Partnership for Sustainable Agroforestry (PSAF) project

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

Technical report:

Soil, Biodiversity & Biomass of Agroforestry Systems in Baucau area (Timor-Leste)

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1 EXECUTIVE SUMMARY

The aim of this study is to characterise the soil, biomass and biodiversity characteristics of the main agroforestry systems (AFS) in Baucau District, Timor-Leste. For this purpose, the following five AFS were selected: i) Crop system including a wooded fallow phase (CF), ii) Sylvopastoral (SP), iii) Young agroforest (YA), iv) Home garden (HG), and v) Forest garden (FG).

Questions and hypothesis:

For soil study, we conducted our experimental design to test the following three hypotheses:

i) As Gariuai and Samalari are on different geomorphological units and geological substrates, we assumed that the soils of Gariuai are different from those of Samalari;
ii) As Gariuai has always been inhabited for at least 50 years, we assumed that there is a relationship between AFS and Gariuai soil properties. The cause of this relationship would be that farmers have had time to adapt the AFS to the intrinsic properties of the soil (e.g. textural class) and/or that AFS have had time to modify some chemical properties of the soil (e.g. organic carbon content) in a different way. Therefore, we assumed that today Gariuai soils are different depending on the AFS; and
iii) As people from Samalari left the village during Indonesian occupation, consequently the land was left in fallow until they rehabilitated it recently in 2005. Thus, we assumed that there is no relationship between AFS and Samalari soil properties. The cause would be that the AFS did not have time to modify the soils in a different way. Therefore, we assumed that today Samalari soils are similar regardless of the AFS.

For Inventories of woody biodiversity and above-ground biomass in AFS, we conducted our experimental design to answer the question: How to characterise AFS by their contribution to ecosystem services (carbon sink and biodiversity conservation)?; and to test the following three hypotheses:

i) The AFS studied differ in their above-ground biomass and degree of biodiversity;
ii) The chronology of transition between the AFS studied shows an increase in above-ground biomass in AFS from the establishment of annual fields (alternating with fallows) or sylvopastoral systems (kept open by fire, cutting and cattle), to old agroforests; and
iii) The above-ground biomass comes mainly from the woody biomass of trees and palms with a trunk or stipe diameter (DBH) greater than 32cm.

Methods:

For the soil sampling we made 3 replications per AFS type in Gariuai (Baucau plateau) and in Samalari (Matebian foothills). For Field measurements we have applicated part of the Biofunctool tool set, especially VESS (Visual Evaluation of Soil Structure). For laboratory measurements, we performed physical and chemical analyses: particle size distribution, calcium carbonate content, total organic carbon (Corg) and total nitrogen (N), pH, available phosphor

(Olsen method), cation exchange capacity (CEC) and exchangeable cations (Ca, Mg, K, Na, Al, Mn and H).

The Inventories of woody biodiversity and above-ground biomass are made in the same plots sampled for soil analysis. All trees above 32 cm Diameter at Breast Height (DBH) were measured on each plot. Trees between 10 and 32 cm DBH were measured on five quadrats of 100 m^2 each: one at each corner and one at the center of the plot. The DBH and height of each tree were measured (using a clinometer for height) and the local Tetum name was recorded. The Latin names were then associated to each Tetum name with a bibliography search. The aboveground biomass (AGB) was estimated using the Chave et al. (2014) equation 4 that includes diameter (D), tree height (H), and species-specific wood density as predictors. The species-specific wood densities were retrieved from the Dryad repository "Global Wood Density Database". For the specific case of palm species (Cocos, Borassus, Corypha, Areca, Arenga), for which there were no specific biomass allometries available, their biomass was estimated by multiplying their estimated stipe volume (basal area x H stipe x a shrinkage factor of 89%) by an average wood density of 0.6. For each tree we also asked the farmer if the tree was planted by him or the previous land owner or if the tree grew "by itself" and he decided to keep it (natural assisted regeneration).

Results:

The textural classes of Gariuai soils were very variable: clay, clay loam, silty clay loam, loam, silt loam (Figure. 2). This variability is partly explained by the AFS, since the Sylvopastoral (SP) and Young Agroforest (YA) soils were only silt loam and clay loam, respectively. But this variability was also high within each of the three others AFS named Forest garden (FG), Home garden (HG), Crop and fallow (CF).

The calcium carbonate content of Gariuai soils ranged between 0 and 84%. This variability is partly explained by the AFS, since soils of Crop and fallow and Sylvopastoral had no (or almost no ≈ 1%) calcium carbonates. We also showed a good relationship between calcium carbonate content and pH.

The organic carbon content of Gariuai soils ranged between 2 and 5.5% in the 0-10 cm layer. This variability was not explained by the content of fine elements as is usually observed in natural tropical forest. Instead, it depends on AFS: Sylvopastoral had the highest organic carbon content, while Crop and fallow had the lowest, and the other AFS had intermediate contents.

FG and HG were the most diverse systems (between 8 and 11 species planted and not planted) in both villages. Less diversity was found in Gariuai's plot compared to Samalari, especially YA, as more spontaneous trees are kept in the system there. SP (except in Samalari), CF and YA are the least diverse systems: they are kept open by fire, cutting and cattle grazing and/or there is a restrictive selection of cultivated species such as fruit trees or introduced timber trees (?).

The tree density (number of standing trees per ha) was similar between Gariuai and Samalari for FGs and SPs (about 110 and 35 trees/ha respectively). However, tree density is higher in the annual fields (CF) and homegarden (HG) of Samalari than of CF & HG of Gariuai. This may be due to the limited means of cutting and non-mechanised cultivation practices in the Samalari area (more mountainous area). On the other hand, YA tree density is higher (?) in Gariuai than in Samalari. It can be explained by easier access to water than in Samalari, but also by the fact that farmers have had more time in Gariuai to introduce young trees (selected by them, bought or provided by the projects) in their YAs, while in Samalari they have only been back for 20 years.

In Gariuai, the Above Ground Biomass (AGB) is highly variable, ranging from 13t/ha for annual cropping systems including fallow (CF) to almost 230 t/ha for old agroforests (FG) which reflects a high density of large trees (higher above-ground biomass than the standards assessed for tropical forests by FAO). For all systems, most of the above-ground biomass is represented by large trees (more than 32cm in diameter), except for the sylvopastoral systems in Samalari which could describe the intensive use of large trees during the rehabilitation of the village especially for sacred house building that had been burnt in the 1970's.

Discussion

This study confirmed that historical dynamics embedded with each study area are a big factor for variability that needs to be documented and taken into account in result analysis.

We identified and characterized 5 types of agroforestry systems (AFS) especially by their tree density and biodiversity content. We have also shown that there are interactions between these systems, particularly in terms of fertility transfers.

Finally, the results confirm that AFS bring agro-ecological benefits through carbon storage in biomass and soils although it needs time to establish this dynamic (at least 20 years). The results on the composition of these AFS and their location in the village land also show that farmers have a detailed knowledge of the functions of agroforests within their production system, as well as the soils on which they cultivate them. The analysis of the AGB is a good example to illustrate the interactions that exist between AFS different uses, available resources, and the historical trajectories of the territory.

Conclusion:

For soil, the hypothesis 1 was validated: overall, the main soil properties in Gariuai were different from those in Samalari.

The hypothesis 2 was partly validated: in Gariuai, there is a relationship between AFS and soil properties, but this relationship is mainly due to sylvopastoral soils that were clearly different from the soils of Forest garden, Home garden and Young agroforest.

The hypothesis 3 was validated: in Samalari, there is no relationship between AFS and soil properties. Samalari soils were similar regardless of the AFS.

For biomass and biodiversity, the hypothesis 1 is validated: the AFS studied differ in their above-ground biomass and degree of biodiversity.

The hypothesis 2 is partly refuted: biomass does not increase in a linear way if we follow the transition chronology from one AFS system to another. In fact, biomass depends on the type of management and the degree of harvesting or enrichment of each AFS. There may be a decrease in biomass between CF and YA (Samalari) or YA and HG (Gariuai). Biomass in FG on the other hand is always higher than CF.

The hypothesis 3 is refuted: the above-ground biomass of smaller trees may be greater than the above-ground biomass of larger trees. Indeed, the case of SP in Samalari shows that it would be interesting to adapt the study protocol for non-woody biomass in these agroforests.

