Partnership for Sustainable Agroforestry (PSAF) project

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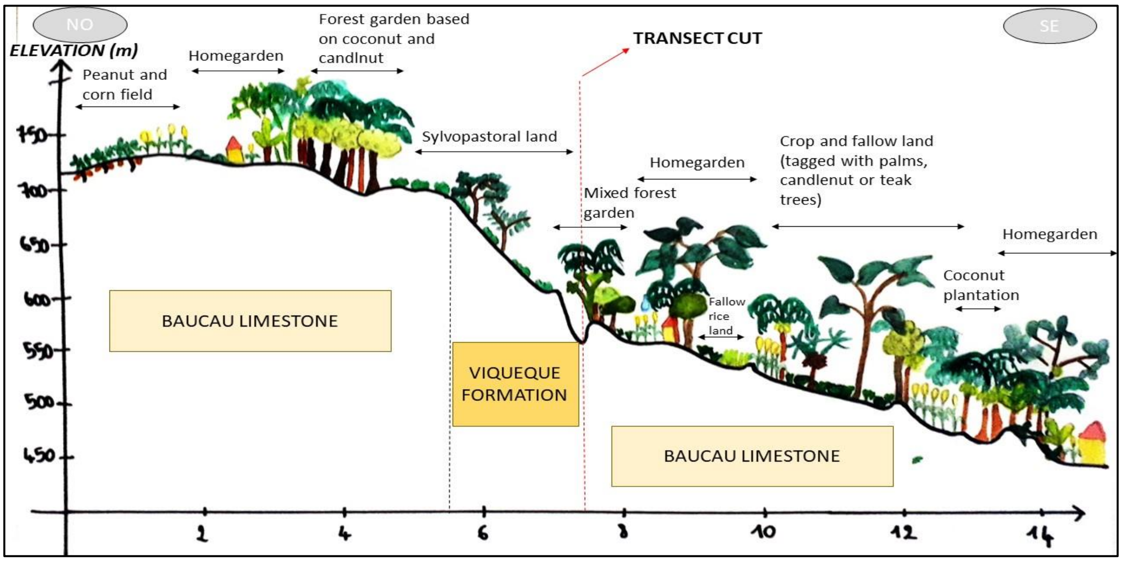
CIRAD long-term adaptive research programme to support and underpin the implementation of PSAF.




Technical report:

# Socio-economic functions of Agroforestry Systems in Baucau area (Timor-Leste)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# Executive summary

Within the framework of Ai ba Futuru-Partnership for Sustainable Agroforestry (PSAF), which aims to promote agroforestry systems (AFS) in Timor Leste, GIZ commissioned CIRAD to carry out a diagnostic study of agroforestry systems in the project area between January 2020 and June 2022.

This report shares the results of this diagnostic, based on the study of agroforestry systems in two *suco* [1]of Baucau region. This study aimed at collecting information about uses, perception and economic return of AFS according to local communities. The study focuses on the dynamics of AFS within a village territory and over time. It was done across scales, from the field to the village territory. In order to characterize AFS general economic functions, models were developed to illustrate the income that can be generated by some of these systems.

**Question and hypothesis**

The following research question (Q) and hypothesis (H) were used to develop our research methods:

Q: What are the place and importance of AFS in the household economy and the territory?

- H1: Agroforestry practices are embedded in Timorese agricultural systems and society
- H2: The AFS studied are resilient and support food and household economic income
- H3: The AFS studied are labour intensive and allow diversification of agricultural activities in the territory throughout the year
- H4: The AFS studied are historical markers of a territory and the family dynamic (throughout generations)

**Methods**

To test the hypotheses, we needed to understand the types of AF system present in the study areas and the species associated with them. This way, we could better understand their functions and how they contribute to meet identified needs.

We also studied how these systems were distributed in a village territory, including the historical dynamics at work and the local communities' perceptions of their land at the present and in the future through Ocelet (https://agritrop.cirad.fr/562043/), a tool for modelling spatial dynamics. In parallel, we identified socio-economic indicators associated with these different systems (e.g., labour requirement, gross margins, return on labour according to the gross margins calculated). The objective was to better understand the degree of economic resilience that these systems bring to households in terms of diversification of income over the year and distribution of work time.

Inventories of 68 different farm fields, 115 semi-directive interviews, participatory mapping in 2 case studies and scoring exercises (using Pebble Distribution Methods) in one case study resulted in a multi-dimensional dataset collected for 1,5 years. To cross-check information, we conducted inventories and semi-directive interviews during the rainy and the dry season.

**Results**

[1] 1: administrative term to design a group of 3 to 10 villages together. Each village (*aldea*) has elected its representent ("xiefe aldea") and the communities of all the village together also elected a *suco* representent ("xiefe suco")

Five agroforestry systems were identified in the region of Baucau: Crop and Fallow (CF), Sylvopastoral areas (SP), Young Agroforest (YA), Home Garden (HG) and Forest Garden (FG).

Their characteristics are summarized in the following table:

| ENGLISH NAME | CROP SYSTEM INCLUDING A FALLOW PHASE (CF) | SYLVOPASTORAL (SP) | YOUNG AGROFOREST (YA) | HOME GARDEN (HG) | FOREST GARDEN (FG) |
|---|---|---|---|---|---|
| ***Tetum/tetum terik name*** | *To'os muda muda, to'os udan, to'os la permanenti, to'os foun* | *Ai bobur laran, ai loek laran, tree's name-laran (main tree and/or functional tree), pastagem* | *To'os tuan, quintal foun, to'os posa, posalaki…* | *To'os uma hun, to'os uma oin, quintal* | *Abat* |
| **Species characteristics** | | | | | |
| Density of trees inside the plot (low, medium, high) | Low | Medium | Medium-Low | Medium-High | High |
| Main crops and animal husbandry | Corn, peanut, sweet potatoes, cucurbitaceae, beans, horses, buffalo, goats and sheep | Horses, cows, buffalo, goats and sheep | Chili, papaya, condiment, vegetable, banana | Corn, cassava, taro, yam, vegetable, condiment, banana, bamboo, papaya cucurbitaceae, beans, chili, pigs and chicken. | Yam, condiment |
| Main trees planted | Candlenut, Coconut, Teak, *Gmelina* | Teak | Teak, *Swietenia mahagoni* , *Gmelina* , Coconut, Citrus, *Gliricidia* | Citrus, Coconut, Breadfruit, Mango, Candlenut, Teak, *Gmelina* , Goyava | Palm (betel, coconut), Mango, Breadfruit, *Gmelina* , Teak, Candlenut |
| Main trees not planted | *Eucalyptus alba* , *Timonius* , Rosewood, Tamarind, Kussum tree, *Ziziphus mauritiana* , *Albizia julibrissim* , *Corypha* | *Eucalyptus alba* and *Timonius* , Rosewood, Tamarind, Kussum tree, *Ziziphus mauritiana, Delonix regia, Sesbania grandiflora, Leucaena leucocephala, Albizia julibrissim* , Sandalwood, Palm (*Borassus* , *Corypha* ) | *Timonius* , Kussum tree, Rosewood (Samalari), Palm (*Borassus* , *Corypha* ), *Sesbania grandiflora* , *Leucaena leucocephala* | Palm (*Borassus* , *Corypha* ), Kussum tree, Custard apple, *Leucaena leucocephala* , *Sesbania grandiflora* , Tamarind, Wild candlenut, Cotton tree | *Arenga* , *Corypha* , *Borassus* |
| **Social land use regulation** | | | | | |
| Land ownership | Household | *Knua* | Household | Household | *Knua* or household |
| Labour | Household or Exchange of services (neighbours, relatives…) | No specific labour | Household | Household | No specific labour |
| Resources ownership | Household or exchange services (neighbours, relatives…) | Common and *knua* (tree trunk) | Household | Household | *Knua* or household |
| Main use | Food for self-consumption, animal food, economic income | Animal food, construction, firewood, traditional medicine | Economic income, firewood, land securization | Food for self-consumption, economic income, animal food | Construction, firewood, traditional medicine, food for self-consumption, economic income, land securization |
| **Infrastructure** | | | | | |
| Water availability | Raining season | Raining season | All year or only raining season | All year | All year or only raining season |
| Fence/Hedgerow | Depend | No | Depend | Depend | No |
| **History track** | | | | | |
| Date of installation (crop and/or livestock system) | 0 to 3 years | > 50 years | 2 to 10 years | > 5 years | > 50 years |
| Precedent crop system | Sylvopastoral land (pasture, savana or secondary forest), Forest garden | Savana, forest | Crop system including a fallow phase, Sylvopastoral land (pasture, savana or secondary forest), Forest garden | Crop system including a fallow phase, Young agroforest | Home garden, young agroforest |

Using participatory mapping in two *aldeas* we clarified the farmers' perceptions of the distribution of agroforestry systems in their territory and better understood their spatial distribution.

Seasonal calendars were developed as a model for 3 typical agroforestry systems (CF manual, diversified HG and FG) to describe the practices and the labour requirements of each system all along the year.

Based on semi-directive interviews, we calculated and compared the gross products, operating costs, gross margins, and intensification rate associated to this model. Examples of “good”, “bad”, “potential” years were used to illustrate environmental and economic variations.

The results are summarized in the table below:

| AFS | GP TOTAL ($/ha/year) | OPERATING COSTS ($/ha/year) | GROSS MARGIN ($/ha/year) | INTENSIFICATION RATE (%) |
|---|---|---|---|---|
| HG 0-2 YEARS | 3949 | 351 | 3598 | 10 |
| HG 3-5 YEARS | 4376 | 505 | 3871 | 13 |
| HG 6-15 YEARS | 9141 | 4348 | 4793 | 91 |
| HG 16-20 YEARS | 6004 | 2452 | 3552 | 69 |
| FG NORMAL YEAR | 1759 | 0 | 1759 | 0 |
| CF NORMAL YEAR | 1816 | 160 | 1656 | 10 |
| FG BAD YEAR | 1727 | 0 | 1727 | 0 |
| FG GOOD YEAR | 1987 | 0 | 1987 | 0 |
| FG POTENTIAL | 5094 | 0 | 5094 | 0 |
| CF BAD YEAR | 943 | 160 | 783 | 20 |
| CF GOOD YEAR | 2575 | 160 | 2415 | 7 |

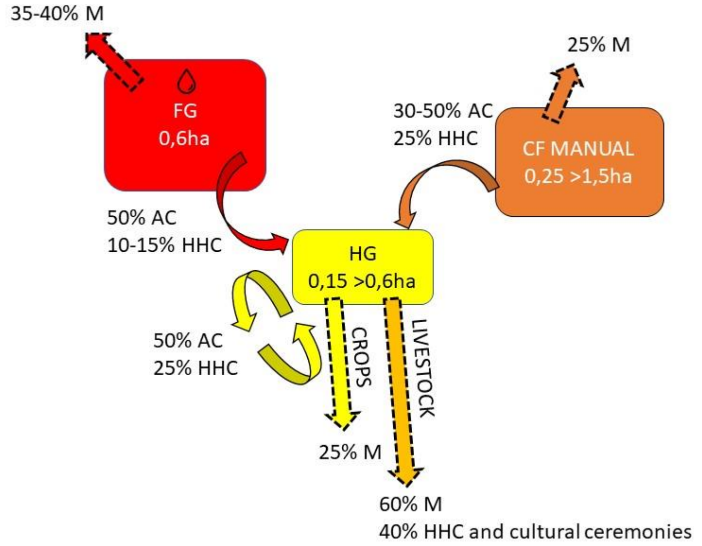
The return on labour in the model was compared with different “opportunity costs”, i.e., non-farming activities in rural areas:

| AFS | Return on labour ($/working day) | Opportunity cost ($/day) | Statut |
|---|---|---|---|
| HG 0-2 YEARS | 14 | 5 | Road or farmer ober |
| HG 3-5 YEARS | 15 | Civil Servant - Junior | |
| HG 6-15 YEARS | 16 | 9 | D level |
| HG 16-20 YEARS | 10 | 11 | C level |
| FG NORMAL YEAR | 16 | 14 | B level |
| CF NORMAL YEAR | 7 | 18 | A level |
| FG BAD YEAR | 16 | Civil servant - Experienced | |
| FG GOOD YEAR | 22 | 10 | D level |
| FG POTENTIAL | 20 | 13 | C level |
| CF BAD YEAR | 3 | 18 | B level |
| CF GOOD YEAR | 10 | 24 | 1 level |

To take into account the entire cost of labour, we included self-consumption in the calculation. These results show that the return on labour of these AFSs is similar or higher than other employment opportunities in rural areas. Return on labour is particularly high in the most diversified systems (HG and FG). CF is the only system that can have a lower return than the labour wage. A job in a rural area (e.g., civil servant) can also be combined with agricultural activities for the same person.

The following figure illustrates the difference of gross margin allocation, particularly the distinction between “market income” and “self-consumption income”:

Gross margin distribution : Animal Consumption share (AC), Household consumption share (HHC) and Market share (M)




**Discussion**

The diversity of products extracted from AFS systems contributes to households' food security because a great part of the gross margin is allocated to self-consumption. It also contributes to other needs. AFS can generate incomes for the households, wood for fuel and construction, and animal feed. Because the AFS do not rely on one function only, they are resilient to economic variations.

We compared the resilience of CF and FG systems to environmental shocks (e.g., pest, climate disaster). Our results suggest that households are likely to improve their capacity to cope with these shocks if a high diversity of species is cultivated in the same plot. Farmers combine products ready to be harvested at different periods of the year. They also use livestock, as part of the AFS, to secure a source of income in case of unforeseen circumstances.

To transform agroforestry systems or to promote them, we need first to consider the highly dynamic interactions between each system across time and space. Using participatory mapping and Ocelet, we proposed a model on the possible evolutions of AFS in the next 50 years in the village of Osso Luga. The model is showing an increase in areas for young agroforests and other farming systems, because of the population growth and following the future construction of new road infrastructures.

**Perspectives and limits of the study**

In the project sites, farmers have developed agroforestry systems well adapted to their harsh environment (i.e., steep mountains, hard clayish soils, heavy rains, and lack of water during several months of the year) to make them economically viable and sustainable. These AFS provide to the farmers regular income, food security, and a statute in the village. Any project looking at transforming these AFS needs to be careful not to disturb and change these balanced and complex systems.

Scaling up these systems by combining AFS with other cropping and livestock systems, as presented in S.Mazin *et al* (2022), is essential to better understand the household strategies related to their farming types.

The main limits of this study are in terms of scale and lack of detailed data collection on market labour requirement and wood product for self-consumption (e.g., firewood, house construction, handcraft, fence). Additional studies of comparable AFS are needed in the country that would strengthen the results of the present study. Other typical AFS and non-AFS systems should also be studied using the same approach and methods to widen the comparison and scale up the economic analysis to the farming system and farming income.

Limited time and human resources to collect and analyse the data prevented us from proposing further analysis based on participatory mapping and the modelling of possible future agroforestry evolution.

The Ocelet model shows a probable evolution of the AFS in the project sites, which was limited to the type of data that was collected. It should be finetuned with more measurements, for example on the climate variability and the farmers' coping strategies, or on the evolution of the land tenure system. It could also consider systems that were not the focus of this study, such as: rice fields and horticultural systems.

## Conclusion and Recommendations

Based on our research findings, the following table summarises recommendations that can be made at a technical level and at an institutional level for future projects working on agroforestry and will local farmers in Timor Leste.

| Result/discussion | Technical recommendation | Institutional recommendation (Agroforestry Strategy) |
|---|---|---|
| **Farmer's knowledge of agroforestry systems** | Before proposing new agroforestry schemes, technicians need to have an **accurate understanding of the existing local/traditional agroforestry systems**. Such complex systems have often been in place for ages, and they are usually adapted to local ecosystems, population's needs, and local markets. The CIRAD typology [1] can serve as a base to communicate with farmers, although the technician still needs to understand how farmers describe and name their agroforestry system. Technicians could then improve the current typology. | Agroforestry strategy and innovation are smoothly and progressively incorporated into existing agroforestry systems (AFS) and land tenure systems to avoid conflicts, non-adoption of the systems, market risk and natural disaster. |
| **Six types of capital (land, labour, financial, social, cultural, natural) influence the households' capacity to implement AFS** | Six types of "capital" must be estimated to assess one household's possibilities to implement or amend AFSs:<br>• **Land tenure and labour arrangements** (i.e., private family property with or without mutual support, sharecropping, joint property)<br>• **Revenues and savings** (i.e., possibility to hire manpower or | |

| | | |
|---|---|---|
| | to invest)<br>• **Social network and kinship**<br>• **Cultural knowledge and technical know-how**<br>• Access to **natural resources** (e.g., water, biodiversity, trees, soils).<br><br>This should also inform the way AFS help (or not) to build resilience against shocks (for example: periods of drought, floods, cyclones, variations in the price of products, population migration) | |
| **Farmer's preferences about the species to be planted** | Before proposing new species or AF patterns to be planted by farmers, technicians should discuss with all relevant stakeholders at the *aldea* scale on (1) local priorities for AFS, (2) species the farmers would like to plant in each category of AFS, (3) objectives of the new plantations, and (4) markets and value chains for these products. | MAF (Ministry of Agriculture and Fisheries) and/or project manager should facilitate the selection of species to be planted, where, and according to what type of AFS. These development services should consider:<br>• The production objectives (for family self-consumption and/or income generation)<br>• The management of the farming system, including weed and pest control, animal feed requirements<br>• The existence of markets. |
| **Specific labour requirement spread over the year with different peaks of activity** | The technicians need to know the working calendars of each type of AFS present in the intervention zone to avoid periods of most intensive activity for farmers (e.g., December, February, April, August, September, and October), in order to:<br>• Adapt the set-up of information meetings and training sessions<br>• Anticipate the set-up of nurseries<br>• Deliver seedlings at the most favourable times for planting e.g. January and/or March) | 1. Agroforestry project managers should facilitate the transport and distribution of seedlings through contracts with the local private sector. This will reduce the time and cost of the intermediate chain and favour local logistical resources.<br>2. The improvement of road infrastructures and the training and travel capacities of technicians are essential levers for running these operations. This will also contribute to the development of rural communes that are still isolated from urban centres. |
| **Importance of multi-scale analysis to identify development levers** | The technicians should consider different levels of analysis to detect development levers. Three important levels are identified:<br>• **Practices:** at the plot level (AFS)<br>• **Farmer strategy** in the overall | The government should facilitate the development of the sectors that drive agroforestry production:<br>• A diversity of organisations (e.g., producer organisations, private companies, cooperatives, producer |

| | | |
|---|---|---|
| | economic activity of the household (interaction between the different agroforestry and non-agroforestry plots, off and non-farm activities)<br>• **Value chains** embedded in specific socio-environmental and economic conditions at the village and country level that allow production and sales.<br><br>*Note:* our research highlighted that a large part of the production is often not sold because there is no outlet. The problem does not lie at the practices level but rather at the value chain level. The technician could support farmers to find reliable outlets. | unions)<br>• To promote and protect local products to enhance their consumption (e.g., Agroforestry Fair,2022).<br>• To facilitate wood sale legalization (taxes and professional fees are too high for small farmers) |

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# List of Acronyms

AFS: Agroforestry systems

CF: Crop and Fallow system

CIRAD: The French Agricultural Research Centre for International Development

FG: Forest Garden

GIZ: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbHGerman Development Cooperation)

GM: Gross Margin

GP: Gross Product

HG: Home Garden

ICRAF: International Council for Research in Agroforestry

PDM: Peeble Distribution Method

PSAF: Partnership for Sustainable AgroForestry

SP: Sylvopastoral areas

UNTL: Universidade Nacional Timor Lorosa'e (National University of Timor Leste)

YA: Young Agroforest

# Glossary of terms

**Cropping system**: "The range of technical methods used on fields treated in an identical manner. Each cultivation system is defined by two criteria: the nature of the crops and the cropping sequence (which used to be called crop rotation), and the crop management sequences applied to these different crops, including the choice of crop varieties" (Sebillotte 1990).

**Farming system**: "The coherent combination, in time and space, of means of production (land, labour force, equipment, capital) dedicated to plant and/or animal production" (Dufumier, 1987)

**Gross margin and operating costs**: "The gross margin is equal to the gross product minus operational cost (also called operating expenses, intermediate consumption or variable costs), to which subsidies, if any, are added. Operational cost, which corresponds to expenses incurred in the act of production, processing, and marketing" (E. Penot, 2010)

**Gross labour valorisation**: "The gross labour valorisation is equal to the gross margin divided by the family labour time. It is another way of expressing the concept of labour productivity. Semi-directive interview" (E. Penot et al., 2010)

**Gross product**: At the plot level, the gross product per surface unit (acre, hectare or other) corresponds to the yield (minus any post-harvest losses) multiplied by the unit selling price of the products. (E. Penot et al., 2010)

**Land productivity**: "The productivity of land measures the contribution of this factor to production. It is calculated as follow: Productivity of land = Quantity produced/Surface of production" (E. Penot 2010)

**Livestock system**: "A group of techniques and practices carried out by a community to exploit the plant resources in a given space by the animals in conditions compatible with the objectives and the constraints of the environment" (Lhoste, 1985)

**Productivity**: Productivity is the relationship between an output and the resources used to produce it: the factors of production. Production refers to the goods and/or services delivered. The factors of production are labour, technical capital (installations, machines, tools, etc.), capital employed, intermediate consumption (raw materials, energy, transport, etc.), as well as factors that are less easy to grasp but extremely important, such as accumulated know-how (Insee, 2016)

# I. INTRODUCTION

## I.1. Background

The systematic promotion of agroforestry systems in Timor-Leste was relatively new when Ai ba Futuru-Partnership for Sustainable Agroforestry (PSAF) started. Therefore, it is essential to establish an adequate basis for demonstration and applied research and development (R&D) to ensure sound production, processing and marketing practices (Peltier *et al.*, 2020). This refers to identifying and developing suitable, sustainable, and profitable agroforestry value chains, associated agroforestry systems, management, and marketing practices.

Ai ba Futuru project is working on agroforestry in Timor-Leste[2]. Associated with this programme, CIRAD was assigned a two-year adaptive research programme to support and underpin the implementation of PSAF, with three research topics related to:

1) market/value chain analyses,
2) immediate ecological benefits from agroforestry systems as well as socio-economic impacts, and
3) the implications of both for building resilience towards the effects of climate change.

Agroforestry-specific recommendations from this research will be included in the country's extension material. They will also contribute to long-term forestry sector policy and decision-making.

The research results will also contribute to the identification of constraints limiting the increase in production, income and/or employment from agroforestry systems and related value-chains; the identification of immediate/short-term socio-ecological benefits from the establishment/expansion of agroforestry production systems.

The activities of CIRAD's scientific team consisted in producing a technical, ecological, and socio-economic diagnosis of current and future agroforestry systems by developing models showing the transition between the different systems.

