Support gender equity and social inclusion

Social inclusion and gender equity should be ensured when making policies as well as during agroforestry interventions. The agroforestry programme should cover all sections of communities, such as ethnic groups, marginalized people, women, youth.

- Acknowledging the importance of gender and social inclusion in designing and implementing agroforestry
- Ensuring that poor and socially marginalized groups benefit from, or are not adversely impacted by, interventions
- Improving women's access to agroforestry opportunities and associated benefits
- Ensuring the agroforestry programmes or technologies are sensitive to gender issues, especially when women are labourers

3.4.3 Ensure safeguards and tenure rights

Safeguarding tenure rights is important because agroforestry interventions can create tension amongst stakeholders in areas where land rights are not clear, restricting adoption owing to lack of clarity about ownership. Land tenure rights should be ensured so that agroforestry programmes do not negatively affect communities.

- Identifying and understanding land tenure rights in areas targeted for agroforestry interventions
- Involving all stakeholders when planning agroforestry interventions and respecting their rights and aspirations
- Ensuring free, prior and informed consent of rights holders who could be adversely or otherwise affected by agroforestry interventions

3.5 Technical design principles

3.5.1 Design agroforestry options based on context

The successful implementation of agroforestry depends on effective designs based on local contexts linked to national, subnational and global conditions.

- Developing user-friendly decision tools to assess information, identify opportunities and constraints and make choices about agroforestry options
- Selecting agroforestry based on the specific needs, interests or purposes of individual and public stakeholders
- Designing agroforestry options based on information of biophysical parameters, such as topography, land use, soil, climatic conditions, and socio-economic conditions, such as gender, market information and relevant policies
- Providing technical guidance through training and extension education for proper management of agroforestry

3.5.2 Select agroforestry components in a participatory manner

The careful selection of tree and crop species, livestock breeds and fish/aquatic components is crucial for the successful implementation of agroforestry. The selection of components should be based on the principle, *The right species of trees, crops, livestock and/or fish in the right place for the right purpose with respect for local rights*.

- Identifying plant, livestock and aquatic species that match local biophysical condition while considering future changes in climate regimes

- Discussing in detail with local stakeholders to identify the uses of trees, crops, livestock, fish and the specific species to be cultivated
- Ensuring active participation of key stakeholders, especially farmers, investors, extension workers and government agencies

3.6 Communication and scaling principles

3.6.1 Effectively communicate agroforestry knowledge

The proper dissemination of knowledge about the development and management of agroforestry is important to encourage widespread adoption and continuous development of agroforestry.

- Identifying knowledge and communication needs and gaps of all stakeholders through participatory methods
- Strengthening the knowledge management and communication capacity of institutions involved in agroforestry to effectively share skills, provide technical support, and monitor results and impacts

3.6.2 Plan for effective scaling up and sustainability

The scaling up of agroforestry must be carefully planned to achieve lasting impact, taking into account universal and contextual perspectives.

- Engaging stakeholders for effective planning of scaling interventions
- Examining and understanding the potential, limits, and internal and external opportunities, including biophysical and socio-economic conditions, which may have an impact on scaling
- Focusing on the scaling of agroforestry in both technical and institutional aspects
- Reviewing scaling approaches, processes and achievements periodically to address gaps

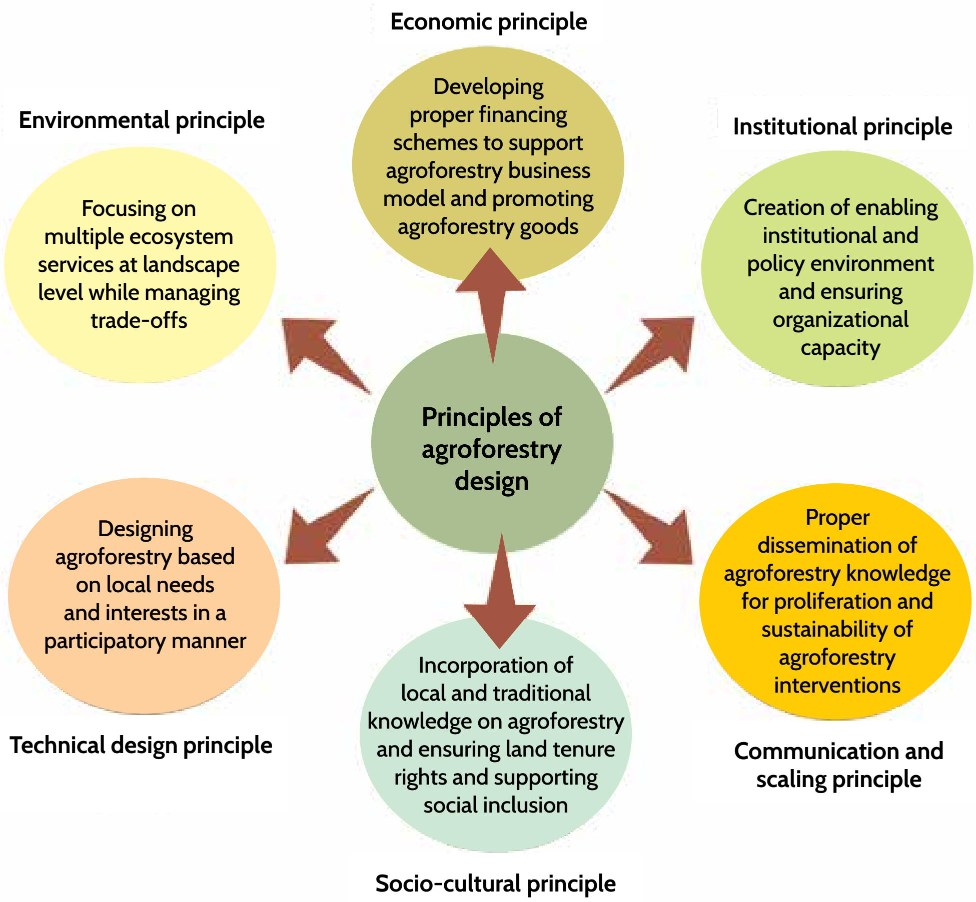

Figure 3. Principles of agroforestry design

Adapted from Catacutan et al. 2018.

4 Existing agroforestry in Timor-Leste

Major agroforestry models practised in Timor-Leste have been identified by the United Nations Development Programme (UNDP 2018). Figures 4, 5, 6 and 7 depict common agroforestry models in Timor Leste (adopted from Paudel et al. 2022).

The major successful agroforestry systems in Timor-Leste feature mainly mixed cropping of fruit and timber species with spices. The major fruit species preferred are jackfruit, banana, mango, pineapple and orange. The major timber tree species intercropped with fruit trees are mahogany, sandalwood, moringa and albizia.

The various existing successful agroforestry models are in different locations of Timor-Leste, identified by a team from Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ 2022) (Table 1).

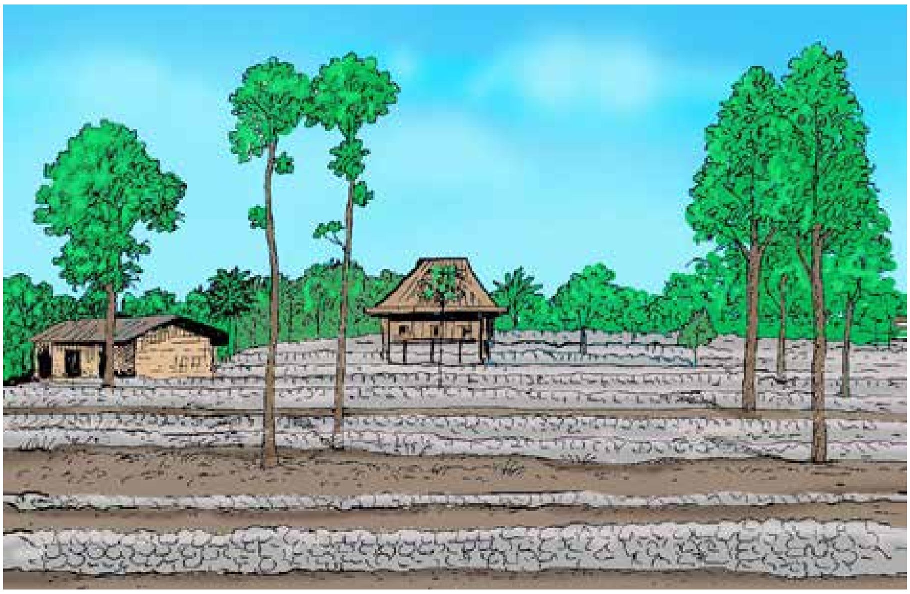

Figure 4. Alley cropping in the hilly region to reduce occurrence of landslides and facilitate flow of water in the long term

Figure 5. Hedge-row plantings on steep, hilly areas to conserve soil

Figure 6. Randomly mixed trees and annual crops with irregular spacing in lowland areas

Figure 7. Alternate row planting with seasonal cultivation between rows on flat and wide areas

Table 1. Agroforestry models employed in Timor-Leste, with biophysical information

	Agroforestry model	Major crop	Supporting crop	Location (municipality)	Altitude (m)	Rainfall (mm/yr)
1	Vanilla-based (Timber + fruit + spices + staple food)	Vanilla	Casuarina, albizia, black pepper, jackfruit, cassava, mango, banana, cacao	Ermera	500–1500	1500–3000
2	Casuarina-based (Timber + fruit)	Casuarina	Pineapple, orange, guava, mango, jackfruit	Manatuto	500–1500	1500–3000
3	Clove-based (Timber + fruit + spices)	Clove	Mahogany, jackfruit, mango, rambutan, coconut, coffee, turmeric	Aileu	500–1500	1500–3000
4	Coconut-based (Timber + fruit + staple food)	Coconut	Jackfruit, rambutan, teak, orange, pineapple, mahogany, banana, maize, and cassava	Viqueque	100–500	500–1500
5	Breadfruit-based (Timber + fruit + spices)	Breadfruit	Coconut, jackfruit, citrus, mango, papaya, bamboo, betel nut, pepper	Baucau	100–500	500–1500
6	Mahogany-based (Timber + fruit + spices)	Mahogany	Jackfruit, mango, moringa, coconut, pineapple, turmeric	Liquica	0–100	500–1500
7	Coffee-based (Timber + fruit + bamboo)	Coffee	Albizia, jackfruit, banana, gmelina, bamboo, teak	Aileu	500–1500	1500–3000
8	Dragon fruit-based (Timber + fruit + vegetables + other foods)	Dragon fruit	Orange, banana, pineapple, cassava, pumpkin, maize, sandalwood, citrus, coffee, leucaena	Baucau	500–1500	1500–3000
9	Sandalwood-based (Timber + fruit + vegetables)	Sandalwood	Pineapple, mahogany, casuarina, candlenut, tomato, brinjal	Bobonaro	0–100	500–1500

5 Agro-ecological zones of Timor-Leste

Timor-Leste has six agro-ecological zones (AEZ) based on Altitude and north–south orientation (Figure 8). As well as these six agro-ecological zones, areas above 2000 m altitude have been identified as a temperate zone (Table 2).

Information on biophysical parameters — such as altitude of the area, aspect (north or south), average rainfall and soil type — is vital for the selection of crops and suitable agroforestry models for a region. Matching agroforestry models to AEZ conditions could be one way to assign the 'best fit' agroforestry in Timor-Leste.

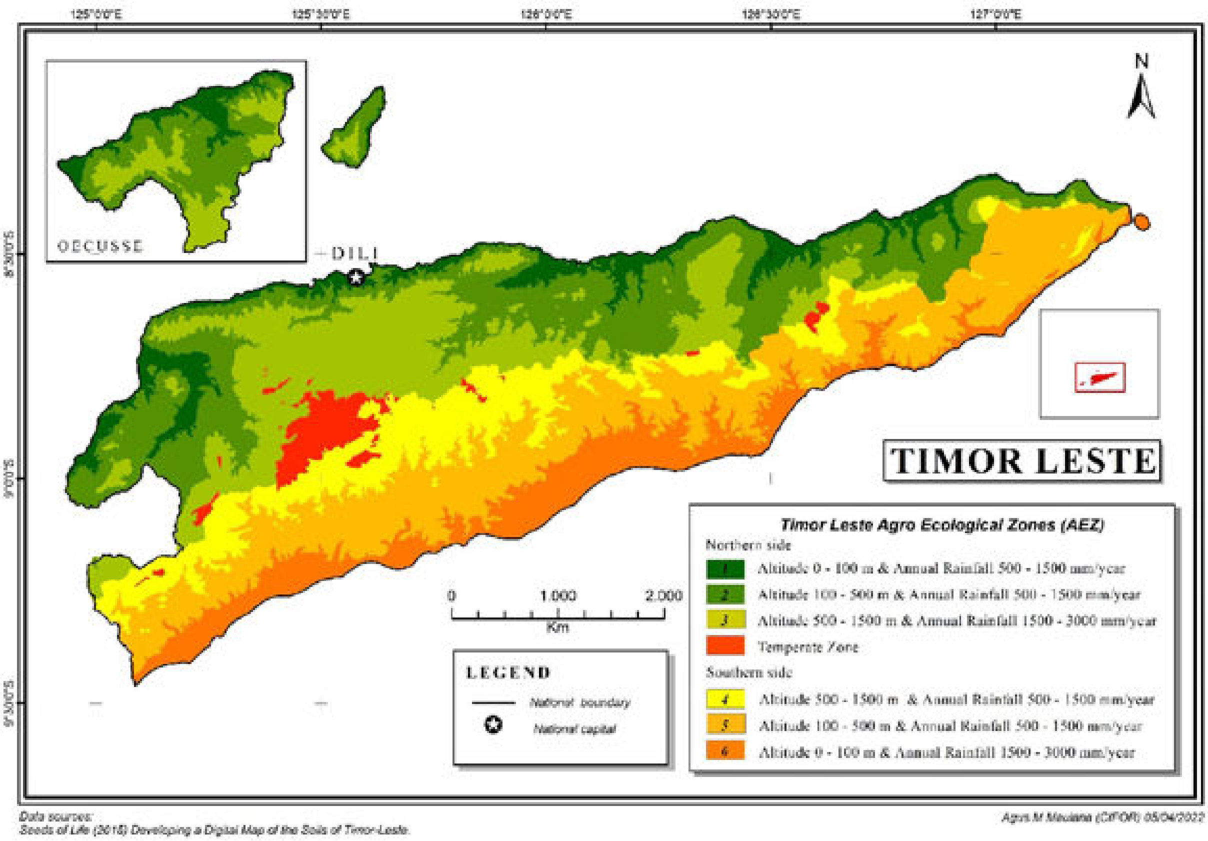

Figure 8. Agro-ecological zones of Timor-Leste

Table 2. Details of agro-ecological zones (AEZ) with major crops

Zone (% of total land area)	Altitude (m)	Rainfall (mm/year)	Major crops
AEZ 1: Northern coastal lowlands (10)	<100	500–1500	Rice, maize, cassava, coconut
AEZ 2: Northern slopes (23)	100–500	500–1500	Maize, cassava, rice, cowpea
AEZ 3: Northern uplands (19)	500–1500	1500–3000	Red beans, coffee, maize, rice, cassava
AEZ Temperate uplands (2)	>2000	>2000	Potatoes, wheat, barley, arrowroot
AEZ 4: Southern uplands (14)	500–1500	500–1500	Maize, cassava, rice, sweet potato, cowpea
AEZ 5: Southern slopes (21)	100–500	500–1500	Maize, cassava, rice, sweet potato, cowpea
AEZ 6: Southern coastal lowlands (11)	<100	1500–3500	Rice, maize, cassava, coconut

Source: Adapted from Fox (2003).

Soil types in Timor Leste vary in each AEZ. Vertisols, Mollisols and Inceptisols are the dominant soil types, covering almost 72% of the country's total land area. Table 3 and Figure 9 present detailed information of the distribution of soil types.

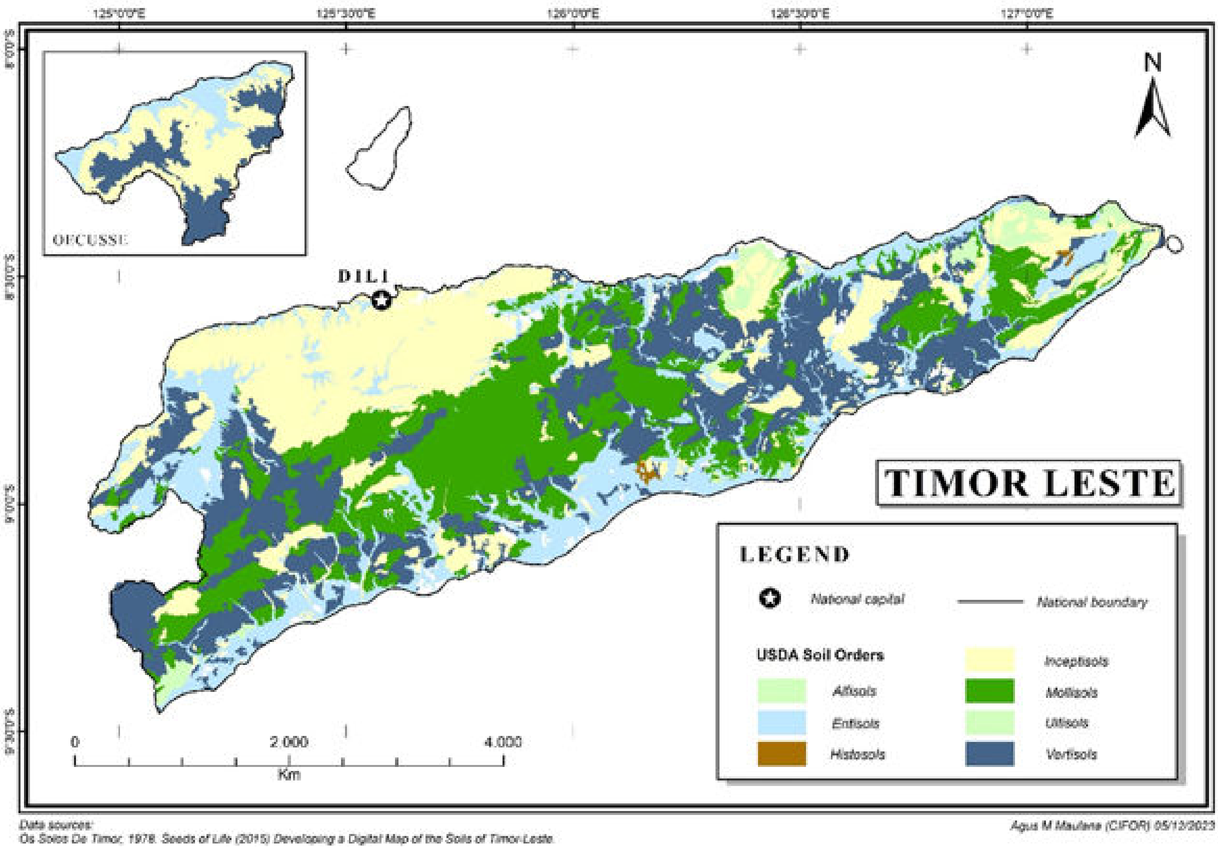

Figure 9. Soil map of Timor-Leste

Table 3. Soil types in Timor-Leste

Soil type	Area (ha)	Percent
Vertisols	374,688.70	24.58
Mollisols	370,416.74	24.30
Inceptisols	349,804.51	22.95
Entisols	263,590.49	17.29
Others	124,687.68	8.18
Alfisols	22,125.03	1.45
Ultisols	16,560.53	1.09
Histosols	2,224.34	0.15

Source: Spatial analysis by CIFOR-ICRAF, 2023

Vertisols have a high content of expanding clay minerals, easily shrinking and swelling owing to changes in water content. This soil type will mostly crack during the long dry season and be very sticky during the rainy sesson when water content is high. These soils are rich in calcium and magnesium material and lack organic content (1–6%).