From this conclusion, several practical and institutional recommendations are proposed in the following tab:

Result/Discussion	Technical recommendation	Institutional recommendation
1 : Identification of 5 distinct AFS	The typology should be used to communicate with farmers about agroforestry (relative to uses and functions). English names need to be translated and reinterpreted according to the local language.	Adapt the semantics used in the projects to the locally used names
2 : Systems characterised by their variation in density and biodiversity	Understand the functions of the different agroforestry types implemented and explained by farmers (with their necessary density variations) to adapt techniques and improve the system. The density of woody plants concerns the intermediate storey (shrubs) and the dominant storey (large trees), which must be managed by the farmers to provide the optimum amount of light to the crop understorey, depending on the species grown.	Strengthen teaching and technical application capacity on the diversity of agroforestry systems (including traditional systems already present and identified in Timor Leste).
3 : Interactions between the 5 AFS: fertility transfers	Technicians need to consider the interactions that exist within farmers' production systems. Fertility transfers are a good example: animals eat in some plots, crops and wood are harvested in others, while dung, ash, litter, etc. are concentrated near houses or livestock pens, so that organic or mineral elements are concentrated there. When they notice a drop in fertility on a plot of land, the technicians can rely on other "innovative" farmers who are already implementing techniques to valorise manure by organising group meeting and visits to their homes in order to disseminate these techniques to as many people as possible. Technicians can also propose to share, with farmer who wish, new techniques and plant materials to which they have easier access (through literature, their experiences outside the village, etc.).	Promote communication between different disciplines and between different professions: between technicians (livestock, agriculture, forestry), with universities (teachers and students) and with farmers.
4 : Agro-ecological benefits of AFS: carbon storage in biomass and soils.	Technicians should promote agroforestry as a system that can restore soil fertility after several decades. If agroforestry is presented as a short-term solution, it would discredit technicians and discourage farmers from disseminating agroforestry practices.	In economic strategies related to carbon markets, not only "forests" but all agroforestry systems that have proven their capacity to store carbon in biomass and soils must be taken into account.
5 : Farmers' knowledge of agroforestry in relation to their production system	To improve agroforestry systems, the technician must take into account the farmers' knowledge of their soils (thickness, sensitivity to erosion, "fertility" for the dispersal of elements, compatibility/incompatibility of the type of soil with certain plant species) and of the uses and functions of spontaneous species (fodder, firewood, timber, fruit, fermentation, etc.) as well as species that have been introduced over the past few years (fruit trees, timber-producing trees).	Adapt agricultural development programmes to the resources (knowledge, plant species, etc.) already present locally.

2 INTRODUCTION

2.1 Background

The systematic promotion of agroforestry systems in Timor-Leste is rather new. It was important that an adequate basis of both demonstration and applied research and development (R&D) was established in order to ensure sound production, processing and marketing practices (CIRAD, 2019 and Peltier *et al.*, 2020). This referred especially to the identification and development of suitable, sustainable and profitable agroforestry value chains, associated agroforestry systems, management and marketing practices. The Ai ba Futuru – Partnership for Sustainable Agroforestry (PSAF) project[1] works specifically on the promotion of sustainable agroforestry in Timor-Leste. Associated to this project, CIRAD implemented a long-term adaptive research programme to support and underpin the implementation of PSAF.

Three potential topics for research were selected, related to market/value chain analyses, immediate ecological benefits from agroforestry systems as well as socio-economic impacts, and the implications of both for resilience building towards the impacts of climate change. Agroforestry-specific recommendations have been made and need to be included into the country's extension material as well as to contribute to long-term forestry sector policy- and decision-making.

Specifically, research results have contributed to:

- The identification of constraints limiting 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.

One of the activities of CIRAD's scientific team consisted in a technical, ecological and socio-economic diagnosis of current and future agroforestry systems.

In 2018, the agrarian systems of the 4 municipalities of Timor, where GIZ implements the PSAF project, were very poorly understood. This could be seen, for example, by reading the document that described the baseline at the start of the project (Butterworth & Kielwein, 2018). In this document, traditional agroforestry systems are hardly mentioned and only products that come either from cultivated fields, or forests, or rangelands are described. However, if we refer to the description of the agrarian systems commonly used by the scientific community, in particular by ICRAF (WAC), and more specifically by NAIR (1985), the majority of the cultivated land of the 4 municipalities falls into different categories of agroforestry systems (including sylvopastoral areas).

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

In order to better meet the needs of the rural and urban populations of Timor, it is essential to fully understand the functioning of the main types of agrarian systems that can be described. The division of each farm's activities in several types of cropping systems needs to be taken into account, including agroforestry systems with dense cover (with tubers in understory), with light cover (with cereals and legumes in understory), totally open fields (cereals or legumes), mono-specific orchards, forest plantations, pastures with hedges and tree cover or not, etc. These systems have to be placed in the context of a historical evolution, taking into account the traditions of the first known masters of the land, the current ethno-linguistic group, the contributions of the colonizers, state services, various projects and, finally, current economic conditions of the managers of the system: elderly or young person, with or without labor, with or without extra-agricultural income (pension, transfers from city dwellers or expatriates (remittances), etc.). These systems will also have to be located in relation to landscape transects, taking into account the type of soil, altitude, rainfall and the supply of groundwater or irrigation.

2.2 Objectives of the report

This report aims to present the parameters of the field study conducted between June and September 2021 in two communities, Gariuai and Samalari, in order to characterize technical and ecological benefits of AFS. These parameters rely on soil, biomass and biodiversity study among a sample of 30 AFS plots spread between the two different areas.

We have assumed that once these systems have been described, or even modeled, it will be easier for future projects to plan their contributions to a much higher number of farmers, with a much higher profitability of the action. At the end of this report we propose a series of practical recommendations for technicians and institutional bodies to support the promotion of agroforestry systems based on the results we provide.

3 METHODS

3.1 Study Area

We have selected two communities from the project target communities: Gariuai and Samalari *Suco* (group of villages). They are located in the centre of the district at different altitudes between 50 and 1200m and a rainfall of about 1200mm/year.

According to Metzner J. (1977), Gariuai and Samalari are located on 2 different geomorphological units (Plateau vs Matebian Foothill) and on 2 different geological substrates (Baucau limestone – Pleistocene formation vs Bobonaro Scaly Clay – Mid-Miocene formation).

Gariuai and Samalari have had a different past history. Gariuai has been inhabited for at least 50 years while Samalari was abandoned during the Indonesian occupation and only re-settled in 2005. During its period of abandonment, the different agroforestry systems in Salamari became fallow.

3.2 Five mains Agroforestry systems selected for soil, biomass and biodiversity studies

The AFS typology found in Baucau district was adapted from Nair (1985) and the perception of the farmers on their different type of field and forest areas.

3.2.1 Crop system including a wooded fallow phase (CF)

Specific characteristics: 2 to 4 main crops including corn, very low density of trees (in patch, isolated inside or on the border of the plot), fallow (from 3 month to 10 years), no access to water for irrigation.

3.2.2 Sylvopastoral (SP)

Specific characteristics: wide non-cultivated and collective area, no fence, subject to fire, superficial soil.

Main husbandry: horse and buffalo (Gariuai) or goats and sheep (Samalari)

3.2.3 Young agroforest (YA)

Specific characteristics: young tree and/or palm growing, commercial crops, access to water for irrigation, live fence, no animals inside

3.2.4 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.

3.2.5 Forest garden (FG)

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

3.3 Soil study

3.3.1 Questions and hypotheses

We conducted our experimental design to test the following three hypotheses.

i) As Gariuai and Samalari are on different geomorphological units and geological substrates, we assumed that the soils of Gariuai are different from those of Samalari;

ii) As Gariuai has always been inhabited for at least 50 years, we assumed that farmers had time to adapt the AFS to the intrinsic properties of the soil (e.g. textural class) and/or that AFS have had time to modify some chemical properties of the soil (e.g. organic carbon content) in a different way. Therefore, we assumed that today Gariuai soils are different depending on the AFS;

iii) As AFS in Samalari have been changed or displaced since the recent rehabilitation of the village, these AFS did not have time to modify the soils. Therefore, we assumed that today Samalari soils are similar regardless of the AFS.

3.3.2 Sampling: selection of typical plots from farmers in the 2 selected zones

Three replications per AFS type was realized in each zone which resulted in a total of 15 plot per suku studied (Gariuai and Samalari). The strategy was to cover two areas with different typical environmental condition, especially regarding the historical and the geomorphological characteristics.