The agrarian systems of the four municipalities of Timor-Leste, in which GIZ is working under the umbrella of PSAF, are still poorly understood (see Butterworth & Kielwein, 2018). Traditional agroforestry systems are hardly mentioned in the baseline study for this project, and only products from cultivated fields, forests or rangelands are described. However, suppose we refer to the description of the agrarian systems commonly used by the scientific community (e.g., ICRAF) and, more specifically, by Nair (1983). In that case, most of the cultivated land in the four municipalities falls into different categories of agroforestry systems (including sylvopastoral).

To better meet the needs of the rural and urban population in Timor-Leste, it is essential to understand the functioning of the main agrarian systems. The division of each farm's activities in several cropping and livestock systems needs to be understood. It includes the agroforestry systems with dense cover (presence of tubers in understory), with light cover (presence of cereals and legumes in understory), totally open fields (cultivation of cereals or legumes),

[2] https://www.giz.de/en/worldwide/70499.html

mono-specific orchards, forest plantations, pastures with hedges and tree cover or not. These systems need to be placed in the context of their historical evolution, i.e., the traditions of the first known landlords, the current ethnolinguistic group, the impact of the colonisation, the contribution of public services, various projects, and the current economic conditions of the system's managers: elderly or young person, with or without labour, with or without extra-agricultural income (e.g., retirement funds, transfer of city dwellers or expatriates). To understand these systems, we need to study the type of soil, altitude, rainfall, and groundwater or irrigation supply.

## II.2. Objectives of the report

This report shares preliminary results based on a multiscale study on agroforestry systems (AFS) in four villages of Baucau region to inform about their socio-economical characteristics. We focused first on the historical and landscape level to represent the dynamic of AFS among space and time and their general socio-economic function. At a more restrictive scale (AFS system themselves) we developed models to represent the income that can be generated by these systems. This will provide an understanding for planning future development projects targeting a higher number of farmers, with higher profitability of future actions at the country level.

The report is organised in a method section, which describes the study area and the socio-economic methods used to conduct this study (i.e., interview techniques used, qualitative and quantitative methods, participatory mapping, scoring exercises, and prospective models).

The result section describes the five main agroforestry systems in Baucau, the typology of these AFS, including their dissemination and spread in a village territory. We describe the practices and economic returns for three main agroforestry systems and their interactions to diversify the household level income. We discuss their economic resilience and their perspective of evolution. Finally, we identify the remaining knowledge gaps that need to be filled through further research.

Based on this report, we propose a bundle of pragmatic solutions adapted to each context, which should help the farmers and decision-makers in the country to benefit from agroforestry. Among other things, AFS can provide them with various local products, healthy and resilient to climate change, maintain biodiversity and the carbon stock above and below ground levels, and adapt progressively to social and economic changes.

# II. Methods

## II.1. Study Area

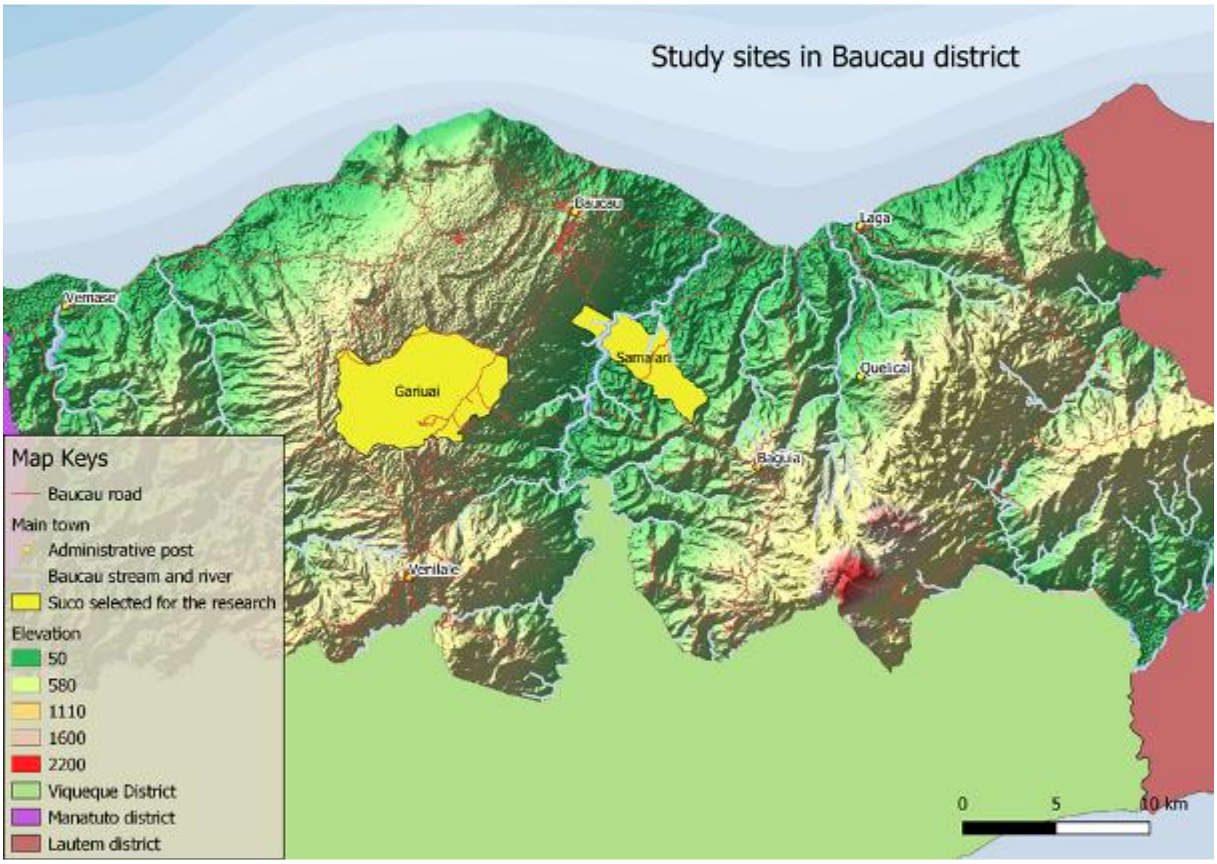



*Figure 1: Baucau map and study areas in 2021. (Source: M. Cogné, map adapted from https://data.humdata.org/dataset and https://download.geofabrik.de)*

In 2021, two *suco* (i.e., an administrative cluster of 3 to 10 villages) were selected from the project **target communities:** Gariuai and Samalari (Figure 1). These two *suco* are divided into 8 and 4 *aldea* (i.e., a village of less than 2000 inhabitants). For each *suco*, three aldea were selected for our study. They are representatives of Baucau in terms of their distribution in the landscape, their history (e.g., migrations, infrastructure development), and their different access to the market in Baucau Vila (presence or absence of asphalted roads). These two *sucos* were also selected for logistic reasons as they are less than 1,5 hours away from Baucau Vila by motorbike. This helped regular visits by the junior expert and the students.

**Landscape distribution in the mountainous district of Baucau:** the 2 *sucos* are located at the centre of Baucau district but at different altitudes (between 50 and 1200 m) and with a same annual rainfall of about 1200mm/year.

**Different chronologies during the colonial period:** there are two different accounts of settlement: Gariuai was continuously occupied during the colonial period, while Samalari (especially the main *aldea* studied, Osso Luga) was deserted during the Indonesian occupation for more than 20 years. People started to resettle the village in 2005.

**Different access to services:** Gariuai, one of the closest *suco* from Baucau Vila, benefits from two asphalted roads (one from Baucau to Viqueque, another crossing the *aldea* of Darasula and linking the village to the main Dili-Lospalos road). Regular markets are organised during the week, companies and farmer organisations exist to connect the producers to faraway markets, especially for trading candlenut, peanut, sweet potatoes and corn. Chinese cement companies, road construction, carpenters, and civil servants are also present. An educational training centre (Fatumaka college) and schools (primary to high school) can be found in the *suco*. Electricity, water, and irrigation infrastructures are also present.

Samalari has three *aldea* separated from Baucau Vila by the Seiçal River, which isolates these villages during the rainy season as there is no bridge for crossing it. Because the mountain villages were rehabilitated only recently, there is no asphalted road. There is no market inside the *suco* area; to access markets, local people must go on the other side of the river or close to the sea. They sell their products in other neighbouring *suco* "Bazar" or go to Baucau Vila. Direct selling (especially for animals) can occur between producers and people outside the village. Very few other activities than farming are available on the eastern side of the river. School is provided only until primary school, while a secondary school is located in the neighbouring *suco* down to the sea. Electricity has been available since 2017, and some public water tanks are also present. There is irrigation infrastructure for rice fields on the riverside, although it needs some maintenance. People living in the mountain rely on their private tanks if they want to grow crops during the dry season.

**Different internships:** the fieldwork in Gariuai and Osso Luga was implemented by three interns, i.e., two interns from the Agriculture Department of the National University of Timor Leste (UNTL) and one intern from the National Agronomic School of Montpellier SupAgro (France). A binational team studied the functions and repartitions of Agroforestry systems in one village of each targeted *suco*. The other Timorese student studied the functions of AFS at the technical and economic level. The students were accompanied in the field by the junior expert and remotely supervised by three other CIRAD researchers from France.

## II.2. Activity schedule

Research activities were conducted in 2021 and 2022, as shown in the timetable (Table 1) below:

*Table 1: Planning of activities 2021-2022. (Source: M. Cogné)*

| JANUARY 2021 | FEBRUARY 2021 | MARCH 2021 | APRIL 2021 | MAY 2021 | JUNE 2021 |
|---|---|---|---|---|---|
| | Function of species (including non-woody species) and AFS plot inventories in Gariuai and Samalari sucos | - Analysis of the results and final typology of AFS in Baucau<br>- Organisation of the internships (communication with researchers, teachers, students and GIZ, logistic and teaching materials from the research results, protocols) | | Theoretical preparation of Timorese student for their internships (concepts, protocols…) and general field work | 4 different field study :<br>- Species inventory and biomass measures in AFS plots<br>- Soil measures and observations in AFS plots<br>- **Semi-directive survey on AFS practices and economic income**<br>- **Semi-directive interviews on social organization, participative mapping and Peeble Distribution Score methods on AFS functions at the aldea level** |
| | | | **Arrival of Timorese students in Baucau** | **Arrival of french student in TL** | **Arrival of French student in Baucau** |
| Selection of students and contracts with their universities | | | | | |

| JULY 2021 | AUGUST 2021 | SEPTEMBER 2021 | OCTOBER 2021 | NOVEMBER 2021 | DECEMBER 2021 |
|---|---|---|---|---|---|
| 4 different field study :<br>- Species inventory and biomass measures in AFS plots<br>- Soil measures and observations in AFS plots<br>- **Semi-directive survey on AFS practices and economic income**<br>- **Semi-directive interviews on social organization, participative mapping and Peeble Distribution Score methods on AFS functions at the aldea level** | | Timorese student report on species inventory and biomass of AFS (tetum version) | *Data analysis* | **French student master thesis report on socio-economic functions of AFS (french version)** | *Data analysis* |
| | | | | | **Timorese student report on practices and economic functions of AFS (tetum version)** |

| JANUARY 2022 | FEBRUARY 2022 | | | | |
|---|---|---|---|---|---|
| **Timorese student report on socio-economic functions of AFS (tetum version)** | *Data analysis* | Draft reports on **Technical, socio-economic** and ecologic functions of AFS in Baucau and other PSAF districts | | | |
| CIRAD mission : extension of diagnosis in other PSAF target districts : AFS typology checking and updates, focus on production system and basic necessities analysis | | | | | |

## II.3. Research question and hypothesis

The following research question and hypothesis were used to develop our research methods:

Q: What are the place and importance of AFS in the household economy and the territory?

- H1: Agroforestry practices are embedded in Timorese agricultural systems and society
- H2: The AFS studied are resilient and support food and household economic income
- H3: The AFS studied are labour intensive and allow diversification of agricultural activities in the territory throughout the year
- H4: The AFS studied are historical markers of a territory and the family dynamic (throughout generations)

## II.4. Socio-economic functions of AFS

To address the previous hypotheses, we needed to understand what type of AFS were present in the study areas and the species associated with them in order to better understand their functions and therefore the needs they met. We also looked at how these systems were distributed within a village territory, considering the historical dynamics at work and the villagers' perceptions of their agrarian space. In parallel, we also identified socio-economic indicators associated with these different types of system (labour requirement, gross margins, valuation of work according to the gross margins calculated, etc.) to better understand the degree of economic resilience brought by these systems to the households, especially in terms of diversification of income over the year and distribution of work time.

### II.4.a. Qualitative and quantitative study to assess smallholder farming and characterize agroforestry systems through semi-directive interviews (Barral et al., 2012):

Several types of semi-directive interviews (Table 2) were conducted in Baucau district between 2020 and 2021 with a junior expert and students (Figure 2).

*Table 2: Semi-directive interviews conducted in Baucau district. (Source: M. Cogné)*

| Method | Number of interviews | Topic | Investigator | Location | Period |
|---|---|---|---|---|---|
| Semi-directive interview | 40 | History and farming systems | Junior Expert (1) | 9 PSAF sucos, Baucau district | February and October 2020 |
| Semi-directive interview | 35 | Farming systems | UNTL students (4) | Gariuai and Samalari PSAF sucos, Baucau district | May-June 2021 |
| Semi-directive interview | 30 | Technico-economic characteristics of AFS | UNTL student (1) | Gariuai and Samalari PSAF sucos, Baucau district | July to August 2021 |
| Semi-directive interview | 10 | Key informant interviews (structural organization and local rules) | UNTL and Montpellier SupAgro students (2) | Cairiri and Osso-Luga PSAF aldeas, Baucau district | June to August 2021 |

*Figure 2: Semi-directive interview between B. Fernandes and a farmer in the village of Osso Luga. (Source: J. Nunes Viegas)*

### II.4.b. AFS species inventories and their functions:

Inventories of the biodiversity and functions of agroforests were done in February 2021 to characterise the typology of the AFS.

The following protocol (Table 3) was applied in the field:

*Table 3: AFS inventory protocol. (Source: M. Cogné and R. Peltier)*

| | |
|---|---|
| **Activity 1** | Delimitation of the plot (= farmer field) with GPS (or "artificial" plot of 0,5ha in sylvopastoral area following a transect) |
| **Activity 2** | Delimitation of 10*10m quadrat in each corner and one in the centre of the plot |
| **Activity 3** | Annotation of the local and scientific names of all plants and trees inside the quadrat with their function identified by the farmer himself |
| **Activity 4** | Evaluation of the relative importance considering the land covered by each species compared to the others in each quadrat on a scale from 0 (0-10%) to 4 (>75%) |
| **Activity 5** | General observation in each quadrat (e.g. soil, rocks, slope, general soil cover…) |

These inventories were mainly done in the *suco* of Gariuai. However, a selection of plots in the *suco* of Samalari for other research activities (soil and biodiversity studies that are not part of this report) also allowed to cross-check the detailed information collected in Gariuai.

### II.4.c. Participatory mapping:

Participatory mapping was used to locate the AFS and other agricultural areas identified by the local people inside their village territory in Osso Luga (Mountains, *suco* Samalari) and Cairiri (Plateau, *suco* Gariuai). The methods used the guidelines proposed by Boissière et al. (2019). The authors present the different steps of conducting participatory mapping in Indonesian villages, starting with a base-map displaying important landscape features (e.g., roads, rivers, settlements, important buildings), the research team facilitated group discussions to draw on the map the location of the different AFS.

In the project's sites, four focus groups (Table 4) in each *aldea* were involved in the mapping exercise, as follow:

*Table 4: Repartition of the focus groups according to age and gender. (Source: adapted from Martin 2021)*

| | Gender | Age statut | Number of participants |
|---|---|---|---|
| **Focus group 1** | Men | Elder | 4 to 5 |
| **Focus group 2** | Women | Elder | 4 to 5 |
| **Focus group 3** | Men | Youth | 4 to 5 |
| **Focus group 4** | Women | Youth | 4 to 5 |

***Note:*** *"Elder" people were considered as people aged over 30 years old (with children and sometimes grandchildren), and "Youth" were considered as people aged under 30 years old (with no children or no adult children).*

The purpose of the participatory mapping was to capture the different visions of agriculture and space in their village according to gender and age (Figure 3). The objective was to complete the village map featuring the different AFS.

These focus groups were also complemented by ground check. The students went to the different places in each village territory to check the location of fields and important areas of the landscape as indicated by the villagers during the focus group discussions, using a GPS to pinpoint them on the satellite/digital map (see Martin 2021, and Boissière et al. 2019).

*Figure 3: Participative mapping workshop in Osso Luga. (Source: J. Nunes Viegas)*

## II.4.d. Pebble Distribution Method

A scoring exercise, called the Pebble Distribution method (PDM), was used to qualify and quantify the way villagers perceive the uses of farming activities (including AFS) in the village of Osso Luga.  Groups of villagers used the PDM to assess the importance of different land types (here AFS) according to different categories of use.

As for the participatory mapping exercises, four groups differing in age and gender were selected for the PDM (Figure 4). It helped to consider the diversity of perceptions of AFS uses for food, fodder, as a source of income, medicine, firewood and construction.

*Figure 4: Peeble Distribution Score workshop organised by the two students, A. Araujo (front left) and R. Martin (front right) in Osso Luga. (Source: J. Nunes Viegas).*

The methods to conduct PDM are described by Sheil et al. 2002 (p30): "*In each stage of the exercise, informants were asked to distribute 100 counters (buttons, seeds or pebbles) between labelled and illustrated cards in proportion to their 'importance'. Interviewers also ensured that the comparative nature of the exercise was understood by giving at least three examples at the start of each exercise*".

The reason for using focus group discussions for the PDM was to allow villagers who do not speak out in mixed groups to share their knowledge and perceptions. But they do not represent the entire village. The purpose and design of the PDM were not to get in-depth and statistically significant data but to collect general information from the four small groups. PDM only provides general trends, information, based on the participants' knowledge only. They do not represent the entire population of the village.

### II.4.e. Modulization tool using Ocelet

The formalisation of knowledge in agroforestry systems models should help put this knowledge to experimentation through simulations.

This allowed us to evaluate and possibly improve the description of the modelled processes and their integration into a systemic representation.

Ocelet is a tool for modelling spatial dynamics based on a "business" programming language that allows representing and simulating processes at stake in a geographical space. It relies on the concept of "interaction graphs" (to integrate different forms of relationships, e.g., spatial, functional, social) within the same model, between the entities of a system (Degenne and Lo Seen, 2016). Three levels presented in Figure 5 in the construction of the model to be considered:

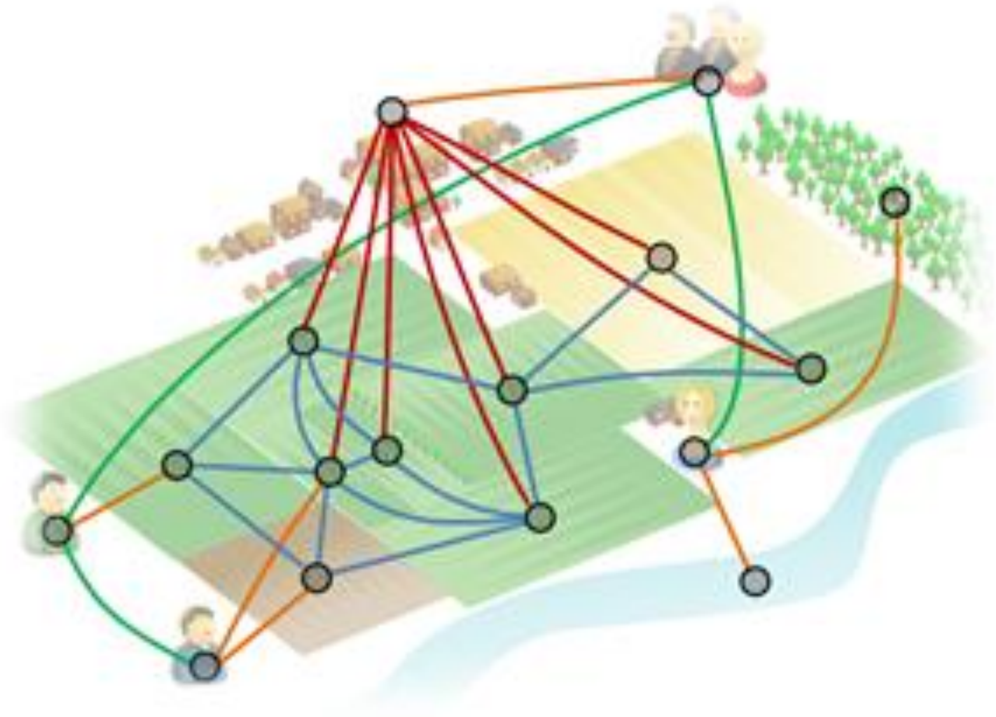


*Figure 5: Interaction graph for modelling with Ocelet. (Source: Degenne 2016)*

The different levels of Ocelet model are reported by Degenne and Lo Seen (2016) as below:

1- The individual level: objects are placed with their properties and services (data from geographic coordinate surveys using field observation, participatory field observation, and participatory mapping)
2- The interactions level: the relationships between the different objects are defined (given through focus group surveys as well as surveys of resource persons)
3- The systemic level and its dynamics: the initial model is described, and its evolution over time is observed. The model includes the determination of the time steps of the evolution and the description of behaviours following the results of the participatory methods.

The data collected was used as inputs for the modelling system based on the above methods. The previous results allowed us to understand the past evolution of agroforestry systems in the two villages, and from these results, we were able to draw possible future behaviours. However, we could not go too far in developing the model because more quantitative data was lacking.

### II. 3.f. Economic calculation

The series of interviews described in part II. 3.a ("Technico-economic characteristics of AFS") aimed to collect detailed information on Crop and Fallow (CF), Home Garden (HG) and Forest Garden (FG) systems that were considered to be the most practical systems to characterize considering our own time schedule, and the most representative to describe differences between agroforestry systems (in terms of tree density and biodiversity, labour requirement and diversity of trade). All information collected was cross-checked using semi-directive interviews.

- **Labour requirement:**

During the interviews, we collected specific information about the detailed farming schedule per selected agroforestry system (i.e., CF manual, HG and FG). Each practice was associated to a number of people and number of hours spent for it (or days) and then homogenized per hour and hectare.

- **Gross product and gross margin**

The gross products were calculated based on the price that farmers sell the products when it is just harvested. We did not consider prices of product sold at the market unless it is sold by farmers themselves. We also converted quantities in function of the information collected during the interviews considering standard price and weight for “bags” (from 10 to 50kg), buckets, cup or other individual units. The gross product was calculated as following:

***Gross product ($/ha) = yield(quantity/ha)*price ($/quantity)***

This gross product is what is considered as “output”. The price used in the calculation is at the “farmgate”.