Mollisols are rich in organic matter and chemical material, including Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}, which are essential plant nutrients.

Inceptisols are in the early stage of soil profile development. The majority are found in mountainous regions.

6 Agroforestry in Timor-Leste

Agroforestry has been traditionally practiced in Timor Leste and known as *Kuda haur* or mix planting. However, the practice is still conducted in small scale and majority to support subsistence of rural communities. Up-scaling agroforestry practice for reforestation and restoration degraded lands required understanding of suitability species (tree and crops) to environmental conditions of different agro-ecological characteristics. Followings are some recommendations of suitable species could be combined for agroforestry models in different agro-ecological zones in Timor Leste.

6.1 AEZ 1: Northern Coastal Lowlands

Topography and altitude: The northern coastal lowlands cover about 10% of the total area of Timor-Leste. Altitude is usually less than 100 masl. Gradients are usually less than 15%. **Geology and soils**: Entisols and Inceptisols. **Climate**: The annual precipitation in this zone ranges 500–1500 mm/year. Annual temperatures range 25–27.5 ˚C (Molyneux et al. 2012).

Soil conservation techniques: Gabion check dam, ridge terraces, bio-pore infiltration holes, riverbank protection, rainwater reservoir, drainage, and waterfall building etc.

Suitable agroforestry: Mahogany, sandalwood, teak and rosewood are high value timber species that are suitable for AEZ 1. Table 4 shows potential combinations of species (timber trees, fruit trees and food crops) that can be grown in agroforestry models in AEZ 1.

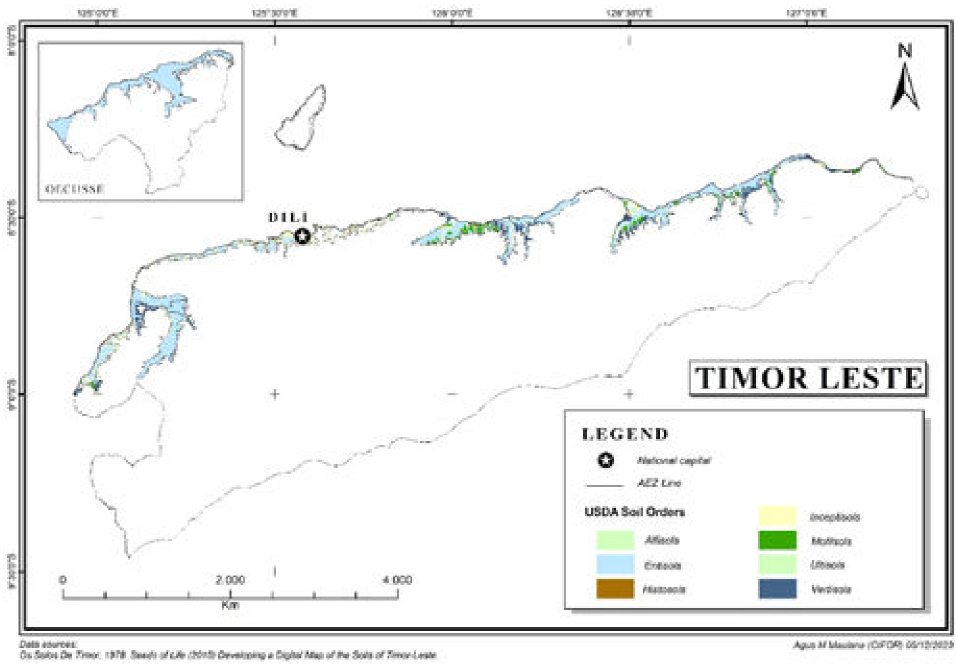

Figure 10. Soil map, AEZ 1: Northern Coastal Lowlands

Table 4. Agroforestry models for AEZ 1 with main and intercrop species

Major species (multipurpose tree, middle to upper strata)	Fruit species (middle strata)	Spice and cash crop (middle to lower strata)	Annual crop (lower strata in early application before complete shading)
Mahogany (*Swietenia macrophylla*) Teak (*Tectona grandis*) Sandalwood (*Santalum album*) Casuarina (*Casuarina equisetifolia*) Acacia (*Acacia mangium*) Rosewood (*Pterocarpus indicus*) Sesbania (*Sesbania grandiflora*) Leucaena (*Leucaena leucocephala*) Moringa (*Moringa oleifera*) *Gliricidia sepium* Bamboo (*Phyllostachys* spp)	Dragon fruit (*Selenicereus monacanthus*) Coconut (*Cocos nucifera*) Rambutan (*Nephelium lappaceum*) Jackfruit (*Artocarpus heterophyllus*) Lemon (*Citrus limon*) Breadfruit (*Artocarpus altilitis*) Pineapple (*Ananas comosus*) Banana (*Musa* spp) Mango (*Mangifera indica*) Guava (*Psidium guajava*) Papaya (*Carica papaya*) Snake fruit (*Salacca zalacca)* Candlenut (*Aleurites moluccanus*)	Black pepper (*Piper nigrum*) Cinnamon (*Cinnamomum verum*) Ginger (*Zingiber officinale*) Turmeric (*Curcuma longa*) Cocoa (*Theobroma cacao*)	Maize (*Zea mays*) Sweet potato (*Ipomoea batatas*) Yam/ubi (*Dioscorea alata*) Pumpkin (*Cucurbita moschata*) Velvet bean (*Mucuna pruriens*) Chayote (*Sechium edule*) Cassava (*Manihota esculenta*) Taro (*Colocasia esculenta*) Peanut (*Arachis hypogaea*) Pigeon pea (*Cajanus cajan*)

Source: MAF (2022), GIZ (2022).

6.2 AEZ 2: Northern Slopes

Topography and altitude: The northern slopes cover about 23% of the total area of Timor-Leste. Altitude ranges 100–500 masl. Gradients range 15–40%. **Geology and soils**: Inceptisols, Entisols; some areas have Mollisols. **Climate**: The annual precipitation in this zone ranges 500–1500 mm/year. Annual temperatures range 22.5–25 °C (Molyneux et al. 2012).

Soil conservation techniques: Broad channel terraces, bench terraces, rainwater reservoir, drainage and waterfall building, grass planting, brushwood check dam etc.

Suitable agroforestry: Mahagony, sandalwood and rosewood are valuable timber trees that are suitable for AEZ 2. High value agricultural species, such as coffee, cacao, vanilla and cinnamon are also suitable in this zone. Table 5 presents species suitable for agroforestry models in AEZ 2.

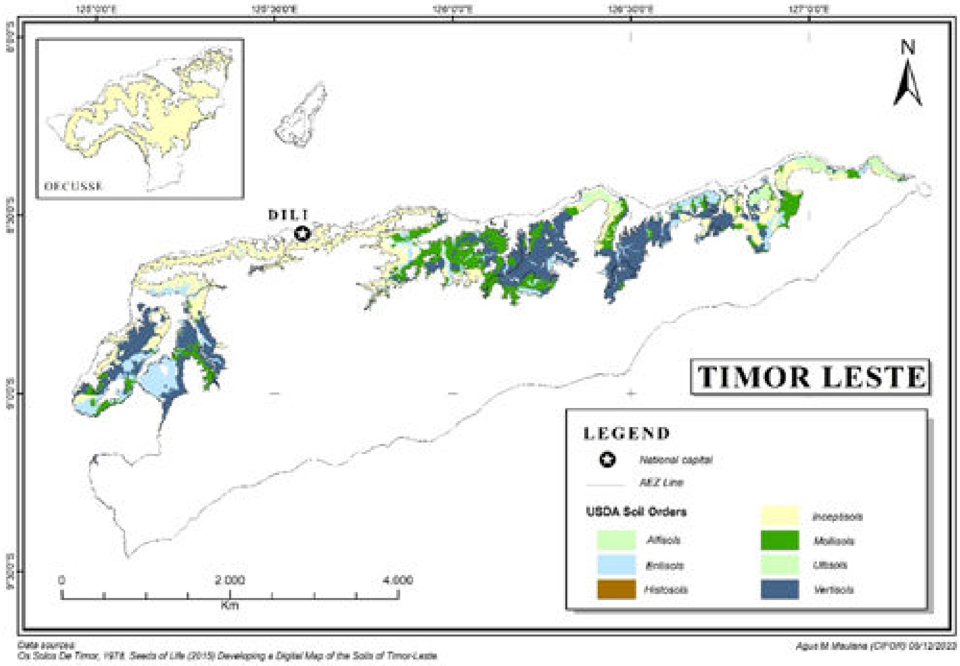

Figure 11. Soil map, AEZ 2: Northern Slopes

Table 5. Agroforestry models for AEZ 2 with main and intercrop species

Major species (multipurpose tree, middle to upper strata)	Fruit species (middle strata)	Spice and cash crop (middle to lower strata)	Annual crop (lower strata in early application before complete shading)
Mahogany (*Swietenia macrophylla*) Sandalwood (*Santalum album*) Casuarina (*Casuarina equisetifolia*) Acacia (*Acacia mangium*) Albizia (*Falcataria moluccana*) Rosewood (*Pterocarpus indicus*) Sesbania (*Sesbania grandiflora*) Leucaena (*Leucaena leucocephala*) Moringa (*Moringa oleifera*) *Gliricidia sepium* Bamboo (*Phyllostachys* spp)	Rambutan (*Nephelium lappaceum*) Jackfruit (*Artocarpus heterophyllus*) Lemon (*Citrus limon*) Breadfruit (*Artocarpus altilitis*) Avocado (*Persea americana*) Pineapple (*Ananas comosus*) Banana (*Musa* spp) Mango (*Mangifera indica*) Guava (*Psidium guajava*) Papaya (*Carica papaya*) Snake fruit (*Salacca zalacca*) Candlenut (*Aleurites moluccanus*)	Coffee (*Coffea* sp) Vanilla (*Vanilla planifolia*) Black pepper (*Piper nigrum*) Cinnamon (*Cinnamomum verum*) Cloves (*Syzygium aromaticum*) Ginger (*Zingiber officinale*) Turmeric (*Curcuma longa*) Cocoa (*Theobroma cacao*) Elephant foot yam (*Amorphophallus konjac*)	Maize (*Zea mays*) Sweet potato (*Ipomoea batatas*) Yam/ubi (*Dioscorea alata*) Pumpkin (*Cucurbita moschata*) Velvet bean (*Mucuna pruriens*) Chayote (*Sechium edule*) Cassava (*Manihota esculenta*) Taro (*Colocasia esculenta*) Peanut (*Arachis hypogaea*) Pigeon pea (*Cajanus cajan*)

Source: MAF (2022), GIZ (2022).

6.3 AEZ 3: Northern Uplands

Topography and altitude: The northern uplands cover about 19% of the total area of Timor-Leste. The Altitudes range 500–1500 masl. Gradients range 15–40%. **Geology and soils**: Inceptisols, Entisols; some regions have Mollisols, Alfisols and Ultisols. **Climate**: Annual precipitation in this zone ranges 1500–3000 mm/year. Annual temperatures range 20–22.5 ˚C (Molyneux et al. 2012).

Soil conservation techniques: Broad channel terraces, bench terraces, rainwater reservoir, drainage and waterfall building, grass planting, brushwood check dam etc.

Suitable agroforestry: Mahagony, sandalwood, rosewood, coffee, vanilla and clove are valuable timber and agricultural species that have suitability for AEZ 3. Table 6 details combinations of timber and food species suitable for agroforestry models in AEZ 3.

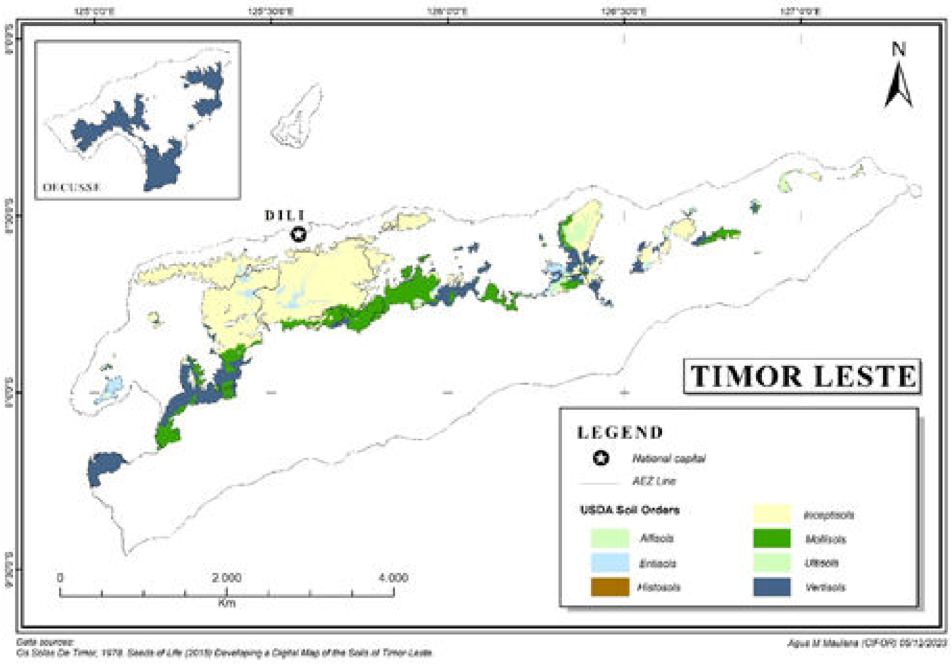

Figure 12. Soil map, AEZ 3: Northern Uplands

Table 6. Agroforestry models for AEZ 3 with main and intercrop species

Major species (multipurpose tree, middle to upper strata)	Fruit species (middle strata)	Spice and cash crop (middle to lower strata)	Annual crop (lower strata in early application before complete shading)
Mahogany (*Swietenia macrophylla*) Sandalwood (*Santalum album*) Casuarina (*Casuarina equisetifolia*) Acacia (*Acacia mangium*) Albizia (*Falcataria moluccana*) Rosewood (*Pterocarpus indicus*) Sesbania (*Sesbania grandiflora*) Bamboo (*Phyllostachys* spp)	Jackfruit (*Artocarpus heterophyllus*) Avocado (*Persea americana*) Orange (*Citrus sinensis*)	Coffee (*Coffea* sp) Vanilla (*Vanilla planifolia*) Clove (*Syzygium aromaticum*) Ginger (*Zingiber officinale*) Turmeric (*Curcuma longa*) Elephant foot yam (*Amorphophallus konjac*)	Sweet potato (*Ipomoea batatas*) Yam/ubi (*Dioscorea alata*) Pumpkin (*Cucurbita moschata*) Chayote (*Sechium edule*) Taro (*Colocasia esculenta*)

Source: MAF (2022), GIZ (2022).

6.4 AEZ Temperate Uplands

Topography and altitude: The temperate uplands cover about 2% of the total area of Timor-Leste. Altitudes are more than 2000 masl. Gradients are above 40%. **Geology and soils**: Mollisols. **Climate**: This AEZ receives annual precipitation of more than 2000 mm/year. Annual temperature ranges 10–17.5 ˚C (Molyneux et al. 2012).

Soil conservation techniques: Bench terraces, grass planting, all types of check dams and riverbank protection etc.

Suitable agroforestry: Implementation of agroforestry in this AEZ requires careful species selection and soil conservation techniques because the zone has slopes above 40%. Table 7 provides information of species that could be suitable for agroforestry models.

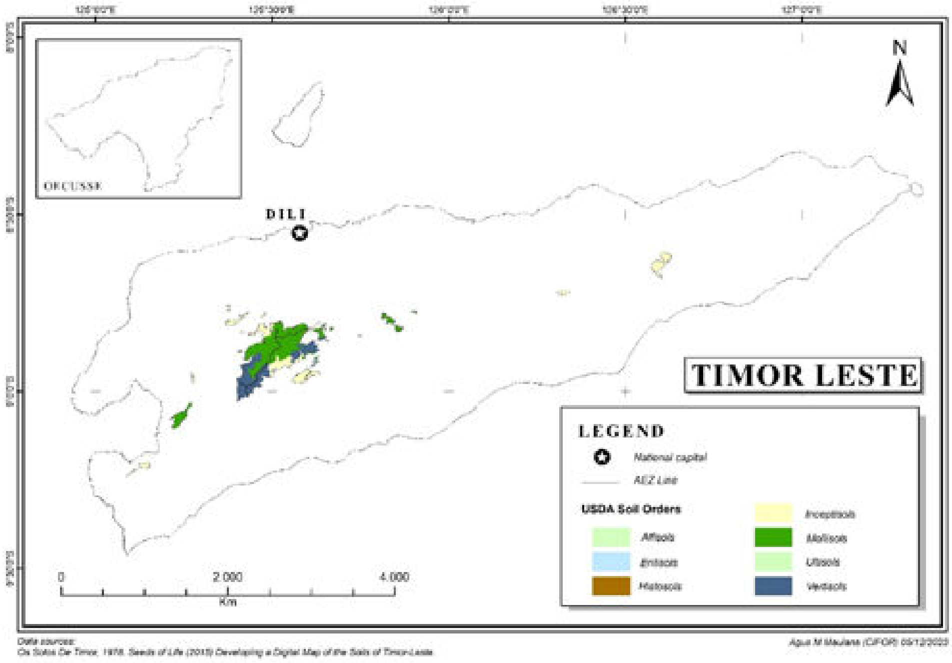

Figure 13. Soil map, AEZ Temperate Uplands

Table 7. Agroforestry models for AEZ Temperate Uplands with main and intercrop species

Major species (multipurpose tree, middle to upper strata)	**Fruit species (middle strata)**	**Spice and cash crop (middle to lower strata)**	**Annual crop (lower strata in early application before complete shading)**
Mahogany (*Swietenia macrophylla*) Sandalwood (*Santalum album*) Casuarina (*Casuarina equisetifolia*) Acacia (*Acacia mangium*) Albizia (*Falcataria moluccana*) Rosewood (*Pterocarpus indicus*) Sesbania (*Sesbania grandiflora*) Bamboo (*Phyllostachys* spp)	Jackfruit (*Artocarpus heterophyllus*) Avocado (*Persea americana*) Orange (*Citrus sinensis*)	Coffee (*Coffea* sp) Vanilla (*Vanilla planifolia*) Clove (*Syzygium aromaticum*) Ginger (*Zingiber officinale*) Turmeric (*Curcuma longa*) Elephant foot yam (*Amorphophallus konjac*)	Potato (*Solanum tuberosum*) Wheat (*Triticum*) Barley (*Hordeum vulgare*) Arrowroot (*Maranta arundinaceae*)

Source: MAF (2022), GIZ (2022).

6.5 AEZ 4: Southern Uplands

Topography and altitude: The southern uplands cover about 14% of the total area of Timor-Leste. Altitudes range 500–1500 masl. Gradient range 15–40%. **Geology and soils**: Entisols and Mollisols; some areas have Inceptisols. **Climate**: The annual precipitation in this zone ranges 500–1500 mm/year. Annual temperatures range 20–22.5 ˚C (Molyneux et al. 2012).

Soil conservation techniques: Broad channel terraces, bench terraces, rainwater reservoir, drainage and waterfall building, grass planting, brushwood check dam etc.

Suitable agroforestry: Mahagony and sandalwood are valuable timber trees that are suitable for AEZ 4. Various cash crops, such as maize, cassava and yam, could be suitable for lower strata in the early period of an agroforestry model. Table 8 presents species that have suitability with the environmental conditions in AEZ 4.