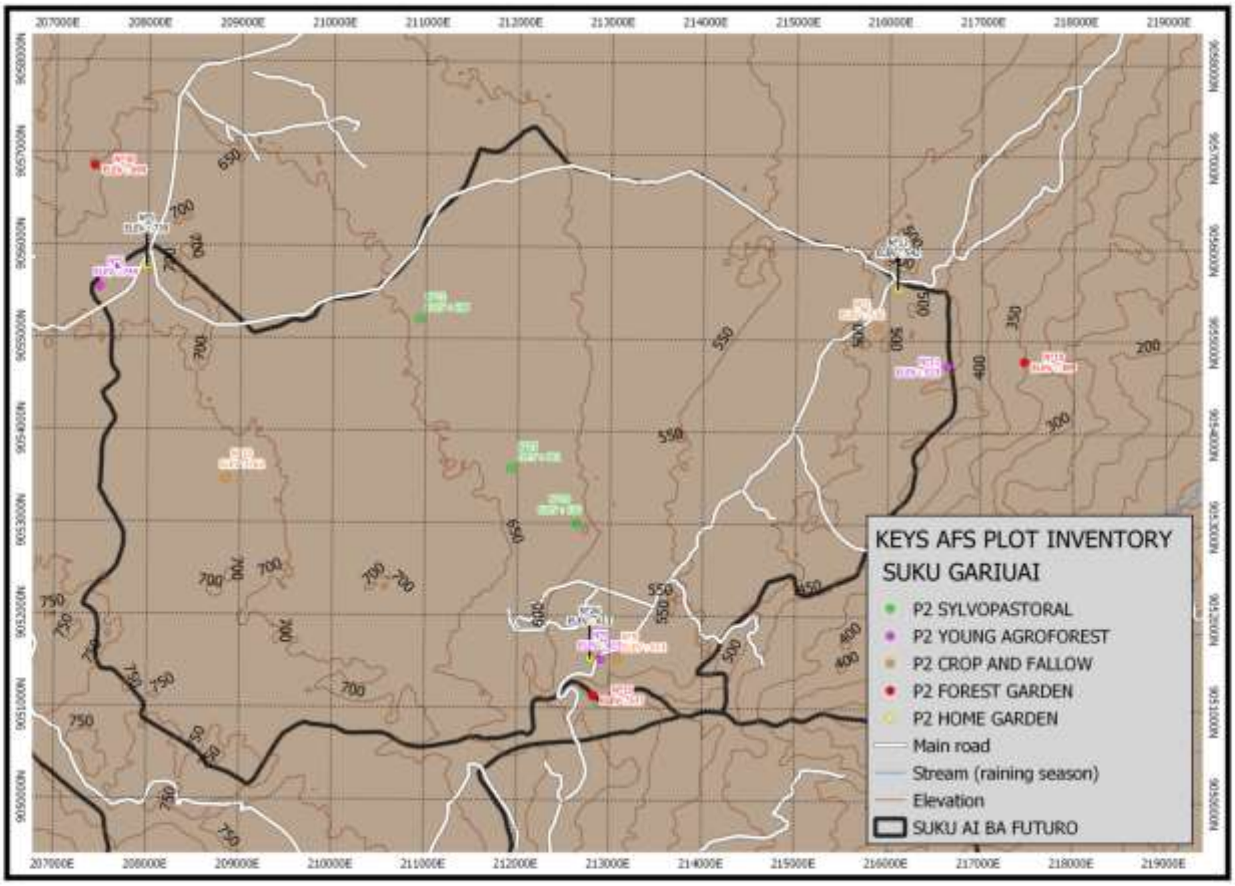


Figure 1: Distribution of sampled plots on the Gariuai Plateau: Suku GARIUAI (centre), Darasula village (left), Cairiri village (bottom), Bahamori village (right)

Each plot was sampled through a transect by three high-central-low points.

3.3.3 Field measurements

A part of the Biofunctool tool set (Thoumazeau A. *et al*, 2019) was applied, especially VESS (Visual Evaluation of Soil Structure = estimation of the soil structure via a scoring method ranging from 1 to 5, by evaluating in particular the compaction of the different layers observed.).

Soils were sampled with an auger at two depths (i.e. 0-10 cm and 10-30 cm), then analyzed in a laboratory to measure their physical and chemical properties.

3.3.4 Laboratory measurements

The physical and chemical analyses focused on particle size distribution, calcium carbonate ($CaC0_3$) content, total organic C, total N, pH, available P (Olsen method), CEC and exchangeable cations (Ca, Mg, K, Na, Al, Mn, H).

3.4 Inventories of woody biodiversity and above-ground biomass in AFS

3.4.1 Question and hypotheses

Question: How to characterise AFS by their contribution to ecosystem services (carbon sink and biodiversity conservation)?

Hypotheses:

i) The AFS studied differ in their above-ground biomass and degree of biodiversity;

ii) The chronology of transition between the AFS studied shows an increase in above-ground biomass in AFS from the establishment of annual fields (alternating with fallows) or sylvopastoral systems (kept open by fire, cutting and cattle), to old agroforests; and

iii) The above-ground biomass comes mainly from the woody biomass of trees and palms with a trunk or stipe diameter (DBH) greater than 32cm.

3.4.2 Two study areas

Biomass and biodiversity inventories were done in the same plots as soil sampling, that is to say three villages in Gariuai (Baucau plateau) and one village in Samalari (Matebian foothills).

3.4.3 Measurement of woody trees with a diameter of 10-32cm and greater than 32cm

All trees above 32 cm Diameter at Breast Height (DBH) were measured on each plot. Trees between 10 and 32 cm DBH were measured on five quadrats of 100 m^2 each: one at each corner and one at the center of the plot. The DBH and height of each tree were measured (using a clinometer for height), and the local Tetum name was recorded. The Latin names were then associated to each Tetum name with a bibliography search. For each tree we also asked the farmer if the tree was planted by him or the previous land owner or if the tree grew “by itself” and he decided to keep it (natural assisted regeneration).

3.4.4 Calculation of above-ground biomass

The aboveground biomass (AGB) was estimated using the Chave *et al*. (2014) equation; that includes diameter (D), tree height (H), and species-specific wood density as predictors. The species-specific wood densities were retrieved from the Dryad repository "Global Wood Density Database". For the specific case of palm species (Cocos, *Borassus, Corypha, Areca, Arenga*), for which there were no specific biomass allometries available, their biomass was estimated by multiplying their estimated stipe volume (basal area x H stipe x a shrinkage factor of 89%) by an average wood density of 0.6 [refs: https://www.wood-database.com/red-palm/].

4 RESULTS

4.1 Soils

4.1.1 Gariuai soils vs Samalari soils

Overall, Gariuai soils were less clayey, but instead more silty and sandy than Samalari soils. The soils at both sites had high cation exchange capacity (CEC) which is mainly due to exchangeable calcium, leading to an imbalance in the Ca:Mg ratio (i.e. above 7). The Gariuai soils had lower exchangeable Ca, Mg, K and Na content than the Samalari soils. However, they had higher organic C, total N and available P content (Table 1).

Table 1: Summary of physical and chemical properties of soils (averages ± SD) in Gariuai and Samalari plots for the 0-10 cm soil layer. All soil characteristics were determined in fifteen soil plots.

Properties	Gariuai	Samalari
Clay (%)	30 ± 18	56 ± 9
Silt (%)	48 ± 15	29 ± 3
Sand (%)	22 ± 9	15 ± 7
$CaCO_3$ (%)	25 ± 32	22 ± 24
pH water	7.3 ± 1.1	8.5 ± 0.3
Organic C (%)	3.6 ± 1.1	2.4 ± 0.8
Total N (‰)	3.1 ± 1.1	2.1 ± 0.7
C:N	11.8 ± 1.5	11.2 ± 1.4
P (mg kg^{-1})	24.8 ± 33.0	7.2 ± 2.7
CEC (cmol+ kg^{-1})	25 ± 10	36 ± 8
Ca (cmol+ kg^{-1})	22.0 ± 9.7	30.4 ± 6.3
Mg (cmol+ kg^{-1})	1.2 ± 0.8	2.9 ± 1.2
K (cmol+ kg^{-1})	0.3 ± 0.3	0.9 ± 0.3
Na (cmol+ kg^{-1})	0.0 ± 0.0	0.7 ± 0.8
BS (%)	94 ± 5	97 ± 2
Ca:Mg	25 ± 15	13 ± 5

4.1.2 Interaction between soil texture and AFS

The textural classes of Gariuai soils were very variable: clay, clay loam, silty clay loam, loam, silt loam (Figure 2). This variability is partly explained by the AFS since the sylvopastoral and young agroforest soils were only silt loam and clay loam, respectively. But this variability was also high within each of the three others AFS (Forest garden, Home garden, Crop and fallow).

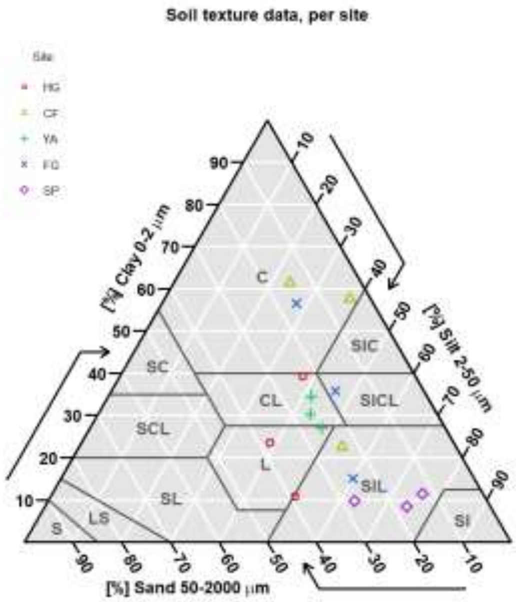


Figure 2: Particle size distribution and textural classes of the 15 Gariuai samples at 0-10 cm depth. C=Clay; CL=Clay Loam; L=Loam; SIC=Silty clay; SICL= Silty Clay Loam; SIL= Silt Loam.

The textural classe of Samalari soils was exclusively clay, regardless of the AFS (Figure 3).