We did the same conversion process to count the operating costs, or “input”, necessary to grow the type of system analysed (including seeds, animal food, crops and livestock, if any, and paid temporary labour). This quantity of input was also averaged to the size of the system (ha) inside the farming system.

The gross margin (GM) was calculated as follows:

***GM($/ha)/ = output ($/ha)-input ($/ha) = gross product – operating costs***

- **labour valorisation (return on labour) and intensification rate**

The labour valorisation, or return on labour, was calculated considering the total GM and the total amount of family hours (averaged per ha) spent in one year to implement the agroforestry system with a standard amount of 8 hours per day. It is used to express the labour productivity for each agroforestry system.

***Labour valorisation ($/day) = GM ($/ha)/AFS family work (day/ha)***

The intensification ratio is used to show how dependent the gross margin of a system is on input costs. It was calculated as follows:

***Intensification rate = [operating costs ($/ha)/gross margin ($/ha)]*100***

# III. Results

This section describes our research results and is organized in six topics: first, a description of the main agroforestry systems with their characteristics; second, the socio-ecological typology of AFS; third, the presentation of two case studies in Osso Luga and Cairiri villages; fourth, a system description of the technical associations between crops and livestock in AFS; fifth, economic models for 3 typical AFS; and sixth, the distribution and allocation of gross margins within the AFS and outside.

## III.1. Five main Agroforestry systems

In Baucau district, 5 AFS were identified through different characteristics described below (Table 5):

1) Crop system including a fallow phase (CF)

**Specific characteristics:** 2 to 4 main crops including corn, very low density of trees (in patches, isolated inside or on the plot's border), fallow (from 3 months to 10 years), no access to water.

2) Sylvopastoral (SP)

**Specific characteristics:** wide non-cultivated area, no fence, subject to fire, shallow soil.
**Main husbandry:** horse and buffalo (Gariuai), goats and sheep (Samalari).

3) Young agroforest (YA)

**Specific characteristics**: young trees and/or palm growing, commercial crops, access to water, living hedge, no animals inside.

4) Home garden (HG)

**Specific characteristics**: The house is attached or inside the plot, associated with small husbandry (pig and/or chicken). Dense system where crops (mainly for subsistence and animal food) are mixed with fruit trees.

5) Forest garden (FG)

**Specific characteristics:** mixed old trees (>15 years), spontaneous and planted, usually located close to a stream, low management.

*Table 5: Definition of the five main AFS. (Source: Nair (1983) and data analysis M. Cogné)*

| Typology reference adaptd from "An Introduction to Agroforestry"(PKR Nair, 1993) | CROP SYSTEM INCLUDING A FALLOW PHASE (CF) | SYLVOPASTORAL (SP) | YOUNG AGROFOREST (YA) | HOME GARDEN (HG) | FOREST GARDEN (FG) |
|---|---|---|---|---|---|
| ***Tetum/tetum terik name*** | *To'os muda muda, to'os udan, to'os la permanenti, to'os foun* | *Ai bobur laran, ai loek laran, tree's name-laran (main tree and/or functional tree), pastagem* | *To'os tuan, quintal foun, to'os posa, posalaki…* | *To'os uma hun, to'os uma oin, quintal* | *Abat* |
| System | Agrosylvopastoral | Sylvopastoral | Agrisylviculture | Agrosylvopastoral | Agrosylvopastoral |
| Subsystem (Practices) | Multipurpose trees and shrubs on crop land (Trees scattered haphazardly or according to some systematic patterns on bunds, terraces or plot/field boundaries) | Trees on rangelands or pasture (Trees scattered irregularly or arranged according to some systematic pattern) | Plantation crop combination ((i) Integrated multistorey (mixed, dense) mixtures of plantation crop, (ii) Intercropping with agricultural crops ) | Homegarden involving animals ( Multistorey combination of various trees, crops and animals around homesteads) | Multilayer tree gardens (multispecies, multilayer dense plant associations with no organized planting arrangements) |
| Temporal arrangement of trees | Intermittent | Coincident | Interpolated | Interpolated | Coincident |

## III. 2. Socio-ecological typology of AFS in the district of Baucau:

The different inventories conducted in four villages (*aldea*) targeted in Gariuai and Samalari allowed us to summarize the information qualifying a detailed typology of AFS in Baucau district, based on the landscape features and the historical differences.

Locations of the February 2021 inventories are reported in Annex 1.

The total plot inventoried per type of AFS in Baucau are reported in the following table (Table 6):

*Table 6: Farm plot inventoried in Gariuai and Samalari (Source: M.Cogné)*

| | CROP SYSTEM INCLUDING A FALLOW PHASE (CF) | SYLVOPASTORAL (SP) | YOUNG AGROFOREST (YA) | HOME GARDEN (HG) | FOREST GARDEN (FG) |
|---|---|---|---|---|---|
| Inventories in Gariuai | 8 | 6 | 6 | 8 | 5 |
| Inventories in Samalari | 6 | 6 | 9 | 10 | 4 |
| Mean size of the plot (ha) | 0,3 to 1,25 | 200 to 500 (village scale) | 0,2 | 0,3 | 0,5 |

Agroforestry systems were analysed using interviews and field data collection. Their typology is summarized in the table below (Table 7):

*Table 7: Comparative table of AFS. (Source: M. Cogné).*

| ENGLISH NAME | CROP SYSTEM INCLUDING A FALLOW PHASE (CF) | SYLVOPASTORAL (SP) | YOUNG AGROFOREST (YA) | HOME GARDEN (HG) | FOREST GARDEN (FG) |
|---|---|---|---|---|---|
| ***Tetum/tetum terik name*** | *To'os muda muda, to'os udan, to'os la permanenti, to'os foun* | *Ai bobur laran, ai loek laran, tree's name-laran (main tree and/or functional tree), pastagem* | *To'os tuan, quintal foun, to'os posa, posalaki…* | *To'os uma hun, to'os uma oin, quintal* | *Abat* |
| **Species characteristics** | | | | | |
| Density of trees inside the plot (low, medium, high) | Low | Medium | Medium-Low | Medium-High | High |
| Main crops and animal husbandry | Corn, peanut, sweet potatoes, cucurbitaceae, beans, horses, buffalo, goats and sheep | Horses, cows, buffalo, goats and sheep | Chili, papaya, condiment, vegetable, banana | Corn, cassava, taro, yam, vegetable, condiment, banana, bamboo, papaya cucurbitaceae, beans, chili, pigs and chicken. | Yam, condiment |
| Main trees planted | Candlenut, Coconut, Teak, *Gmelina* | Teak | Teak, *Swietenia mahagoni* , *Gmelina* , Coconut, Citrus, *Gliricidia* | Citrus, Coconut, Breadfruit, Mango, Candlenut, Teak, *Gmelina* , Goyava | Palm (betel, coconut), Mango, Breadfruit, *Gmelina* , Teak, Candlenut |
| Main trees not planted | *Eucalyptus alba* , *Timonius* , Rosewood, Tamarind, Kussum tree, *Ziziphus mauritiana* , *Albizia julibrissim* , *Corypha* | *Eucalyptus alba* and *Timonius* , Rosewood, Tamarind, Kussum tree, *Ziziphus mauritiana, Delonix regia, Sesbania grandiflora, Leucaena leucocephala, Albizia julibrissim* , Sandalwood, Palm (*Borassus* , *Corypha* ) | *Timonius* , Kussum tree, Rosewood (Samalari), Palm (*Borassus* , *Corypha* ), *Sesbania grandiflora* , *Leucaena leucocephala* | Palm (*Borassus* , *Corypha* ), Kussum tree, Custard apple, *Leucaena leucocephala* , *Sesbania grandiflora* , Tamarind, Wild candlenut, Cotton tree | *Arenga* , *Corypha* , *Borassus* |
| **Social land use regulation** | | | | | |
| Land ownership | Household | *Knua* | Household | Household | *Knua* or household |
| Labour | Household or Exchange of services (neighbours, relatives…) | No specific labour | Household | Household | No specific labour |
| Resources ownership | Household or exchange services (neighbours, relatives…) | Common and *knua* (tree trunk) | Household | Household | *Knua* or household |
| Main use | Food for self-consumption, animal food, economic income | Animal food, construction, firewood, traditional medicine | Economic income, firewood, land securization | Food for self-consumption, economic income, animal food | Construction, firewood, traditional medicine, food for self-consumption, economic income, land securization |
| **Infrastructure** | | | | | |
| Water availability | Raining season | Raining season | All year or only raining season | All year | All year or only raining season |
| Fence/Hedgerow | Depend | No | Depend | Depend | No |
| **History track** | | | | | |
| Date of installation (crop and/or livestock system) | 0 to 3 years | > 50 years | 2 to 10 years | > 5 years | > 50 years |
| Precedent crop system | Sylvopastoral land (pasture, savana or secondary forest), Forest garden | Savana, forest | Crop system including a fallow phase, Sylvopastoral land (pasture, savana or secondary forest), Forest garden | Crop system including a fallow phase, Young agroforest | Home garden, young agroforest |

## III.3. Case studies in the *sucos of* Gariuai and Samalari:

In this section, we describe how the 5 AFS identified among the district of Baucau were perceived by inhabitants and which functions they fill. We chose to characterise their socio-economic functions through 2 *aldeas* case studies (Osso Luga and Cairiri).

### III.3.a. Case study in the village of Osso Luga

During the scoring exercise (PDM), we identified and used similar functions (or categories of use) as for the inventories in February 2021 (Annex 3). In addition, we compared in Figure 6 their importance regarding household needs, including the importance of other agriculture practices (i.e., horticulture and rice).

For example, according to villagers participating in the PDM exercise, the "sylvopastoral" areas generally contribute the most to four categories of use: feed, construction, medicine, and firewood. "Crop and fallow" area is important as a source of income and feed. "Young agroforests" are important for self-consumption and "home gardens" for self-consumption and as a source of income. "Forest gardens" are important for construction (with sylvopastoral areas), firewood and medicine. "Horticulture" is important for self-consumption and as a source of income. Rice importance is low for any of these use categories because its development has been limited to the riverside (see the participatory mapping).

But the functions were scored for the same time of the year also because PDM only allows us to get general information from a small group of participants (see the method section, on scoring exercises). An analysis of the importance of each AFS for the different categories of use and according to the different seasons in the year would require more in-depth interviews.

The participatory mapping activities were based on local perceptions and allowed us to understand better the repartitions of the different land uses (Figure 7). Finally, we conducted ground-truthing for some of the features on the map to verify the location of these land uses.

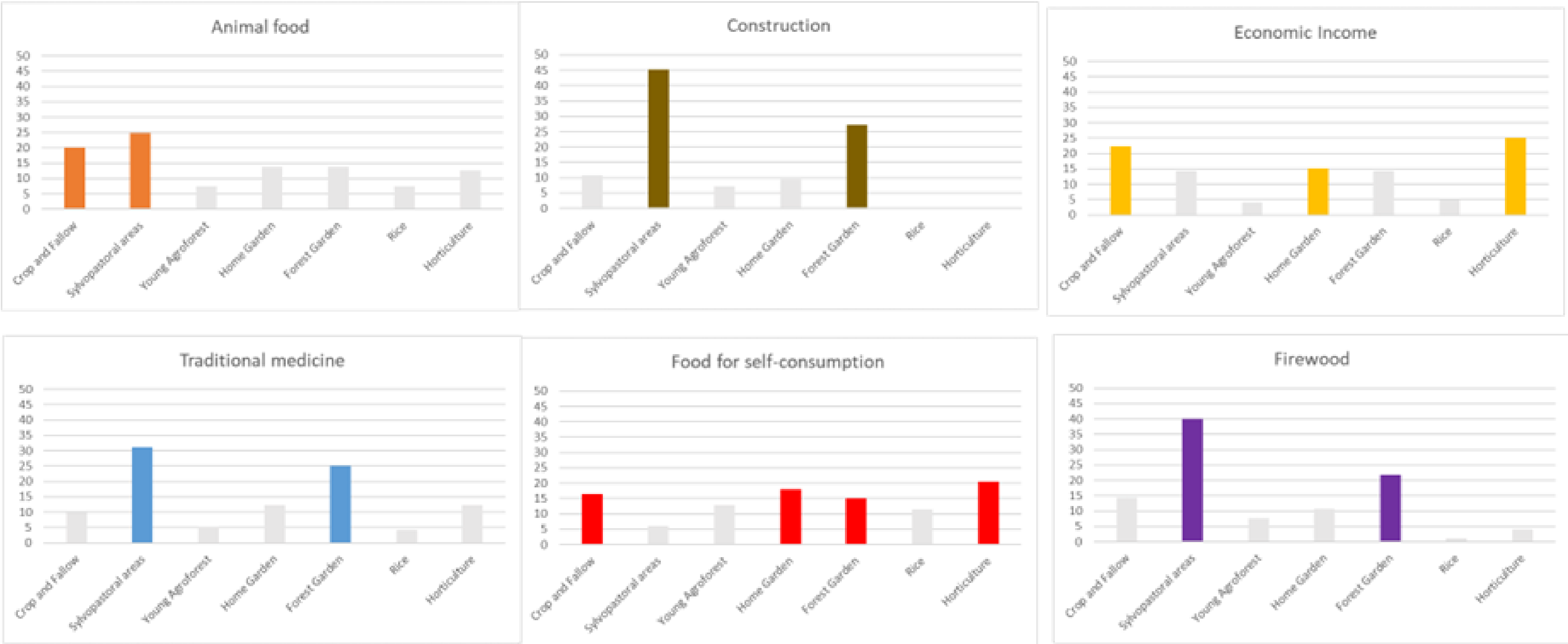
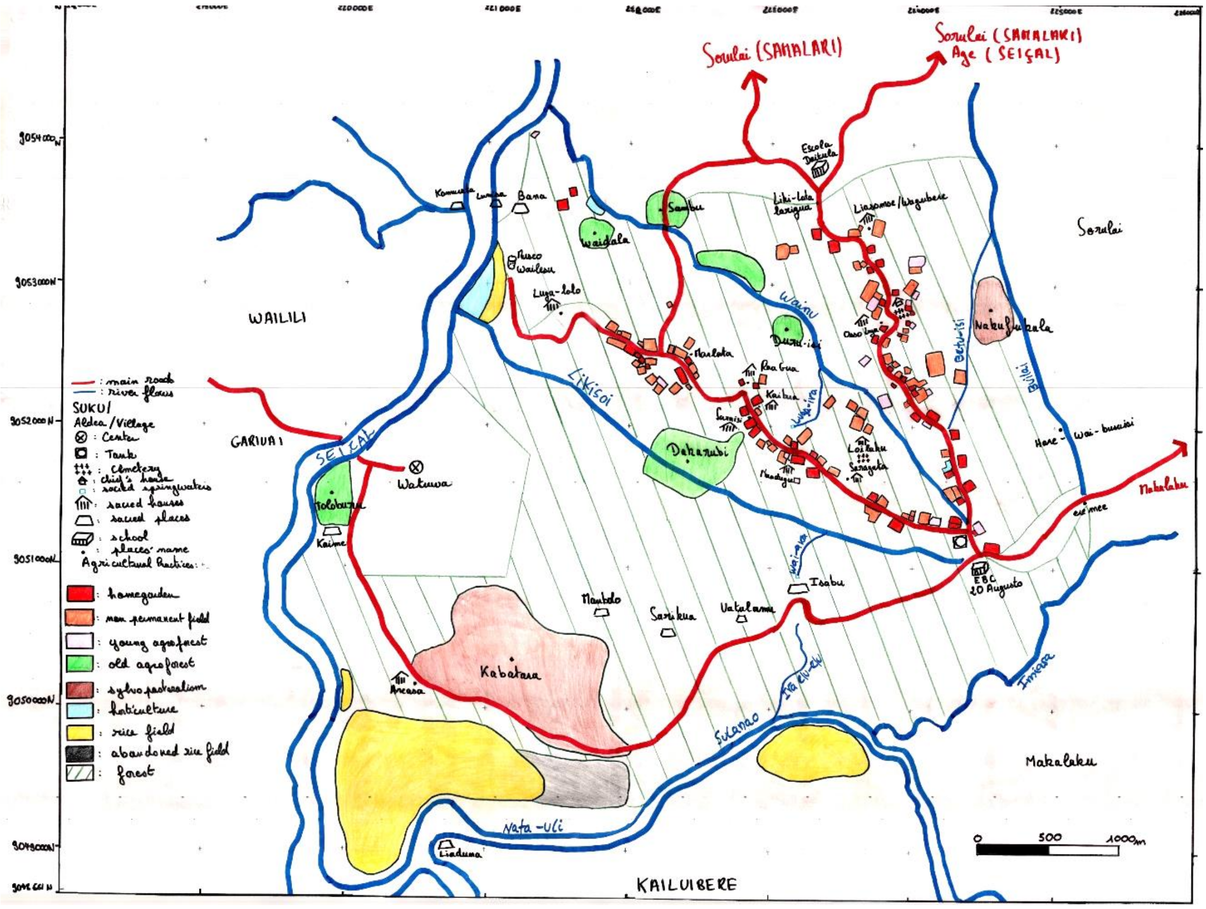



*Figure 6: Importance of the different AFS according to different categories of use according to local perceptions (Source: R.Martin, 2021)*

Osso Luga is a village from the mountain, which experienced the displacement of its population during the Indonesian occupation. The road that crosses the village from North to South began to be rehabilitated after the independence. A new road was built there from South-West to South-East in 2017. The village was rebuilt in 2005. It has limited access to irrigation during the dry season (July to October), with water points located higher in the mountains allowing water to be channelled into reservoirs.




| Légende | Langue locale (Tetun) | Anglais | Français |
|---|---|---|---|
| | Toos uma hun | Homegarden | Jardin de case |
| | Toos kuda no husik | Crop and fallow/ Non permanent field | Système cultural avec une phase de friche |
| | Toos joven | Young agroforest | Jeune agroforêt |
| | Fatin pastagem | Sylvopastoralism | Sylvopastoralisme |
| | Abat laran | Old agroforest | Vieille Agroforêt |
| | Horticultura | Horticulture | Horticulture |
| | Natar | Rice field | Rizière |
| | Natar abandonado | Abandoned rice field | Rizière abandonee |

| Légende | Langue locale (Tetun) | Anglais | Français |
|---|---|---|---|
| Aldea, SUKU | Aldea, SUKU | Village, Groupment of villages | Village, Groupement de villages |
| | Dalan | Road | Route |
| | Mota | River flows | Cours d'eau |
| | Centrum | Center | Centre |
| | Tanki | Tank | Réservoir |
| | Uma Xefe | Chief's house | Maison du chef |
| | Eskola | School | Ecole |
| | Rete | Cemetery | Cimetière |
| | Uma adat | Sacred house | Maisons sacrées |
| | Fatin lulik | Sacred places | Endroits sacrés |
| | Fatin naran | Places name | Nom des endroits |

*Figure 7: Participatory map of Osso Luga: a mountainous village abandoned during Indonesian occupation (source: R.Martin, 2021)*

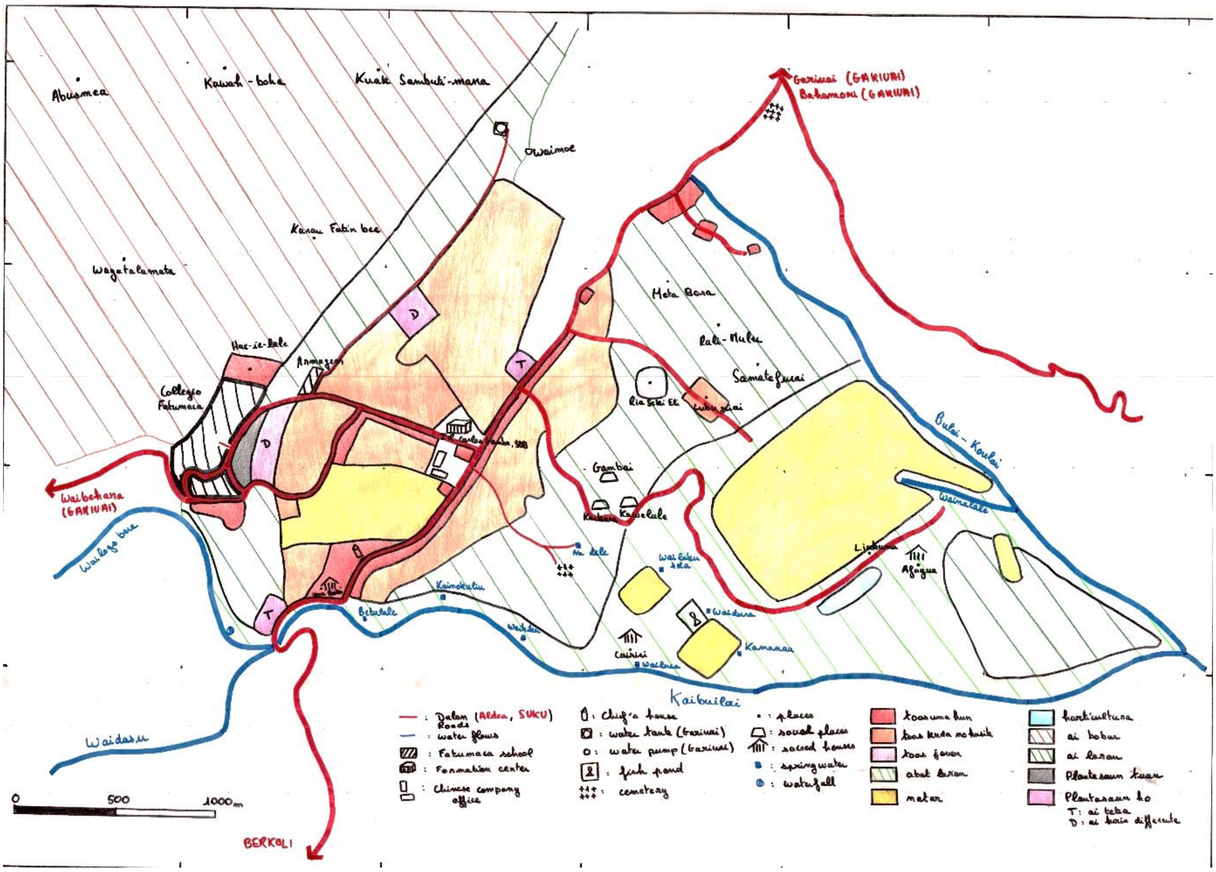
The map (Figure 7) shows the five different AFS and their location in the village's territory. It presents other agricultural systems, i.e., rice fields, abandoned rice fields, and horticulture. It also displays essential features in the landscape, such as settlement, water bodies, roads, sacred places, and their toponymy. Old agroforests and rice fields are located near the rivers and settlements, home gardens, crop and fallows and young agroforests are alongside the road. Rice fields near the rivers can become horticultural systems during the dry season.