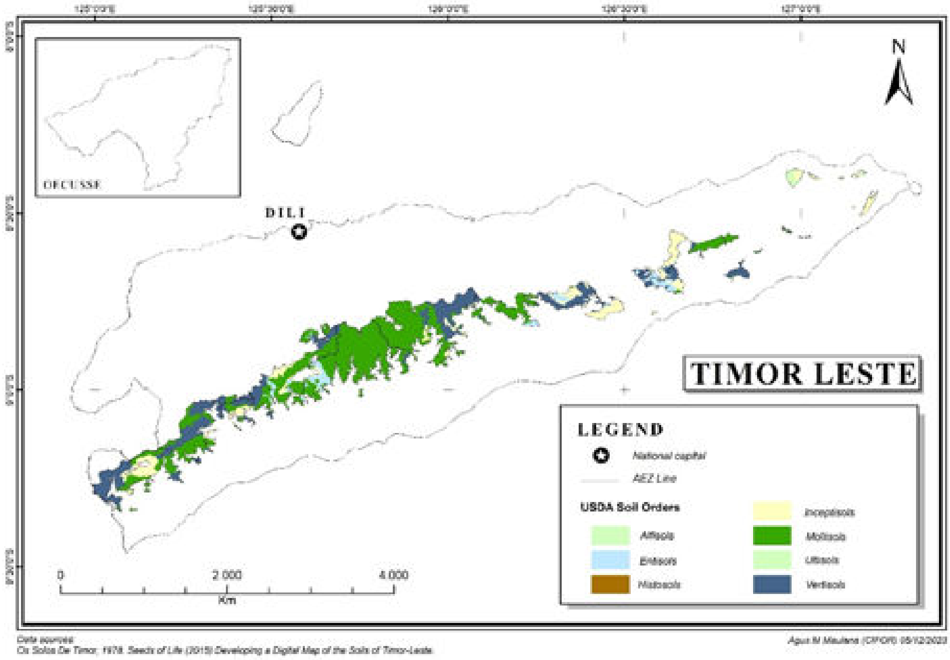

Figure 14. Soil map of AEZ 4: Southern Uplands

Table 8. Agroforestry models for AEZ 4 with main and intercrop species

Major species (multipurpose tree with middle to upper strata)	Fruit species (middle strata)	Spices and cash crop (middle to lower strata)	Annual crops (lower strata in early application before complete shading)
Mahogany (*Swietenia macrophylla*) Sandalwood (*Santalum album*) Casuarina (*Casuarina equisetifolia*) Acacia (*Acacia mangium*) Sesbania (*Sesbania grandiflora*) Bamboo (*Phyllostachys* spp) Leucaena (*Leucaena leucocephela*) Moringa (*Moringa oleifera*) Gamal (*Gliricidia sepium*)	Dragon fruit (*Selenicereus monacanthus*) Coconut (*Cocos nucifera*) Rambutan (*Nephelium lappaceum*) Jackfruit (*Artocarpus heterophyllus*) Lemon (*Citrus limon*) Breadfruit (*Artocarpus altilis*) Orange (*Citrus sinensis*) Pineapple (*Ananas comosus*) Banana (*Musa* spp) Mango (*Mangifera indica*) Guava (*Psidium guajava*) Papaya (*Carica papaya*) Snake fruit (*Salacca zalacca*) Candlenut (*Aleurites moluccanus*)	Black pepper (*Piper nigrum*) Ginger (*Zingiber officinale*) Turmeric (*Curcuma longa*) Cocoa (*Theobroma cacao*) Elephant foot yam (*Amorphophallus konjac*)	Maize (*Zea mays*) Sweet potato (*Ipomoea batatas*) Yam/ubi (*Dioscorea alata*) Pumpkin (*Cucurbita moschata*) Velvet bean (*Mucuna pruriens*) Chayote (*Sechium edule*) Cassava (*Manihota esculenta*) Taro (*Colocasia esculenta*) Peanut (*Arachis hypogaea*) Pigeon pea (*Cajanus cajan*)

Source: MAF (2022), GIZ (2022).

6.6 AEZ 5: Southern Slopes

Topography and altitude: This zone covers 21% of the total area of Timor-Leste. Altitudes range 100–500 masl. Gradients range 15–40%. **Geology and soils**: Vertisols; some areas have Mollisols and Inceptisols.

Climate: This zone receives annual precipitation ranging 500–1500 mm. Annual temperatures range 20–27.5 ˚C (Molyneux et al. 2012).

Soil conservation techniques: Broad channel terraces, bench terraces, rainwater reservoir, drainage and waterfall building, grass planting, brushwood check dam etc.

Suitable agroforestry: Main species that are suitable for agroforestry in AEZ 5 are presented in Table 9. The species in AEZ 5 are similar to AEZ 2.

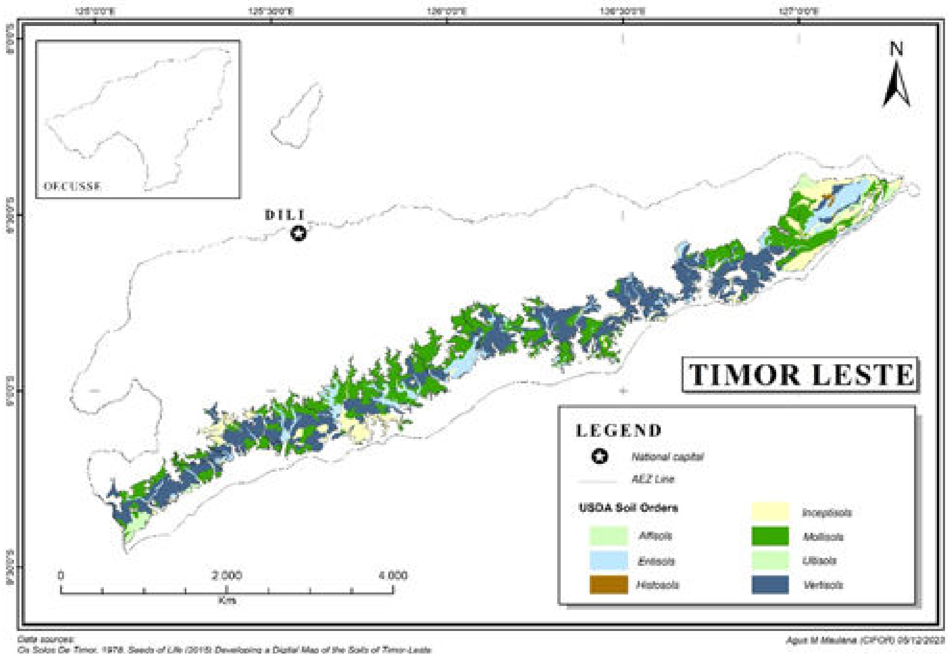

Figure 15. Soil map of AEZ 5: Southern Slopes

Table 9. Agroforestry models for AEZ 5 with main and intercrop species

Major species (multipurpose tree, middle to upper strata)	Fruit tree species (middle strata)	Spices and cash crops (middle to lower strata)	Annual crops (lower strata in early application before complete shading)
Mahogany (*Swietenia macrophylla*) Sandalwood (*Santalum album*) Casuarina (*Casuarina equisetifolia*) Acacia (*Acacia mangium*) Albizia (*Falcataria moluccana*) Rosewood (*Pterocarpus indicus*) Sesbania (*Sesbania grandiflora*) Leucaena (*Leucaena leucocephela*) Moringa (*Moringa oleifera*) *Gliricidia sepium* Bamboo (*Phyllostachys* spp)	Rambutan (*Nephelium lappaceum*) Jackfruit (*Artocarpus heterophyllus*) Breadfruit (*Artocarpus altilis*) Avocado (*Persea americana*) Orange (*Citrus sinensis*) Lime/Lemon (*Citrus limon*) Pineapple (*Ananas comosus*) Banana (*Musa* spp) Guava (*Psidium guajava*) Papaya (*Carica papaya*) Mango (*Mangifera indica*) Snake fruit (*Salacca zalacca*) Candlenut (*Aleurites moluccanus*)	Coffee (*Coffea* sp) Vanilla (*Vanilla planifolia*) Black pepper (*Piper nigrum*) Cinnamon (*Cinnamomum verum*) Ginger (*Zingiber officinale*) Clove (*Syzygium aromaticum*) Turmeric (*Curcuma longa*) Cocoa (*Theobroma cacao*) Elephant foot yam (*Amorphophallus konjac*)	Maize (*Zea mays*) Sweet potato (*Ipomoea batatas*) Yam/ubi (*Dioscorea alata*) Pumpkin (*Cucurbita moschata*) Velvet bean (*Mucuna pruriens*) Chayote (*Sechium edule*) Cassava (*Manihota esculenta*) Taro (*Colocasia esculenta*) Peanut (*Arachis hypogaea*) Pigeon pea (*Cajanus cajan*)

Source: MAF (2022), GIZ (2022).

6.7 AEZ 6: Southern Coastal Lowlands

Topography and altitude: The southern coastal lowlands cover around 11% of the total area of Timor-Leste. This AEZ lies at altitudes lower than 100 m and is characterized by 0–15% gradients, implying a dominance of flatland. **Geology and soils**: Mostly Entisols; some areas have Mollisols and Inceptisols. **Climate**: Annual precipitation ranges 1500–3500 mm. Annual temperatures range 25–27.5 ˚C (Molyneux et al. 2012).

Soil conservation techniques: Gabion check dam, ridge terraces, bio-pore infiltration holes, riverbank protection, rainwater reservoir, drainage, waterfall building etc.

Suitable agroforestry: Table 10 shows species that are suitable for agroforestry in AEZ 6. A wide range of species are suitable for the environmental conditions in AEZ 6, such as mahogany, teak, sandalwood (valuable timber species), maize, cassava (staples).

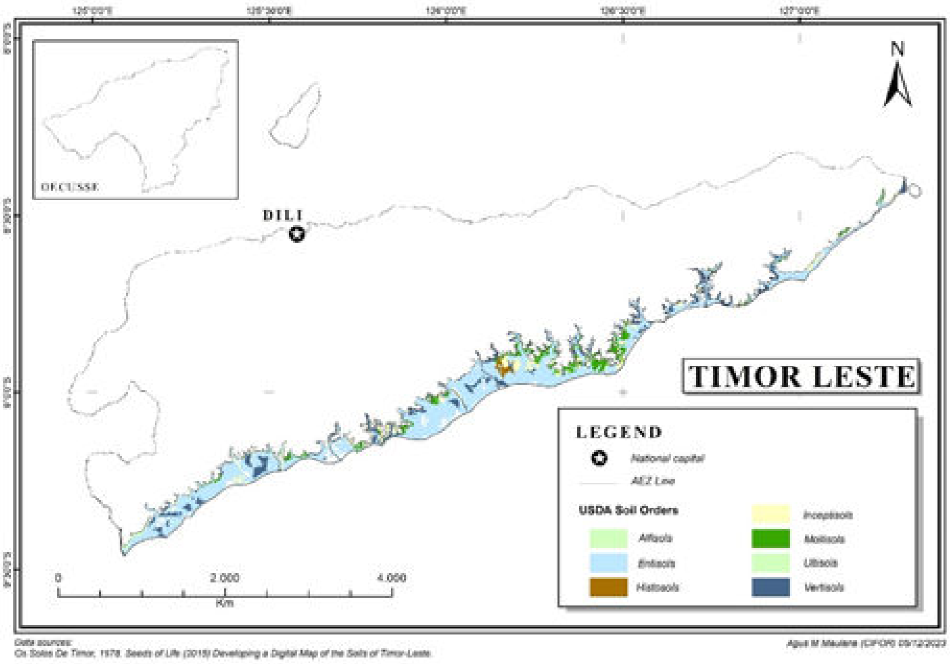

Figure 16. Soil map, AEZ 6: Southern Coastal Lowlands

Table 10. Agroforestry models for AEZ 6 with main and intercrop species

Major species (multipurpose tree, middle to upper strata)	Fruit tree species (middle strata)	Spice and cash crop (middle to lower strata)	Annual crop (lower strata in early application before complete shading)
Mahogany (*Swietenia macrophylla*) Teak (*Tectona grandis*) Sandalwood (*Santalum album*) Casuarina (*Casuarina equisetifolia*) Acacia (*Acacia mangium*) Sesbania (*Sesbania grandiflora*) Leucaena (*Leucaena leucocephela*) Moringa (*Moringa oleifera*) *Gliricidia sepium* Bamboo (*Phyllostachys* spp)	Dragon fruit (*Selenicereus monacanthus*) Coconut (*Cocos nucifera*) Rambutan (*Nephelium lappaceum*) Jackfruit (*Artocarpus heterophyllus*) Breadfruit (*Artocarpus altilis*) Orange (*Citrus x sinensis*) Lime/Lemon (*Citrus limon*) Pineapple (*Ananas comosus*) Banana (*Musa* spp) Guava (*Psidium guajava*) Papaya (*Carica papaya*) Mango (*Mangifera indica*) Snake fruit (*Salacca zalacca*) Candlenut (*Aleurites moluccanus*)	Black pepper (*Piper nigrum*) Ginger (*Zingiber officinale*) Turmeric (*Curcuma longa*) Cocoa (*Theobroma cacao*) Elephant foot yam (*Amorphophallus konjac*)	Maize (*Zea mays*) Sweet potato (*Ipomoea batatas*) Yam/ubi (*Dioscorea alata*) Pumpkin (*Cucurbita moschata*) Velvet bean (*Mucuna pruriens*) Chayote (*Sechium edule*) Cassava (*Manihota esculenta*) Taro (*Colocasia esculenta*) Peanut (*Arachis hypogaea*) Pigeon pea (*Cajanus cajan*)

Source: MAF (2022), GIZ (2022).

7 Major multipurpose tree species: Propagation techniques and nursery management

Table 11. Multipurpose trees' propagation techniques and nursery management

***Swietenia macrophylla* (mahogany)**	
Seed collection	Mahogany is usually propagated from seeds. The seeds from a mother tree in good health and form give the best results. Seed production fluctuates from year to year owing to variation in flowering phenology, failure of pollination, or fertilization. Flowering and fruiting occur annually at 10–15 years-old. Flowering occurs July–September whereas fruiting occurs December–February. Dry fruits and capsules collected can be stored whereas unripe capsules should be dried to open and release seeds. Germination capacity of fresh seeds is around 80–90%.
Sowing and nursery management	The seeds are sown in a bed of sand in furrows or holes that are 3–7 cm deep. Germinating seeds require shade and a moist environment. A square spacing of 10 x 15 cm results in seedlings with a height of 30–60 cm. To obtain seedlings of 100 cm in height, a spacing of 20 x 30 cm is recommended. The seeds can also be sown in containers. Seedlings from containers are suitable for dry sites. In order to produce healthy and fast-growing plants, proper maintenance of seedlings in the nursery is necessary. It is important to conduct weeding in the nursery every 2–4 weeks until seedlings are ready for planting. The nursery should also be watered before seedlings are lifted for transport, to avoid strain and breakage. Root pruning in the nursery helps to create fibrous roots and should be carried out 4 weeks before lifting.
Planting	The seedlings can be planted when they are 50–100 cm tall. Keeping roots moist increases the survival rate of seedlings. Before planting, the planting site should be cleared of all weeds. The optimum spacing is 2 x 3 m. Since mahogany requires shade for optimum growth, integrating it with *Paraserianthes falcataria* and *Manglieta glauca* can be effective. In order to intercrop agricultural crops and vegetables with this species, wider spacing of 4–5 x 4–5 m is recommended.
***Tectona grandis* (teak)**	
Seed collection	Teak starts producing seeds around 5–6 years-old. The seeds from 20-year-old trees are usually recommended. The seeds are produced annually and are collected January–March by sweeping the fruits below the trees. After collecting the fruits, they are sun-dried for 2–3 days and then the seeds are collected by removing the pericarps. Seeds are then left to dry under the sun. The germination rate is usually slow, i.e., 50%, but sometimes it reach 80%.
Pre-sowing	Before sowing the seeds, pre-sowing treatments are carried out to remove the seed coats by either of these methods: 1) Natural weathering (seeds are placed under natural conditions, such as rain and sun); 2) artificial weathering (seeds are put in a bag and soaked in water for 3–4 days then left to dry. The process is repeated till the seed coats are cracked); 3) pit method (seeds are put in a pit for 7 days with alternate layers of grass and straw; water is inserted through holes); 4) alternate wetting and drying

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Table 11. Continued

	(seeds are soaked in water at night and dried in sun during the day); 5) biological method (seeds are inoculated with fungi, such as *Scytalidlium* to degrade the seed coats); 6) chemical method (seeds are treated with conc. sulphuric acid for 20 minutes); 7) scorching (seeds are spread on the ground and covered with a thin layer of grass and leaves, running fire is allowed); and 8) cow manure treatment (seeds are left in cow manure for a week and then sown).
Sowing and nursery management	Nurseries are prepared 1 year before planting. Before sowing seeds, the soil of the nursery is prepared. Soil is dug out for 45–50 cm and stones, stubble and stumps are removed. Then the seed beds are prepared. Pre-treated seeds are sown in lines in seedbeds of height 7.5–10 cm. The standard seed bed is of size 12 x 1.2 m where around 2.5–3 kg of seeds is sown to produce 1200–1500 seedlings. Sowing is usually done April–June. After sowing the seeds, daily watering is carried out for up to 1 year, except during the rainy season.
Vegetative propagation	Teak can be propagated using vegetative methods. Grafting and budding methods are more appropriate than branch cutting for teak. The rooting time of a cutting is 8–15 days and the survival rate of rooted stock is 90–100%.
Santalum album **(sandalwood)**	
Seed collection	Sandalwood is an obligate root hemiparasite, meaning it requires a host plant species to provide water and nutrients through its roots. Therefore, the successful cultivation of sandalwood requires careful attention to the selection of host plants and the management of the growing environment. Sandalwood seeds are collected from trees 15–20 years-old and can be stored at room temperature up to 2 years with no loss of viability. Seeds of a suitable host species that is compatible with *Santalum album* can also be collected. The host should have a symbiotic relationship with sandalwood, meaning it can form a mutually beneficial association with the sandalwood tree. Proven suitable species for Timor-Leste and neighbouring islands include *Acacia* spp, *Casuarina* spp, *Paraserianthes* spp and *Sesbania* spp. Other potential hosts include *Gliricidia sepium*, *Melaleuca cajuputi*, *Cymbopogon nardus* and *Leucaena leucocephala*.
Sowing and nursery management	The fresh seed have a dormancy period of 2 months. Manual scarification can also break this. The seed will germinate in about 8–14 days. The sandalwood seeds can be planted in polybags (30 x 14 cm) containing sand, soil and manure at a ratio of 2:1:1) together with one or two seeds of a host plant or next to a seedling or, in a field nursery, an established host plant so that they can establish a parasitic connection. Preferably, host plants should be well established. Prune established host plants periodically so that they do not hamper the growth of the sandalwood seedlings.
Planting	Sandalwood seedlings 6–8 months-old of height 15–35 cm with well-developed root systems are preferred for planting. Before transplanting, harden the seedlings by reducing the frequency of watering and expose them to full sunlight for 10–15 days. The best time for planting out is at the start of the wet season, when the soil is moist and the temperature moderate. If raised in a covered nursery, the sandalwood and hosts can be planted out in the same pit, prepared as described below. If the sowing was direct in a field nursery, the pits would have been prepared in the same manner and the host plant already established before introducing the sandalwood seed. Prepare pits of 30 x 30 x 30 cm at spacing of 3 x 3 or 4 x 4 m, depending on soil fertility and rainfall (drier and less fertile areas should have wider spacing). Fill pits with a mixture of topsoil and manure or compost at a ratio of 3:1. For seedlings transplanted from a covered nursery, remove the sandalwood seedlings and hosts from the polybags, taking care not to damage the roots or root nodules.

