MONITORING OF GROWTH AND HEALTH OF NATIVE TREE SPECIES IN AGROFORESTRY SYSTEMS IN THE PERUVIAN AMAZON USING MOBILE ELECTRONIC DEVICES

FINAL REPORT

AUTHOR: JULIO VASQUEZ, Plant your Future

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I. INTRODUCTION

It is estimated that over 7.9 million hectares of the Peruvian Amazon Rainforest have been deforested to date, an area approximately the size of Scotland. On average, 150,000 hectares disappeared every year in the period 1990 – 2000, a rate which represents, as the Peruvian Ministry for the Environment (MINAM) declared, a gigantic economic and ecological loss (MINAM, 2011[1]). In fact, this trend was accompanied by substantial biodiversity loss while contributing to climate change and perpetuating poverty amongst local communities. Unsustainable smallholder agriculture and ranching are the principle drivers of deforestation and degradation in the Amazon basin of Peru. Plant your Future (PyF) aims to relieve smallholders of their reliance on these activities by implementing a market-orientated agroforestry model following a pragmatic approach.

Since 2012 PyF has been working with smallholders to restore degraded lands, promote sustainable agriculture and reduce deforestation pressures near the buffer zone of the Allpahuayo Mishana reserve. This work has consisted of establishing agroforestry plots of native fruit and timber species, on smallholder lands. To date we have implemented 20 hectares of agroforestry systems using a two-stage process; the first stage trees were planted 43 months prior to their evaluations; the second stage trees were planted 20 months prior.

The PyF project has however, encountered certain limitations, mainly as a result of insufficient technical information regarding the criteria that impact the growth and health of timber and fruit species within the agroforestry plots. The project's limitations further challenge the adoption of large-scale agroforestry; indeed, this will only be conceivable when a clear technical methodology exists for the guaranteed success of these systems and justifies the time, energy and resource investments that are required of the farmers with regards to the establishment and maintenance of agroforestry systems.

To address these issues and limitations, PyF initiated the "Monitoring of Growth and Health of Native Tree Species in Agroforestry Systems in the Peruvian Amazon using Mobile Electronic Devices" Project, with the Support of the Rufford Foundation. This Project aimed at developing a monitoring tool to evaluate the different criteria that impact the growth and health of native fruit and timber species in the agroforestry plots. This tool guides the identification and selection of potential species for future agroforestry plots. The monitoring system put in place quantified the amount of carbon captured and the potential sale of carbon credits which will also benefit the farmers in the medium term.

II. OBJECTIVES

General Objective:

- Develop a monitoring tool that enables a rigorous assessment of the different criteria that impact the growth and health of the native fruit and timber species in the agroforestry plots.

Specific Objectives:

- Develop a customised Open Data Kit (ODK) form, to be accessed through mobile devices and that facilitates the recording of data collected during the monitoring of the trees.
- Determine the main criteria that impact the development of the tree on degraded lands in the Peruvian Amazon
- Identify and select the appropriate fruit and timber species for the establishment of future agroforestry plots.
- Improve the skills and technical abilities of the farmers with regards to the assessment and evaluation of the criteria and the use of mobile devices.
- Generate monitoring information on the carbon captured by the trees in the project.

III. MATERIALS AND METHODS

3.1 AREA OF INTEREST

The study investigated 21 agroforestry plots, distributed between kilometres 14 and 33 of the Iquito-Nauta highway, close to the Allpahuago Mishana National Reserve (Figure 1). These plots of land are located within the Palo Seco, Moralillo, Varillal and 13 de Febrero communities. These are all found in the San Juan Bautista District of the Maynas Province (Loreto Department, Peru).

The climate within the research area is classified as both humid and warm, with a mean annual temperature of 26°C and an average annual precipitation of 2,600 mm. The winter season is not particularly different with precipitation and temperature levels remaining fairly consistent throughout the year. In addition, this area is marked by high humidity levels, fluctuating between 80-88% (SENAMHI).