The sylvopastoral areas are shared between pasture (with a dominance of grass) and forest (with a dominance of trees that grew back from abandoned fields during the Indonesian occupation). They are occupying most of the space on the map.

## III.3.b. Case study in the village of Cairiri

In Cairiri, villagers were not displaced during the Indonesian occupation, but new families were established during that time. Road and irrigation have been present for several decades. The villagers have regular access to a source of water during the rainy and dry seasons. The same types of AFS and other agricultural systems can be found in Cairiri, as in Osso Luga. Other types of systems have also been identified on the map (Figure 8), such as mono-plantations of teak, and pluri-specific plantations carried out by the church and the government that do not follow the same features as in forest gardens (i.e. "abat laran").

"Crop and fallow" systems take an important part of the *aldea* area, which can be explained by the access and use of tractors in Cairiri. *Eucalyptus* forests (in sylvopastoral areas) are also important in the village territory, as well as forest gardens located close to the rice fields. On the contrary, young agroforests are among the least represented systems.



| Légende | Langue locale (Tetun) | Anglais | Français |
|---|---|---|---|
| | Toos uma hun | Homegarden | Jardin de case |
| | Toos kuda no husik | Crop and fallow/ Non permanent field | Système cultural avec une phase de friche |
| | Toos joven | Young agroforest | Jeune agroforêt |
| | Abat laran | Old agroforest | Vieille Agroforêt |
| | Natar | Rice field | Rizière |
| | Horticultura | Horticulture | Horticulture |
| | Ai bobur | Eucalyptus forest | Forêt d'eucalyptus |
| | Ai laran | Secondary forest | Forêt secondaire |
| | Plantasaun tuan | Old plantation | Vieille plantation |
| | Plantasaun ho<br>T : ai teka<br>D : ai horis differente | Plantation with<br>T: teak<br>D : different kind of trees | Plantation avec :<br>T : Thèque<br>D : different types d'arbres |

| Légende | Langue locale (Tetun) | Anglais | Français |
|---|---|---|---|
| | Dalan (Aldea, SUKU) | Road (Village, Groupment of villages) | Route ((Village, Groupement de villages) |
| | Mota | River flows | Cours d'eau |
| | Fatumaka escola | Fatumaka school | Ecole de Fatumaka |
| | Sentru Formasiaun | Formation center | Centre de formation |
| | Xinés sede | Chinese company office | Quartier general d'une entreprise chinoise |
| | Uma Xefe | Chief's house | Maison du chef |
| | Tanki | Tank | Réservoir |
| | Bomba bee | Water pump | Pompe à eau |
| | Kolam ikan | Fish pond | Etang de poissons |
| | Rete | Cemetery | Cimetière |
| | Fatin naran | Places name | Nom des endroits |
| | Uma adat | Sacred house | Maisons sacrées |
| | Fatin lulik | Sacred places | Endroits sacrés |
| | Bee matan | Springwater | Sources d'eau |
| | Cascata | Waterfall | Chute d'eau |

*Figure 8:Participatory map of Cairiri : Baucau plateau village inhabited for several centuries. (Source: R.Martin, 2021)*

# III.4. AFS association of crop and livestock systems inside the farming system

In the previous sections, we learned about the distribution and general functions of AFS especially in two villages (case study), which are representative of the historical and geomorphological characteristics of Baucau region. In this section, we chose to focus on the interactions between AFS and technical combination of trees, crops and livestock within the systems.

## III.4.a. General management of farming activities

Figure 9 represents the different farming activities in the study zone. A family (i.e., a household that can integrate several generations under one roof as an "extended family") can associate all these activities inside its farming system or only a part of it. The "minimum survival farming system" is to associate a home garden (HG), a crop and fallow field (CF) and have access to a Forest Garden and/or a sylvopastoral area. The size of the crops and livestock systems can also vary significantly from one farm to another.

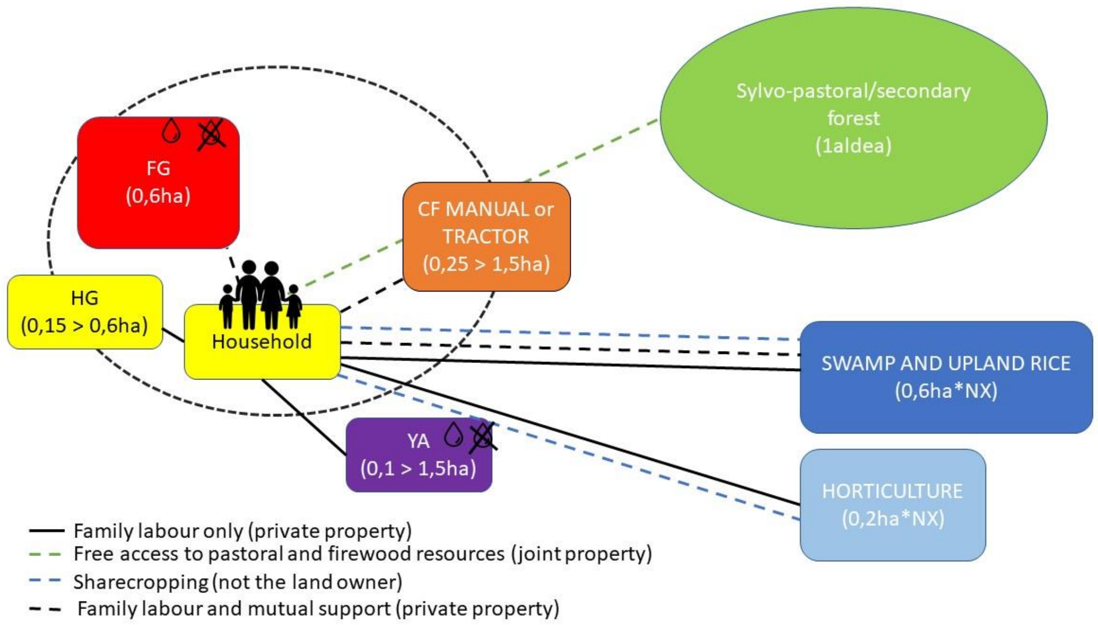



*Figure 9: Labour and land ownership in AFS. (Source: Analysis of J. Dos Santos, B. Fernandes and M. Cogné data, 2022).*

The figure 9 illustrates the different types of ownership associated with the various farming areas. Ownership status greatly influences the development of the different AFS: the family can own the land, the family can share the resources in a share-cropping system, or the family can share the labour with other families.

These crop and livestock systems also depend on other factors, such as: access to water for irrigation during the dry season, fuel mechanization, access to the main road connecting the district places, transport of marketable products and access to a non-farm source of income (e.g., external job, remittance, veteran pension).

Moreover, the farming system depends not only on these factors but also on the strategic repartition of farming activities within the seasons and throughout the years.

### III.4.b. Farming activity schedule: similarities and differences between agroforestry systems:

We present here three typical agroforestry calendars that differ significantly in their integration of crop and livestock systems together and the labour invested:

- Crop and Fallow system using only manual labour (Figure 10)
- Home garden system with access to water during the dry season (Figure 11, 12, 13, 14)
- Forest garden system with access to water during the dry season (Figure 15)

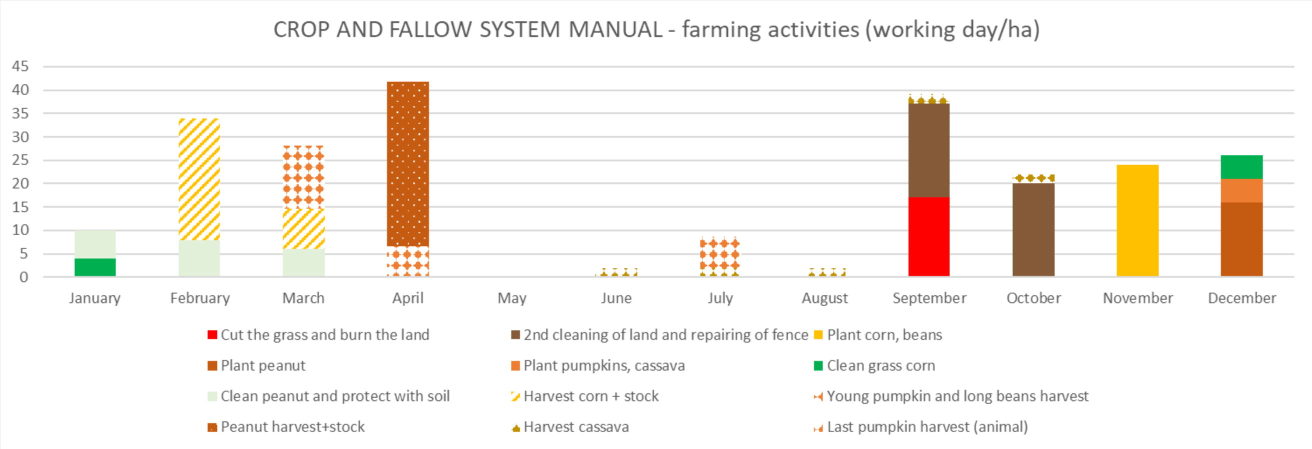



*Figure 10: Labour requirement for a Crop and Fallow system (CF) using only manual labour during a crop year. (Source: Analysis of B. Fernandes and M.Cogné data, 2022)*

The total hours spent have been calculated as around 238 hours/ha/year. They include mostly family labour and sometimes shared labour between families for the more intensive work, such as the harvest of corn and peanut and the preparation of the land (i.e., fencing, weeding, tilling).

The minimum number of people needed is two persons/ha. The peak of activities is during September (preparation of the field), February (first corn harvest) and April (peanut harvest). The labour decreases consequently from May to August.

Although most of the work is associated with corn and peanut cultivation, other products such as cassava, pumpkins, and beans can be considered in the system. In addition, during the dry season (from end of July until September), most of the crops have been already harvested. It allows the farmer to let animals (cows, horses, goats) feed themselves with post-harvest products and other grasses that start to regrow spontaneously inside the AFS.

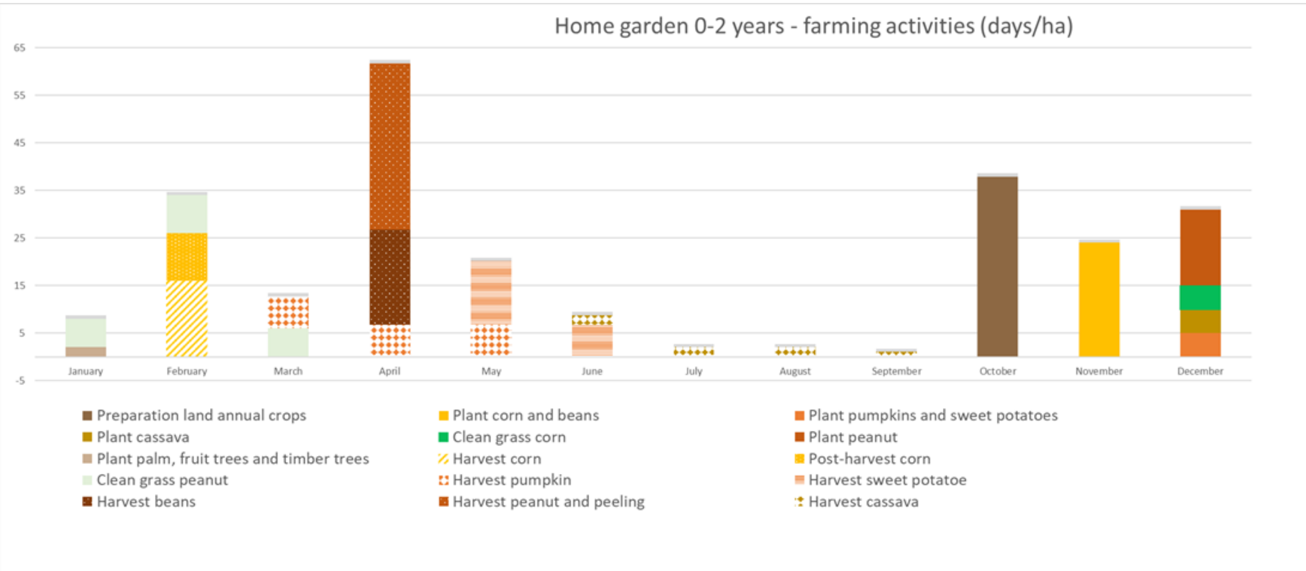



*Figure 11: Labour requirement for an HG system that has access to water during the dry season designed for 20 years: phase 0-2 years. (Source: Analysis of B. Fernandes and M.Cogné data, 2022)*

The two first years of a Home-Garden (HG) system (Figure 12) is similar to the CF system presented above (Figure 11). However, it integrates more crops (e.g., sweet potatoes), the planting of palm, fruit and timber trees, and the integration of small livestock farming. The preparation of the land can also be postponed to October.

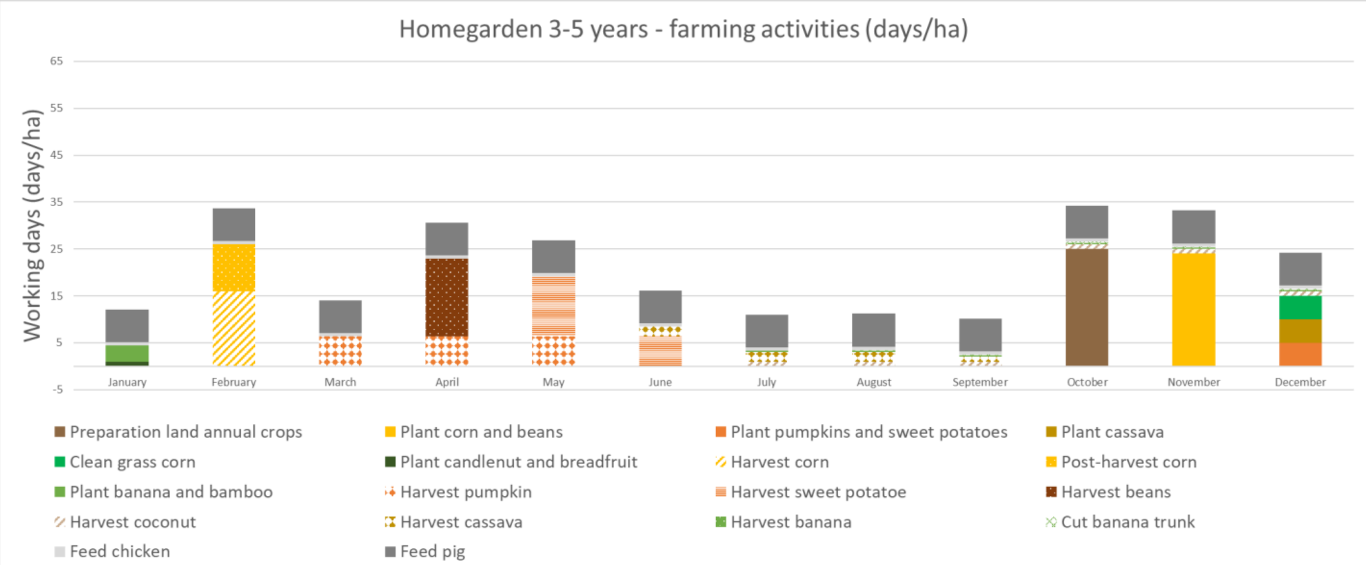



*Figure 12: Labour requirement for an HG system that has access to water during the dry season designed for 20 years: phase 3-5 years. (Source: Analysis of B. Fernandes and M.Cogné data, 2022).*

After the 3rd year (Figure 12), the farmer continues to plant various palms, trees and bamboos. Understory cash crops (e.g., banana) start to replace other crops that need the sun to grow (e.g., peanut) and can begin to be harvested six months after the first planting.

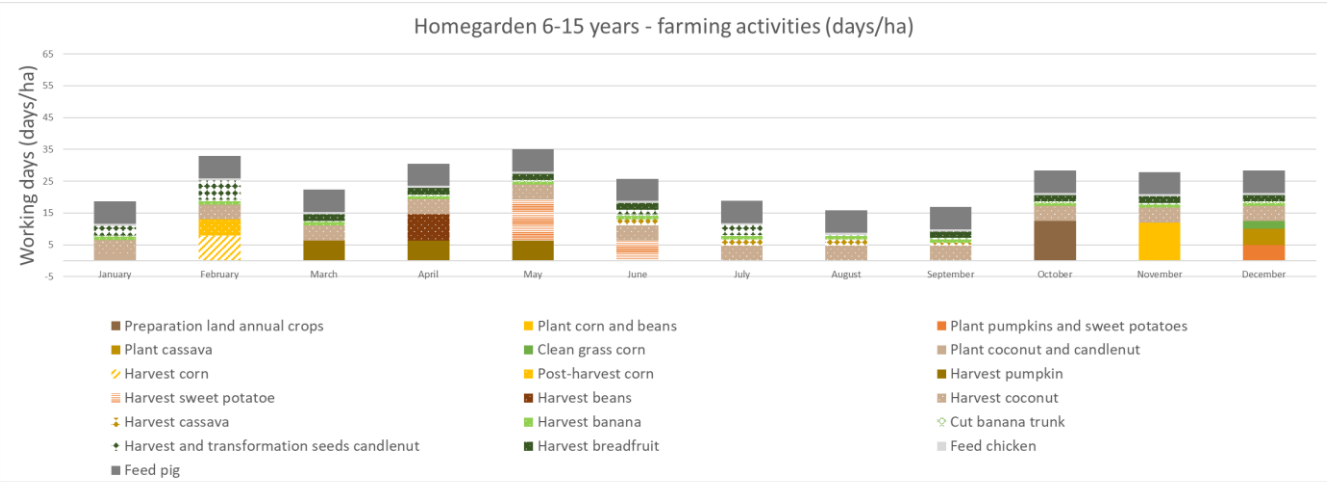



*Figure 13: Labour requirement for an HG system that has access to water during the dry season designed for 20 years: phase 6-15 years. (Source: Analysis of B. Fernandes and M. Cogné data, 2022)*

After the 5th year (Figure 13), annual labour for crops, such as corn and beans, decreases significantly because of the lack of sunlight as the trees are growing. This phase of the home garden is also the time to harvest the fruits from palms and trees planted during the 1st year (Figure 11). The farmer also continues to grow new seedlings of fruit trees and palm trees and will start to harvest them after five more years. In the model, we chose to show the planting and harvesting of coconut, candlenut, and breadfruit as they are the three main trees and palm trees planted by the farmer in Baucau, in areas with access to water. Another change during this phase of HG is that the family can also start to raise a couple of pigs and keep about four pigs all along the year to be fed with the farm's production.

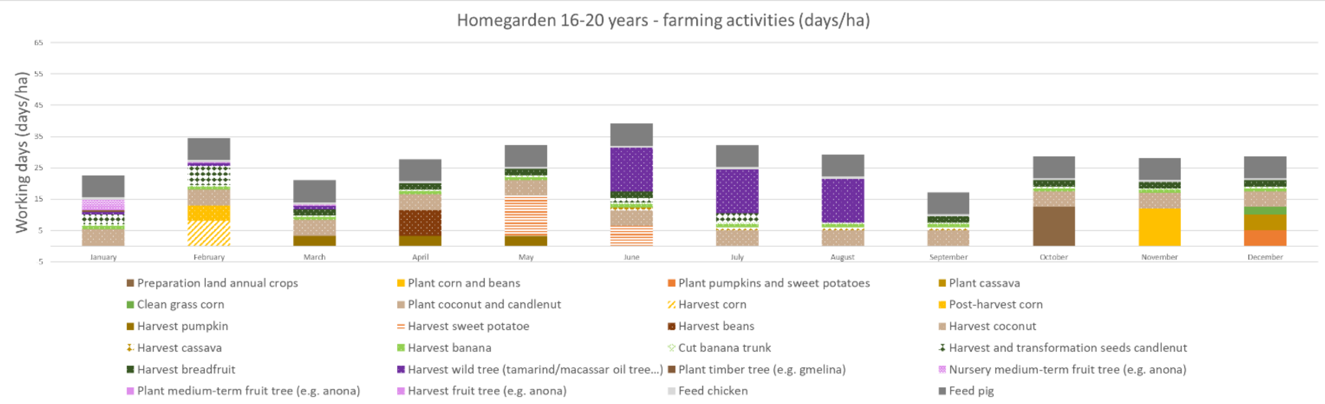


*Figure 14: Labour requirement for an HG system that has access to water during the dry season designed for 20 years: phase 16-20 years. (Source: Analysis of B. Fernandes and M.Cogné data, 2022)*

After more than 15 years, the trees have grown too big and generate too much shadow to plant annual crops (Figure 14). The farmer grows then other types of understory fruit trees (e.g., *Annona*) and collects valuable tree products (e.g., tamarind, Macassar oil tree) from the trees he/she did not cut previously.

When we compare these typical labour calendars, first, it is important to notice that all the work is provided by the family alone. We observe a gradual increase of this family labour (from 251 hours/year/ha to 341 hours/year/ha) and an evolution of the distribution of activities over the months. At the beginning, activities occur mainly during the rainy season until they get more balanced all along the year. Moreover, one ha of HG can be handled by one person during the first years, whereas it cannot after the 5th year.