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Table 11. Continued

	Plant the sandalwood seedlings in the centre of the pits along with the host, at a depth of 2–3 cm, and 1–3 m distance of seedling from the host, depending on the size of the host (preferably at least 1 m height; the greater the height the greater the spacing). Press the soil firmly around the seedlings and water them immediately. Apply mulch. Water regularly, especially during the dry season, until well established. Prune the host plant periodically to avoid shading and competition with the sandalwood. Host plants should be maintained at a height of 1–1.5 m with a canopy diameter of 0.5–1 m. Protect both host and sandalwood from pests and diseases (spraying etc) and grazing livestock (fencing, netting).
Casuarina equisetifolia **(casuarina)**	
Seed collection	Flowering and fruiting of casuarina usually occurs regularly once or twice a year. Female cones mature 18–22 weeks after anthesis and open to release fruits. The optimum time to collect seeds is February–March. Fruits are dried before extracting seeds. Seeds usually don't require pre-treatment. The viability of seed is up to 3 months, however, the germination capacity of seed is very low, i.e., 20%.
Sowing and nursery management	Seeds are germinated in beds or trays containing sand or a mixture of sand and peat moss. The seedbed size should be 1 x 5 m. After watering, seeds are spread in the seedbed and covered with a thin layer of fine sand. 10% BHC powder can help to avoid damage caused by insects; it is spread in the bed and covered with straw. The germination of seed occurs between 5–22 days. Watering should be done twice a day.
Planting	Seedlings germinated from seed are transferred to secondary beds or polythene bags after 4 weeks or when they attain a height of 8–10 cm. Seedlings are transplanted in the secondary bed made of sand, manure and soil with a 4 cm distance between each plant. Seedlings raised in polybags grow well in rain-fed areas. Planting out just before or during rain ensures high survival under rain-fed conditions. The pit size for container-raised plants is 30 x 30 x 30 cm. The recommended spacing is 1.5 m.
Acacia mangium **(acacia)**	
Seed collection	Acacia starts to flower and produce seeds 18–20 months after planting. The mature fruits of acacia are available from July. The seeds are collected either from the trees or from the ground. The pods and seeds should not be left too long to dry in the sun as this can reduce viability. The funicle can be removed manually by rubbing the seed over a sieve. The seeds are orthodox and can retain viability for several years when stored in an air-tight container. Mature seeds are pre-treated by immersion in boiling water for 30 seconds followed by soaking in cold water for 24 hours. The germination rate of seeds is very high, i.e., 75–90% after treatment.
Sowing and nursery management	Seeds are sown in seedbeds and transplanted after 6–10 days. Sowing in a germination tray and transplanting after the radicle emerges is a successful technique for acacia. Direct sowing should be carried out under a shade net. Seeds need to be covered after sowing by using coarse-washed sand or gravel that prevents damping off and provides air exchange and water drainage. Adequate moisture and fertilizers are essential for seedling growth. Seedlings are retained in the nursery for 12 weeks or till they attain a height of 25–40 cm. Root pruning and hardening off of seedlings before planting are recommended.
Plantation	Seedlings are planted manually during the rainy season. The planting hole should be around 13 cm in diameter and 20 cm deep. Spacing between seedlings can vary 2 x 2–4 x 4 m. Weeding 2 months after planting is recommended.
Pterocarpus indicus **(rosewood)**	
Seed collection	Flowering and fruiting occur every year. Fruit development takes around 3–4 months. Fruits are persistent in the tree for some time after maturity, therefore, there is no limit to the collection of seeds. Collection can be done directly from the tree or from the ground after fruits are released. In order to extract seeds manually, the fruits

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Table 11. Continued

	should not be dewinged. However, dewinging is necessary to reduce bulk. The dewinging can be done using hammer mills or brushing machines with hard brushes. The dewinged fruits can then be stored until sowing. Seed extraction should not be done until shortly before sowing because extraction often implies damage to the seed. The seeds are orthodox and can be stored at low temperatures and moisture content for several years. The seeds are not dormant and therefore don't need pre-treatment.
Sowing and nursery management	Seeds are sown in nursery flood beds or in plastic bags. The germination rate is around 24–40% at 4–15 days after sowing. The seedbed should be mulched and partial shade should be provided. Seedlings can be transplanted to a seedbed at a spacing of 5 x 20 cm for 3–4 months before planting out as bare-rooted seedlings. For direct sowing, 2–4 pods should be placed in a hole of 2 x 2 m.
Plantation	Seedlings should be planted at a spacing of 1 x 1 m. The nursery-raised plantings should be planted in the field during the rainy season. The recommended height of planting stock is 75–100 cm if bare-rooted and 22–30 cm if potted seedlings. For the planting, holes about 15 cm in diameter and 15–20 cm deep should be made.
Vegetative propagation	Rosewood can be propagated through cuttings. Shoot cuttings are prepared from branches 2–3.5 cm in diameter and 1–2 cm long with all leaves and side branches removed. For planting from cuttings, a hole of 20 cm in diameter and 30 cm deep should be made.
Sesbania grandiflora **(sesbania)**	
Seed collection	Seeds are collected when ripe from trees of best form during April–May. The viability of the seed is up to 1 year. No pre-treatment is required before sowing.
Sowing and nursery management	Seeds are sown during warm weather when the soil temperature is at least 25 °C. The best time to sow is October–January. Seeds can be sown in polybags soon after collection and watered regularly. The germination rate is around 90%. The growth of seedlings is very rapid. Seedlings are fit for planting within 1 month.
Planting	The seedlings are planted at 1.5–2 m spacing.
Vegetative propagation	Sesbania can be propagated by cuttings and seedlings.
Leucaena leucocephela **(leucaena)**	
Seed collection	Leucaena is usually self-fertile. The seed should be collected from uniform, standing trees during November–December. The viability of seeds is up to 2 years, however, they last longer if refrigerated. The seeds do not germinate unless scarified or the seed coat is scratched with a knife or treated with hot water.
Sowing and nursery management	The seeds can be directly sown in polybags in April. The seed usually germinates in 8 days, however, the germination rate of leucaena is only 40%. For a small nursery, any type of seedling container can be used. Proper weeding is necessary for direct sowing. The roots of seedlings raised more than 6–8 weeks in containers become rootbound leading to poor root growth in the field. Seedlings should not be kept too long in the nursery or open-ended containers should be used. Regular root-pruning is necessary. The seedlings' soil should be mixed with peat or other organic matter in the nursery.
Planting	The establishment of leucaena is slow, with at least 6 weeks in the small seedling stage. Bare-root seedlings are planted in rows by lifting them from the beds. Transplanting nursery-grown stock will give higher survival rates than direct seeding. Stump cuttings can also be used, for which the root should be cut at 15 cm, shoot at 25 cm, and should be kept moist until they are planted. The spacing for the planting should be 1x1–2x2m for woodlots. These trees should be thinned to wider spacings as they mature. Good initial land preparation and weed control are extremely important.
Moringa oleifera **(moringa)**	
Seed collection	Moringa trees flower and fruit annually or twice a year. The trees are able to produce fruits 3 years after planting. A mature tree can produce up to 1600 pods (fruits). The

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Table 11. Continued

	pods can directly be harvested from the trees. The seeds are viable for up to 1 year. The seeds can be treated by soaking in water overnight before sowing or by cracking the shells before planting.
Sowing and nursery management	In the nursery, polybags of 18 cm height and 12 cm diameter can be used for seedling establishment. The soil for seed sowing should be light, consisting of soil and sand. In each polybag, 2–3 seeds are sown 1–2 cm deep. The polybags should be moist but not too wet. Germination occurs within 5–12 days. Extra seedlings should be removed from polybags leaving only one in each bag. Seedlings can be planted out in the field when they reach a height of 60–90 cm. When planting, cut a hole in the bottom of the polybag big enough to allow the roots to emerge.
Planting	For planting out moringa seedlings, a pit about 50 cm deep and wide should be dug out. The pit helps with retaining moisture in the root zone, which helps in rapid rooting. Compost mixed with fresh topsoil should fill the pit. Planting should be done after rainfall. After planting, it is recommended not to water heavily for the first few days. The spacing for moringa is about 3 x 3 m. Planting trees in an east–west direction ensures sufficient sunlight and airflow
Vegetative propagation	Moringa can be planted through cuttings. Hardwood should be used. Cuttings should be 45 cm to 1.5 m long and 10 cm thick. Cuttings can be planted directly or in sacks in the nursery.
Gliricidia sepium	
Seed collection	Gliricidia flowers November–December and fruits ripen in January–February. Each fruit (pod) consists of 8–10 seeds. Pods are collected in February–March before they dehisce on the tree. The pods are then dried in the sun for 3–4 days to separate the seeds. The viability of seeds is 1 year. The seeds can be stored for a longer time if refrigerated. As a pre-treatment, seeds are soaked in hot water and allowed to cool during the night before sowing the next morning.
Sowing and nursery management	In the nursery, two seeds per polybag can be sown in March. It is better to use an open-ended container to allow proper root growth. Regular root pruning is necessary. The polybags should consist of soil and organic matter. The use of fungicides is recommended for large-scale plantings. Watering should be done regularly. Gliricidia requires shade for germination. The germination can be noticed within 10 days. The germination rate of gliricidia is very high, i.e., 90%. The seeds attain plantable size within 4 months.
Planting	At the seedling stage, they are susceptible to weed competition therefore transplanting nursery-grown plants is recommended. Good initial land preparation and weed control are important before planting. Seedlings around 3–4 months-old are planted on bunds at 50 cm spacing during the rainy season. For steep slopes, the spacing between seedlings should be less than 20 cm in order to control soil erosion. The trees should be thinned to wider spacings as they mature.
Vegetative propagation	Gliricidia plants from stem cuttings grow faster than those grown from seeds. Large-sized cuttings around 1–2.5 m in length and 6 cm in diameter are made from branches that are 1.5–2 years-old. Small cuttings are made from branches that are 6–12 months-old. Small cuttings are of length 30–50 cm. The cuttings are made from straight and healthy branches.
***Phyllostachys* spp (bamboo)**	
Seed collection	Seeds are collected both from clumps and the ground. Seeds are generally produced in the early part (mid-February–May) of the year and are healthy and more viable.
Seed germination and nursery management	Bamboo seeds are sown in polythene bags under shade because this facilitates higher seed germination than in direct sunlight. Clean, high-quality seeds treated with insecticide are used to produce planting material in the nursery. Soil and manure (3:1) should be used as germination media, which should be wet. Usually, bamboo species start germination within 3–7 days of sowing. The seedlings are grown best in partial shade rather than direct sunlight or full shade. The seedling needs regular watering and weeding in the nursery.

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Table 11. Continued

Vegetative propagation (single node culm cutting)	Single node culm cutting is a very useful technique for species like *Bambusa*, which often produces seeds and cannot be planted in quantity by traditional techniques. The cutting consists of a single node with its branches cut back to 10–20 cm and half the internode on each side can be used in new techniques that allow branches to be oriented correctly. Culms 2- or 3-years-old with strong branching can be used because they are considered to be more successful. The cuttings are planted when the buds are ready to burst. It has been noted that if cuttings obtain enough water and do not dry out, the shoot develops in 1–2 weeks.
Vegetative propagation (rhizome planting)	This traditional method is employed with various species of bamboo. It involves the preparation and planting of a bulky 'offset' cutting, which comprises the whole or a subsequent part of a 1-year-old rhizome section with a 1–3 m length of culm attached. This is very reliable if applied properly. The culm with its entire rhizome should be removed in late May or early June during the rainy season and the rhizome should be protected from the sun so that new shoots on the rhizome and culm will not be damaged.
***Falcataria moluccana* (albizia)**	
Seed collection	Albizia typically flowers when trees are 3 years-old. In some areas, flowering occurs twice a year in March–June and October–December. After 2 months of flowering, ripe pods appear on the tree. The pods dehisce when ripe, still attached to the tree, thereby scattering seeds on the ground. It is difficult to collect the scattered seeds from the ground therefore the pods should be collected just before maturity when they are brownish in colour. The pods should be collected during the morning or afternoon. The brown pods are easily opened to release seeds. The seeds can be extracted by beating the fruits in a sack using a stick. The seeds are orthodox and the viability lasts for 1–1.5 years.
Sowing and nursery management	The untreated seeds germinate irregularly. Germination may start after 5–10 days but sometimes it is delayed for up to 4 weeks. For uniform germination, a small quantity of boiling water can be added to the seed. Then the seed should be soaked in warm water for 12–24 hours before sowing. The germination rate ranges 80–100%. Seed are sown on a seedbed by pressing them gently into the soil. The seedbed should be of size 5 x 1 m. The sown seeds are then covered with a layer of sand up to 15 mm thick. The soil in the seedbed should be loose and well-drained.
Planting	The seedlings can be transplanted to the field when they attain a height of 20–25 cm. The seedlings reach this height by around 8–11 weeks. Container-grown plants are often transplanted to the field when they reach 4–5 months-old. The growth of albizia is very fast and therefore only one complete and three spot weedings are necessary during the first year. The recommended spacing for the planting of albizia is 2 x 4 m because at narrow spacings the seedlings grow very fast and take over the whole area.

Source: Rojas-Sandoval (2019); Fuglie and Sreeja (2014); Nautiyal et al. (2011); Hidayat et al. (2003); Joker (2009); Winrock (1998); Winrock (1990); USDA (1990); Brewbaker (1987); Banik (1987); Ramachandaran et al. (1980); Banik (1980); Das (2021).

8 Major fruit tree species: Propagation techniques and nursery management

Table 12. Fruit trees' propagation techniques and nursery management

***Selenicereus monacanthus* (dragon fruit)**	
Soil preparation	Seed beds should be prepared in a sunny, well-drained environment with plenty of organic matter. Dragon fruit needs more water than other cacti and requires soil that retains moisture.
Seed preparation and planting	To prepare the seeds, ripe dragon fruit is cut in half and the black seeds scooped out. The fruit flesh and pulp are washed from the seeds that are then laid on a moist paper towel for at least 12 hours. The seeds are then sprinkled across the seed bed's surface and covered with a thin layer of soil. Seeds should not be sown too deep. The seed bed should be watered frequently. If the soil tends to dry out, the bed can be covered with plastic wrap to trap moisture until the seeds germinate.
Seedling management	As the dragon fruit seedlings continue to grow, thinning should be done to give each new plant space. Mature dragon fruit will need a pot at least 50 cm wide. Once the dragon fruit plant reaches 30 cm height, it will need a support system to grow. The propagation of dragon fruit from seeds is less reliable and requires patience because the time from propagation to fruit production is very long, i.e., 7 years. Dragon fruit is best propagated through cuttings.
Propagation by cuttings	For stem cuttings, a stem segment of 15–38 cm should be used. A slanted cut is made at the base of the stem and it is treated with fungicide. The treated stem segment should be left to dry for 7–8 days in a dry and shaded area. The cutting is then dipped into a rooting hormone and planted directly in the garden or in a container consisting of well-drained soil. The cuttings are able to produce fruit 6–9 months after propagation.
Nursery management	Dragon fruit needs moist soil and a sunny environment and it should not be overwatered. Further, since dragon fruit is a climber, it needs some kind of support to grow on, such as a trellis, fence or wooden stake. To keep the plants disease-free and to ensure proper growth, dead, dying, diseased and overcrowded branches should be pruned.
***Cocos nucifera* (coconut)**	
Soil preparation	For coconut, a well-drained sandy loam or loamy texture soil is required. Coconut can grow in soil with a wide range of pH but it grows best on pH 5.5–7.
Seed preparation	The seeds of coconut are collected as soon as they have ripened. Fresh seeds have more potential to germinate. Checking the embryo and endosperm of a sample seed ensures freshness. To check the freshness, the seed should be cut open and the colour and odour should be assessed; discoloration and foul

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Table 12. Continued

	odour indicate that the seed is not fresh. The pulp and flesh of the fruit should be removed from the seed. To prepare the seed for sowing, it should be soaked in water for 2–3 days. The soaking seed will weaken the outer coat thus allowing it to germinate more easily.
Sowing and nursery management	Seed nuts should be planted in long, thin beds with a 40 x 30 cm spacing either vertically or horizontally in 20 cm deep trenches. Fresh seeds germinate at 27–30 °C. The seed has no dormancy and the growth of the seedling is continuous. The size of the container should allow the taproot to develop completely. When sowing, seeds should be only partially covered, allowing seedlings to immediately be exposed to light. The seeds should be watered twice a week. Germination will take place in 5–6 months. For irrigation, sprinklers, microjet sprinklers and hoses are ideal for coconut nurseries. The polybag nursery technique is appropriate for growing stronger seedlings. High humidity is essential for germination, therefore, constant mist should be provided to prevent the seeds from drying.
***Citrus limon* (lemon)**	
Soil preparation	Lemon trees are able to tolerate drought conditions but perform poorly in waterlogged soil. Therefore, a well-drained sandy loam should be used. The pH of the soil for the planting of lemon should be between 6 and 7.5. For adequate root development, the soil must be deep. Further, lemon trees grow well in full sunlight.
Budding	The best method of propagation of lemon trees is through budding. Budding should be carried out when the stem of the seedling is around 6–9 mm in diameter. Budwood (twigs) should be collected from the previous growth flush or current flush when the twig has begun to harden. Twigs should have well-developed buds and should be of size close to the stem of the seedling to which the bud will be joined. The budwood is then trimmed to create a bud stick around 20–25 cm by removing unwanted wood and leaves. The budwood is joined to the stock by T-budding. A vertical cut should be made in the stem of the rootstock and a horizontal cut should be made at either top or bottom of the vertical cut to produce a 'T' shape. The bud should be removed from the budstick and the bud inserted into the cut on the rootstock. The bud is held in place by wrapping it with budding tape. Once the bud begins to grow and reaches several centimetres in length, it can be removed completely from the seedling.
Planting management	Newly planted lemon trees should be watered regularly. Young trees also require application of fertilizer every month in the first year. Lemon trees should be protected from cold temperatures.
***Artocarpus altilis* (breadfruit)**	
Soil preparation	Breadfruit prefers light and medium soil such as sand, sandy loams, loams, and sandy clay loams. A well-drained soil should be used in any case. Breadfruit can tolerate saline soils as well as coralline and atolls. For optimum growth, soil pH should be maintained around 6.1–7.4.
Propagation	The seeds of breadfruit are rarely used for propagation. The species is best propagated by using root shoots and root cuttings. The root shoots and root cuttings should be collected after the fruiting season is over and when the tree is in an active vegetative stage. Healthy shoots are collected when they are at least 20–25 cm long and the stem has become woody. The attached root is then cut on either side of the shoot. The shoot is then severed from the parent tree. To avoid damage to the shoot's root system, root shoots should be grown under nursery conditions for 3–6 months before out planting. Root cuttings are used to mass-propagate breadfruit. The roots should be collected from healthy trees. Roots with diameters around 1.5–6 cm can be used. The root should be cut into 15–25 cm sections. Treatment with fungicides can prevent the growth of pathogens that cause root rot. The roots are placed in a propagating bed, flats, or individual pots. Cuttings are placed either horizontally or at an angle, but

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Table 12. Continued

	not upright, with a small upper portion of the root exposed. Root cuttings should be kept shaded and moist. Shoots begin to develop from adventitious buds after 3–4 weeks when shoots are 20–25 cm tall with their own root system; they should be carefully uprooted and transplanted into 10–15 litre pots.
Nursery management	Breadfruit plants grow best in partial shade. If plants are to be planted in full sun, gradually move to full-sun conditions in the nursery to harden them to the site conditions at about 2 months-old. Young plants should never be allowed to dry out or be exposed to strong wind.
Planting	When plants have reached the desired size, they can be planted in the field. The number of leaves should be reduced to reduce transpiration. To transplant, a hole is dug of the same depth as the container and twice as wide as the container. A small amount of fertilizer is added to the hole and covered with soil. The breadfruit seedling is then placed in the hole and soil is added along with a top layer of compost. Young plants prefer partial shade. It is best to plant trees at the onset of the rainy season.
***Ananas comosus* (pineapple)**	
Soil preparation	The soil for the planting of pineapple should be sandy loam, well-drained, and rich in organic matter. The pH of the soil should be maintained at 4.5–6.5. Established pineapple plants can tolerate drought but cannot tolerate waterlogged soil because it leads to root rot.
Propagation	Pineapple is propagated through vegetative means that include crowns, slips, and suckers. Propagation from a sucker is the most used method for commercial plantings. Pineapple suckers arise from leaf axils whereas slips grow from the stalk below the fruit. Suckers and slips are cut from the parent plant and are used to produce new plantings. The cuttings should be cured for some days before planting. Pineapple is set out in double rows with the plants staggered 25–30 cm apart within the double row and allowing a further 60 cm between double rows.
Nursery management	Mulching around the pineapple plants can help to conserve soil moisture. To encourage growth, ratooning is recommended. Removing suckers and slips from developing plants can help the plant to focus energy on producing fruit. The application of nitrogen and potassium benefit pineapple. For the first few months, little fertilizer is required whereas the need for fertilizer increases as the plant approaches flowering.
***Musa* spp (banana)**	
Soil preparation	The soil should be mixed with composted organic matter or a sand–peat–moss mixture. The soil should be 0.5–1 m deep, consisting of organic matter. The range of pH should be 6.5–7.5. An alluvial soil is the best for banana cultivation.
Propagation	Banana is best propagated by asexual means, especially through suckers. Under ideal conditions, a banana plant can produce 8–10 suckers per plant in the first year but the number of suckers diminishes in following years. All the useless suckers should be cut before they grow too big. Only 1–2 strong suckers should be left for the next generation, therefore, only one new sucker should be grown every 3 months. The suckers are removed from clumps of banana plants with a spade when they reach at least 1 m tall, during the warmer months. Planting should be done close to the surface. Large leaves are cut off the sucker leaving only young leaves or no leaves at all.
Planting management	The planting distance for banana plants differs according to the variety. Small stature bananas may be planted 6 m or more from other plants and as close as 2.5 m from other small stature banana plants. Large banana varieties should be planted at 3.5 m or more from other banana plants. The plants should be watered thoroughly upon planting and a heavy layer of mulch should be placed around the suckers immediately after planting.