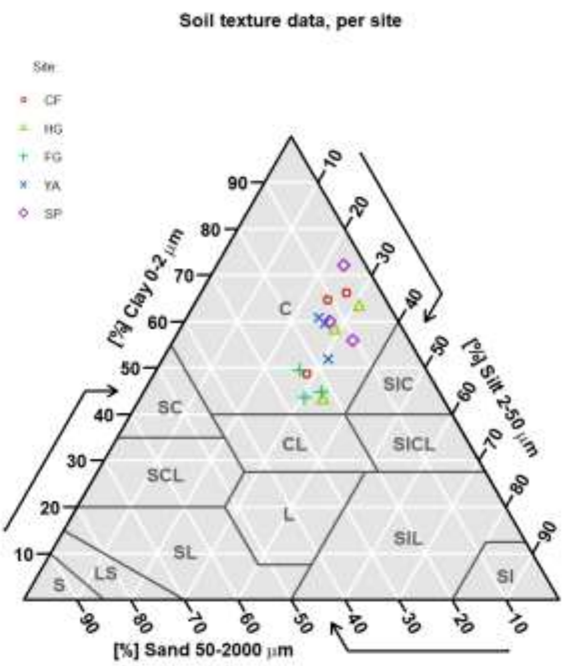


Figure 3: Particle size distribution and textural classes of the 15 Samalari samples at 0-10 cm depth. C=Clay.

4.1.3 Relation between chemical properties and AFS: calcium carbonates (CaCO3) and organic carbon (Corg)

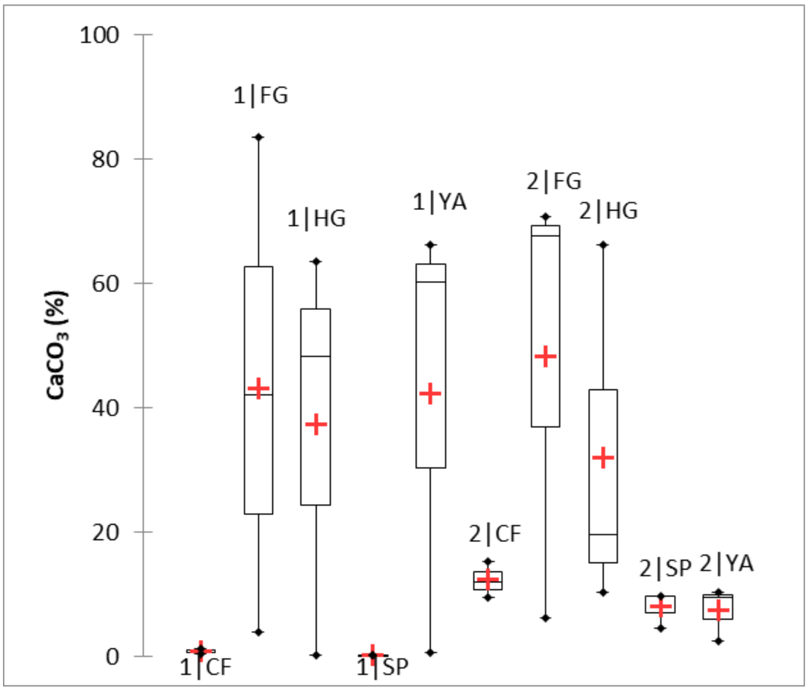


Figure 4: Calcium carbonate content at 0–10 cm soil layer as a function of site (1= Gariuai ; 2= Samalari) and AFS (CF= Crop and fallow; ; FG= Forest garden; HG= Home garden; SP= Sylvopastoral; YA=Young agroforest).

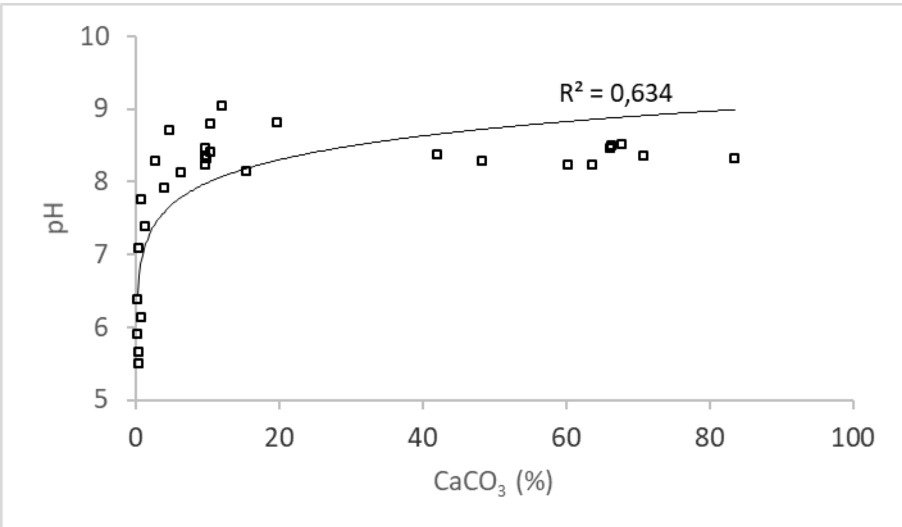


Figure 5: Diplot correlation of calcium carbon content ($CaCO_3$) and pH in the 0-10 cm soil layer for all 30 plots measured in Samalari and Gariuai

The $CaCO_3$ content of Gariuai soils ranged between 0 and 84%. This variability is partly explained by the AFS, since soils of Crop and fallow and Sylvopastoral had no (or almost no ≈ 1%) $CaCO_3$ (Figure 4). These soils were also acidic or neutral (pH between 5.5 and 7.4), in contrast to the soils that contain $CaCO_3$, which were basic. Indeed there is a relationship between $CaCO_3$ and pH (Figure 5).

The $CaCO_3$ content of Samalari soils ranged between 3 and 71%. This variability is partly explained by the AFS, since $CaCO_3$ contents of Crop fallow, Sylvopastoral and Young agroforest were lower than 15% (Figure 4). As all Samalari soils contained $CaCO_3$, they were all basic (pH between 8.2 and 9.1).

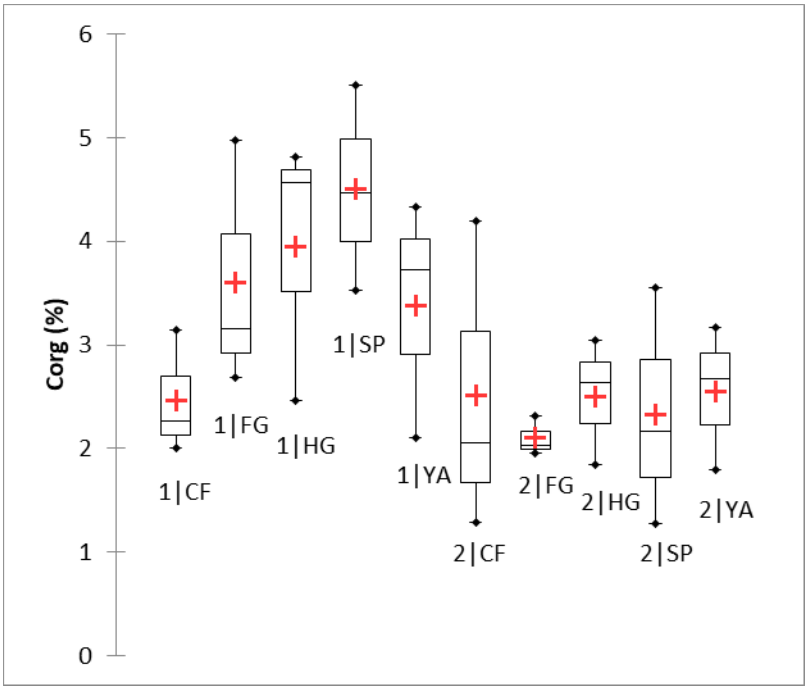


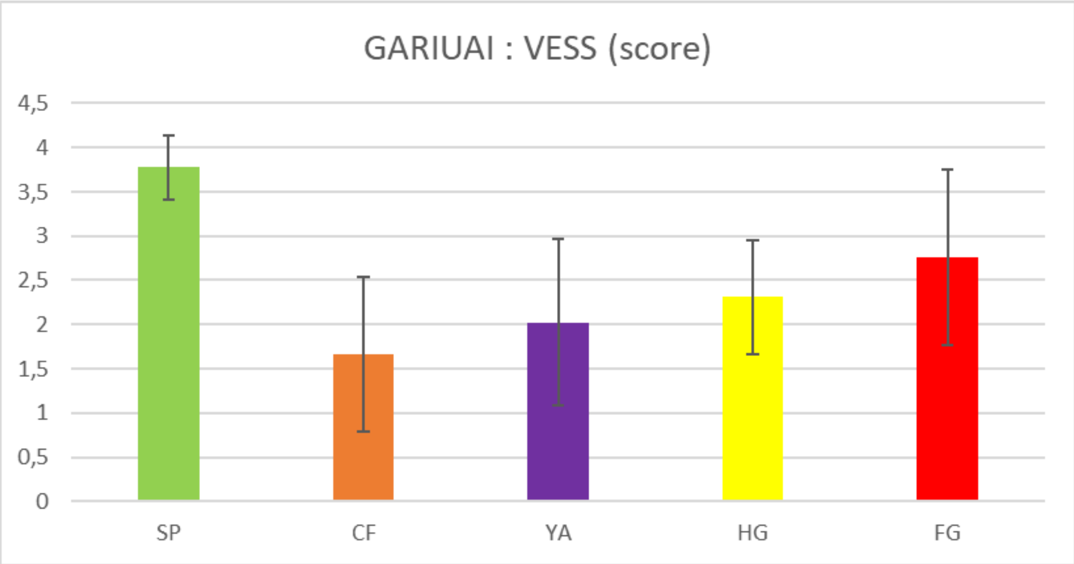
Figure 6: Organic carbon content at 0–10 cm soil layer as a function of site (1= Gariuai ; 2= Samalari) and AFS (CF= Crop and fallow; ; FG= Forest garden; HG= Home garden; SP= Sylvopastoral; YA=Young agroforest). The boxes represent the first and the third quarti