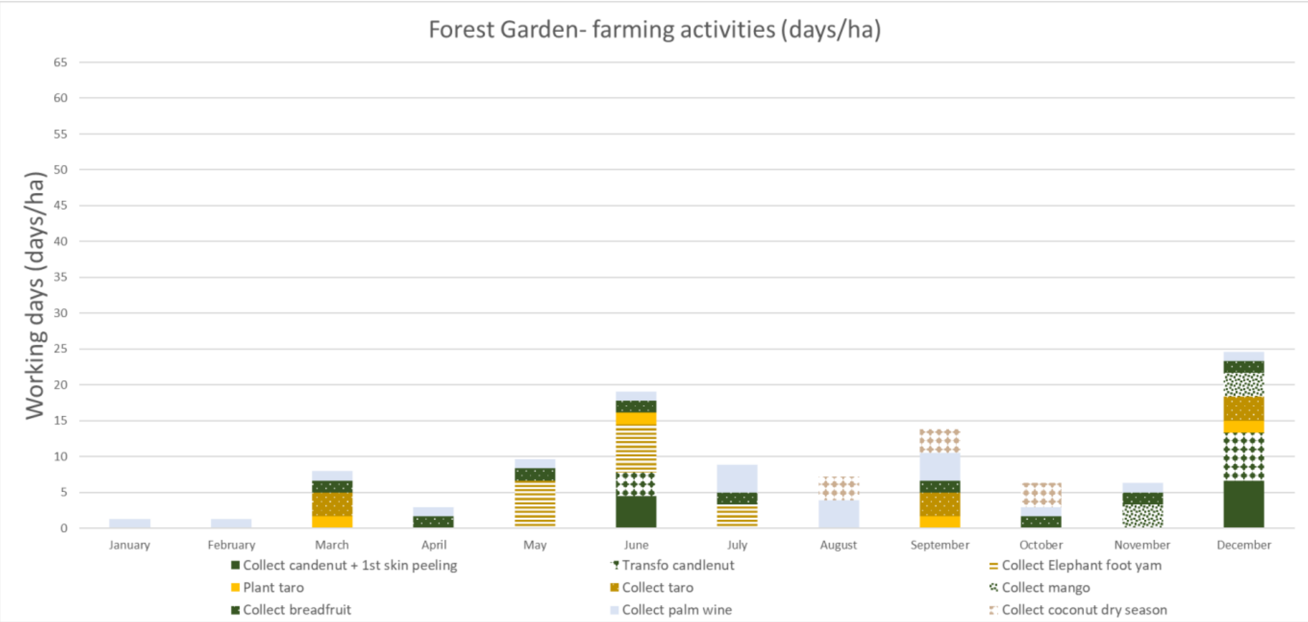


*Figure 15: Labour requirement for a Forest Garden specialising in palm wine. (Source: Analysis of B. Fernandes and M.Cogné data, 2022)*

In this model, we represent the calendar for a diversified forest garden (FG) that has access to water (Figure 15). The labour peaks are reached in December (25days/ha) and in June (19 days/ha). Thus, this type of system requires a minimum of 1 person per ha to work. The rest of the labour is distributed throughout the year with a minimum time spent in the forest garden during the rainiest months (January, February and April). The time allocated to this system is mainly spent on elephant foot yam collect as well as candlenut harvest and transformation.

Finally, we can draw several observations from these three AFS models:

- There is a diversity of farming activities (e.g., crops, livestock, trees management) between and within the systems over time.
- Labour calendars are complementary as the peaks of labour are not spread equally throughout the year. It allows a household to handle all these activities in a certain area.
- The complexity of the work (i.e., with a multiplication of tasks) increases with the number of trees planted, but the working time decreases (e.g., from a peak of more than 55 hours/month in CF to a peak of less than 40 hours/month in HG).
- More trees planted make it possible to secure an income all along the year: the harvest does not only happen at the end of the rainy season but also at the beginning and during the dry season.

## III.5. Economic calculation for 3 typical AFS: CF manual, HG and FG

In this section we model diverse economic returns for 3 typical AFS. The models reveal the contribution of different agricultural products to the overall gross margin of AFS and the dependence of these systems on external inputs. We also model variations in yields that can occur in the event of climatic changes and market accessibility. Finally, the models are analysed from a labour perspective to compare their productivity with other potential non-agricultural economic activities available in rural areas.

### III.5.a. Comparison of the gross product (GP) considering yield variations: example of CF manual system

The Gross Product/ha (GP/ha) of a typical Crop and Fallow system using only manual labour (CF manual) was calculated using the data collected during the interviews about the yields and prices for each product. Different GP were also calculated according to yield variations (Table 8).

*Table 8: Gross Product (GP) per production in CF manual system and differences of GP between typical year (white), "good year" with high yields (green)," bad year" with low yields (red). (Source: Analysis of B. Fernandes and M.Cogné data, 2022)*

| PRODUCT | QUANTITY (kg or unit) | SURFACE (ha) | YIELD (kg or unit/ha) | PRICE SOLD ON THE FIELD ($/kg or $/unit) | GROSS PRODUCT/HA ($/ha) |
|---|---|---|---|---|---|
| Corn mean prod (kg) | 400 | 0,5 | 800 | $ 0,53 | 426,7 |
| Corn low prod (kg) | 352 | 1 | 352 | $ 0,53 | 187,7 |
| Corn max prod (kg) | 1500 | 1 | 1500 | $ 0,53 | 800,0 |
| Peanut skin mean prod (kg) | 200 | 0,25 | 800,0 | $ 0,36 | 288,0 |
| Cassava low prod (unit) | 200 | 0,5 | 400 | $ 0,38 | 150,0 |
| Cassava high prod (unit) | 400 | 0,72 | 556 | $ 0,38 | 208,3 |
| Pumpkin low prod (unit) | 540 | 0,86 | 627,906977 | $ 0,25 | 157,0 |
| Pumpkin mean prod (unit) | 1800 | 1,4 | 1285,71429 | $ 0,25 | 321,4 |
| Pumpkin high prod (unit) | 1000 | 0,72 | 1388,88889 | $ 0,25 | 347,2 |
| Long beans mean prod (kg) | 240 | 1 | 240 | $ 2,00 | 480,0 |
| Long bean max prod (kg) | 420 | 1 | 420 | $ 2,00 | 840,0 |
| Long bean min prod (kg) | 80 | 1 | 80 | $ 2,00 | 160,0 |

*Notes: "peanut skin" is the quantity of peanut sold without taking out the pods*

In this design, farmers do not have any operational expenses, except the seeds they keep for the following year. We calculated their total expenses/year/ha as below (Table 9):

*Table 9:Total operation costs per year to gross 1ha of CF manual system. (Source: Analysis of B. Fernandes and M.Cogné data, 2022)*

| INPUT | QUANTITY (kg or unit)/ha | Price/ha |
|---|---|---|
| Corn seeds | 80 | $ 43 |
| Cassava seeds | 100 | $ 38 |
| Long beans seeds | 5 | $ 10 |
| Peanut seeds | 150 | $ 54 |
| Pumpkin seeds | 64 | $ 16 |
| TOTAL | | **$ 160** |

*Notes: operational costs in Table 9 can increase if the farmer needs to pay workers to provide short-term services.*

In the end, the total Gross Margin/ha (GM/ha) that farmers can reach from this system is:
GM(min) = GPmin-INPUT = 943-160 = 783 $/ha
GM(max) = GPmax-INPUT = 2484-160 = 2324 $/ha

### III.5.b. Comparison of gross margins (GM) between CF, HG and FG

The gross margin/ha/year and the intensification rate (%) of the other typical systems described in part III.4.b has been calculated and reported in the Table 10.

*Table 10:Total Gross Product (GP), Operating costs and Gross Margin (GM) per designed system. (Source: Analysis of B. Fernandes and M.Cogné data, 2022)*

| AFS | GP TOTAL ($/ha/year) | OPERATING COSTS ($/ha/year) | GROSS MARGIN ($/ha/year) | INTENSIFICATION RATE (%) |
|---|---|---|---|---|
| HG 0-2 YEARS | 3949 | 351 | 3598 | 10 |
| HG 3-5 YEARS | 4376 | 505 | 3871 | 13 |
| HG 6-15 YEARS | 9141 | 4348 | 4793 | 91 |
| HG 16-20 YEARS | 6004 | 2452 | 3552 | 69 |
| FG NORMAL YEAR | 1759 | 0 | 1759 | 0 |
| CF NORMAL YEAR | 1816 | 160 | 1656 | 10 |
| FG BAD YEAR | 1727 | 0 | 1727 | 0 |
| FG GOOD YEAR | 1987 | 0 | 1987 | 0 |
| FG POTENTIAL | 5094 | 0 | 5094 | 0 |
| CF BAD YEAR | 943 | 160 | 783 | 20 |
| CF GOOD YEAR | 2575 | 160 | 2415 | 7 |

*Notes: These results represent the total GP and GM per ha to represent the "land productivity". Thus, they need to be compared to the existing surfaces used by farmers (generally less than 0,5 ha per type of system).*

*Notes 2: In the calculation of GM for HGs (6-15years and 16-20years) the elephant foot yams that are collected in the forest gardens are considered as inputs to feed the pigs for 3 months (see labour requirements of FGs, Figure 15). On the other hand, elephant foot yams are considered as outputs in the FGs although they are not sold on the market.*

We notice first an increase in the home gardens' GM that reach a peak during the "mature period" between the 6th and the 15th year (i.e., from 3500$/ha/year to almost 5000$/ha/year). This is attributed to the complexification of the agroforestry system due to the plantation of more trees and crops, together with the raising of livestock over the years. Then the productivity per ha of this typical HG decreases slightly to reach a stable level around 3500$/ha/year when the farmer reduces farming activities, due to the farmer's age and the hardship of the labour.

In this design, FG reaches the second highest productivity per ha (i.e., from1700$/ha/year to 2000$/ha/year). In the calculation, we considered the quantity sold according to the farmers. Although, we also found out that more than half of tree and palm production are not collected. For comparison, we calculated the "potential" gross margin for a FG where all fruits and potential wine production would be sold. In this case, FG gross margin would reach the highest productivity value with a gross margin of more than 5000 $/ha/year.

Among all systems, CF manual has the lowest GM/ha/year result with about 1660 $/ha/year.

For most of the systems, the rate of intensification is low. It means they have a low dependency on inputs and are therefore resilient to input prices variation. However, intensification rate for HG systems from the 6th to the 20th year increases significantly. This is due to the rearing of pigs which require a substantial food input that cannot be provided only by the crops and trees from the HG system itself.

### III.5.c. Comparison of daily labour valorisation and opportunity costs

The daily labour valorisation ($/working day) was calculated for each modelled AFS. Table 11 compares these results with other "opportunity costs", e.g., other job salary standards available in Timor Leste.

*Table 11:daily labour valorisation compared with several other opportunity costs (Source: Analysis of B. Fernandes and M.Cogné data, 2022; RDTL, 2016)*

| AFS | Return to labour ($/working day) | Opportunity cost ($/day) | Statut |
|---|---|---|---|
| HG 0-2 YEARS | 14 | 5 | Road or farmer ober |
| HG 3-5 YEARS | 15 | Civil Servant - Junior | |
| HG 6-15 YEARS | 16 | 9 | D level |
| HG 16-20 YEARS | 10 | 11 | C level |
| FG NORMAL YEAR | 16 | 14 | B level |
| CF NORMAL YEAR | 7 | 18 | A level |
| FG BAD YEAR | 16 | Civil servant - Experienced | |
| FG GOOD YEAR | 18 | 10 | D level |
| FG POTENTIAL | 20 | 13 | C level |
| CF BAD YEAR | 3 | 18 | B level |
| CF GOOD YEAR | 10 | 24 | 1 level |

Table 11 shows that agroforestry systems have similar or higher return on labour than the usual salary for rural workers (5USD/day) and even several grades of civil servant salary.

However, we also observe that CF system is the least labour productive, and income return reaches the lowest rate during harsh years (low yields).

It is important to note that this calculation focuses on the production schedule, it does not include the time allocated to market.

Although the return on labour in agroforestry systems is relatively high in our calculation, the difficulty of the work is also high due to low mechanisation, hard climate conditions, clayish and steep soils. Moreover, the rise of population density and conflicts on land property (e.g., state and customary rules) result in limited land access for many farmers (i.e., often less than 1 ha for each type of AFS). And yet, secured land access is necessary to develop systems that involve planting trees and the permanent use of the land for decades.

## III.6. Distribution and allocation of gross margins at the AFS and the farming system level.

In this section, we take a typical HG system to illustrate the contribution of crop and livestock systems to the total gross margin (GM). Table 12 shows the evolution of these shares over time and as the production system changes.

*Table 12:Contribution of livestock and crop systems to the total GM of HG model. (Source: Analysis of B. Fernandes and M. Cogné data, 2022; RDTL, 2016)*

| HG PHASE | %GM LIVESTOCK | %GM TREES AND CROPS |
|---|---|---|
| 0-2 YEARS | 4 | 96 |
| 3-5 YEARS | 11 | 89 |
| 6-15 YEARS | 34 | 66 |
| 16-20 YEARS | 23 | 77 |

Over the years, the home garden system becomes more complex, diversified, and the share of the gross margin provided by the livestock system becomes more important. The diversification depends on the interaction between the different systems, as illustrated in Figure 16 below.

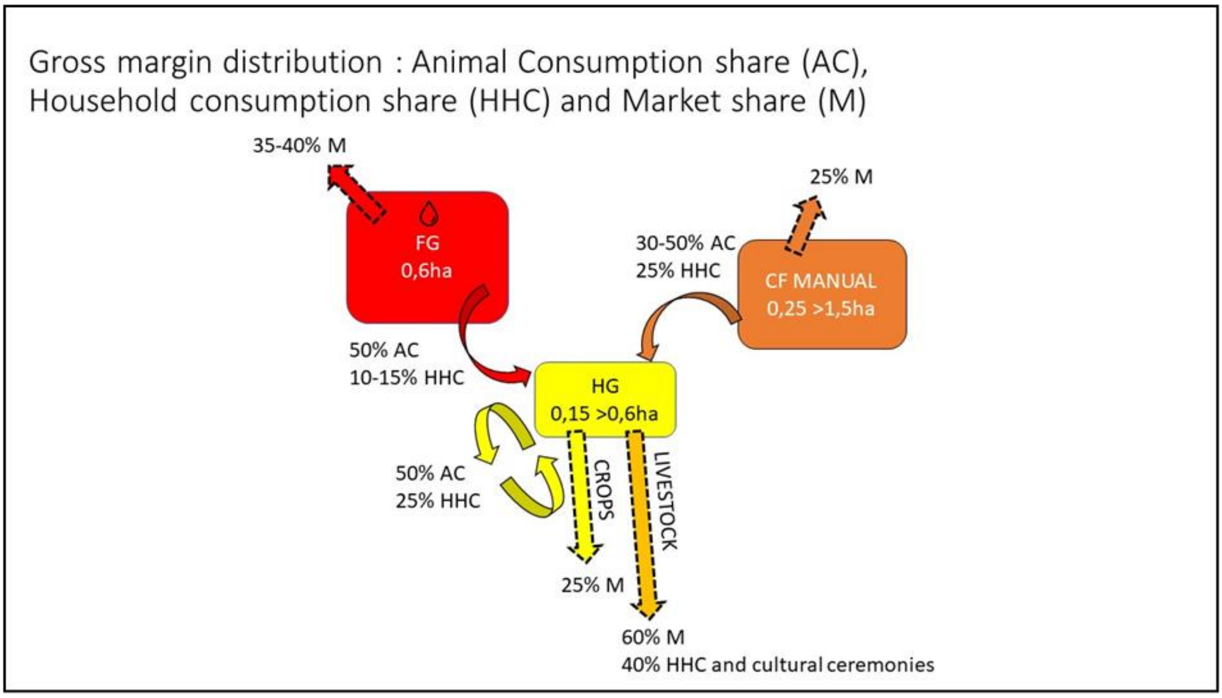



*Figure 16: production exchanges between AFS. (Source: Analysis of B. Fernandes and M.Cogné data, 2022; RDTL, 2016, see Annex 7)*

The share of livestock consumption, household consumption and market selling was calculated based on information collected during interviews and illustrated in Figure 16.

When the home garden is "mature" (i.e., between 6 and 16 years old), 75% of the crops produced are redistributed to the animals (i.e., 50%) and the household (i.e., 25%). Only 25% is sold to the market (more data on the part sold to the market is available in annex 7). The main farmers' priority is, therefore, self-consumption for better resilience. This closed loop (see the yellow arrow in Figure 16) enables farmer to invest in the livestock system (i.e., feed), from which a significant share will be sold (i.e., 60%) or used for household consumption and ceremonies (i.e., 40%). Although the livestock system is « less productive » than the crop system in terms of GM (see Table 12), it contributes significantly to the total income of the household providing near 1000$/ha/year while 25% of crops share provides 785$/ha/year (see Annex 4 and 5).

However, this livestock system associated with the HG would not be possible if it was not supported by the crops produced from the same HG and other associated AFS (e.g., FG and CF systems) in the same farming system. The two crop/livestock systems are linked to each other in HG system and with the FG and CF systems.

The interaction between the AFS systems enables Timorese farmers from our sample to reduce significantly the financial capital invested in their farming system and make them rely more on family labour. Each system contributed to a minimum of 15 to 25% of their total GM to household consumption, which allowed them to reduce their expenses in purchasing food.

The calculation of the FG GM in the hypothetical case all products are sold resulted in an increase of more than twice the value of the typical GM (5000$/ha/year vs 2000$/ha/year in the best case today). This suggests the high potential for strengthening and developing agroforestry value chains if all the products could be marketed. Indeed, the production waste or underused (more than 50%) due to the lack of market and conservation means is a key issue that needs to be addressed in order to promote agroforestry production.

## III.7. AFS prospective evolution using Ocelet model

In 2021, R. Martin proposed a possible evolution of the repartition of AFS in the village of Osso Luga for 50 years using the software Ocelet (Degenne, 2016, Martin, 2021). In the model, he took into account different probabilities such as i) the transition between agroforestry and non-agroforestry systems analysed in previous studies, ii) the number of people in a household, their age and the probability of transmission from the parents to their heirs, iii) the topo-geography and infrastructure features (e.g., proximity to the road, distance to sacred place) and iv) the climatic events (e.g., strong wind, flood). The results are shown in the model below Figure 17:

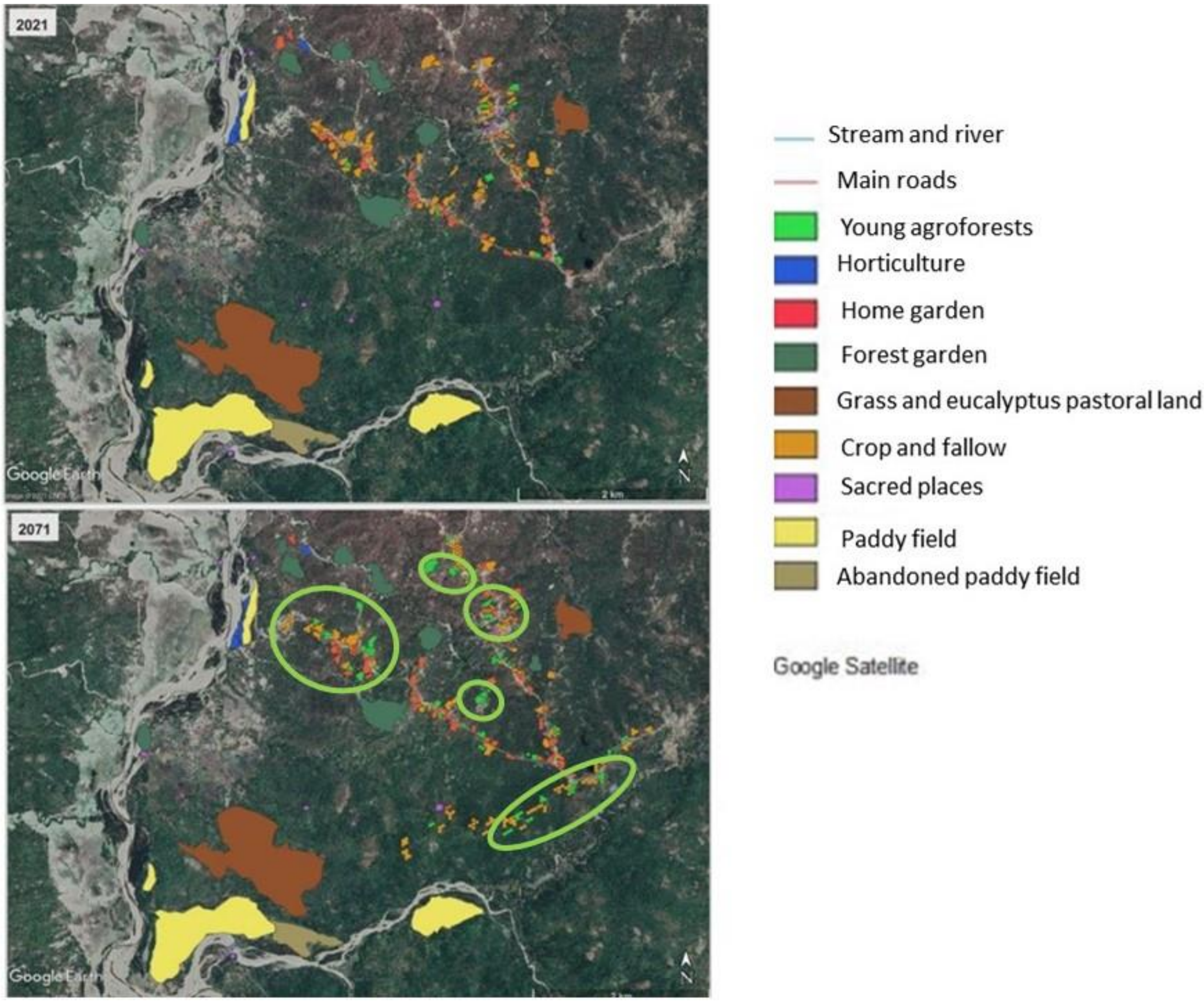



*Figure 17: evolution of AFS and other agricultural areas in Osso Luga village designed over 50 years. (Source: R. Martin, 2021)*

The model shows an increase of farm field closed to the new road (i.e., the road crossing south-west to south-east on Figure 17). In particular, there is a significant increase in young agroforests (YA) over the 50 years compared to the other modelled AFS (see green circle on Figure 17).

# IV. Discussion

## IV.1. Economical resilience of AFS

The diversity of products extracted from AFS systems contributes to households' food security because a great part of the gross margin is allocated to self-consumption (Figure 16). It also contributes to other needs. AFS can generate incomes for the households, wood for fuel and construction, and animal feed. Because the AFS do not rely on one function only, they are resilient to economic variations. Therefore, any action that seeks to encourage farmers to reduce their share of production for self-consumption to increase their cash income must be done with caution so that it does not disrupt AFS balance.

Our models also suggest that labour productivity of AFS is higher than most other job opportunities, especially in rural areas. However, they rely on a greater hardship than other jobs, and they also highly depend on land ownership status. Non-farm activities can also be cumulated with other farming activities. Civil servants, such as teachers or extension officers (rank D, C and B), are often involved in farming activities. Their status usually enables them to raise their initial capital to invest in the farming system.

## IV.2. Resilience to environmental shock

In this section, we compare CF and FG systems' capacities to resist environmental shock (e.g., pest/drought/long raining season).

According to the interviews, farmers qualified a "good year" when the system is not attacked by any pests or impacted by any climate hazard, resulting in high yields. On the contrary, they qualified a "bad year" when the system is affected by one of these factors, resulting in a drop of the usual yields.