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Table 12. Continued

***Mangifera indica* (mango)**	
Seed collection	Flowering in mango species occurs annually December–April and fruiting occurs 100–150 days after flowering. The fruits can be harvested during June–July. Mango seeds lose viability very rapidly. It is necessary to clean the seed as soon as possible after its removal from the fruit. Then the seeds should be dried in the shade for a day or two. Before planting, the outer husk must be removed. The easiest way to extract the embryo is to cut the husk at the stalk end of the fruit to create a small slit. Then the husk should be opened with a seed-opening tool.
Sowing and nursery management	A large tray filled with potting medium can be used to sow mango seeds. Recommended potting medium typically consists of fertilizer, coarse river sand, vermiculite, and sphagnum peat moss. Seeds are planted about 1 cm apart. The concave edge of the kidney-shaped seed should be faced downwards and the top part of the seed left uncovered. If the seed is green in a few days, it is healthy and if the seed is brown or black, it is rotting and should be replaced with another seed. As the seeds germinate, they can be carefully removed from the seedling bed and planted into individual pots. Germination takes 10–14 days.
Planting management	Usually, mango seedlings are planted when they are 4–18 months-old. The planting time is April–October when the plants are dormant. While planting, leaves should be removed to reduce the rate of water loss through transpiration. Natural mulch, leaf litter, hay, bagasse or composted manure should be spread around the base of the tree to conserve soil moisture and suppress weeds.
***Psidium guajava* (guava)**	
Seed collection	Ripe fruits are harvested from selected plants of good form and health. The fruit is collected when the green cover turns yellow. The seeds are then removed, washed in running water, and dried in the shade for 10 days. Stratification is not needed for guava seeds. The seeds remain viable for up to 1 year.
Sowing and nursery management	The seeds can be sown in polybags that consist of a substrate with good drainage. For germination, a warm soil temperature (21–30 °C) is important. The germination rate is higher than 90% and usually takes around 15–20 days.
Planting	The field should be ploughed, harrowed and levelled before digging pits of 0.6 x 0.6 m, usually before the rainy season. The pits should be filled with soil mixed with organic matter (20 kg) and 500 g of superphosphate. In poor soils, a bigger pit size is recommended (1 x 1 m) with a higher amount of organic matter. The onset of the monsoon is the best time to plant guava. There should be at least 6 x 6 m spacing for guava.
Propagation (vegetative)	Guava also propagates by vegetative methods such as via cuttings, air layering, grafting and budding. The air-layering method is the most successful method to grow guava.
***Carica papaya* (papaya)**	
Seed collection	To collect papaya seeds, a healthy, ripe papaya is needed. The fruit is cut into half lengthwise and a spoon can be used to scrape out the seeds. Then the sarcotesta should be broken to remove the seeds from it. To break the sarcotesta, the seeds are placed in a sieve and pressed against the sides of the sieve (a spoon can also be used for this). After the seed coat is broken, the inner seeds can be scooped out. Then the seed is washed with lukewarm water to remove any remaining jelly. The seeds are spread on paper towels on a tray. The tray should be placed in a warm location but not in sunlight as this might destroy the seeds' viability.
Sowing and nursery management	The nursery beds should be 3 m long, 1 m wide and 10 cm high. The sowing can be done in pots or polybags. The seeds are first treated with 0.1 % phenylmercuric acetate, which is a fungicide, herbicide and algicide, also known by names such as Agrosan gn 5, Algimycin, Advacide PMA 18, Benzene (acetoxymercurio), Bufen, Celmer, Ceresan, Contra crème, Cosan PMA, Gallotox, Hong Nien, Liquiphene, Mersolite, Mergal A25, Metasol 30, Mercuriphenyl acetate,

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Table 12. Continued

	Mercuron, Monosan, Neantina, Norforms, Nildew AC 30, Nuodex PMA 18, Nylmerate Pamisan, PMA, PMAC, PMAS, Phenylmercury acetate Phenylmercuric acetate Phenomercuric acetate, Phenylmercuriacetate, Phenyl mercury ammonium acetate, PMAL, Scutl, Seedtox, Shimmer-ex, Spor-kil, TAG, Tag HL-331, and Unisan. Then the seeds are sown 1 cm deep in rows 10 cm apart and covered with a fine compost of leaf mould. Watering is required during the morning hours. The nursery beds should be covered with polythene sheets or dry rice straw to protect the seedlings. When seedlings reach a height of 15–20 cm after about 2 months, they can be transplanted to the field.
Planting management	Papaya seedlings are planted during spring (February-March), monsoon (June–July), and autumn (October–November). The seedlings are planted in pits of 60 x 60 x 60 cm. In summer months, the pits are dug about two weeks before planting and filled with topsoil and farmyard manure. Tall varieties are planted at greater spacing whereas medium and dwarf varieties are planted at closer spacing, Normally, a spacing of 1.8 x 1.8 m is followed. High-density cultivation with a spacing of 1.5 x 1.5 m/ha enhances returns to the farmer but also requires more inputs.
***Salacca zalacca* (snake fruit)**	
Seed collection	*Salacca zalacca* start to fruit once they are 3–5 years of age. The fruit can be harvested all year. The fruit is collected just before it ripens and it is left to ripen in an indoor environment. The seeds can be stored in a dark place at room temperature until sowing.
Sowing and nursery management	In the tropics, there is no definite season to sow the seeds; sowing can be done all year. To grow seedlings in a container, the soil should be light and rich in humus, organic matter and peat moss. The soil should be moist. The bottom of the pot should have holes and fine gravel for drainage. Seeds should be placed sideways and half-buried in the potting mix. The seeds are sown 2–5 cm deep from the top of the seeds. The germination time is around 1–3 months. Seedlings require shade and fertilization and soil should be kept acidic and humid.
Planting	The seedlings of snake fruit are transplanted once they reach a height of 40 cm. Planting should be done at the beginning of the rainy season. The plants should be planted 2.5 m apart. The soil around the seedlings should be topped with biochar, manure, compost etc and mulched. Snake fruit requires shade for proper growth.
***Aleurites moluccanus* (candlenut)**	
Seed collection	Flowering and fruiting of the candlenut tree begin when trees are 3–4 years-old. Flowering occurs September–October or several times a year. The seeds are mature when the fruits change colour to yellowish brown. Fruits can be collected directly from the tree or from the ground. The best time to collect seeds is during November–December. To extract seeds, fruits are pressed or lightly beaten, then washed and dried. Fresh fruits are allowed to decay for a few days which makes it easier to peel off the outer husk in order to expose the hard shell that encloses the seed. The germination rate is around 80%. Seeds can be stored for several months after drying to 10–12% moisture content.
Sowing and nursery management	The seeds are sown in a seedbed at spacing of 5 x 5 cm. Seeds are pressed gently into the soil and then covered by a layer of dried leaves or grass 3–10 cm thick. The grass is then burnt for around 3 minutes and then the hot seeds are thrown into cold water to crack the hard shells. Germination occurs 15–20 days after sowing. Candlenut has a large, thick tap-root so seedlings should be grown in 2–4-litre root-training containers. A well-drained potting medium consisting of peat moss, perlite, vermiculite, compost, dolomite lime, gypsum and slow-release fertilizer is recommended. Seedlings can be transplanted into the field after 3–4 months when they reach a height of about 25 cm and stem diameter of 12 mm.
Planting	Candlenut should be planted at the beginning of the rainy season. The land should be cleared of weeds. In agroforestry systems, spacings of 8 x 8 m and 6 x 6 m are recommended, however, the spacing depends on the purpose of the planting.

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Table 12. Continued

***Persea americana* (avocado)**	
Seed collection	The avocado plant produces fruit in 2–3 years after planting. For seed, ripe fruits should be collected and the seed removed from the fruit. The use of a knife can damage the seed so the seed should be gently removed by hand. The seed is then cleaned under warm running water using a soft brush or cloth so that all flesh is removed. It is then wrapped in a a damp paper towel. The seed starts to germinate after a few weeks. The seed will crack open, revealing a deep split, and a root will grow from deep inside the seed. When the root is 7–8 cm long, it can be planted in the container in the nursery.
Sowing and nursery management	Avocado requires well-drained, aerated soil. Avocado trees produce a shallow root system and thus require warm soil for efficient water and nutrient uptake. Seeds can be sown directly in the soil or in the container. Approximately 2–3 seeds are usually sown together and thinned later to leave the strongest seedling. Seedlings are grown in containers for around 2–3 months before planting at the final site.
Planting	Avocado seedlings should be planted in the spring when the soil is warm in an area that receives full sun and has protection from the wind. The planting pit should be a little wider than the root ball. The seedling is gently put into the pit. Slow-release fertilizer can be added to the pit at planting then carefully backfilled. Trees should be planted 4.5–6 m apart in rows spaced 6 m apart. Young trees should be irrigated and the root ball should not be allowed to dry out. Trees should be watered every few days.
***Citrus sinensis* (orange)**	
Seed collection	Seeds are collected from ripe fruits and washed with water and soap then peeled. The seeds can be scarified with fingernails to rid the various membranes that protect the inner part of the seed and can delay germination.
Sowing and nursery management	The seed can be sown in a greenhouse during March. Germination usually takes place within 2–3 weeks. Seedlings are liable to dampen off so they must be watered regularly. The seed is polyembrionic, i.e., two or more seedlings arise from each seed. When there are too many seedlings, they can be pricked out into individual pots and grown in the greenhouse for at least three growing seasons.
Planting	Orange seedlings are planted out in the summer. For planting, pits about 75 x 75 x 75 cm should be dug at 7 x 7 m spacing and filled with topsoil. The seedlings should be provided with some protection from any cold spells during their first few winters. The trees can tolerate drought conditions but perform poorly in waterlogged soil. Orange trees grow best when planted in a well-drained sandy loam. The optimum soil pH is 6–7.5. Soil must be deep enough to permit adequate root development. Newly planted trees require proper irrigation. Trees planted in sandy soil require watering more frequently. Young trees also require a light application of fertilizer every month in the first year.
Propagation (vegetative)	Orange plants grown from seeds may not bear fruits for the first 8–10 years. Grafting and budding are usually applied to propagate orange seedlings. Grafting is a process by which a scion from one plant is joined to the rootstock of another to produce a new tree. Budding is a type of grafting where scion that is joined to the rootstock consists of a single bud.
***Artocarpus heterophyllus* (jackfruit)**	
Seed collection	Jackfruit can take 4–14 years to bear fruit, usually in two main seasons, although off-season fruiting is also common. The fruits usually ripen from March–June, April–September, or June–August. Seeds are collected from trees with outstanding growth and fruit qualities. The fruit is opened with a knife and seeds are separated from the fleshy sheaths. The thin, slimy coating around the seed should be removed and the seeds rinsed in water to remove any remaining pulp. The largest seeds give the earliest and highest germination and produce strongest seedlings. Seeds should be dried in the shade for about an hour but

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Table 12. Continued

	they should not be allowed to dry out as this will kill them. Germination of seeds sown within a few days of harvesting is usually high, i.e., 90%. Seed don't retain viability when stored for extended periods. Seeds don't require pre-treatment. Soaking in water or a dilute gibberellic acid solution for 24 hours prior to sowing hastens germination.
Sowing and nursery management	Seeds are sown at a depth of 2 cm and can be laid flat or can be planted with the hilum pointing down. A well-drained medium consisting of peat moss, perlite, vermiculite, a little compost, dolomite lime and an organic fertilizer should be used. In the nursery, 2–4-litre root-training containers are recommended. The seedlings should not be allowed to root through the container into the underlying substrate. Germination begins at 1–3 weeks or up to 6 weeks. Daily watering is often necessary once seeds germinate. Seedlings can be transplanted when they have reached a height of 20 cm and diameter of 9 mm. This can take around 3–4 months.
Planting	Seedlings should be transplanted in field before they become root bound. Transplanting seedlings when they have just filled their growing container will ensure minimal trauma to the root system. In ideal conditions, the survival rate of seedlings in the field can be 90%.
Direct seeding	If the planting locations are well prepared, weed free and frequently tended for the first 6–12 months of growth, direct seeding can be the best propagation method. For direct seeding, an area is prepared for each planting spot, cleared of weeds and dug over to a depth of 50 cm if the soil is compacted. Seeds are planted 2–3 cm deep. Sowing several seeds at each site allows selecting the most promising seedling. Direct seeding, however, requires frequent maintenance.
Nephelium lappaceum **(rambutan)**	
Seed collection	Seeds are usually extracted immediately after the harvest of ripe fruits and placed in paper bags at room conditions
Propagation from seed and nursery management	The seeds of rambutan are recalcitrant and short-lived; losing viability quickly. Unwashed or pre-treated seeds remain viable for 3–4 weeks in moist sawdust or charcoal. Seeds must not be allowed to dry out before planting. Freshly harvested seeds germinate readily when sown directly and horizontally on their flattened side after they are extracted and washed. Germination usually occurs in 10–14 days. The rate of germination is 80–90%. The seedlings should be kept under semi-shade. The trees propagated from seeds dela fruit bearing. Also, the seedlings grown from seed are not true to the mother tree. Thus, seedlings are used primarily as rootstocks for grafting and not for orchard establishment.
Propagation (vegetative)	Rambutan is best propagated by asexual means, which include budding — where buds are inserted into 1–2 years-old well-grown rootstocks — inarching or approach grafting, and air layering to produce well-rooted propagules.

Source: Henrietta et al. (2022); GoWA (2022); Plant Village (2022); Perween et al. (2018); DeAndrade et al. (2017); Krisnawati et al. (2011); Lacey et al. (2009); Lazaneo (2008); Ragone (2006); Elevitch and Manner (2006); Singh (2005); Bartholomew et al. (2002); American Horticulture Society (1999); Ploet et al. (1994).

9 Major cash crops: Propagation techniques and nursery management

Table 13. Cash crops' propagation techniques and nursery management

Piper nigrum (black pepper)	
Preparation of cuttings	Black pepper can be propagated from dry seeds, however, this crop is commonly propagated from cuttings or stolons of established plants. Cuttings are usually taken from the secondary runners of the plant and should possess 1–2 leaves. The cuttings are soaked in cold water overnight to completely remove the sap. The cuttings should be crosscut.
Nursery management	For black pepper, a deep, well-drained soil should be used that can retain water. The soil should be rich in organic matter and the pH should be between 5.5–6. The pit size in the nursery should be 7 x 12 cm so that the roots won't break during transplanting. The soil mixture should include farmyard manure and phosphate. Mixing manure and soil ensures that the soil will not be sticky and scattered. The cuttings are then rooted in the seedbeds or containers. Watering the cuttings twice a day is important.
Planting	After cuttings gain 4–7 new leaves, they are transplanted, which is usually carried out early in the rainy season, i.e., May–June. For field planting, a pit 50 x 50 x 50 cm should be dug out. The bottom of the pit should be filled with topsoil. The plantings should be supported by 4 m high trellis. Optimum spacing is 8 x 8 m. Newly planted pepper plants needs to be watered regularly.
Cinnamomum verum (cinnamon)	
Seed collection	Cinnamon flowers during January and fruits ripen June–August. Seeds are collected from the pulp of the fruit then are washed and dried. Cinnamon seeds loose viability very fast, therefore, they should be planted as soon as possible after extraction.
Preparation of cuttings	Cinnamon is propagated vegetatively from cuttings, layering or by dividing the root ball. A cutting is taken by removing a partially mature shoot consisting of at least one node from an established mother plant.
Nursery management	Seeds are sown in nursery beds or polybags filled with good quality potting soil and composted manure. The seedbeds should be provided with shade and kept moist with frequent watering. Germination usually occurs after 20 days. Cuttings are planted in a polybag so that they can develop their own root system. Cuttings can be grown under the protection of a polyethylene covering that is removed gradually to harden the seedlings for field planting. Seedlings can be transplanted when they are 12–18 months-old.
Planting	Before transplanting, a pit is dug large enough to accommodate the root ball. The seedlings are then planted in the pit and it is backfilled with topsoil. To aid root development, adding rock phosphate to the pit is recommended. Trees are either grown in a small group to produce a single clump or are planted individually. In the field, spacing of 0.9–1.2 m between trees is recommended for commercial plantations.

continued on next page

Table 13. Continued

***Zingiber officinale* (ginger)**	
Preparation of rhizome	Ginger is vegetatively propagated from small sections of the rhizome that are called sets. Sets are produced by cutting a small (3–6 cm) section from a living rhizome. Each piece should process at least one living bud that will produce shoots.
Nursery management	The sets are pre-sprouted in pots or nursery beds by covering with a layer of soil. The bed should be prepared by digging a fine furrow in the soil and removing any weeds. The addition of lime to the soil can help plant growth by providing calcium. The sets should be planted in early spring at a depth of 5–12 cm, leaving 15–35 cm between plants and 25–30 cm between rows.
Planting	Ginger sets can directly be planted in the field. Ginger tends to grow horizontally, therefore, the soil can be hilled around the growing stems to force a more vertical growth. Soil should be hilled 3–5 times during the growing season. Any exposed rhizomes should be covered with soil and weeds should be removed. The addition of fertilizer, phosphorus, calcium and organic matter in the soil before planting can benefit the growth of ginger. A side dressing should be made 25–30 cm from the row of plants owing to ginger being easily damaged by fertilizer application. Side dressings should be made every 2–3 weeks during the growing season so that ginger is supplied with adequate nutrients.
***Curcuma longa* (turmeric)**	
Preparation of rhizomes	Turmeric is propagated with a small section of rhizomes called sets. Turmeric roots remaining from the end of the previous season are dug up to collect the rhizomes, which are washed to remove dirt. The fleshy rhizomes should be stored in a dark, cool and dry place until late winter or early spring. The new sprouts appear on the rhizomes during this time. Then the rhizomes are cut into sections. While cutting rhizomes, it should be ensured that each segment consists of 1–2 buds that can produce shoots to grow rhizomes as a plant.
Nursery management	While rhizome can be directly planted in the field, they can be first grown in containers in a nursery. A container should hold soil at least 30 cm deep and be of a width to permit adequate root growth. While planting turmeric in the ground, the soil should be dug to a depth of at least 30 cm. A well-drained, slightly acidic soil with organic matter should be used for turmeric.
Planting	The rhizomes are planted in September–October in a warm soil, 5–7 cm deep and oriented so that sprouts grow upwards. Turmeric rhizomes are usually planted on the ridges of the furrow. Turmeric requires high levels of nutrients so ample amounts of organic matter in the form of well-rotted manure, compost or mulch should be applied throughout the growing season. Turmeric is ready for harvest and processing 6–9 months after planting.
***Coffea* sp (coffee)**	
Seed collection	Big and ripe fruits are collected from trees with well-shaped crowns and branches during October–November. Seed coats are removed by hand and the seeds sterilized in about 1% of sodium hypochlorite. The coffee seeds are rinsed in water and imbibed in demineralized water. Coffee seeds take a long time to germinate. To speed the germination process, the coffee seeds should be soaked in water for 48 hours before sowing.
Sowing and nursery management	Pre-treatment of seeds by using azospirillum and phosphobacterium can be done. Seeds are usually sown in December–January in a bed, 1.5–2.5 cm apart with the flat side downwards, in regular rows. The seeds are covered with a thin layer of fine soil and a layer of rice straw. It is necessary to water the beds daily and protect them from direct sunlight. Germination may take around 6–8 weeks.
Planting	For planting coffee in the field, a pit 50 x 50 x 60 cm should be dug. The soil should then be fertilized with manure before starting the planting. Integration with other crops when planting can help protect the coffee from wind damage and limit weed growth. Coffee planting is usually carried out June–July.