The organic carbon content of Gariuai soils ranged between 2 and 5.5% in the 0-10 cm layer. This variability was not explained by the content of fine elements (Clay + fine silt < 20 µ) (result not shown) as is usually observed in natural tropical forest (Zinn et al. 2005). Instead, it depends on AFS: Sylvopastoral had the highest organic carbon content, while Crop and fallow had the lowest, and the other AFS had intermediate contents (Figure 6)

The organic carbon content of Samalari soils ranged between 1.3 and 4.2 % in the 0-10 cm layer. This variability was not explained neither by the content of fine elements (Clay + fine silt < 20 µ) (result not shown), nor by the AFS (Figure 6)

4.1.4 Physical characterisation 0-30cm: soil compaction

Gariuai VESS results showed that soils were more compacted on less worked soils with an increase from CF score 1.5 (system worked with tractor) to SP score 3.8 (animal trampling, no labour). Samalari VESS results also showed the same results, although the variability between systems was less important as the systems are worked manually. HG score 2 was the lowest as it was the system worked more regularly (Fig. 7).



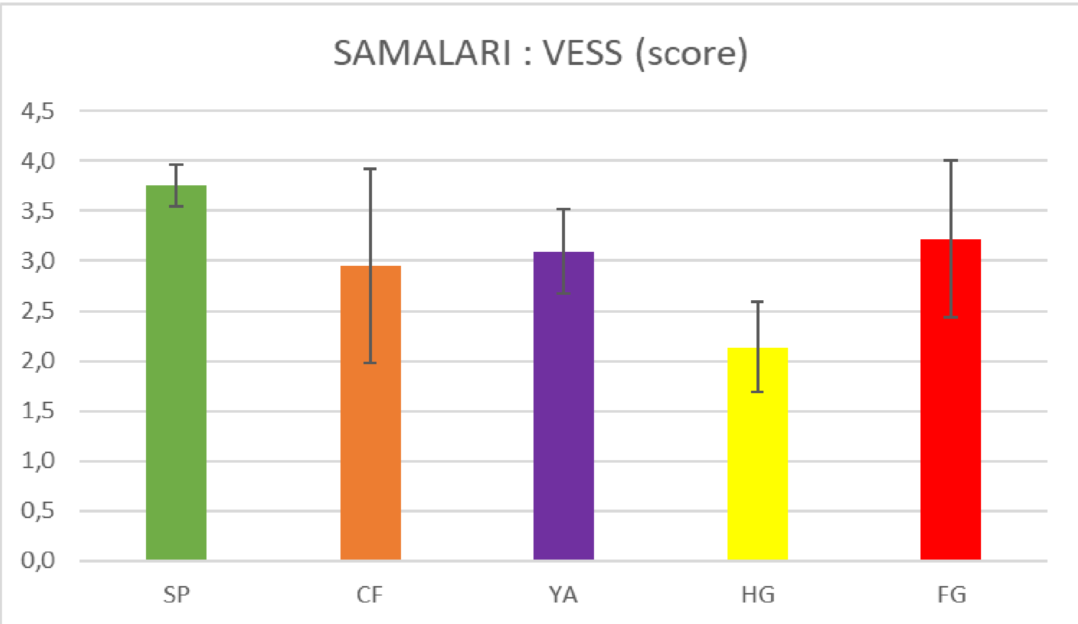


Figure 3: Visual assessment of soil structure (VESS) in Gariuai (top) and Samalari soils (bottom) using a scoring method (from 1 for poorly structured, loosely compacted soils, to 5 for more compacted soils) as a function of AFS (CF= Crop and fallow; FG= Forest garden; HG=Home garden; SP= Sylvopastoral; YA= Young agroforest)

4.2 Inventories

4.2.1 Biodiversity of trees >32cm diameter

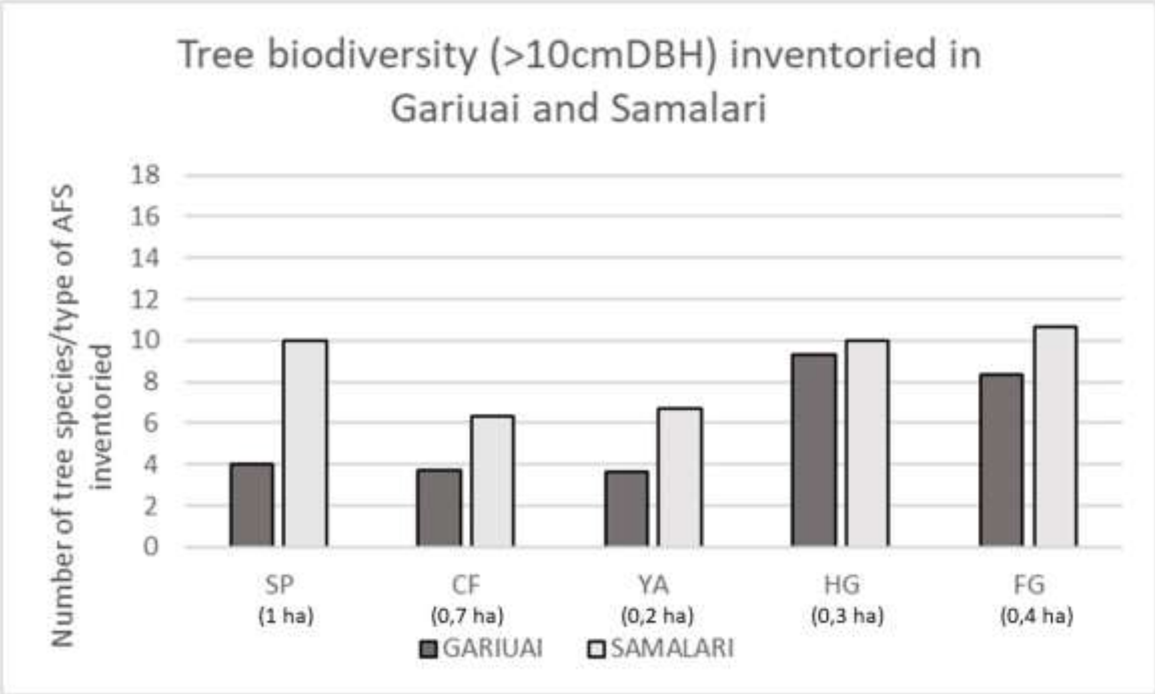


Figure 4: Number of different tree species (> 10cm diameter) inventoried in Gariuai and Samalari per type of AFS (CF= Crop and fallow; FG= Forest garden; HG=Home garden; SP= Sylvopastoral; YA= Young agroforest). The mean surface area of each plot had been reported on the graph.The number of different species in the 3 replicate plots was counted and averaged per type of plot.

FG and HG were the most diverse systems (between 8 and 11 species planted and not planted) in both villages (Fig. 8). Less diversity is found in Gariuai's plot. Especially, YA of Samalari were almost twice as diverse as Gariuai's ones, while they contained more spontaneous trees kept in the system. SP (except in Samalari), CF and YA were the least diverse systems: they are supposed to be kept open by fire, cutting and cattle grazing and there is a limited selection of cultivated species such as fruit trees or introduced foresters. The Samalari SP showed a number of tree species equivalent to that found in the plots inventoried in the FG and HG. However, the species were different: FG and HG are palm-dominant while SP are represented by legumes (fodder trees) and spontaneous timber trees (wood-energy and timber).