*Table 13:Comparison of Gross Margins (GM) variations between "normal", "good", and "bad" years for CF manual and diversified FG . (Source: Analysis of B. Fernandes and M. Cogné data, 2022)*

| AFS | GP TOTAL ($/ha/year) | OPERATING COSTS ($/ha/year) | GROSS MARGIN ($/ha/year) | DIFFERENCE BETWEEN GOOD AND BAD YEAR | COMPARISON TO NORMAL YEAR |
|---|---|---|---|---|---|
| FG BAD YEAR | 1727 | 0 | **1727** | **260** | **-32** |
| FG GOOD YEAR | 1987 | 0 | **1987** | | **228** |
| CF BAD YEAR | 943 | 160 | **783** | **1633** | **-873** |
| CF GOOD YEAR | 2575 | 160 | **2415** | | **759** |

*Notes: As most Timorese farmers, the farmer in this design does not have access to chemical inputs such as fertilisers and pesticides.*

Table 13 suggests that the gap between a "bad" and a "good" year is much smaller for the FG system than for CF manual system. On the other hand, when the field is neither attacked by pests nor constrained by climatic events, the CF manual system shows better productivity than FG. These results mean that the farmer takes fewer risks with the FG systems, although the CF system have better potential to increase household incomes when the constraints of pests and climate change are lifted.

This comparison, combined with results from III.4.b suggests that households likely improve their capacity to cope with hazardous climatic events if a high diversity of species is cultivated in the same farm plot. They combine products ready to be harvested at different periods of the year and can maintain a small livestock system that allows them to secure a source of income in case of unforeseen circumstances.

## IV.3. Transformation of AFS over time:

Our results suggest that agroforestry systems are complex not only in their implementation (i.e., diversity of crop-livestock-tree plantation associations) but also in their evolution over time within a territory.

The purpose of Figure 18 is to show that AFS can be used in various sites inside one farming system. Meanwhile, they are also the result of a continuous transformation of the systems. This was illustrated with the evolution of the HG model for 20 years. FG is also the result of a system's transformation during more than 20 years, while CF and SP systems can be considered the "initial step" of all these systems.

HG and FG systems are not the final step of the agroforestry transformation. For example, the farmer's heirs can also change the AFS by thinning and planting new young trees (YA) or annuals crops (CF). If the HG system is not managed intensively, it can become a forest garden and/or a sylvopastoral area.

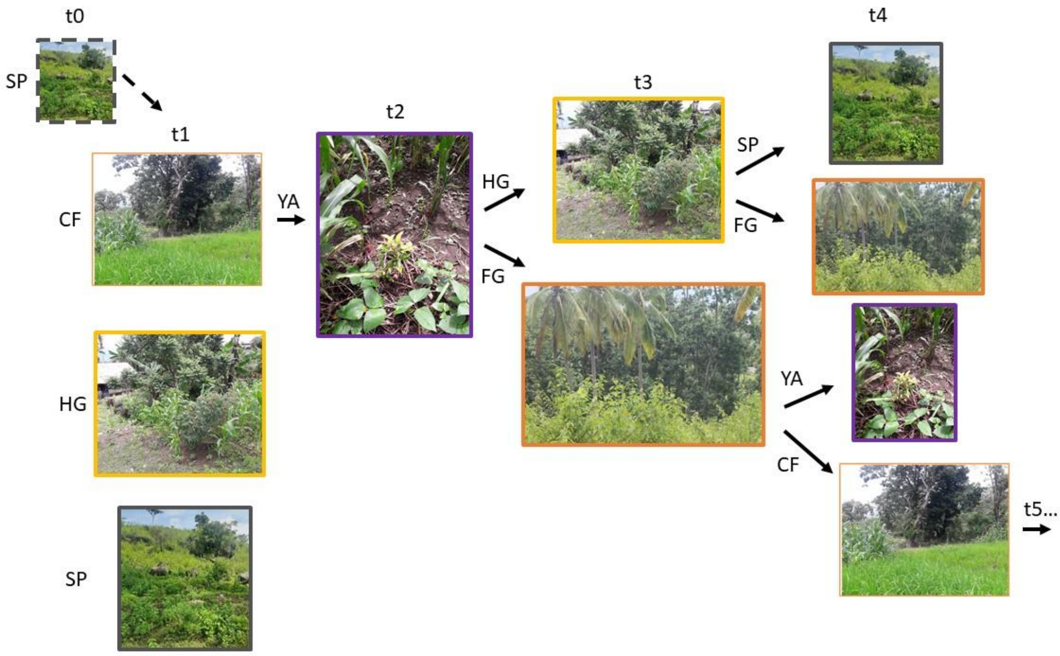



*Figure 18: example of AFS transition from one to another over more than 30 years (from t0 to t5). (Source: Analysis of B. Fernandes and M.Cogné data, 2022; RDTL, 2016)*

On a territorial scale, Ocelet model (Figure 17) illustrates the possible expansion of Osso Luga village on the new road crossing the map from southwest to northeast. It also shows the possible augmentation of young agroforests and other farming systems, because of the population growth and the construction of new road infrastructures.

# V. Perspectives and limit of the study

In the project sites, farmers have developed agroforestry systems well adapted to their harsh environment (i.e., steep mountains, hard clayish soils, heavy rains, and lack of water during several months of the year) to make them economically viable and sustainable. These AFS provide the farmers with regular income, food security, and a status in the village. Any project looking at transforming these AFS need to be careful not to disturb and change these balanced and complex agroforestry systems.

Scaling up to farming system analysis by combining AFS with other cropping and livestock systems, as presented in S. Mazin *et al* (2022), is essential to better understand the household strategies related to their types of farms.

Detailed economic descriptions using gross margin indicators are essential to understand the “gains and losses" and how they are linked to the different types of AFS. The different tasks during the year and the time allocated to them are also essential to target improvements in labour productivity and adapt farmers’ technical training to their schedule.

This study is based on the analysis of data collected during 2020 and 2021. For comparison, it should be reproduced in other villages and for other agroforestry, crop, and livestock systems. In addition, labour requirement and gross margins were calculated only for three typical systems: CF manual, diversified HG and FG. Other typical AFS (e.g., sylvopastoral, young agroforests, CF motorized, FG specialized) and non-AFS (e.g., dry and irrigated rice farming, horticulture, tree mono-plantation) should also be studied using the same approach and methods to widen the comparison and to be able to calculate the income of the whole farm.

Time for selling AFS products to the market should also be included into the labour requirement if farmers can sell directly their products to local markets or in towns. To improve the gross margins results, another survey should be included on tree and palm products used for fuel, housing construction and fence that are important “self-consumed income” in the household economy. The survey could be combined with direct field measures. In this study, limited time and human resources led us to reduce our survey to income and self-consumption of food products only (fruits, crops and animals).

Limited time and human resources also prevented us from proposing further analysis based on participatory mapping. The Ocelet model shows a possible evolution of the AFS in the project sites, but was limited to the type of data collected. It should be finetuned with more measurements, for example on the climate variability and the farmers’ coping strategies, or on the possible evolution of the land tenure system. This would help to develop a more accurate model of AFS evolution and distribution within the village territory in the future, by considering climate and land ownership factors. Ocelet model could also consider systems that were not the focus of this study, such as: rice fields and horticultural systems. The model could also be used for other villages, for comparison, and to better illustrate changes at the landscape level.

# VI. Conclusion

The five agroforestry systems presented in this report contribute to the household economy through their diverse functions. They represent a source of diversified income, nutritious food, and other needs (e.g., animal feed, construction materials, medicines, firewood). As a result, they become more complex as the households' needs also become more complex (i.e., increase of household members, diversification of the tree-crops-livestock combination for market activities and self-subsistence).

The diversity of income that AFS brings all over the year and the variation of labour requirements allow households to diversify their activities. Many households invest in their children's education, first at the district centre and then in Dili. Others can also save money and send a family member to England, Korea, or Australia to secure a monthly source of income from remittance. As a consequence, part of the heirs will not come back to the farm. However, an important part of the income gained in the city or abroad is generally sent to those who stay in the village and a part of what the villagers receive will be re-invested in farming activities. These results show that farming activities are part of the job cycle that offers education and job opportunities to households. According to our interviews, rural households support this diversity of activities for their heirs, although at least one of the sons should stay in the village to secure the land, as the inheritance of land is mostly passed on to sons.

It is also important to note that unsecured market (e.g., irregular buyers and price fluctuation), associated with low access to phytosanitary services and veterinary care, and climatic hazards, bring challenges to the sustainability of these systems.

Timorese agroforestry systems also have a heritage value for the conservation of valuable species and the transmission of knowledge and skills. This heritage value deserves to be better known, preserved and supported by consumers and governance bodies.

Our recommendation to state extensionists and organisational stakeholders (ministry, NGO and cooperative agencies) who wish to fulfil agroforestry project in Timor Leste are summarised in the Table 14.

*Table 14:Recomendations to state extensionists and institutions*

| Result/discussion | Technical recommendation | Institutional recommendation (Agroforestry Strategy) |
|---|---|---|
| **Farmer's knowledge of agroforestry systems** | Before proposing new agroforestry schemes, technicians need to have an **accurate understanding of the existing local/traditional agroforestry systems**. Such complex systems have often been in place for ages and they are usually adapted to local ecosystems, population's needs and local markets. The CIRAD typology [1] can serve as a base to communicate with farmers, although the technician still needs to understand how farmers describe and name their agroforestry system. Technicians could | Agroforestry strategy and innovation are smoothly and progressively incorporated into existing agroforestry systems (AFS) and land tenure systems in order to avoid conflicts, non-adoption of the systems, market risk and natural disaster. |

| | | |
|---|---|---|
| | then improve the current typology. | |
| **Six types of capital (land, labour, financial, social, cultural, natural) influence the households' capacity to implement AFS** | Six types of "capital" must be estimated to assess one household's possibilities to implement or amend AFSs:<br>• **Land tenure and labour arrangements** (i.e., private family property with or without mutual support, sharecropping, joint property)<br>• **Revenues and savings** (i.e., possibility to hire manpower or to invest)<br>• **Social network and kinship**<br>• **Cultural knowledge and technical know-how**<br>• Access to **natural resources** (e.g., water, biodiversity, trees, soils).<br><br>This should also inform the way AFS help (or not) to build resilience against shocks (for example: periods of drought, floods, cyclones, variations in the price of products, population migration) | |
| **Farmer's preferences about the species to be planted** | Before proposing new species or AF patterns to be planted by farmers, technicians should discuss with all relevant stakeholders at the *aldea* scale on (1) local priorities for AFS, (2) species the farmers would like to plant in each category of AFS, (3) objectives of the new plantations, and (4) markets and value chains for these products. | MAF (Ministry of Agriculture and Fisheries) and/or project manager should facilitate the selection of species to be planted, where, and according to what type of AFS. These development services should consider:<br>• The production objectives (for family self-consumption and/or income generation)<br>• The management of the farming system, including weed and pest control, animal feed requirements<br>• The existence of markets. |
| **Specific labour requirement spread over the year with different peaks of activity** | The technicians need to know the working calendars of each type of AFS present in the intervention zone to avoid periods of most intensive activity for farmers (e.g. December, February, April, August, September and October), in order to:<br>• Adapt the set-up of information meetings and training sessions<br>• Anticipate the set-up of nurseries<br>• Deliver seedlings at the most favourable times for planting e.g. January and/or March) | 1. Agroforestry project managers should facilitate the transport and distribution of seedlings through contracts with the local private sector. This will reduce the time and cost of the intermediate chain and favour local logistical resources.<br>2. The improvement of road infrastructures and the training and travel capacities of technicians are essential levers for running these |

| | | |
|---|---|---|
| | | operations. This will also contribute to the development of rural communes that are still isolated from urban centres. |
| **Importance of multi-scale analysis to identify development levers** | The technicians should consider different levels of analysis to detect development levers. Three important levels are identified:<br>• **Practices:** at the plot level (AFS)<br>• **Farmer strategy** in the overall economic activity of the household (interaction between the different agroforestry and non-agroforestry plots, off and non-farm activities)<br>• **Value chains** embedded in specific socio-environmental and economic conditions at the village and country level that allow production and sales.<br><br>*Note:* our research highlighted that a large part of the production is often not sold because there is no outlet. The problem does not lie at the practices level but rather at the value chain level. The technician could support farmers to find reliable outlets. | The government should facilitate the development of the sectors that drive agroforestry production:<br>• A diversity of organisations (e.g., producer organisations, private companies, cooperatives, producer unions)<br>• To promote and protect local products to enhance their consumption (e.g., Agroforestry Fair,2022).<br>• To facilitate wood sale legalization (taxes and professional fees are too high for small farmers) |

[1] AFS typology: see table 6

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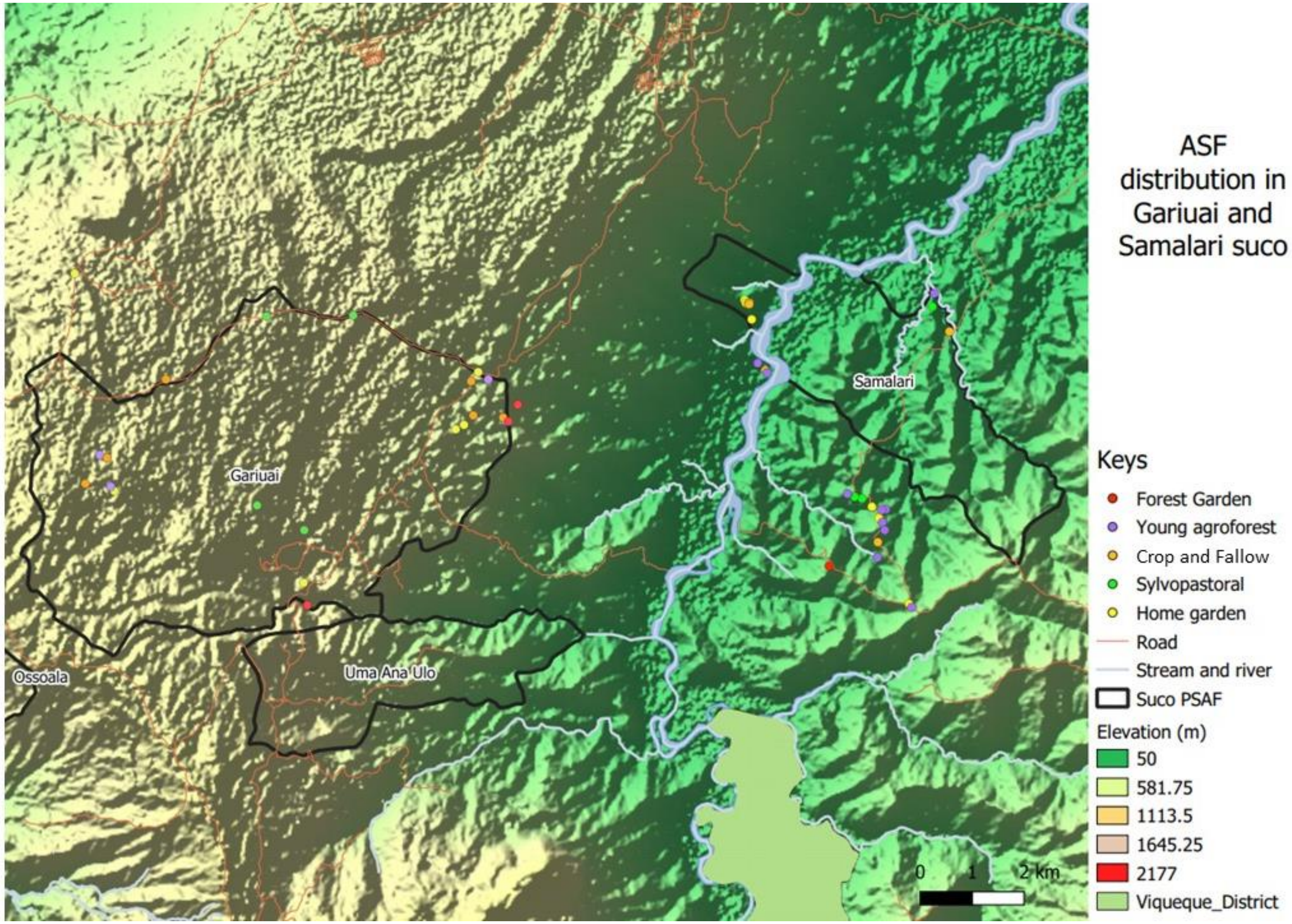
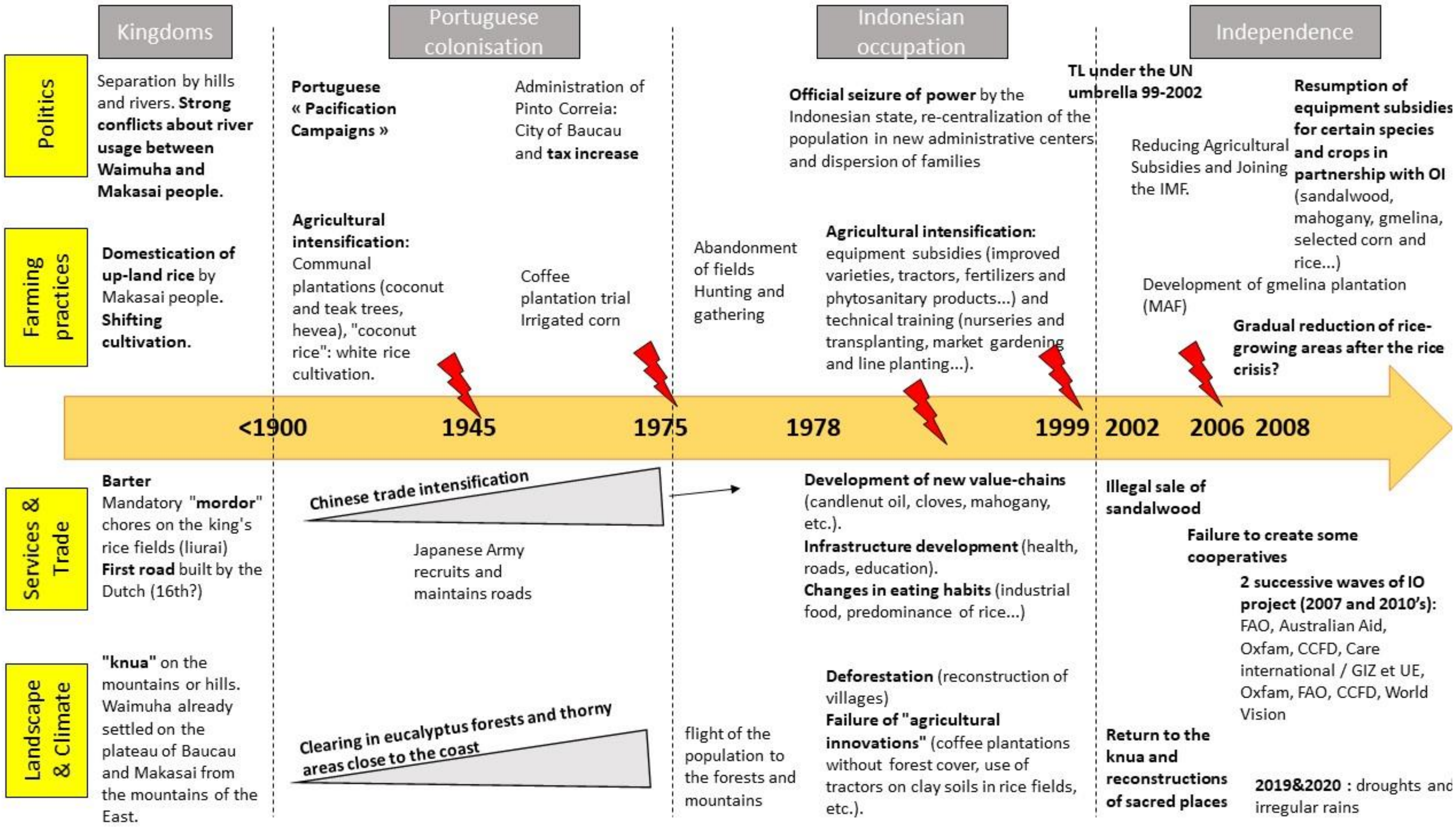
# VIII. ANNEX