continued on next page

Table 13. Continued

***Theobroma cacao* (cocoa)**	
Seed collection	The seeds are extracted from the cocoa pods. Cocoa pods arrive at dry periods at 6 months after the bloom and last for around 10–14 days. The fruiting occurs twice in a year, during May–July and October–March. Healthy, ripe pods are selected from which to extract seeds. The cocoa seeds remain viable for 3 weeks and are usually planted straight after harvest.
Sowing and nursery management	Seeds are sown in a fibre basket or polybag filled with clean soil. The seeds should be placed in a shaded place protected from the sun to prevent scorching. Seedlings grow quickly and are ready to be transplanted around 4–6 months. The nursery for cocoa should be kept free of weeds, however, weeding should not be done once trees have formed a closed canopy. Cocoa should be supplied with organic fertilizers, the amount depending on many factors, such as age of the tree and amount of shading.
Planting	Cocoa seedlings are planted in the field when they are 4–6 months-old. Young plants require some protection from strong sunlight and wind damage and therefore they are planted next to mother trees. The shade helps to keep the trees at a manageable size for maintenance and harvest. The recommended spacing for cocoa seedlings is 3–4 m whereas spacing with shade trees can be 3–6 m. The shade can be reduced when trees have formed a closed canopy.
***Vanilla planifolia* (vanilla)**	
Preparation of cuttings	Vanilla is usually propagated vegetatively from stem cuttings of a mother plant that has not been allowed to flower. Cuttings are best taken during the dry season because at this time growth of vines is slower. A cutting of 1.5 m should be taken and planted at the base of a support tree after removing the lower leaves.
Planting and maintenance	Vanilla is directly grown in the field where a mother tree or support system is present. Cuttings should be planted at least 2 m apart. The support tree should possess a high number of lower branches. Vanilla should be maintained to keep the vines at a manageable height, otherwise, they will continue to grow to the crown of the support tree. When plants reach a height of 1.6–1.8 m they should be bent back over the nearest suitable branch. The end of the shoot should be planted back into the ground and covered with soil. Planting the end of the shoot will encourage the growth of roots that can help to maintain a healthy plant. Vanilla should be mulched with organic mulch, such as grass clippings, to help suppress weeds and conserve soil moisture.
***Syzygium aromaticum* (clove)**	
Seed collection	Clove is propagated from seeds. Healthy mother plants with desirable characteristics should be selected from which to collect the fruits, which are then soaked in water and the skin peeled off to extract the seeds.
Sowing and nursery management	The clove seeds can be planted in prepared nursery beds or polybags. The bed or bag should hold a mixture of soil and manure. The seeds are sown to a depth of 2–5 cm. Optimum spacing between the sown seeds is 12–15 cm. Germination occurs within 1–6 weeks. The seedlings need to be protected from harsh sunlight with proper shade and be kept moist through regular watering. The seedlings can be transplanted when they reach at least 30 cm in height. They should be hardened off by exposing them to sunlight before transplanting in the field.
Planting	For planting in the field, a pit 60 x 60 x 60 cm is required. The seedlings should be planted at a spacing of 8 m. The transplanted seedlings should be provided with temporary shade by intercropping with other crops. After removing the temporary shade, the planting area should be kept free from weeds and a layer of mulch added around the seedlings. Proper irrigation is required during dry periods to prevent stress to the trees. Adding organic fertilizer or manure can provide nutrients.

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Table 13. Continued

Amorphophallus konjac (elephant foot yam)	
Preparation of buds or corms	Elephant foot yam is propagated from small corms or buds produced belowground from the base of the shoot. The corms appear in the second or third year. Elephant foot yam undergoes a dormancy period of 45–60 days. Tubers should be cut into sections weighing around 1–1.2 kg. Each section should consist of at least one cormel (a small corm or cormlet). A crop may be obtained in 1 year.
Planting	Planting is usually carried out during February–March so that setts can sprout with pre-monsoon showers. The planting season is April–May. Cormels are planted at a close spacing of 45 x 30 cm. Before planting, tender buds should be removed as they don't give vigorous growth. The cut pieces are dipped in manure solution to prevent evaporation of moisture from the cut surface. The cut pieces are planted in beds at 45 x 90 cm spacing or in pits 60 x 60 x 45 cm. The pits should be filled with topsoil and farmyard manure before planting. When planting, the sprouting region is kept above the soil. Sprouting takes place in about a month.

Source: Ryczkowski (2022); Osario Montoya et al. (2022); KAU Agri (2022); Agrifarming (2022); TNAU (2016); My Agriculture Information Bank (2011); Wood and Lass (2008); Augstburger et al. (2000); Nishina et al. (1992).

10 Major annual crops: Propagation techniques

Table 14. Annual crops' propagation techniques

***Zea mays* (maize)**	
Propagation	Maize is propagated with seeds. The temperature of the soil should be warm for sowing maize seeds. Mulching 1 week before sowing can maintain soil temperature. Maize seeds should be sown about 2.5 cm deep and 10–15 cm apart allowing 76–91 cm between rows. Maize should be planted in blocks rather than in a single row. Seedlings should be thinned to a final spacing of 20–30 cm when they attain a height of 7.5–10 cm.
Maintenance and care	Maize should be provided with adequate nutrients by applying fertilizer. Maize undergoes a rapid growth 30–40 days after planting. Fertilizer should be applied before this. Plants also require adequate soil moisture throughout the growing period.
***Ipomoea batatas* (sweet potato)**	
Propagation	Sweet potatoes are propagated using vine cuttings. Cuttings from the tips of the vine are the best planting material. Cuttings from other parts of the vine produce lower yields. The cuttings should be long around 30–40 cm. The cuttings are generally taken from young plants 2–3 months-old because they tend to produce higher yields. The entire cutting should be soaked in fungicide or insecticide to reduce the risk of disease. Vine cuttings can be planted immediately after cutting or can be hardened by keeping them damp in a shady place for 1–3 days. During hardening time, roots will begin to grow on the cuttings.
Maintenance and care	Sweet potato can outgrow its planting place, so light pruning and shaping is necessary. A slow-release fertilizer should be applied during planting and a water-soluble fertilizer applied monthly. Plants should be kept moist by watering once a week.
***Dioscorea alata* (yam/ubi)**	
Propagation	Yams are propagated vegetatively from small tubers. Tubers should be planted in trenches at a depth of 15 cm, allowing at least 30 cm spacing between plants and 1.5 m between rows. The soil is often mounded around plants or ridged to aid drainage. It is common practice to stake plants with a 2–4 m support to allow them to climb and ensure that all parts of the plant receive sunlight.
Maintenance and care	Yam requires water distributed evenly throughout the growing season. Yam plants should be mulched after planting to prevent drying out.

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Table 14. Continued

***Cucurbita moschata* (pumpkin)**	
Propagation	Pumpkin can be directly seeded or sown. Seeds should be sown when soil has warmed to at least 15.6 °C. Approximately 1–2 seeds are sown 1.3–2.5 cm deep at least 90 cm apart for bush varieties and 120–150 cm apart for vining varieties. The seedlings are transplanted before the plants develop their second set of true leaves. Lightly moist soil is required for germination. Care should be taken to avoid overwatering. Seed will germinate in 5–10 days.
Maintenance and care	Pumpkin requires plenty of space to grow and a continuous supply of water. Plants should be watered deeply once per week. Mulches can be used to conserve soil moisture. Black polyethylene sheets can warm the soil in cooler areas.
***Mucuna pruriens* (velvet bean)**	
Propagation	Velvet bean is propagated by seeds that are extracted from pods. Seeds harvested from mature fruits are viable for 2 years. The germination rate is 90%, however, the germination percentage declines after 2–3 years. Velvet bean seeds are sown in the last week of June. The optimum distance of planting is 0.75 x 1 m. For better growth of seedlings, the soil should be porous and include farmyard manure.
Maintenance and care	Potassium and phosphorus should be applied along with farmyard manure at the time of sowing. Fortnightly Irrigation is necessary during the dry season whereas monthly irrigation is required in winter.
***Sechium edule* (chayote)**	
Propagation	Chayote is best propagated from seed. A whole fruit is planted in a raised bed. The planting area requires a tilled soil at least 60 cm deep and 90 cm in diameter. The spacing between the plants should be at least 2 m. When the shoots grown from the seed penetrate the skin of the fruit, they should be planted. At planting time, the fruit is buried either on its side or standing up with the broad end of the fruit pointing down. Chayote can also be propagated using cuttings from growing vines. Cuttings of size 15–20 cm should be planted horizontally in a shaded area. The soil around the planted cuttings should be kept moist. The cuttings establish root systems after 1–2 months.
Maintenance and care	For the best growth of chayote plants, regular irrigation is necessary, but they are also vulnerable to waterlogging. The planting should be done in an area that receives full sunlight. Chayote also needs a support, such as a trellis around 2 m high, to support the climbing vines.
***Manihota esculenta* (cassava)**	
Propagation	Cassava is propagated from stem cuttings. The cuttings should be taken from healthy plants that are 10 months-old and have borne tubers. Each cutting should have 1–2 nodes and be around 20 cm long. The cuttings should be dipped in appropriate fungicide to prevent diseases. The cuttings should be planted in a nursery bed that is at least 1 m wide. The stems should be planted horizontally. The optimum spacing is 10 x 10 cm. Stem cuttings should be watered immediately after planting. After 4–6 weeks, the plants can be transplanted to the field. The transplants should be planted at spacing of 75–100 cm with spacing between rows of 1–5 m.
Maintenance and care	Cassava requires full sunlight and is very sensitive to shade. Proper irrigation is required for optimum growth. However, the plants will not tolerate waterlogging. The soil should be kept moist after planting. The soil can be fertilized with cattle and poultry manure.

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Table 14. Continued

Colocasia esculenta **(taro)**	
Propagation	Taro is propagated using rhizomes. For this, a rhizome is cut into pieces that are at least 5 cm long and have at least 1 noticeable bud. The rhizome is then planted 12– 13 cm deep in fertile soil. The soil around the plant should be kept moist during the entire process. It takes around 3 months for the plant to be ready for transplanting but it may take up to a year for a plant to reach maturity.
Maintenance and care	Taro requires a warm, sheltered location for protection from wind. The plants require optimum watering. Over-watering or under-watering may result in yellowing leaves and a collapsed base.
Arachis hypogaea **(peanut)**	
Propagation	Peanut is propagated from seed, which should be sown in loose and crumbly soil. Proper weeding should be done before sowing. The seeds should be sown to a depth of 3–4 cm. It is beneficial to ridge the soil or use flat beds for sowing seeds because this will make harvesting easier. Peanuts can be grown as a sole crop or intercropped with other crops.
Maintenance and care	Peanut plantings should be kept free from weeds so that there is no competition for nutrients. During the dry season, plants should be provided with additional irrigation. Peanut has nitrogen-fixing bacteria in the root so does not require additional nitrogen. However, calcium is required for good pod fill.
Cajanus cajan **(pigeon pea)**	
Propagation	Pigeon pea is directly propagated from seed. The seeds should be sown at a depth of 2.5–10 cm in well-drained soil. The optimum spacing between the plants is 30–50 cm with 150 cm between rows. Higher seeding rates should be used if the plant is grown as a green manure. Pigeon pea is usually intercropped with millet, cotton, sorghum or peanut.
Maintenance and care	Proper weeding is necessary to prevent competition with the initially slow-growing seedlings. Pigeon pea doesn't require irrigation or fertilization although an application of phosphate is recommended. Irrigation may be necessary if the plants are intensively grown.
Solanum tuberosum **(potato)**	
Propagation	Potato is propagated using seed potatoes, which should be planted as soon as the soil is workable. Before planting, the soil should be prepared by adding compost or well-rotted manure. Potato is commonly grown in hilled rows. Shallow trenches 60–90 cm apart should be dug and then the seed pieces should be placed at 30 cm spacing. The plantings should be covered with 7.5 cm of soil. When the plants reach around 25 cm, the soil should be mounded up around the stem so that half of the stem is covered. This is done to protect shallow tubers from turning green owing to exposure to sunlight. The process should be repeated for the duration of growth. Instead of mounding the soil, straw can be used around the plants.
Maintenance and care	Potato grows best when soil moisture is consistent. The plants require around 2–3 cm of water a week. Water-saturated soil should be avoided because tubers can be poorly formed in such soil and may rot. Potato is a heavy feeder and the addition of balanced fertilizer every week can help increase tuber yields.
Triticum aestivum **(wheat)**	
Propagation	Wheat is propagated from seed. Before sowing, the soil should be worked over. For larger areas, a machine is used for mechanical drilling to create a furrow where seeds are dropped. In small areas, seed can be sown by hand using a hand-cranked seeder. Seeds should be sown at 2–12 cm depending on soil condition. Seeds should be sown deeper in drier soil. After scattering the seeds, the soil should be raked lightly to set the seeds at the desired depth.

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Table 14. Continued

Maintenance and care	Weeding is necessary in the wheat field because weeds can compete for nutrients and also transfer diseases. A nitrogen application is necessary for the proper growth of wheat.
***Hordeum vulgare* (barley)**	
Propagation	The propagation technique and planting method of barley is similar to that of wheat. Seeds are sown in prepared seed beds in rows. For commercial plantation, a machine is used to create a furrow and drop seeds. Seeds should be sown 2–12 cm deep. After sowing, soil should be raked lightly. The barley reaches to maturation around 60–80 days.
Maintenance and care	It is necessary to remove weeds from barley areas. A use of herbicide can be necessary for larger areas. Barley doesn't require too much watering; doing so can cause decay.
***Maranta arundinaceae* (arrowroot)**	
Propagation	Arrowroot is generally propagated through division. During spring, the rhizome should be separated in such that each piece consists of 1–2 unopened growth buds. All mature leaves should be pruned from the divided parts, leaving only young shoots. The divisions are then planted in a loamy soil. The soil should be mulched with straw or leaves to protect from light frost. The plants should be watered 2–3 times a week until new growth start to appear strongly.
Maintenance and care	Arrowroot should not be exposed to calcium or lime because the plant is very sensitive to these minerals. Overwatering or standing water may result in root rot so proper care during watering is necessary.

Source: InDG (2022); Thompson (2022); Anderson (2021); Espinoza et al. (2021); Brito et al. (2021); McVay et al. (2017); Aighewi et al. (2014); Wright (2012); Sheahen (2012); Adekunle et al. (2004); Erhardt (2000); James et al. (2000); Wilson (1998); Hahn et al. (1987); Duke (1983).

11 Soil conservation and management

11.1 Soil conservation techniques

Soil conservation techniques are various farming operational and management strategies implemented to control soil erosion (Baumhardt and Blanco-Canqui 2014). Soil conservation is very important to minimize the loss of natural resources and improve agricultural production (Khan et al. 2021). In Timor-Leste, landscapes with more than 40% slope cover about 44% of the total land area and arable land is limited (Paudel et al. 2022). The proliferation of agroforestry with proper soil management and conservation is requisite to control environmental degradation and ensure food security for the increasing population. Below are major soil conservation techniques that can be employed in Timor-Leste.

11.1.1 Check dams

Check dams are small, low dams constructed in a gully or other watercourse to decrease the velocity of stream flow, to minimize channel scour and promote the deposition of eroded material. They are designed to accept active pressure in future while permitting a safe discharge of water and debris via a spillway. Check dams are classified based on their durability and the material used for construction. Check dams may be temporary — such as brushwood check dams and loose stone check dams — or permanent, such as gabions, masonry or reinforced check dams. Following are major types of check dams.

a. **Brushwood**: made of wooden poles and brush; applicable for small gullies.
b. **Loose stone**: made of loose stones; applicable for small-to-medium gullies.
c. **Boulder**: same as loose stone check dams but large boulders are used.
d. **Gabion**: constructed with large hexagonal or square wire crates (gabion) filled with stones.

Relationship to agroforestry

Check dams can be a viable approach to conserving arable land in sloping and hazard-prone areas, enabling farmers to increase the production of agricultural and forestry species. Planting several agroforestry species that complement the structures can provide multiple benefits for soil conservation and additional income for farmers.

Construction of check dams

a. **Brushwood**: The following steps and specifications should be followed to construct a brushwood check dam.

   i. A trench of about 15 cm deep is made across the gully; wooden poles (150–200 cm long) are driven into the ground at a depth of about one-third to one-half of a pole's length. The spacing of the poles is 30–50cm.
   ii. The tops of the poles in the middle are made lower than the sides to form a notch of the required size to accommodate maximum runoff.

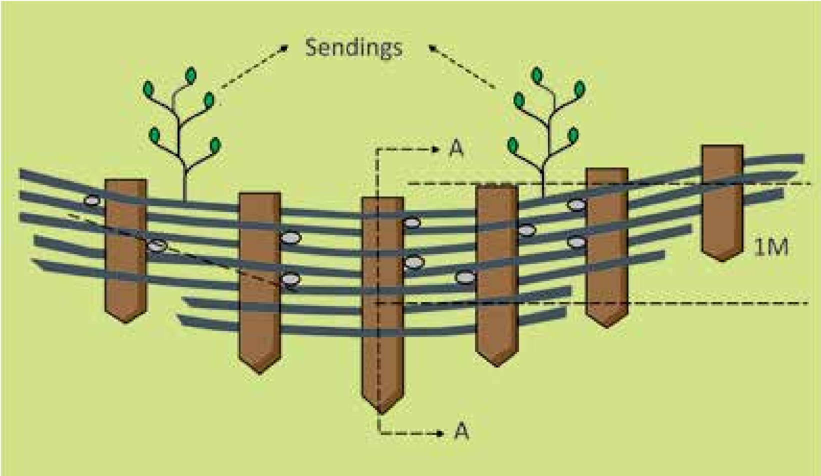

Figure 17. Brushwood check dam

iii. Flexible branches of a tree (e.g., moringa, rosewood, sesbania) and shrubs of 6–18 months-old are woven between the wooden poles driven into the ground until a dam of the required height is obtained.
iv. The ends of interlinked material should enter at least 30 cm into the sides of the gully.
v. The back of the brushwood check dam must be filled up with soil.
vi. A brushwood apron of about 1.5–2.0 times the height of the check dam is necessary to protect the channel from scouring and needs to be anchored with galvanized wire.
vii. Sidewalls should be built to direct the flow to the dam.
viii. Correct the slope of the steep gully head.
ix. General specifications: a) Maximum effective height: 1 m from ground level; b) Minimum foundation depth: wooden poles driven to a depth of 0.75–1 m.

b. **Loose stone/boulder**: The following steps and specifications should be followed to construct a loose stone/boulder check dam.

i. Clear the site and mark the line of construction using string.
ii. The sides of the gully should be cut to a slope of 1:1. The foundation of the wings should be more than 0.5 m. The height of the wing wall must be equal to the depth of the spillway.
iii. The foundation of the dam must be more than the length of the spillway.
iv. For large dams, two wing walls with appropriate foundations are often constructed at the upper side to force the flow into the spillway or notch and prevent it from damaging the banks.
v. Large flat stones/boulders are used on the notch and downstream side for the spillway. The central portion is kept low for the spillway.
vi. When large volumes of run-off are expected, it is advisable to use some concrete in the notch and the crown of the dam or to cover everything with wire netting.
vii. Below the dam, an apron should be constructed of stones.
viii. Large stones are placed in the bottom of the dam and stones of about 50 × 30 cm are used throughout the body of the dam.
ix. On the upstream side, the dam must receive an earth fill for greater strength.
x. Finally, the structures are complemented by planting seedlings and cuttings of suitable species that have dense and widespread root systems.
xi. General specifications: a) Maximum effective height: 1–2 m; b) Minimum foundation depth: half of the effective height; c) Thickness of dam at spillway: 0.5–1 m.