4.2.2 Inventories: tree density within the plot

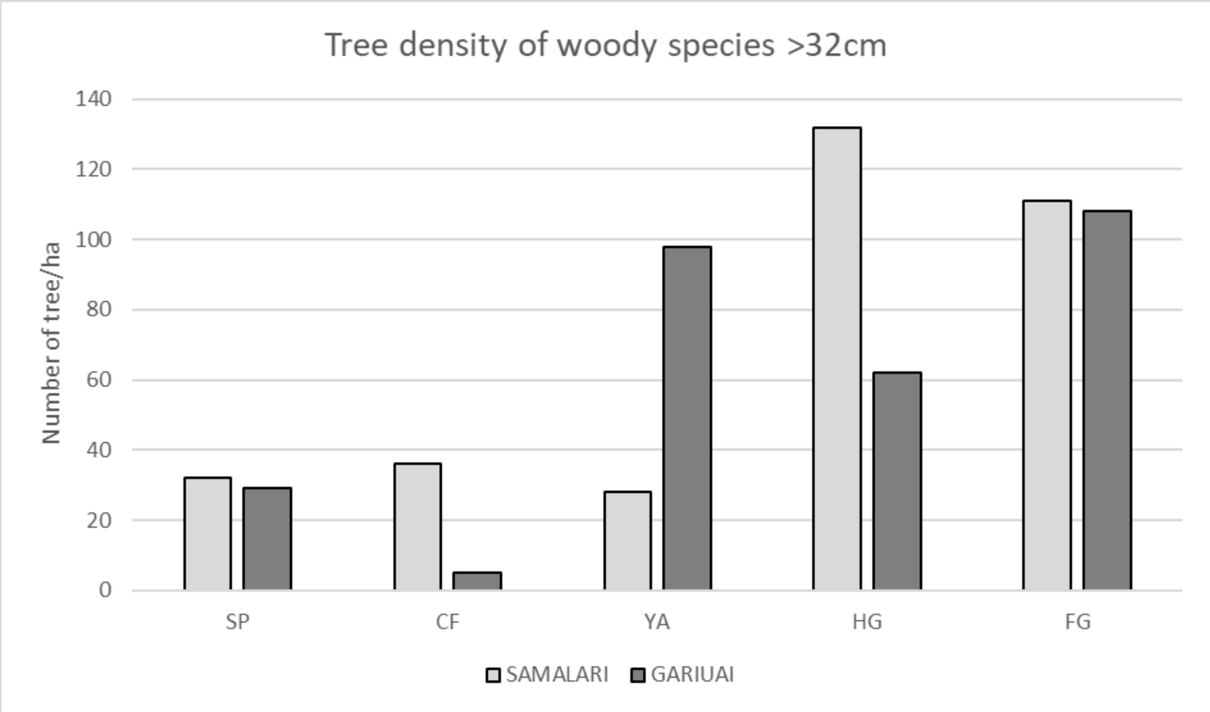


Figure 5: Tree density comparison between the 5 AFS (CF= Crop and fallow; FG= Forest garden; HG=Home garden; SP= Sylvopastoral; YA= Young agroforest) inventoried in Gariuai and Samalari

The tree density (in terms of number of standing trees per ha) was similar between Gariuai and Samalari for FGs and SPs (about 110 trees/ha and 35 trees/ha respectively). The tree density was higher in the annual fields (CF) and homegarden (HG) of Samalari (Fig. 9).

4.2.3 Comparison of above-ground biomass

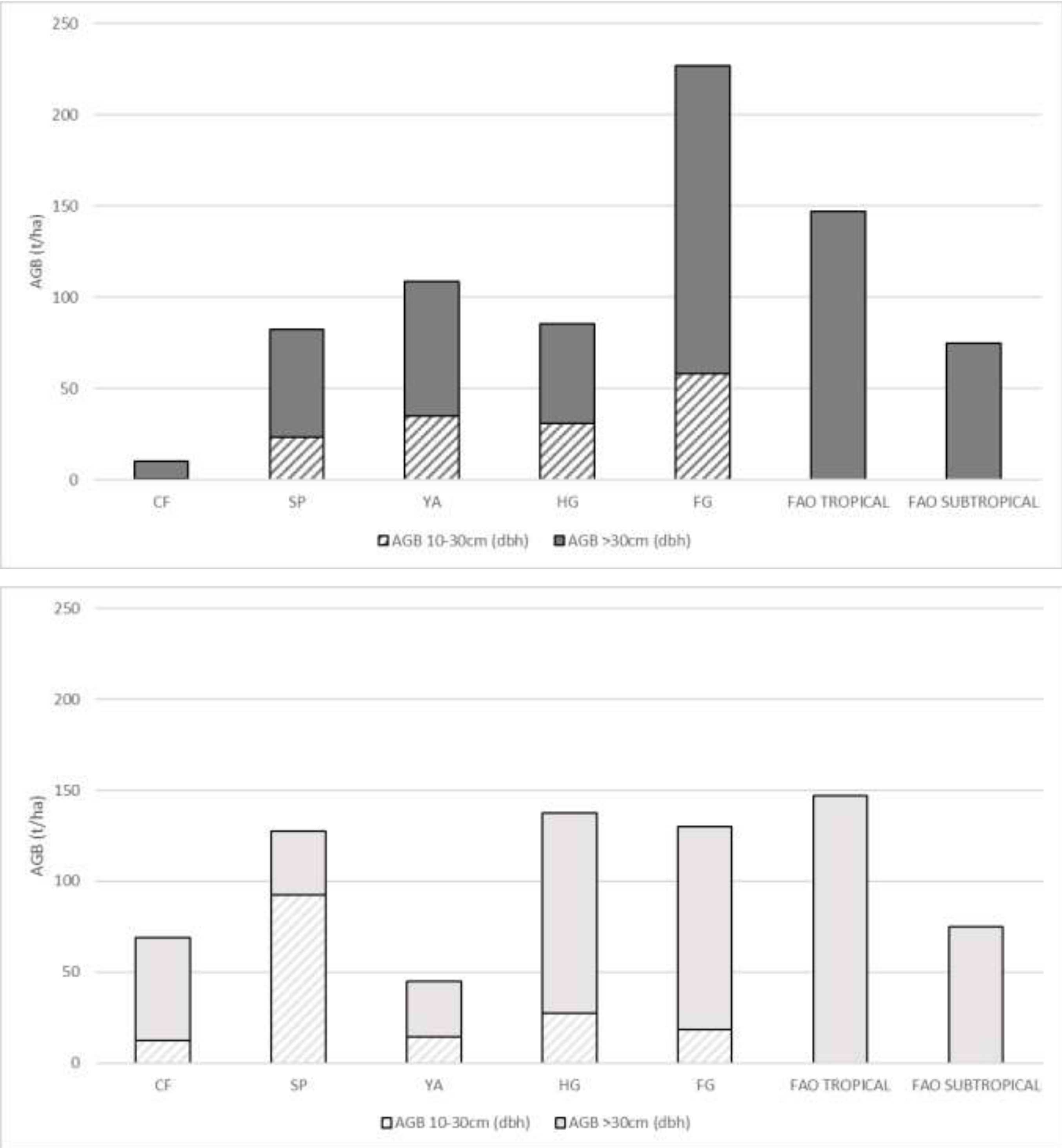


Figure 6 : Comparison of above-ground biomass (AGB) between 5 AFS (CF= Crop and fallow; ; FG= Forest garden; HG= Home garden; SP= Sylvopastoral; YA=Young agroforest) and FAO standards taking into account tree DBH between 10-32cm and more than 32cm in [Top, dark grey] Gariuai and [Bottom, light grey] Samalari.

AGB in each study area and for each system among the two ranges of trees measured at 10-32cm and more than 32cm DBH (diameter at breast height) were calculated. In addition, they were compared with standards for tropical and subtropical forests estimated by Santoro et al, 2021 (FAO project) in Figure 10.

In Gariuai, AGB values were highly variable, ranging from 13t/ha for annual cropping systems including fallow (CF) to almost 230 t/ha for old agroforests (FG) which reflected a high density of large trees (higher above-ground biomass than the standards assessed for tropical forests by FAO). For all systems, most of the above-ground biomass were represented by large trees (more than 32cm in diameter).

In Samalari area (Osso Luga village), as in Gariuai, the majority of above-ground biomass were represented by trees larger than 32cm in diameter, except for the sylvopastoral systems (SP) where trees from 10 to 32cm are in majority. The young agroforest (YA) showed the lowest biomass stock with 45t/ha. In Samalari, FAO standards for tropical forests showed higher values than old agroforests (FG=129t/ha; FAO tropical= 147t/ha).

4.3 Relationship between above ground biomass and soil organic carbon

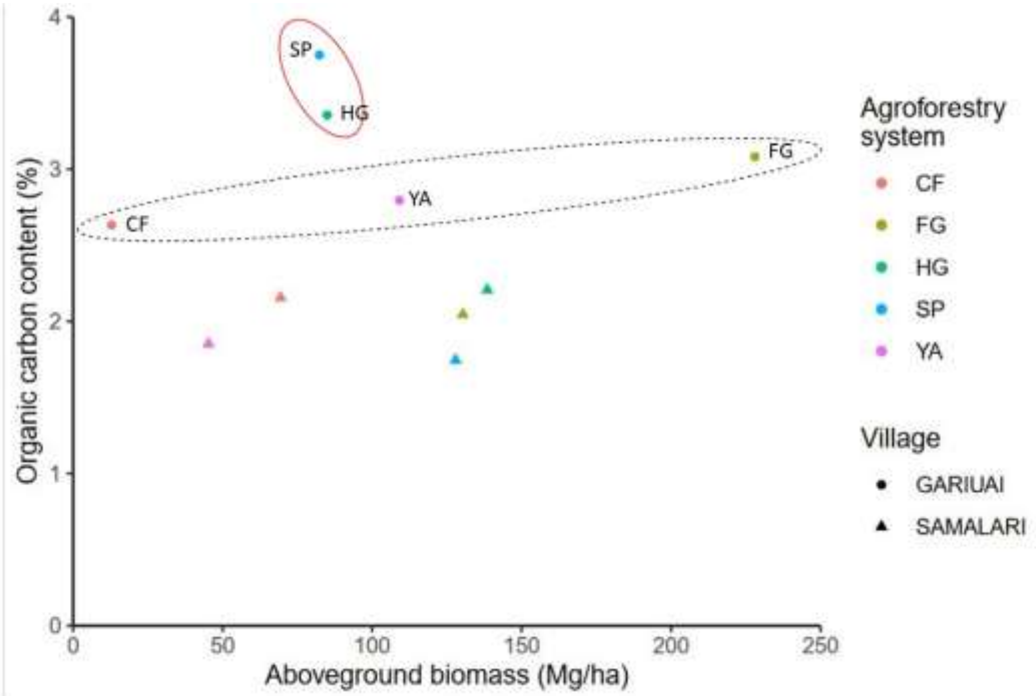


Figure 7: Biplot of organic cabon content in soil (Corg) and aboveground biomass (AGB) in Gariuai and Samalari suco (CF=Crop and Fallow; FG=Forest Garden; HG=Home Garden; SP= Sylvopastoral; YA=Young Agroforest).