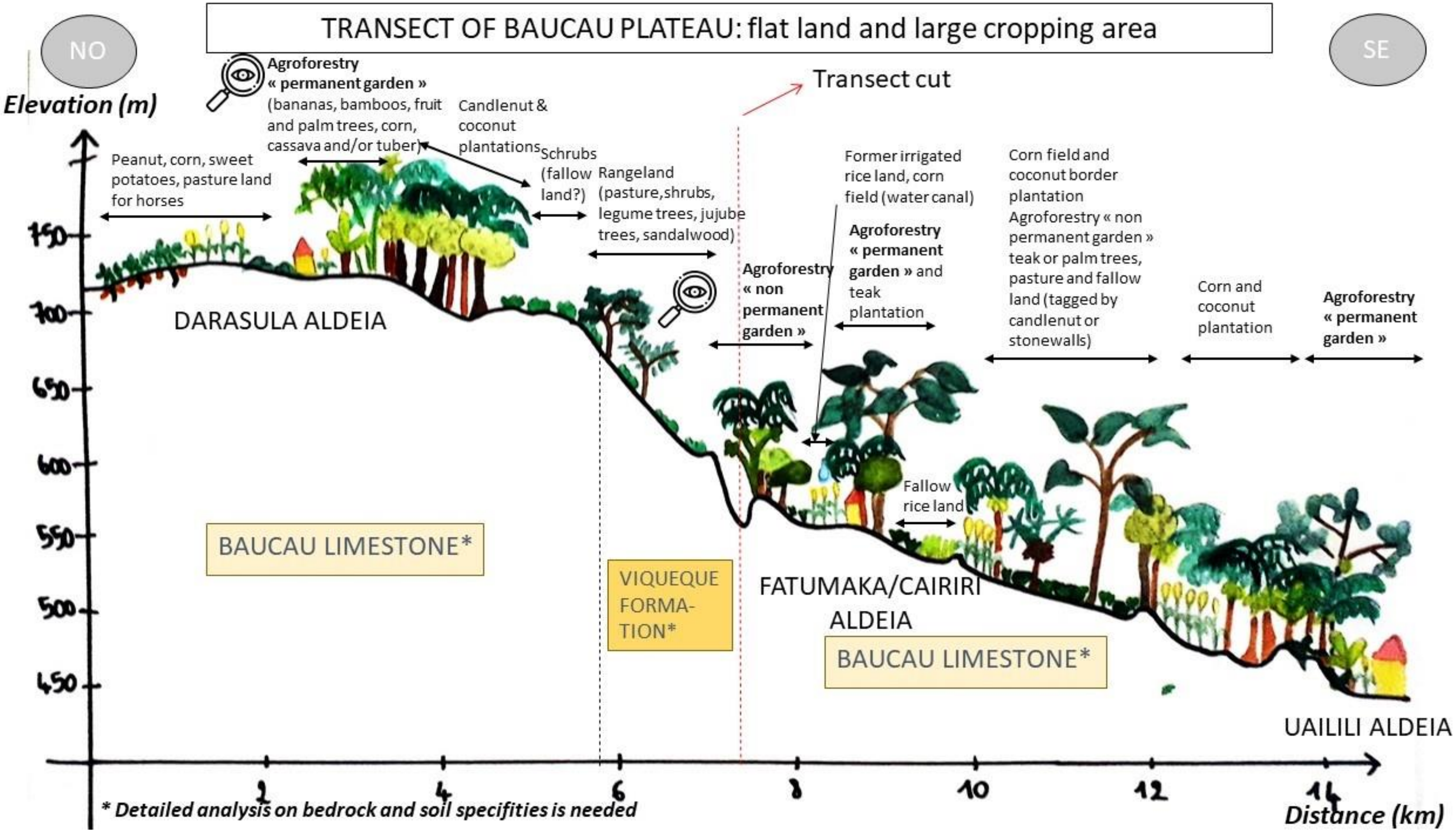
## Annex 1 : Pre-inventory location

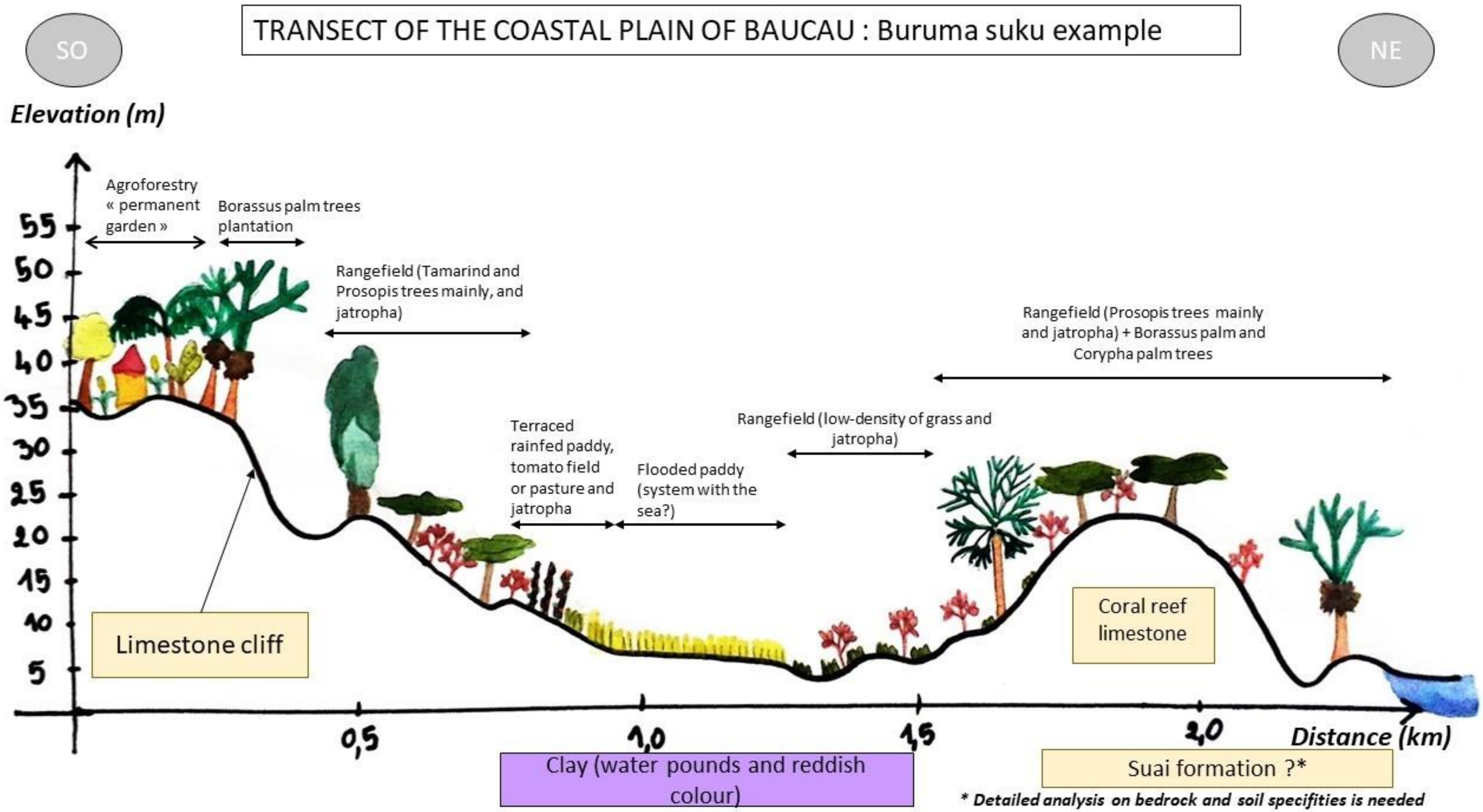


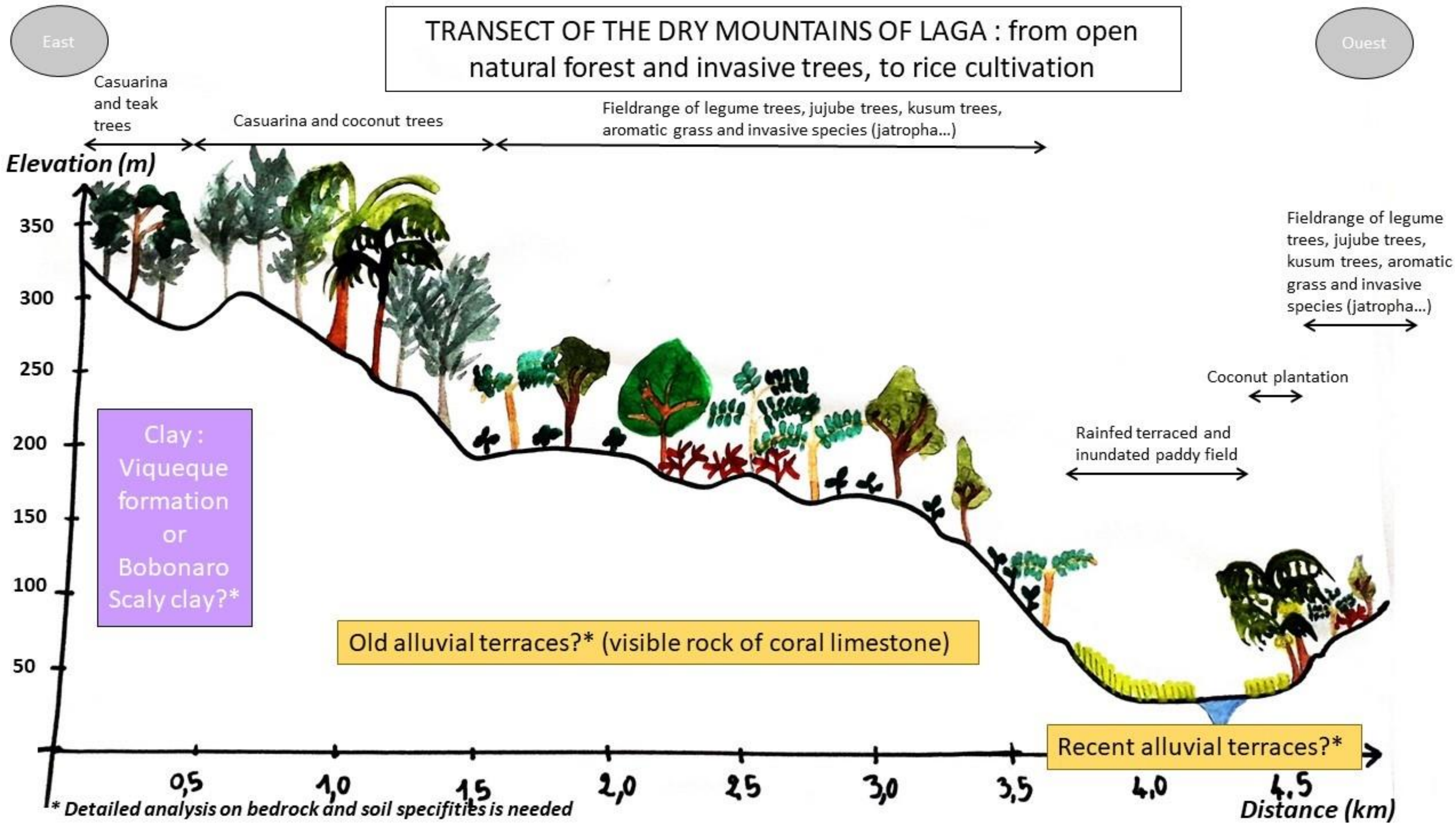
# Annex 2: Historical trajectory of Baucau district (Cogne et al, 2020)



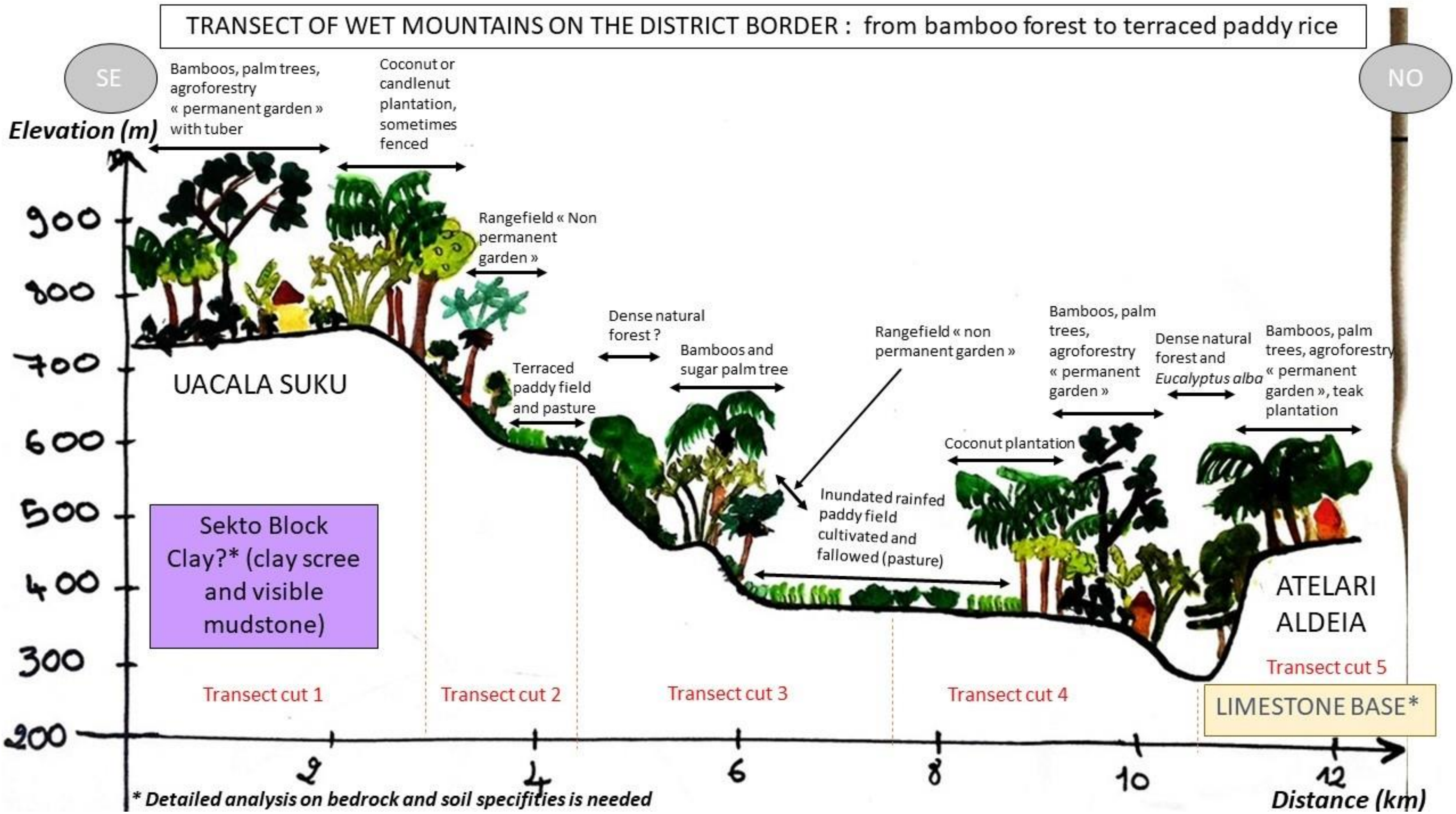
Annex 3: Transect of Baucau landscape (Cogne et al, 2020)




SO
TRANSECT OF THE COASTAL PLAIN OF BAUCAU : Buruma suku example
NE
Elevation (m)
55
50
45
40
35
30
25
20
15
10
5
Agroforestry « permanent garden »
Borassus palm trees plantation
Rangefield (Tamarind and Prosopis trees mainly, and jatropha)
Rangefield (Prosopis trees mainly and jatropha) + Borassus palm and Corypha palm trees
Terraced rainfed paddy, tomato field or pasture and jatropha
Flooded paddy (system with the sea?)
Rangefield (low-density of grass and jatropha)
Coral reef limestone
Limestone cliff
0,5
1,0
1,5
2,0
Distance (km)
Clay (water pounds and reddish colour)
Suai formation ?*
* Detailed analysis on bedrock and soil specifities is needed



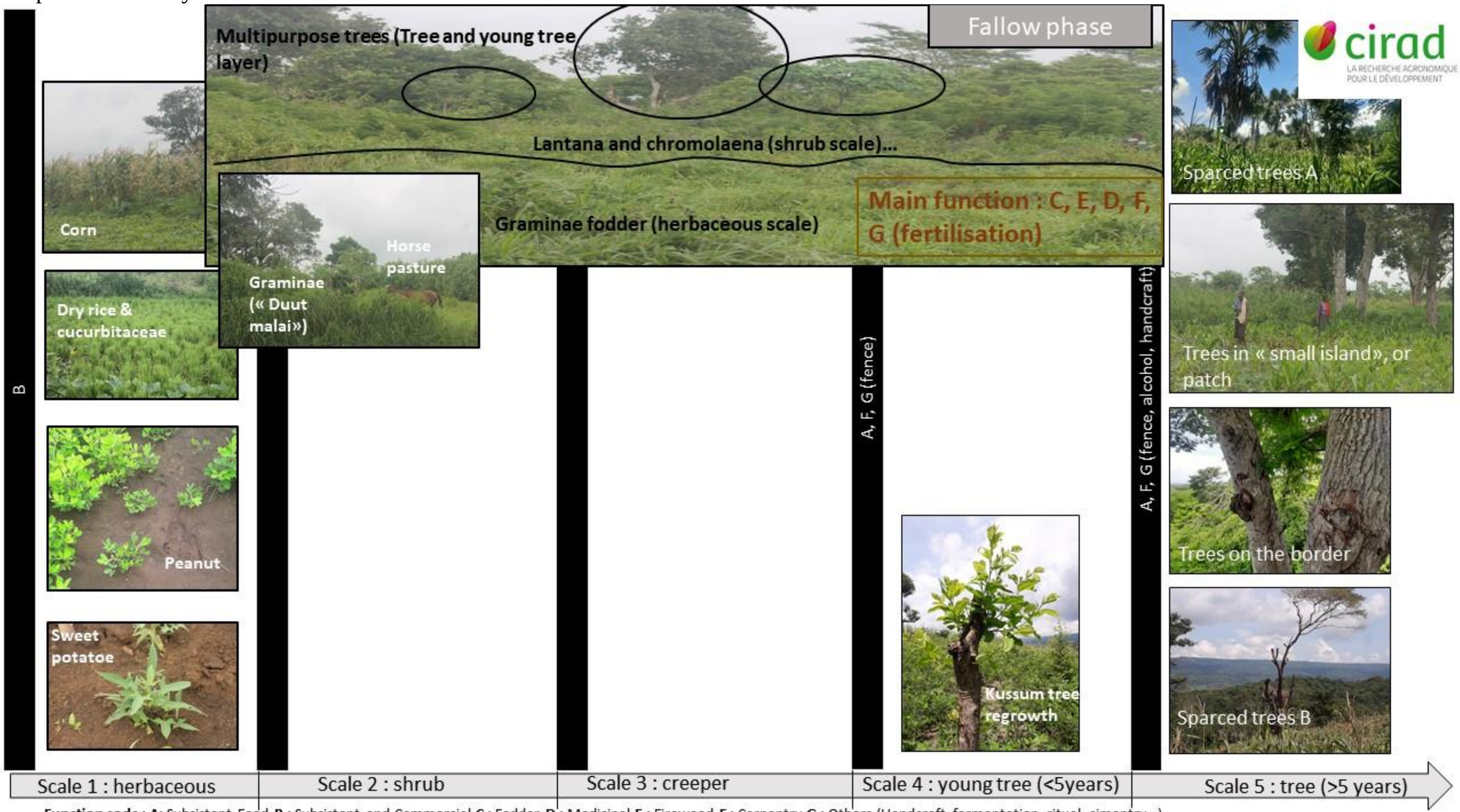
East
TRANSECT OF THE DRY MOUNTAINS OF LAGA : from open natural forest and invasive trees, to rice cultivation
Ouest
Casuarina and teak trees
Casuarina and coconut trees
Fieldrange of legume trees, jujube trees, kusum trees, aromatic grass and invasive species (jatropha...)
Elevation (m)
350
300
250
200
150
100
50
Fieldrange of legume trees, jujube trees, kusum trees, aromatic grass and invasive species (jatropha...)
Coconut plantation
Rainfed terraced and inundated paddy field
Clay : Viqueque formation or Bobonaro Scaly clay?*
Old alluvial terraces?* (visible rock of coral limestone)
Recent alluvial terraces?*
0,5
1,0
1,5
2,0
2,5
3,0
3,5
4,0
4,5
Distance (km)
* Detailed analysis on bedrock and soil specifities is needed



TRANSECT OF WET MOUNTAINS ON THE DISTRICT BORDER : from bamboo forest to terraced paddy rice
SE
NO
Elevation (m)
Bamboos, palm trees, agroforestry « permanent garden » with tuber
Coconut or candlenut plantation, sometimes fenced
Rangefield « Non permanent garden »
Terraced paddy field and pasture
Dense natural forest ?
Bamboos and sugar palm tree
Rangefield « non permanent garden »
Inundated rainfed paddy field cultivated and fallowed (pasture)
Coconut plantation
Bamboos, palm trees, agroforestry « permanent garden »
Dense natural forest and *Eucalyptus alba*
Bamboos, palm trees, agroforestry « permanent garden », teak plantation
900
800
700
600
500
400
300
200
UACALA SUKU
ATELARI ALDEIA
Sekto Block Clay?* (clay scree and visible mudstone)
LIMESTONE BASE*
Transect cut 1
Transect cut 2
Transect cut 3
Transect cut 4
Transect cut 5
2
4
6
8
10
12
Distance (km)
* Detailed analysis on bedrock and soil specifities is needed

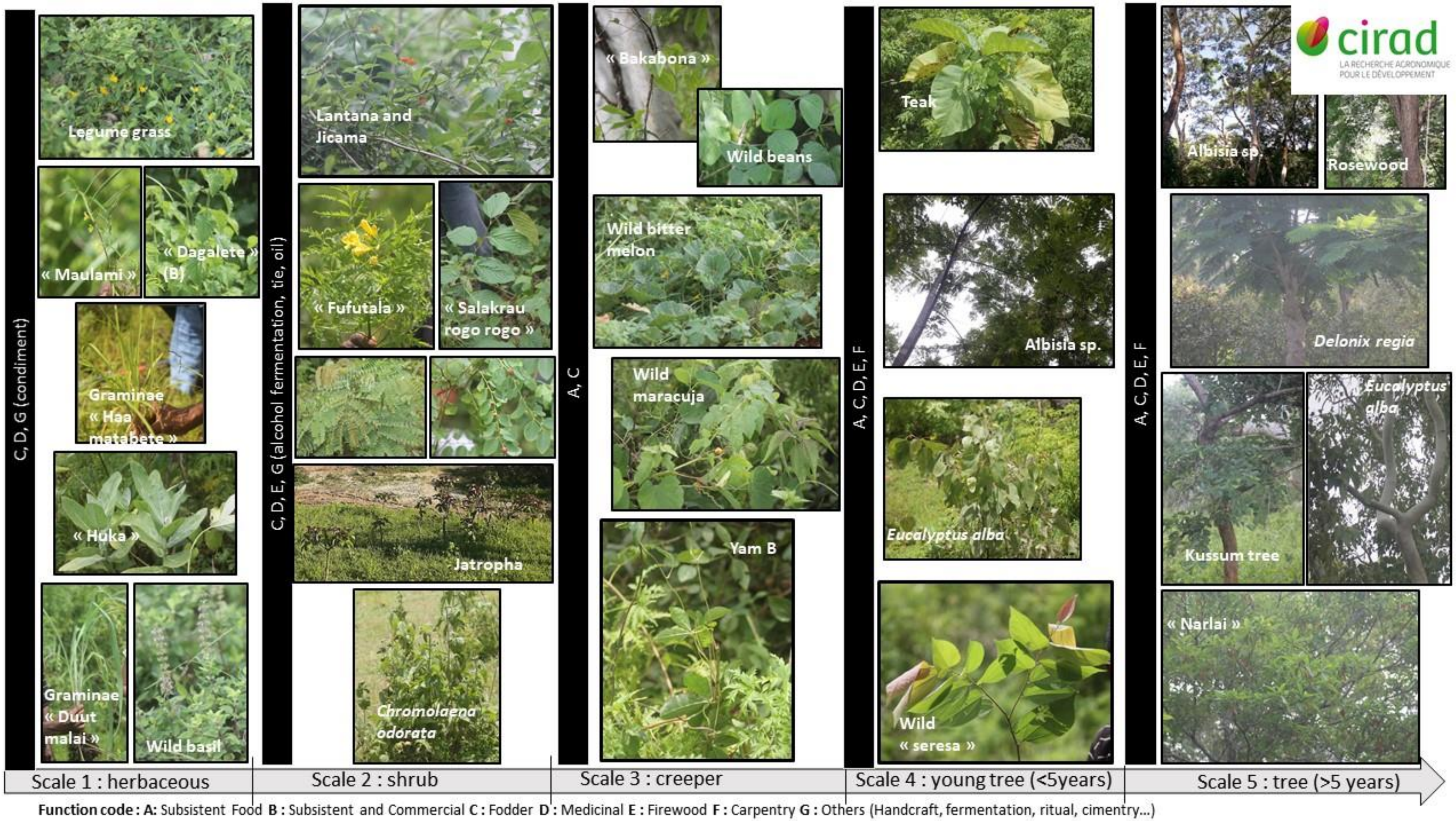
# Annex 4: First inventories of AFS realised in February 2021

Crop and Fallow system:

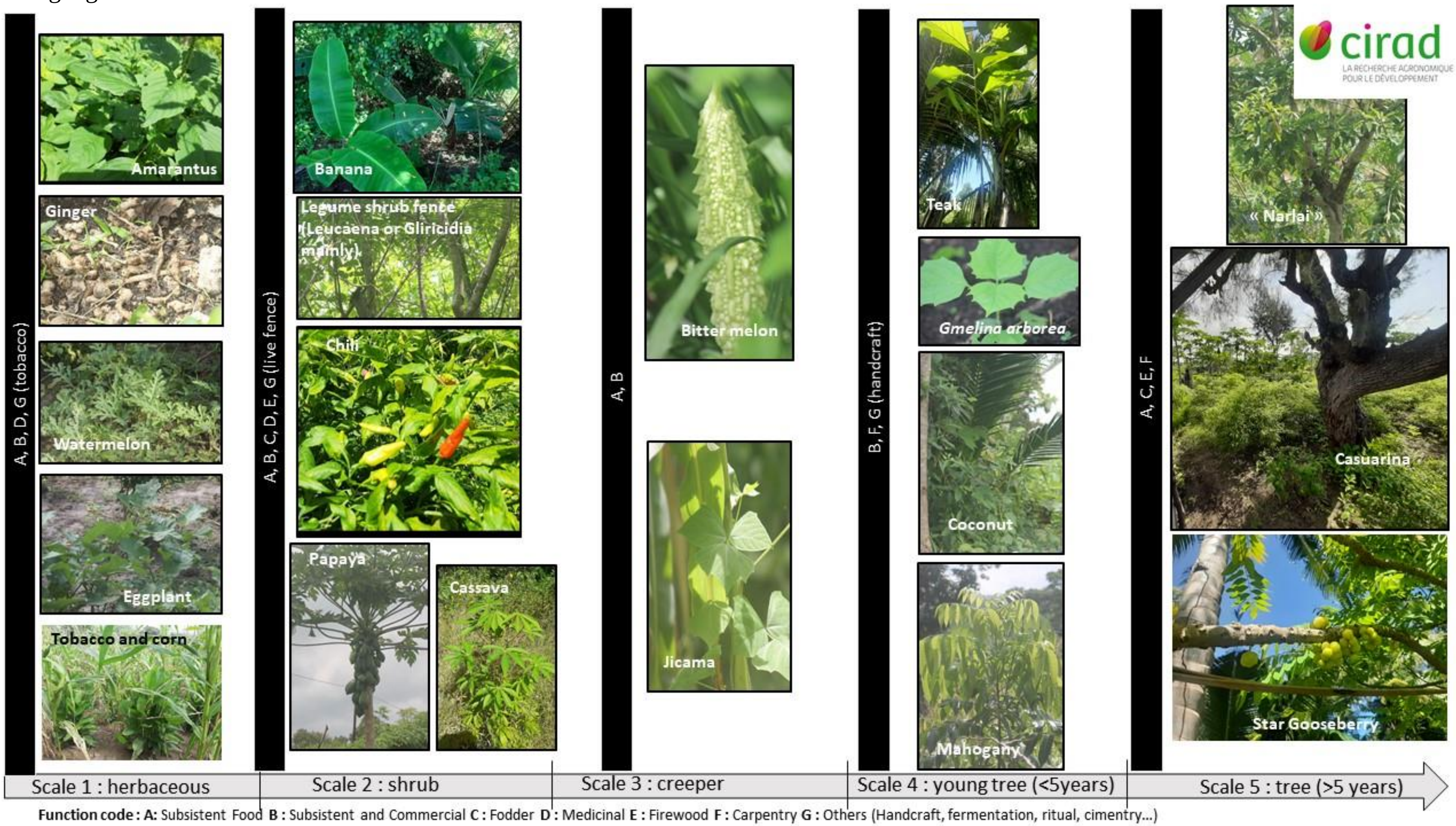



**Function code : A:** Subsistent Food **B :** Subsistent and Commercial **C :** Fodder **D :** Medicinal **E :** Firewood **F :** Carpentry **G :** Others (Handcraft, fermentation, ritual, cimentry...)

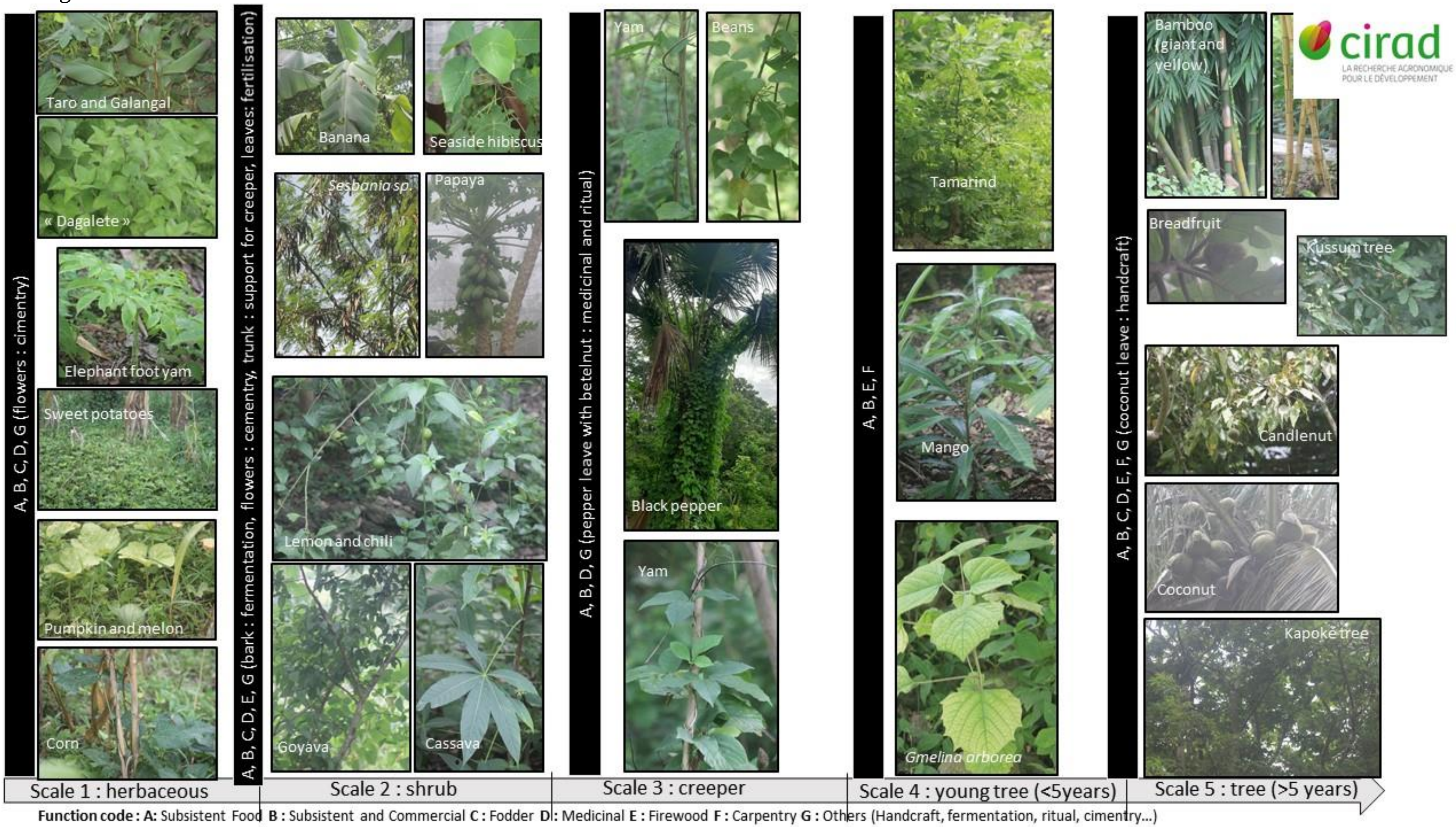
Sylvopastoral area:



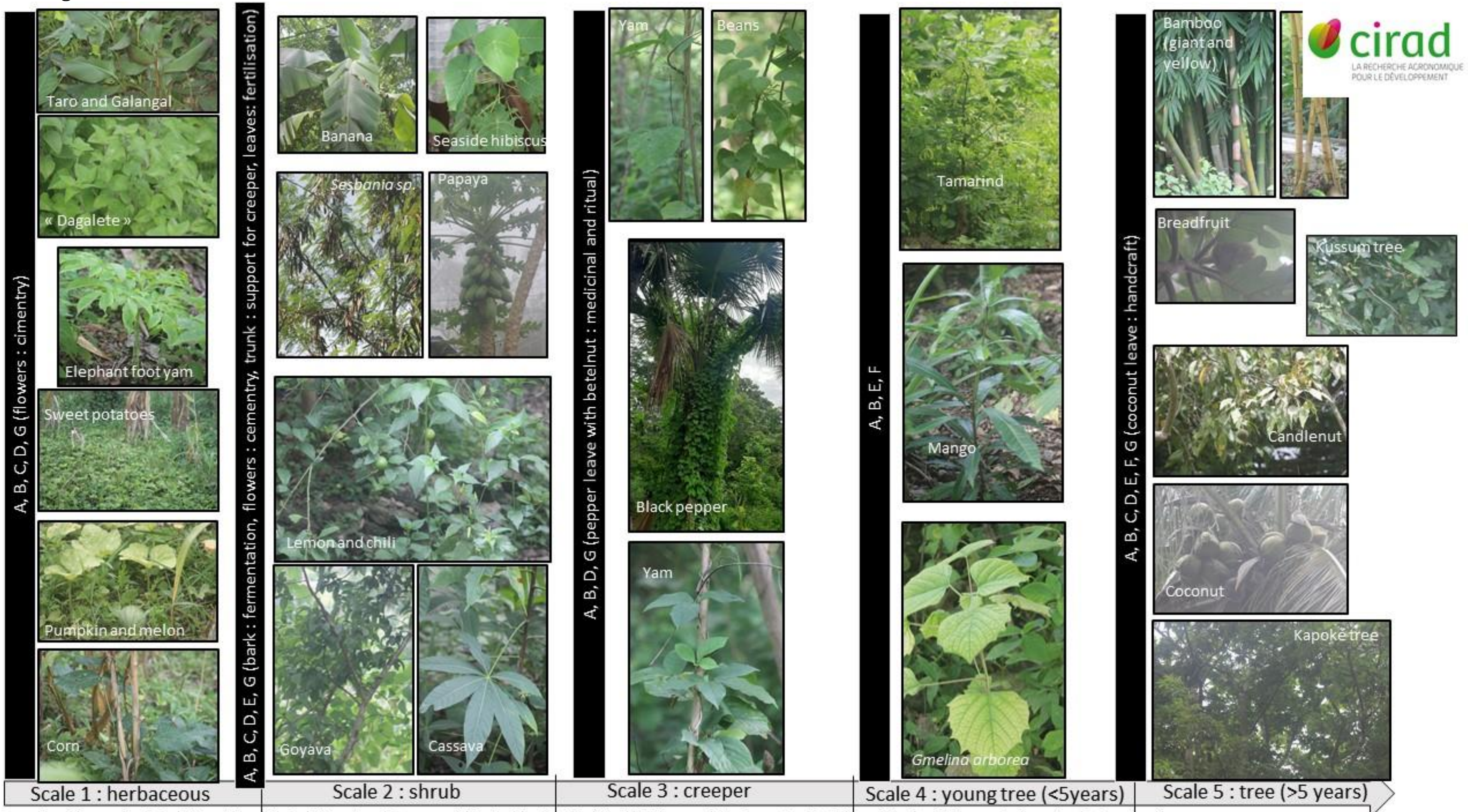
Young Agroforest:



Home garden:


A, B, C, D, G (flowers : cimentry)
Taro and Galangal
« Dagalete »
Elephant foot yam
Sweet potatoes
Pumpkin and melon
Corn
A, B, C, D, E, G (bark : fermentation, flowers : cementry, trunk : support for creeper, leaves: fertilisation)
Banana
Seaside hibiscus
Sesbania sp.
Papaya
Lemon and chili
Goyava
Cassava
A, B, D, G (pepper leave with betelnut : medicinal and ritual)
Yam
Beans
Black pepper
Yam
A, B, E, F
Tamarind
Mango
Gmelina arborea
A, B, C, D, E, F, G (coconut leave : handcraft)
Bamboo (giant and yellow)
Breadfruit
Kussum tree
Candlenut
Coconut
Kapoké tree
cirad
LA RECHERCHE AGRONOMIQUE POUR LE DÉVELOPPEMENT
Scale 1 : herbaceous
Scale 2 : shrub
Scale 3 : creeper
Scale 4 : young tree (<5years)
Scale 5 : tree (>5 years)
Function code : A: Subsistent Food B : Subsistent and Commercial C : Fodder D : Medicinal E : Firewood F : Carpentry G : Others (Handcraft, fermentation, ritual, cimentry...)

Forest garden:




**Function code : A:** Subsistent Food **B :** Subsistent and Commercial **C :** Fodder **D :** Medicinal **E :** Firewood **F :** Carpentry **G :** Others (Handcraft, fermentation, ritual, cimentry...)

# Annex 5: Economic details of HG.

## GP and operational cost of crop and perennial system:

| HG GROSS PRODUCT CS | 0-2 YEARS | GP/ha | 3-5 YEARS | GP/ha | 6-15 YEARS | MEAN | 16-20 YEARS | GP/ha |
|---|---|---|---|---|---|---|---|---|
| PRODUCT1 | Corn | 120 | Corn | 120 | Corn | 60 | Corn | 60 |
| PRODUCT2 | Beans | 792 | Beans | 792 | Beans | 396 | Beans | 396 |
| PRODUCT3 | Pumpkins | 1500 | Pumpkins | 1500 | Pumpkins | 1500 | Pumpkins | 750 |
| PRODUCT4 | Peanut peeled | 200 | Sweet potatoes | 267 | Sweet potatoes | 133 | Sweet potatoes | 67 |
| PRODUCT5 | Sweet potatoes | 267 | Cassava | 760 | Cassava | 380 | Cassava | 190 |
| PRODUCT6 | Cassava | 760 | Coconut | 108 | Coconut | 238 | Coconut | 270 |
| PRODUCT7 | | | Banana | 18 | Banana | 179 | Banana | 204 |
| PRODUCT8 | | | | | Harvest and transforma | 84 | Harvest and transfo | 84 |
| PRODUCT9 | | | | | Harvest breadfruit | 245 | Harvest breadfruit | 490 |
| PRODUCT10 | | | | | | | Harvest fruit trees ( | 41,25 |
| PRODUCT11 | | | | | | | Harvest wild trees ( | 240 |
| **TOTAL** | | **3639** | | **3565** | | **3215** | | **2792** |
| HG OPERATING COSTS CS | **0-2 YEARS** | **Expense/ha** | **3-5 YEARS** | **Expense/ha** | **6-15 YEARS** | **Expense/ha** | **16-20 YEARS** | **Expense/ha** |
| PRODUCT1 | Corn | 43 | Corn | 43 | Corn | 22 | Corn | 22 |
| PRODUCT2 | Beans | 10 | Beans | 10 | Beans | 5 | Beans | 5 |
| PRODUCT3 | Pumpkins | 16 | Pumpkins | 16 | Pumpkins | 16 | Pumpkins | 16 |
| PRODUCT4 | Peanut seeds | 54 | Sweet potatoes | 24 | Sweet potatoes | 12 | Sweet potatoes | 12 |
| PRODUCT5 | Sweet potatoes | 24 | Cassava | 38 | Cassava | 19 | Cassava | 19 |
| PRODUCT6 | Cassava | 38 | | | | | | |
| **TOTAL** | | **185** | **0** | **131** | **0** | **74** | **0** | **74** |

## GP and operational costs of livestock system:

| HG GROSS PRODUCT A | 0-2 YEARS (chicken) | 3-5 YEARS (chicken) | 6-15 YEARS (chicken and pigs) | 16-20 YEARS (chicken and pigs) |
|---|---|---|---|---|
| CHICKEN < 3month | 175 | 490 | 1225 | 525 |
| CHICKEN >3 month | 84 | 270 | 747 | 432 |
| ROOSTER | 51 | 51 | 154 | 154 |
| PIG 0-2month | 0 | 0 | 200 | 200 |
| PIG 2-6month | 0 | 0 | 200 | 900 |
| PIG>6month | 0 | 0 | 3400 | 1000 |
| TOTAL | **310** | **811** | **5926** | **3211** |

| HG OPERATING COSTS A | 0-2 YEARS (chicken) | 3-5 YEARS (chicken) | 6-15 YEARS (chicken and pigs) | 16-20 YEARS (chicken and pigs) |
|---|---|---|---|---|
| CHICKEN FOOD | 130 | 286 | 780 | 390 |
| PIG FOOD | 0 | 0 | 3480 | 1988 |
| PIG INDIV | 0 | 0 | 15 | 0 |
| CHICKEN INDIV | 36 | 88 | 0 | 0 |
| TOTAL | 166 | 374 | 4275 | 2378 |

| Product | Cost chicken food ($/adult unit) | Cost pig food (dollars/adult unit) |
|---|---|---|
| Corn | 9 | 53 |
| Rice | 17,544 | 183,4166667 |
| **TOTAL** | **26** | 182,75 |
| Sweet potato | 600 | 288 |
| Cassava | 392 | 196 |
| Coconut | 365,5 | 91,375 |
| **TOTAL** | | **994** |

# Annex 6: Economic table of FG

| PRODUCT | UNIT (kg/othe | QUANTITY | SURFACE (ha) | YIELD (unit/ha) | PRICE ($/unit) | GROSS PRODUCT ($/ha) |
|---|---|---|---|---|---|---|
| COLLECT 1/2 CANDLENUT (kg) | 25 | 4,5 | 0,5 | 225 | 1 | 225 |
| COLLECT CANDLENUT TOT HYP | 25 | 9 | 0,5 | 450 | 1 | 450 |
| ELEPHANT FOOT YAM (unit) | 1 | 1600 | 0,6 | 2667 | 0,25 | 667 |
| TARO (unit) | 1 | 480 | 0,6 | 800 | 0,25 | 200 |
| BREADFRUIT (unit) | 1 | 360 | 0,5 | 720 | 0,25 | 180 |
| Breadfruit (unit) GOOD YEAR | 1 | 720 | 0,5 | 1440 | 0,25 | 360 |
| Breadfruit (unit) BAD YEAR | 1 | 180 | 0,5 | 360 | 0,25 | 90 |
| MANGO (unit) | 1 | 640 | 0,5 | 1280 | 0,15 | 192 |
| Mango (unit) GOOD YEAR | 1 | 800 | 0,5 | 1600 | 0,15 | 240 |
| Mango (unit) BAD YEAR | 1 | 400 | 0,5 | 800 | 0,15 | 120 |
| PALM WINE AKADIRU (L) RAIN | 1 | 25 | 0,6 | 42 | 0,6 | 25 |
| PALM WINE AKADIRU (L) | 1 | 75 | 0,6 | 125 | 0,6 | 75 |
| PALM WINE TOT | 1 | 2520 | 0,6 | 4200 | 0,6 | 2520 |
| COLLECT 1/3 COCONUT PROD (density moy = 110/ha) (unit) | 1 | 2200 | 1 | 2200 | 0,1 | 220 |
| COLLECT COCONUT TOT | 1 | 6600 | 1 | 6600 | 0,1 | 660 |
| **TOTAL (mean value)** | | | | | | **1759** |
| **TOTAL BAD YEAR** | | | | | | **1727** |
| **TOTAL GOOD YEAR** | | | | | | **1987** |
| **TOTAL POTENTIAL** | | | | | | **5094** |

No operating costs: GP = GM

# Annex 7: Distribution and allocation of gross margins for HG (mature period, 6 to 15years), CF manual (normal year) and FG (normal year)

Notes: HH=part of the GM allocated to family diet, AC=part of the GM allocated to animal food (HH+AC = "self-consumption")

HG 6-15 years:

| Crop product | **6-15 YEARS GM ($/ha)** | **%sold** | **%HH** | %AC |
|---|---|---|---|---|
| Corn | 38 | 0 | 0 | 1 |
| Beans | 391 | 0 | 1 | 0 |
| Pumpkins | 1484 | 0,2 | 0,2 | 0,6 |
| Sweet potatoes | 121 | 0,5 | 0,2 | 0,3 |
| Cassava | 361 | 0 | 0,3 | 0,7 |
| Coconut | 238 | 0,1 | 0,1 | 0,8 |
| Banana | 179 | 0,75 | 0,25 | 0 |
| Harvest and transformation seeds candlenut | 84 | 1 | 0 | 0 |
| Harvest breadfruit | 245 | 0,5 | 0,3 | 0,2 |
| **TOTAL** | 3215 | 0,22 | 0,30 | 0,45 |

| Animal product | 6-15 YEARS GM ($/ha) | %sold | %HH | %AC |
|---|---|---|---|---|
| CHICKEN < 3month | 1225 | 0,75 | 0,25 | 0 |
| CHICKEN >3 month | 747 | 0,5 | 0,5 | 0 |
| ROOSTER | 154 | 0,6 | 0,4 | 0 |
| PIG 0-2month | 200 | 1 | 0 | 0 |
| PIG 2-6month | 200 | 0,75 | 0,25 | 0 |
| PIG>6month | 3400 | 0,5 | 0,5 | 0 |
| TOTAL | **5926** | **0,6** | **0,4** | 0 |

CF manual “normal year”:

| PRODUCT | GM ($/ha) | GM sold (%) | GM HH consumption (%) | GM animal consumption (%) |
|---|---|---|---|---|
| Corn mean prod (kg) | 384 | 0,1 | 0,4 | 0,5 |
| Peanut skin | 234 | 0,75 | 0,25 | 0 |
| Cassava high prod (unit) | 262 | 0,2 | 0,2 | 0,6 |
| Pumpkin mean prod (unit) | 305 | 0,15 | 0,1 | 0,75 |
| Long beans mean prod (kg) | 470 | 0,75 | 0,25 | 0 |
| TOTAL NORMAL YEAR ( | 1655 | 0,40 | 0,25 | 0,35 |

FG “normal year”:

| PRODUCT | GM PRODUCT ($/ha) | GM sold (%) | GM HH consumption (%) | GM animal consumption (%) |
|---|---|---|---|---|
| COLLECT 1/2 CANDLENUT (kg) | 225 | 1 | 0 | 0 |
| ELEPHANT FOOT YAM (unit) | 667 | 0 | 0 | 1 |
| TARO (unit) | 200 | 0 | 0,25 | 0,75 |
| BREADFRUIT (unit) | 180 | 0,5 | 0,5 | 0 |
| MANGO (unit) | 192 | 0,75 | 0,25 | 0 |
| PALM WINE AKADIRU (L) | 75 | 0,75 | 0,25 | 0 |
| COLLECT 1/3 COCONUT PROD (density moy = 110/ha) (unit) | 220 | 0,25 | 0,25 | 0,5 |
| **TOTAL NORMAL YEAR ($/ha)** | 1759 | 0,32 | 0,15 | 0,53 |