Figure 18. Loose stone check dam

c. **Gabion**: The following steps and specifications should be followed to construct gabion check dams.

   i. The structure should enter at least 0.5 m into the side of the gully and should be protected against flash water by wing walls.
   ii. The wing walls with appropriate foundations should be constructed on the upper side to guide the flow into the spillway or notch and prevent it from damaging the banks. The space between the dam and the wing of the walls should be filled with soil.
   iii. The wing walls should enter at least 0.50 m into the side of the gully. The height of the wing walls must be level with the top of the check dam.
   iv. The foundation of the check dam must be more than the length of the spillway.
   v. Large flat stones should be put along the sides of the gabion boxes while smaller ones should be used to fill in the middle. The size of the stones used for construction should be larger than the size of the wire mesh (mesh size of 10 x 10 cm and 15 x 15 cm).
   vi. When debris is expected, it is advisable to protect the spillway and steps in the front part of the dam with a layer of concrete so that the gabion wire is not damaged by falling debris.

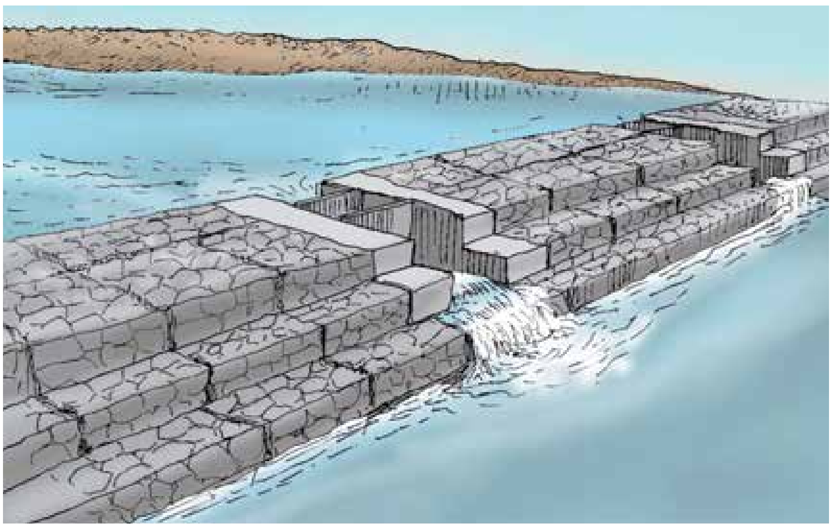

Figure 19. Gabion check dam

vii. The spillway dimensions are computed according to the maximum discharge of the gully catchment.
viii. Below the dam, an apron must be constructed.
ix. The back of the check dam must be filled with soil for greater strength.
x. Finally, the structure is complemented by planting on the gully sides seedlings and cuttings of suitable species that have dense and widespread root systems.
xi. The gabion boxes need to be laced together very strongly with 12-gauge wire.
xii. General specifications: Maximum effective height: may vary but not more than 5 m; Minimum foundation depth: half of the effective height; Thickness of dam at spillway: less than 1 m.

11.1.2 Terracing

What are terraces?

Terraces are level or gently sloping platforms constructed across a slope and supported by either a mechanical (such as a retaining wall) or vegetative barrier and designed to make the land suitable for cultivation and prevent accelerated erosion. A terrace controls direct runoff and reduces a large amount of soil loss. It also retains fertilizers and manure that have been applied, which facilitates better cultivation and management. There are various types of terraces based on their suitability according to the slope condition.

a. **Broad channel terraces** are mainly designed to intercept and then divert excess water safely from a field. They are usually most suited for wetter regions and slopes not exceeding 20%.
b. **Ridge terraces** are designed to intercept and retain excess water by spreading it over wide areas of a field between the ridges. These are best used on gentle slopes (not much over 3%) because the area over which the water is spread can be large without having to make a high ridge.
c. **Bench (step) terraces** can be used on slopes of 20–50% to convert the land into a series of 'steps' separated by near-vertical risers lined with rocks or vegetation for protection.

Relationship to agroforestry

Terraces with agroforestry trees can help to regreen a landscape through improving incremental water infiltration, reducing nutrient depletion and increasing crop productivity. Several annual crops can be grown with multipurpose or fruit tree species on terraces.

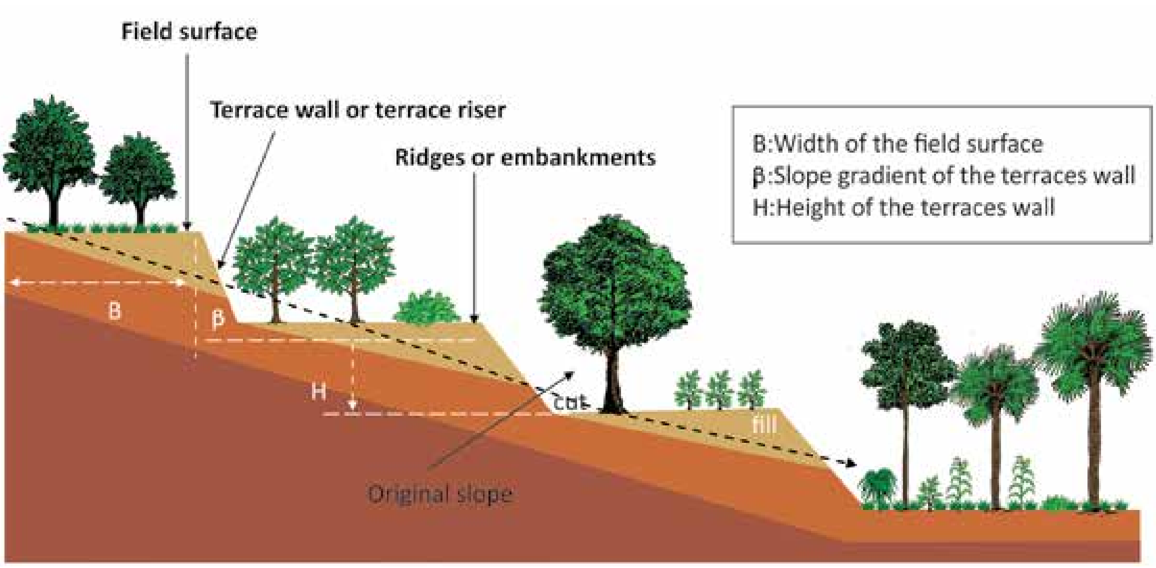

Figure 20. Cross-section of terracing

Note: Terraces are formed by cutting and filling areas. By filling areas, the arable land can be extended to grow multipurpose species in hilly areas.

Source: Adapted from Deng et al. (2021).

Figure 21. Terracing with agroforestry

Construction method

Terraces are constructed manually, the most common method of which is the 'cut and fill' wherein the soil from a higher level is cut away and filled to the lower level. Cutting and filling should be carried out gradually and at an equal pace so that there is neither an excess nor a lack of soil. It is recommended to construct from the base of the hill because this preserves the topsoil, preventing further soil run-off, as compared to starting from the top.

The design specifications of terracing according to FAO (adapted from Khoh and Das 2017) are as follows.

Terrace length: A maximum of 100 m length in one draining direction is recommended for typical conditions in a humid tropical climate. The length of a terrace is limited by the size and shape of the field, the degree of dissections and the type of soil.

Terrace width: The optimum width for handmade and manually cultivated terraces ranges 2.5–5 m; for machine-built and tractor-cultivated terraces, the range is 3.5–8 m. This should be determined by soil depth, tools used for cultivation, type of crop to be cultivated and landowner's preferences.

Terrace grade: Horizontal gradients should range 0.5–1% depending on the climate and soil. Handmade terraces should be employed, if soil depths are adequate, on 7–25° (12–47%) slopes. Machine-built terraces are recommended for slopes above 20° (36%).

Risers and riser slopes: Terrace risers may be made of either compacted earth protected with grass, or made with rocks. For ease of maintenance, the terrace riser height is best not to exceed 2 m. The vertical interval (VI) between two succeeding terraces should be calculated as follows.

$$VI = (S \times Wb) / 100 - (S \times U)$$

where S = slope in percent (%), Wb = width of bench (m), U = slope of terrace riser (m).

11.1.3 Bio-pore infiltration holes

Bio-pore refers to a hole or small tunnels that are formed underground owing to the activities of soil organisms, such as earthworms. Bio-pore infiltration holes are an effective and environmentally friendly technology to handle floods by increasing water infiltration, converting organic waste into compost, reducing greenhouse gas emissions (CO2 and methane), using the roles of soil and plant roots, and addressing problems caused by puddled water, such as dengue fever and malaria.

The bio-pore infiltration hole is a cylindrical hole (usually coated with plastic pipe) that is positioned in the ground vertically. Bio-pore infiltration holes usually have a diameter of 10 cm and are inserted to a depth of 100 cm, which can accommodate 7.8 litres of kitchen waste.

Relationship to agroforestry

Bio-pore infiltration has multiple benefits, including flood control and maintaining soil fertility. The holes can help to maximize the benefits of agroforestry practices, increasing water infiltration up to 40 times which reduces flooding and maximizes groundwater reserves.

Similarly, kitchen waste can be converted into compost by placing it inside the holes. The compost will increase the fertility of the soil and can be used to fertilize plants.

Construction of bio-pore infiltration holes

a. Dig a hole using a ground drill or crowbar. To ease the digging, add water to make the soil looser.

b. If a drill is used, insert it into the soil and when it is full (at approximately 10 cm of soil depth) lift out the drill and remove the soil. Continue in this manner to deepen the hole about 30-100 cm.

c. The distance between each bio-pore infiltration hole in a straight channel is 0.5–1 m. For bio-pore infiltration holes surrounding a tree, make 3 holes in an equilateral triangle position around the tree.

d. The hole edge should be hardened with cement and can be replaced with short pieces of PVC tube. The purpose of this is to prevent soil erosion.

e. Place organic waste (kitchen, garden waste) into the holes. Do not include inorganic waste such as iron, plastic, batteries.

f. When the hole full, close the hole with a perforated lid.

g. If there is not much waste, it's enough to place it at the mouth of the hole. But

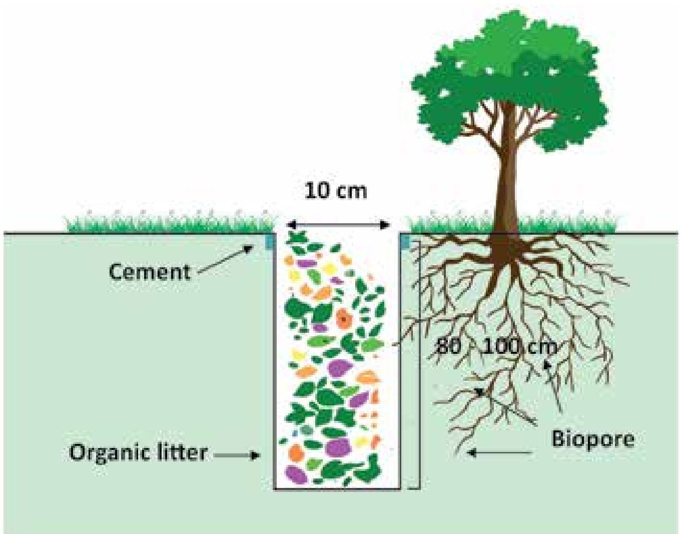

Figure 22. Cross-section of a bio-pore infiltration hole

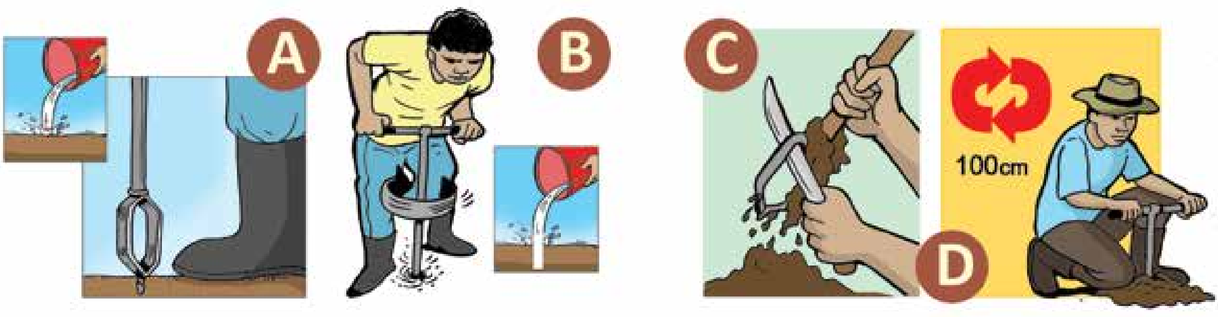

Figure 23. Construction of a bio-pore infiltration hole

if there is quite a lot of waste available, waste insertion will be better assisted by using a blunt stick to shove the waste deeper into the hole. But do not make the waste too dense or compact because it will interfere with the process of water infiltration.

Maintenance of bio-pore infiltration holes

Maintenance activities to be performed on bio-pore infiltration holes are as follow.

a. Bio-pore infiltration holes should always be filled only with organic waste.
b. Organic kitchen waste can usually be extracted as compost after two weeks whereas garden waste can take 2 months. The duration of composting also depends on the type of soil in which the bio-pore infiltration holes are placed. Clay soil takes a little longer for the process of decomposition. Extraction is best done using a bio-pore infiltration holes drill.

11.1.4 Riverbank protection

Riverbank protection is a soil and water conservation technique applied along riverbanks to prevent landslides, reduce the amount of eroded soil entering the river body, improve the quality of river water and suppress the silting. This activity can be carried out in the following areas.

a. Open area of a riverbank that is prone to landslides and erosion.
b. An area of a riverbank with cliffs.
c. Bare river border with no presence of vegetation.
d. Area with high rainfall.

Relationship to agroforestry

Riverbanks can be used to cultivate various agroforestry species that can provide multiple benefits to local communities. Agroforestry can conserve riverbanks while also supporting local livelihoods by increasing productivity.

Construction of riverbank protection

Riverbank protection can be constructed from one or more of the following options, according to field conditions.

a. Planting grass, shrubs and trees; the plants must have deep roots and a dense canopy.
b. Installation of bamboo trusses; can use pieces of bamboo stems or directly plant with bamboo.

Maintenance of riverbank protection

Maintenance activities are as follows.

a. Replacing unhealthy plants.
b. Improvement of bamboo if damaged.

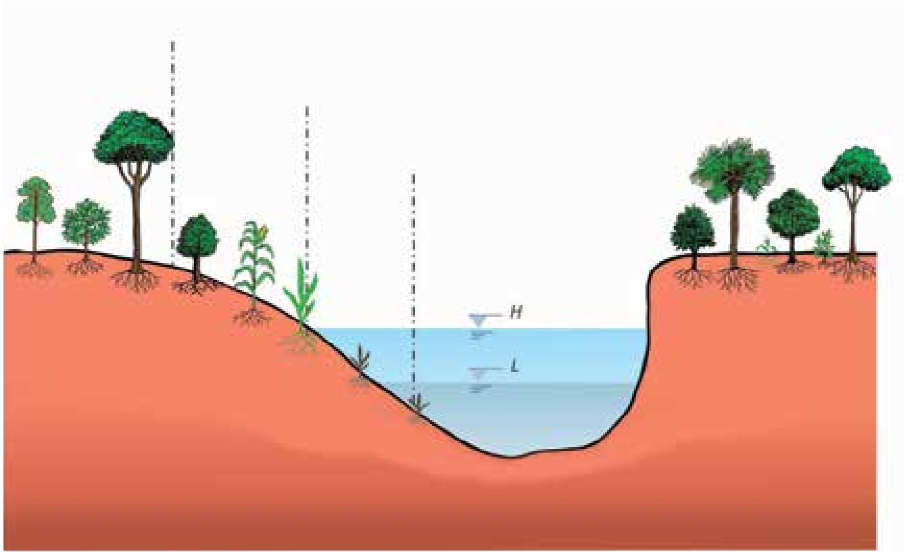

Figure 24. Riverbank protection with various layers of trees, shrubs and grasses

11.1.5 Grass planting

Grasses can be used to reduce soil erosion: the fibrous root system consists of several main roots that branch to form a dense mass of intermeshed lateral roots.

Grass can provide engineering functions, such as armouring, anchoring, catching and reinforcing.

Grass planting can be done in three ways.

Horizontal/contour grass line

This method can be used on any slope less than 65˚ that is very dry and erodible.

Spacing for slopes greater than 30˚ should be 1 x 1 m by 10 x 10 cm

Spacing for slopes 30–45˚ should be 50 x 50 cm by 10 x 10 cm.

For slopes greater than 45˚, the spacing should be 30 x 30 cm by 10 x 10 cm.

Vertical and downslope grass planting

This method can be used on any slope of less than 65˚ on poorly drained and damp sites.

Spacing should be 10 cm between plants and 50 cm between rows.

Diagonal grass planting

Can be used on any slope of less than 65˚ on poorly drained and damp sites.

Spacing should be 10 cm between plants and 50 cm between rows. This design can provide catch-and-drain functions in addition to the armouring and reinforcing provided the by horizontal and vertical grass plantings.

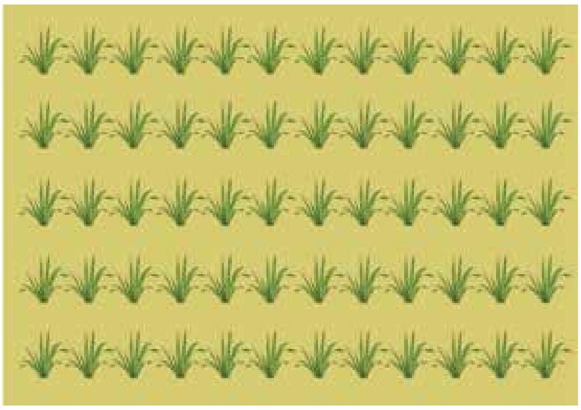

Figure 25. Horizontal grass planting

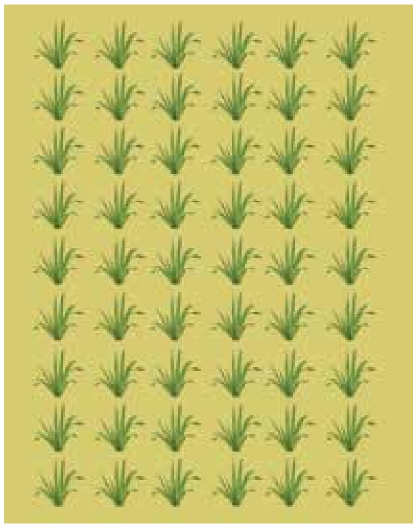

Figure 26. Vertical/down slope grass planting

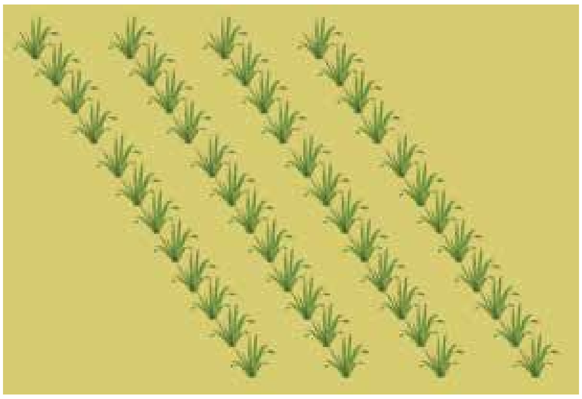

Figure 27. Diagonal grass planting

Relationship to agroforestry

The cultivation of perennial clumps of grass — for example, napier, stylo, broom grass or molasses — can convert erodible slopes into stabilized terraces where farming can be done without any threat of erosion.