Values of soil organic carbon content (%) and aboveground biomass (Mg/ha) were averaged for each type of AFS in each village (Samalari and Gariuai). The results suggested that there is a slight positive correlation between Corg and biomass for CF, YA and FG systems in Gariuai respectively: the more the above-ground biomass increases, the more organic carbon is stored in soil organic matter (Fig. 11).

HG and SP of Gariuai were above the curve drawn by the other systems. It means that these systems stored more organic carbon in the soil than the other systems. This organic carbon may come from other sources than above-ground biomass measured in trees, for example animal and human waste.

We couldn't draw any relation between organic carbon content and above-ground biomass in Samalari.

5 DISCUSSION

5.1 Historical dynamics as a factor of variability in result analysis

The results between Gariuai and Samalari *suco* were very different in terms of soils (Figures 2, 5, 6 and 7) and above-ground biomass content (Figure 10). This can be related to the fact that these two areas are also very different in terms of historical dynamics: on the one hand, an area that has been constantly evolving through human action since the Portuguese colonisation (Gariuai), and on the other hand, an area that was left abandoned for more than 30 years before being re-invested by human hands (*aldea* Osso Luga, *suco* Samalari). This supports our argument that it is preferable to consider the *suco* of Gariuai as a base for the evolution of the agroforestry systems studied, which has been built up over a significant number of years without too much disturbance. Moreover, people who came back in Samalari after 30 years of exile might have changed land ownership, especially since actual homegardens have been displaced close to the main road on the mountain ridge that did not exist before 2002.

5.2 Identification of 5 distinct AFS characterised by their degree of density and biodiversity

Five distinct AFS systems were identified in Baucau district within the two *sucos* studied. Inventories and soil samplings suggest that they are distinguished by two main criteria: the density (Figure 9) and biodiversity (Figure 8) of the selected trees and palm species (cultivated and/or spontaneous). To a lesser extent, these systems can also be characterized by the amount of organic carbon present in the soil (Figure 5). These criteria are related to the different historical knowledge and practices applied in these systems by the farmers: the relative importance given to crops, livestock, cultivated palm and trees (fruits, fodder, handcarft, shadow, fertilization…), forest resources (firewood, timber and fodder especially), tillage and cutting capacity (motorized and/or manual). For example, the lower density observed in CFs and HGs of Gariuai (Figure 9) compared to Samalari may be due to the fact that farmers have more limited means for tree cutting and non-motorised agriculture in the latter village.

This distinction between the five agroforestry systems was made thanks to the different local names by which farmers describe them. We propose a typology summarized in Table 2:

Table 2: Typology of agroforestry systems

	CROP SYSTEM INCLUDING A FALLOW PHASE (CF)	SYLVOPASTORAL (SP)	YOUNG AGROFOREST (YA)	HOME GARDEN (HG)	FOREST GARDEN (FG)
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 julibrissin* , 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*
Other names					
Tetum/tetum terik	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

5.3 Interactions between the 5 AFS: fertility transfers

In the results, we found out that there is a slight correlation between Corg and above-ground biomass content in Gariuai (Figure 11). This suggest that there are interactions between these different AFS within the production system or within the village land. This is expressed in particular at the level of fertility transfers. On the one hand, the density of trees in the system increases the carbon storage capacity in the plant biomass and in the organic matter (litter) through so-called vertical transfers. On the other hand, this plant biomass can be consumed, transformed and transferred between systems via animal and human waste through so-called horizontal transfers, which is probably the case in SP and HG systems of Gariuai. Thus, some systems (in particular SP and HG) would accumulate organic matter by importing it, while others would export it (CF).

5.4 Agro-ecological benefits of AFS: carbon storage in biomass and soils.

In general, the results of soil analysis (Figure 5) and biomass inventories (Figure 10) suggest that all these systems can store significant amounts of carbon, which would contribute to climate change mitigation. In particular, some systems such as homegarden (HG), forest garden (FG) and sylvopastoral (SP) systems approach or exceed the biomass storage standards of tropical forests as assessed by *Santoro et al* (2020). This implies that agroforests should be considered as systems of interest in the carbon payment policies that are currently widespread throughout the world.

However, the different dynamics observed between the soils of Gariuai and Samalari show that the beneficial impacts of agroforestry systems on the physico-chemical characteristics of soils must be interpreted with caution and patience. In the village of Gariuai, where the population has been established for several decades, a difference in texture, structure and organic carbon content can be observed. This is not the case in Samalari where the systems observed are younger (less than 17 years).

5.5 Farmers' knowledge of agroforestry in relation to soils and production system

Soil results suggested that AFS have a relative impact, over a long period of time, on the improvement of the physico-chemical characteristics of soils (Table1, Figure 2 and 6). However, texture (Figure 2) and pH (Figure 4) measured in Gariuai suggest that the choice of farmers to implement a certain type of AFS is influenced by their knowledge of the intrinsic characteristics of these soils. Indeed, there is a clear distinction between the CF and SP systems, which are preferably located on stony, acidic flat lands, while the others (HG, FG, YA) are more likely to be located on the more basic colluvial slopes. This knowledge acquired through experience has been developed over a longer period of time in Gariuai than in Samalari due to the historical influences on population movements in Timor-Leste. In addition, the typology of AFS (Table 2) based on local names and species (cultivated and spontaneous) demonstrates the importance of these systems within Timorese production systems and the detailed knowledge of their uses and functions by farmers.

5.6 Functional uses, resources availability and historical influences on AFS development: AGB comparative analysis

AGB results in Gariuai and Samalari (Figure 10) are quite illustrative of the different factor interaction occurring while AFS are expected to meet needs, depending on the resources available and the historical framework in which they are currently embedded.

The biomass rate in all systems (about 50t/ha and more) shows the importance of **tree conservation by farmers** in all cropping systems in these dry **mountainous areas** (by constraint and/or strategic choice).The linear transition of biomass between one type of AFS to another (especially from CF to YA to FG) is not systematic (see AGB decrease between CF and YA in Samalari, Figure 10) as it is highly dependent on **family strategy** that might change from a generation to another, following specific needs that might have to answer to **unpredictable crisis** at the collective or individual level (ex: war, drought, fluctuating market prices, traditional ceremonies related to death etc.). This tree conservation in all AFS is then essential to answer these different crises at any time and act as "resource stock".

For example, SP biomass comparison reflect several different functions linked to the historical settlement of people in the two different *sucos*. In Gariuai, the area was **continuously exploited** during the different phases of Portuguese and Indonesian occupation until independence. There, the most important above-ground biomass is that of large trees because there is greater pressure from grazing and the collection of firewood due to the greater **population density** in this area than in Samalari. Indeed, in the main common SP area of Gariuai, 7 to 8 villages share the space (which represents around 150ha/village) while in Osso-Luga *aldea* (*suco* Samalari), the SP area is wider (around 250ha). However, the Gariuai SPs values tend to reflect that they are reaching a certain balance with the retention of 1/3 of the saplings to renew the older trees and preserve these areas for grazing as well as the continuous harvesting of firewood for decades.

Another difference highlighted by AGB results is about the technical means available in these two sucos. Contrary to Gariuai, Samalari farmers did not use **motorized tools** (due to the steep slope) to prepare the annual crop fields in the rainy season (CFs). Thus, due to manual labour hardness, farmers left a higher density of trees standing (more than 50t/ha AGB). It was true especially for trees larger than 32cm but also between 10 and 32cm in diameter (DBH). This result can also be explained by the need to have areas of shade during the dry season to allow animals to graze in the fields (fertility renewal) and to avoid soil slumps due to the **steepness** of the slopes (surveys).

In AGB results, we also observe that while there was an increase of biomass in Gariuai YA compared to CF ones, there is paradoxally a decrease in Samalari YAs. This can be explained by the fact that at the time of the measurements in Samalari, the trees were still very young (1 to 3 years old) and the farmers had cleared their fields more extensively to replace the spontaneous trees in the middle of the field with trees planted in rows with regular spacing**.** More **water** available in Gariuai during the dry season may also explain the difference of diameter observed between YA AGB in both sucos.

In addition, home gardens (HG) inventoried in Gariuai had more biomass than the ones of Samalari which can be related to the **historic length of the systems** (i.e. "old" and "new" homegardens). Indeed, in homegardens of Gariuai, some trees have been conserved since more than 50 years while homegardens measured in Samalari have just started to be planted in 2005. It suggests that multi-stage agroforests need time (more than 20 years) to reconstitute themselves from their initial secondary forest stage that have been cleared then replanted over the years. The AGB of Gariuai forest gardens (FG) calculated also had a higher content than in Samalari ones. It suggests a second trend that happened in villages that have gone through big **perturbation** during the Indonesian occupation. When people came back to Samalari, FGs probably constituted **a stock of available resources**, including wood, to rehabilitate the village and income to sell at the beginning.

6 CONCLUSION

6.1 Soils

For soil, the hypothesis 1 was validated: Overall, the main soil properties in Gariuai were different from those in Samalari.

The hypothesis 2 was partly validated: In Gariuai, there is a relationship between AFS and soil properties. This relationship is mainly due to SP soils that were clearly different from the soils of FG, HG and YA.

The hypothesis 3 was validated: In Samalari, there is no relationship between AFS and soil properties. Samalari soils were similar regardless of the AFS.

6.2 Biomass and biodiversity

For biomass and biodiversity, the hypothesis 1 is validated: The AFS studied differ in their above-ground biomass and degree of biodiversity.

The hypothesis 2 is partly refuted: Biomass does not increase in a linear way if we follow the transition chronology from one AFS system to another (from SP to CF to YA to HG then to FG). In fact, biomass depends mainly on the type of management depends mainly on the degree of harvesting or enrichment of each AFS. There may be a decrease in biomass between CF and YA (Samalari) or YA and HG (Gariuai). FG on the other hand always have a higher amount of biomass than CF.

The hypothesis 3 is refuted: The above-ground biomass of smaller trees may be greater than the above-ground biomass of larger trees as it is the case of SP in Samalari. From this result we can deduce that it would be interesting to adapt the study protocol for root biomass and non-woody biomass in these agroforests.

Finally, it is important to note the **evolutionary character of the AFS** identified. Systems that require a reduction in tree biomass at a given time (e.g. CF) are capable of evolving and reconstituting their biomass, and thus increasing carbon storage, to a level that is sometimes even higher than certain standards calculated for tropical forests.

6.3 Recommendations

To conclude this report, we propose several recommendations for the technicians and institutions responsible for the development of agroforestry in Timor Leste (MAF, universities, etc.). This experience and the sampling choices made since the beginning of our research mission allow us to extend these recommendations from Baucau district to the other districts concerned by the Ai ba Futuru project:

Table 3: Technical and institutional recommendations

Result/Discussion	Technical recommendation	Institutional recommendation
1 : Identification of 5 AFS	The typology should be used to communicate with farmers about agroforestry (relative to uses and functions). English names need to be translated and reinterpreted according to the local language.	Adapt the semantics used in the projects to the locally used names
2 : Systems characterised by their variation in density and biodiversity	Understand the functions of the different agroforestry types implemented and explained by farmers (with their necessary density variations) to adapt techniques and improve the system. The density of woody plants concerns the intermediate storey (shrubs) and the dominant storey (large trees), which must be managed by the farmers to provide the optimum amount of light to the crop understorey, depending on the species grown.	Strengthen teaching and technical application capacity on the diversity of agroforestry systems (including traditional systems already present and identified in Timor Leste).
3 : Interactions between the 5 AFS: fertility transfers	Technicians need to consider the interactions that exist within farmers' production systems. Fertility transfers are a good example: animals eat in some plots, crops and wood are harvested in others, while dung, ash, litter, etc. are concentrated near houses or livestock pens, so that organic or mineral elements are concentrated there. When they notice a drop in fertility on a plot of land, the technicians can rely on other "innovative" farmers who are already implementing techniques to valorise manure by organising group meeting and visits to their homes in order to disseminate these techniques to as many people as possible. Technicians can also propose to share, with farmer who wish, new techniques and plant materials to which they have easier access (through literature, their experiences outside the village, etc.).	Promote communication between different disciplines and between different professions: between technicians (livestock, agriculture, forestry), with universities (teachers and students) and with farmers.
4 : Agro-ecological benefits of AFS: carbon storage in biomass and soils.	Technicians should promote agroforestry as a system that can restore soil fertility after several decades. If agroforestry is presented as a short-term solution, it would discredit technicians and discourage farmers from disseminating agroforestry practices.	In economic strategies related to carbon markets, not only "forests" but all agroforestry systems that have proven their capacity to store carbon in biomass and soils must be taken into account.
5 : Farmers' knowledge of agroforestry in relation to their production system	To improve agroforestry systems, the technician must take into account the farmers' knowledge of their soils (thickness, sensitivity to erosion, "fertility" for the dispersal of elements, compatibility/incompatibility of the type of soil with certain plant species) and of the uses and functions of spontaneous species (fodder, firewood, timber, fruit, fermentation, etc.) as well as species that have been introduced over the past few years (fruit trees, timber-producing trees).	Adapt agricultural development programmes to the resources (knowledge, plant species, etc.) already present locally.

To illustrate our point, we also propose various examples of application reported in Table 4.

Table 4: Example to apply technical and institutional recommendation

N°	Example of application
1	See illustrated typology sheet in the socio-economic report (Cogne M. et al, 2022, Annex 3)
2	**Technique:** Promote existing local techniques such as oxen pens in rotation with annual crop fields (CF) or composting and wastewater recycling techniques (orientation of toilets and pig paddocks with the slope to fertilise trees and crops) in homegardens (HG). Other exogenous techniques can also be promoted among "innovative" farmers who wish so, e.g. improved pens (mulching), compost pits located close to CFs to improve fertilisation and reduce material transport distances. **Institutional:** facilitating the means of accompanying technicians (particularly in terms of transports to isolated rural areas) or university internships directly with families and in coordination with the technicians in charge of the suku.
3	
4	**Technique :** Disseminate the preservation/selection of local species considered useful by the village farmers (aldea and/or suku scale) to preserve both cultivated biodiversity and local know-how (e.g. through assisted natural regeneration). It is also necessary to take into account the farmer's personal project: it is preferable to distribute 20 trees that he will plant in the right place, that will meet his production or service requirements and that he will manage with care, rather than planting 100 that he will let burn or be destroyed by livestock. **Institutional:** certify these "useful" spontaneous species selected by farmers to benefit from carbon credit equivalents (and thus reduce the need to import exotic species already certified).
5	**Technique E1:** In sylvopastoral areas, promote the selection and preservation of useful fodder and firewood species and draw up grazing management plans in consultation and coordination with the village(s) that use the area. In particular, by studying together the animals' grazing areas and by putting in place means of protecting young trees adapted to these areas and/or by controlling the animals' grazing (parks/pickets/guards) by explaining the interest in renewing the resources of this area (fodder/firewood) via the techniques adopted by the families of the villages concerned.
	Technique E2: In annual crop fields alternating with fallows (CF) and young agroforests (YA), it is possible to support the selection of species that will outline the perimeter of the plots while leaving good clearings for the cultivation of cereals (hedgerows) according to the need, the production system and the land capacity of the farmer (timber, fodder, fruit) and accompany them in the maintenance of the hedgerows (pruning, spacing of plantations, etc...)
	Technique E3: In young agroforests (YA) or young home gardens (HG), if the trees have been planted at a high density (e.g. 4 x 4 m spacing), as soon as the crowns of the trees meet, the plantation must be thinned to allow them to develop a stronger trunk and to favour fruiting. For example, 1 tree out of 4 planted can be removed when they reach 6m in height (removing the least attractive or most troublesome), 1 additional tree out of 4 planted when they reach 10m in height and 1 tree out of 4 planted when they reach 15m in height.
	Technique E4: In mature agroforests (FG) or dense home gardens (HG) it is often necessary to gradually rejuvenate the stand by cutting fruit trees that are dying or whose products have become of little value. It is also desirable to cut timber-producing trees that have reached the diameter where they can be sawn, or where there is a monetary need. It is then possible to create a clearing of 10 to 20 m in diameter, in which the farmer can grow light-demanding cereals such as rice or maize. Within this cultivated clearing, the farmer can plant young trees of the species he wants, if possible with plant material selected by him or improved by the state services. In this way, the farmer "gardens" the trees in his agroforest, just as he gardens the vegetables in his kitchen garden. Technicians can recommend this type of agroforest renewal by clearing or "gardening" whenever it is preferable to preserve soil fertility, limit erosion, conserve biodiversity, biomass and the eco-climatic environment. In fact, renewal by clear-cutting the agroforest, which leaves the soil bare, rapidly loses the fertility of the plot and its biological capital.
	Institutional: strengthen the training offer in universities, agricultural schools, MAF offices in Dili and in the districts to democratize the term agroforestry and make the link with already existing systems in Timor.

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