Planting improved varieties of grass will provide fodder to livestock as well as bind the soil. The cultivation of broom grass with other major species along a slope can help to generate income for local communities because it is a constituent element in the making of brooms.

11.1.6 Rainwater reservoir

A rainwater reservoir is a pond to gather rainfall for future use. The purposes of rainwater reservoirs are to provide irrigation in the dry season, prevent or reduce flooding in the rainy season, and enhance water infiltration, increase land productivity, extend planting periods and improve farmers' incomes in rain-fed land.

Rainwater reservoirs are applicable in high rainfall and highly populated areas where the water balance is deficit and slope range 8–30% with high runoff conditions.

Relationship to agroforestry

This method can provide water throughout the year, which can help farmers to grow multiple crops (seasonal and unseasonal).

Construction of a rainwater reservoir

The construction of a rainwater reservoir includes soil excavation, clay coating and spillway construction, as follow.

a. **Soil excavation**: After the location, size and shape of the desired rainwater reservoir are determined, the next stage is soil excavation, which can be done through mutual assistance. The procedure of excavation is as follows.

   i. To facilitate soil removal, begins from the perimeter edge of the soil surface.
   ii. To avoid soil entering the rainwater reservoir, if carried by running water, the dike or edge of the reservoir must be made higher than the ground surface.
   iii. The drainage of runoff is made in such a way that the water in the reservoir does overflow. The distance of the drainage channel from the reservoir surface should be 25–50 cm.

b. **Clay coating**: To prevent the reservoir from collapsing, a wet clay paste should be applied to the reservoir wall or dike as thick as 25 cm, starting from the base and then gradually rising to the top of the reservoir. The joints are melded together so that water does not easily seep into the

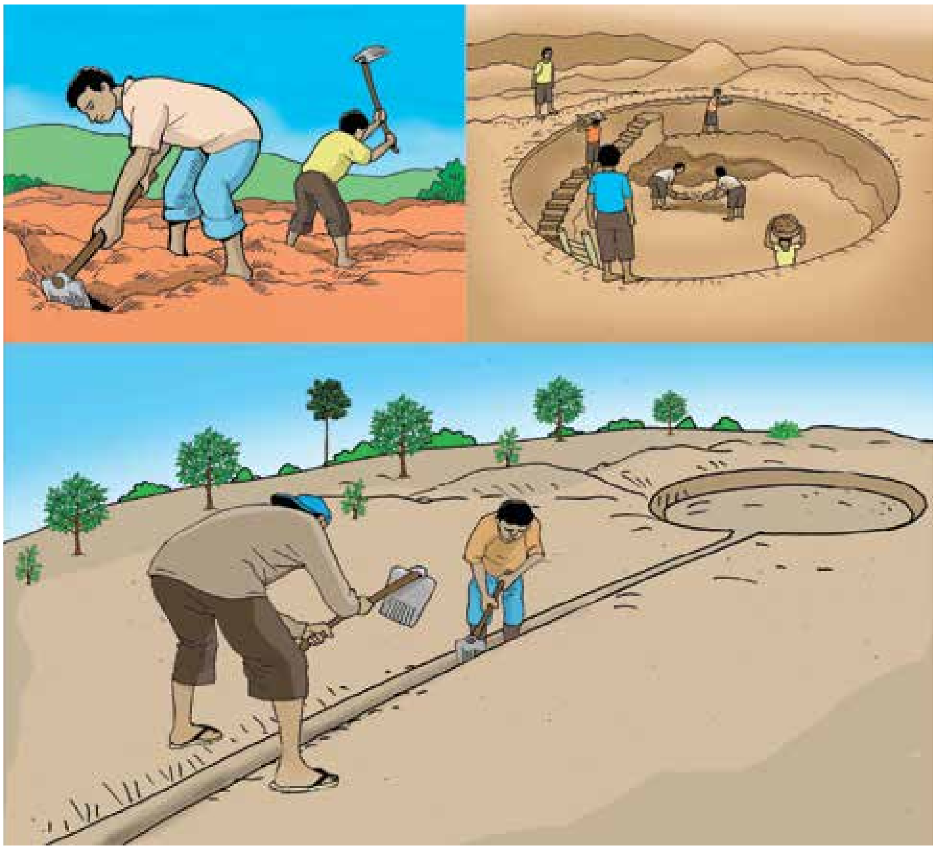

Figure 28. Rainwater reservoir under construction

soil. To suppress landslides, the reservoir wall coverings are best at a slope of 70–80° or in step form.

In sandy soil, water can percolate through the soil quickly. Therefore, the weir wall needs to be coated, which can be with plastic, cement or a mixture of lime with clay. The limestone and clay mixture to strengthen the weir wall is made in a 1:1 ratio of moistened limestone mixed with clay to a paste form. The paste is then affixed to the wall and bottom of the reservoir until it reaches 25 cm thickness.

c. **Spillway construction**: The spillway is made to face the area to be irrigated, with a width of 15–25 cm and a depth of 10–15 cm. The length of the spillway can be adjusted to the needs of the irrigation area.

Maintenance of a rainwater reservoir

The rainwater reservoir should be monitored and maintained regularly as follows.

a. Cleaning the spillway, reservoir edge and weir wall.
b. Dredging mud.

11.1.7 Drainage and waterfall building

Drainage means a channel used to direct water flow to a place for absorbing water into the ground. The function of waterfall building is to complete a spillway so that the water falling into the drainage will not cause erosion and landslides. This method applies to open or cultivated areas on steep slopes (greater than 25%) and a type of soil prone to erosion and landslides.

Relationship to agroforestry

The proper construction of drainage supported by a waterfall prepared from, for example, bamboo can reduce erosion on steep slopes and provide land for growing crops, such as broom grass.

Construction of drainage and a waterfall

a. Dig out the soil according to the profile formed from already-installed supporting posts at least as deep as 50 cm from the cultivation space and the basic width of 50 cm, according to the design.
b. The base of drainage on bench terraces is made with a slope of 0.1–0.5% outward so that the height difference of the channel within 5 m is 0.5–2.5 cm.
c. Every 1 m along the drainage is planted with a 20 cm sodding across the drainage.
d. For waterfall building, two or three pieces of round bamboo stakes should be plugged into the soil as deep as 0.5 m, while the other pieces on the surface of the channel are mounted as high as the waterfall.

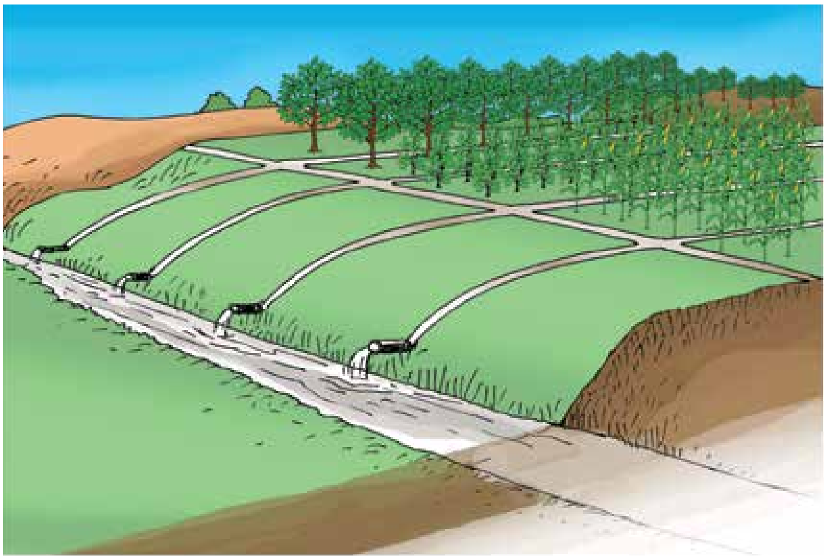

Figure 29. Drainage (spillway) with waterfall

e. Split bamboo is installed transversing the plunge; outer part of the bamboo placed on the outside.
f. Installation of bamboo is arranged from the bottom with both ends inserted into the left and right side of the drainage wall and tied to the round bamboo.

Maintenance of drainage and waterfall

The maintenance to be performed is as follows.

a. Clearing the channel of sediment by dredging and pruning weeds and grass.
b. Repairing the bamboo construction is damage is caused by weathering, direct impact etc.

11.1.8 Wattle fence/live check dam

A wattle fence is a row of fencing or short retaining wall constructed of vegetative material (preferably live cuttings) placed across a slope. It is useful for small, shallow, short slopes. The major functions of a wattle fence are to capture any debris moving down the slope, reinforcement and slope modification. This method is a fast and simple way of soil conservation. It establishes a micro-site for many plant species (thanks to the live cuttings). However, construction is labour and material intensive and applicable only for slopes with a limited amount of debris.

Relationship to agroforestry

This measure can help to achieve multiple benefits, such as reducing sediment in waterways, conserving soil and diversifying sources of income for local people through cultivation of several species on a slope. Species such as bamboo, moringa, rosewood and guava, all of which usually propagate from live cuttings, can be grown using this method.

Construction of a wattle fence

a. Clear all loose material and protrusions and firmly infill any depressions.
b. Mark on the slope the lines where the wattle fences are to be installed.
c. Dig a hole for placing stakes with a crowbar or auger.
d. Place 100 cm long stakes at intervals of about 100 cm along the lines.
e. Place two 50 cm-long stakes between the long stakes. Stakes should protrude about 20–30cm.
f. Dig out a furrow (at least 15 cm deep) along the contours between the stakes.
g. Place the cuttings lower ends in the furrow, bending them along the line of the fence. Weave them in and out between the stakes. Firm the soil back into the furrow.
h. The cuttings should be almost horizontally above each other but with the ends firmly planted in the soil.

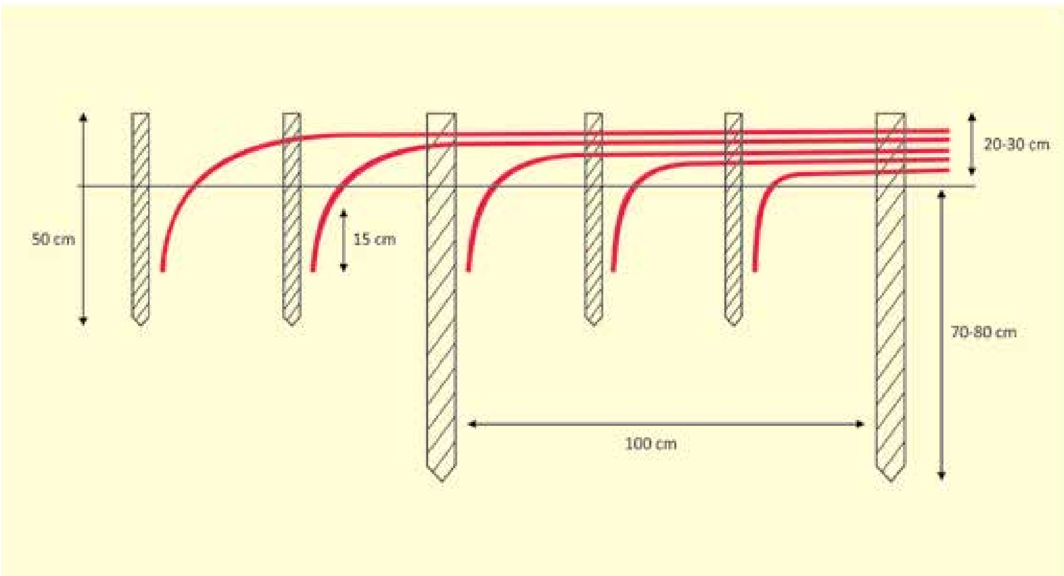

Figure 30. Weaving method for constructing a wattle fence

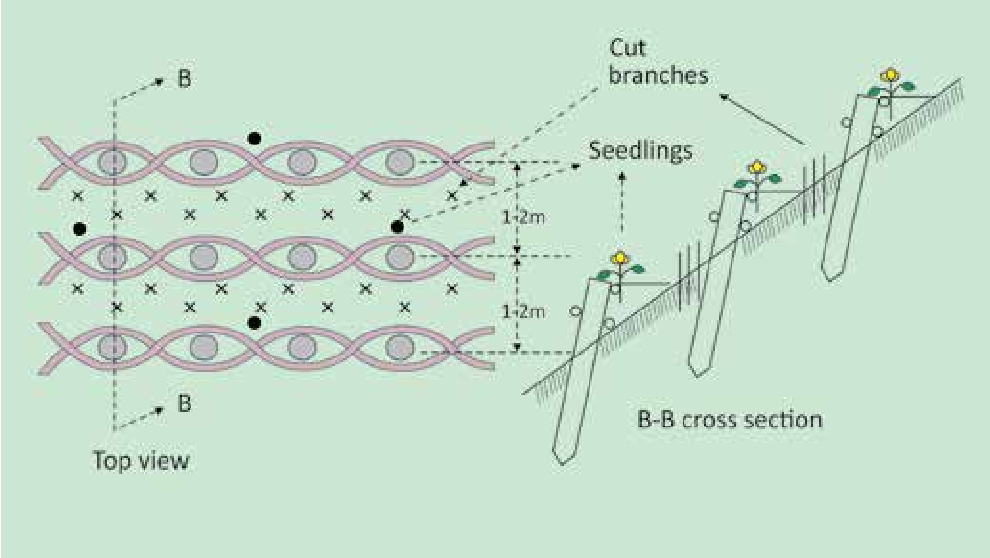

Figure 31. Cross-section and top view of a wattle fence

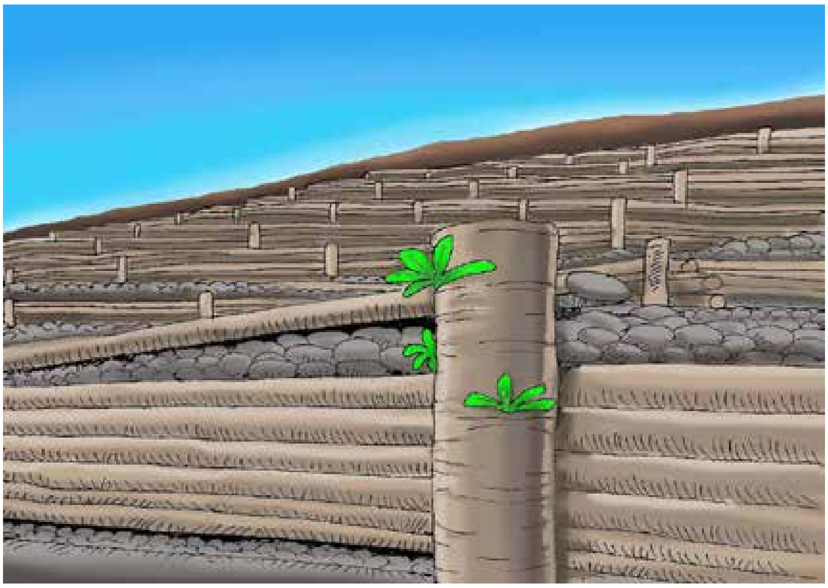

Figure 32. A wattle fence

i. The soil must be filled behind the wattles if planting of tree and grass seedlings and cuttings is to be carried out.

Maintenance of a wattle fence

The following activities should be carried out to maintain a wattle fence in good condition.

a. Some thinning of shrubs may be required after a few years.
b. Regular protection from grazing and human interference is needed.

11.2 Implementing organization and schedule

The implementation of soil conservation activities and their maintenance should be carried out by local communities. The Ministry of Agriculture and Fisheries (MAF) of Timor-Leste can provide the resources as well as extension activities with proper coordination of district or sub-district officials. External technical and financial support can be sought from national and international organizations or donor agencies working in Timor-Leste on natural resource management (Figure 33).

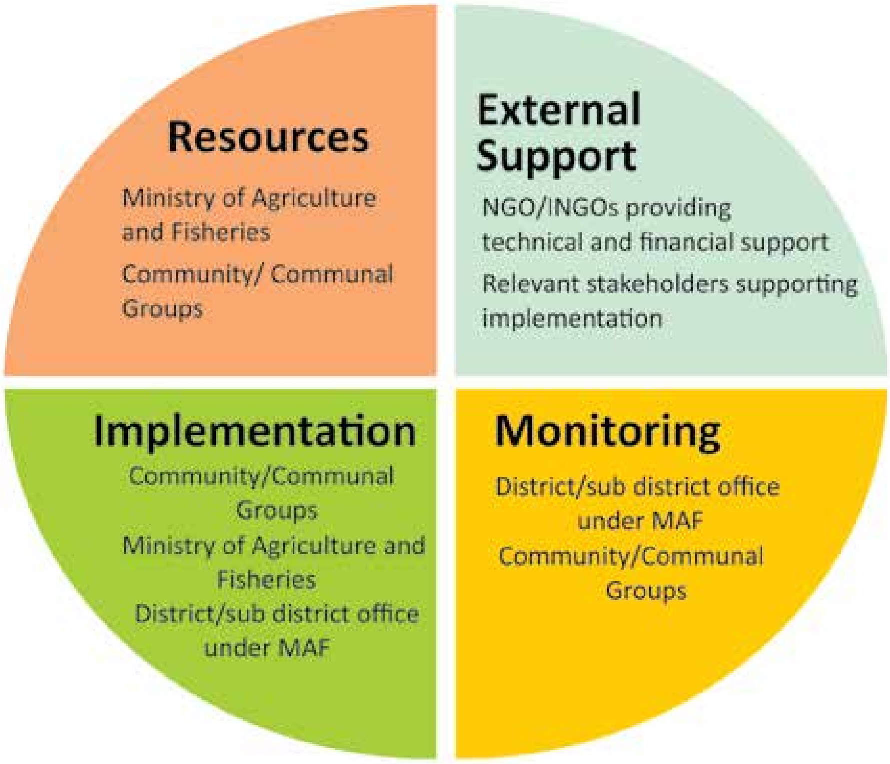

Figure 33. Responsible institutions for soil management

A timetable (Table 10) can be followed for the construction of the soil conservation infrastructure with the proper technical guidance of MAF, supporting organizations and other stakeholders. The applicable months for the construction of different soil management techniques are proposed below.

Table 15. Construction periods of different soil management techniques

Soil management technique	Construction period
Brushwood check dam	During the dormant season if the site is moist. Just before the rain season if the site is dry (May–June).
Loose stone/boulder check dam	Any time of the year when it is convenient, however, a dry period is preferred.
Gabion check dam	Any time of the year when it is convenient, however, a dry period is preferred.
Terracing	Dry season (May–June). Maintenance needs to be conducted twice a year: before rain and during rain period.
Bio-pore infiltration hole	Throughout the year but the surface should be dry, around early dry season between April and May.
Riverbank protection	Throughout the year but preferable before the rain period starts.
Grass planting	Throughout the year.
Rainwater reservoir	Throughout the year but the surface should be dry. The best time is before the rain period starts (October–December).
Drainage and waterfall building	Before rain period starts (October–December).
Wattle fence/live check dam	During the dormant season if the site is moist. Just before the rain period if the site is dry (May–June).

Source: Adapted from Geyik (1986), Sthapit and Tennyson (1991), ICIMOD (2006), Permatasari (2015).

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