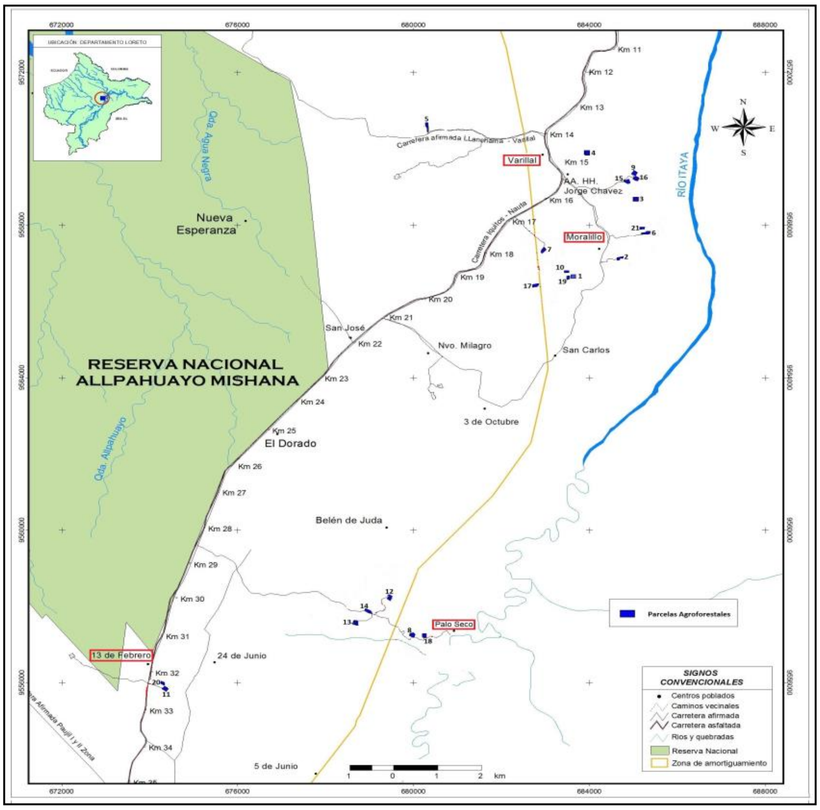

Figure 1: Map depicting the locations of the assessed agroforestry plots (Map: by PyF)

3.2 SELECTING THE CRITERIA

3.2.1 Selection of possible criteria:

The project's first step consisted of drafting up a list of all the possible criteria that could impact upon the growth and health of native fruit and timber tree species in agroforestry systems. This entailed reviewing literature and visiting the plots of land of the Empresa Bosques Amazónicos (BAM) in the city of Pucallpa; this was carried out by several professionals who are experts in these particular species with the help of the PyF team.

3.2.2 Workshop with the farmers:

The second step involved a workshop with the PyF farmers who are from four different communities (See Appendix 1: Photos of meetings and the workshop with the farmers). During the workshop, several themes and ideas were discussed in order to inform and raise awareness about the monitoring process, to explore the function and importance of each of the suggested criteria to be assessed, to agree on participation within the project and to touch upon the anticipated results and benefits. Furthermore, the workshop included some time and space for the farmers to present their opinions, suggestions or questions.

3.2.3 Final selection of the monitoring criteria:

After having informed and requested ideas and input from the farmers, the criteria for evaluation was agreed upon. These criteria, which were later recorded in the forms, were the following:

General information:

- Farmer's name
- Plot number
- Sub Plot focus group number
- Sub Plot's geographical location
- Number of live and dead trees in the sub plot

Technical information:

- Tree name (common or scientific name)
- Date of tree planting
- Diameter at breast height of the tree (cm)
- Total height (m)
- Phytosanitary state of the tree
- Vigour/health of the plant
- Lighting intensity or light exposure
- Maintenance of the tree

Field features (soil related criteria):

- Soil texture
- Slope of the terrain
- Drainage system efficiency

3.3 DEVISING THE FORM AND DOWNLOADING THE COLLECTED INFORMATION

A customised ODK form was created in collaboration with the PyF team and volunteers from England and used to record the information and data. Doing so required telephone/Skype meetings to discuss details and format. The ODK software enabled the form to be used and filled out on mobile devices (phones), for subsequent upload of the information onto a server. The server collected all the data from all of the smartphone mobile devices and this information could then be exported into an Excel archive.

This application provides an efficient method of recording and uploading data and information, compared to the traditional method of using pen and paper to record data and then inputting this into Excel spreadsheets.

The drafted form was used and trialled by PyF volunteers in certain plots of land in order to identify issues with the form and come up with solutions to improve the efficiency of the evaluation and assessments.

The following steps were necessary for devising the form and downloading the information:

a) **Devising the survey form in the Excel format:** As a first step, it was necessary to translate the survey questions into computer code for the Excel archive. The Excel form consists of three levels: one with general questions regarding the agroforestry plots, one with questions on the focus group sub plots and the last one on questions regarding the individual trees. Using "selection" clauses or conditions in the 'relevant' column of the Excel spreadsheet (similar to the 'if' clauses in Excel), these stipulations allowed for irrelevant levels of questions to be skipped; for example, the questions on the plot and sub plot only had to be addressed and completed once.

b) **Upload the completed form to the server and ODK aggregate:** After completing the form, it was uploading to the server and added to the ODK aggregate (an Excel form of with all the evaluations – see Figure 2: How to use the Excel form). The Excel form translates the data into computer coding for a much more efficient process that enable questions to be skipped if irrelevant.

c) **Downloading the forms to mobile devices:** After uploading the form to the server's ODK Aggregate, it was downloaded onto mobile devices; to enable this, the mobile devices had to have an ODK Collect application (See Figure 2: How to use the Excel form).

d) **Registering and recording data using the mobile devices:** Once the forms downloading to the mobile devices, data regarding the plots, sub plots and the trees was recorded. Using this form offers the possibility of not only recording information on selected criteria, but also of including photos that depict the state of the plants and infestations. Following the evaluations, and using an internet connection, the information was uploaded to the server for subsequent analysis (See Figure 2).

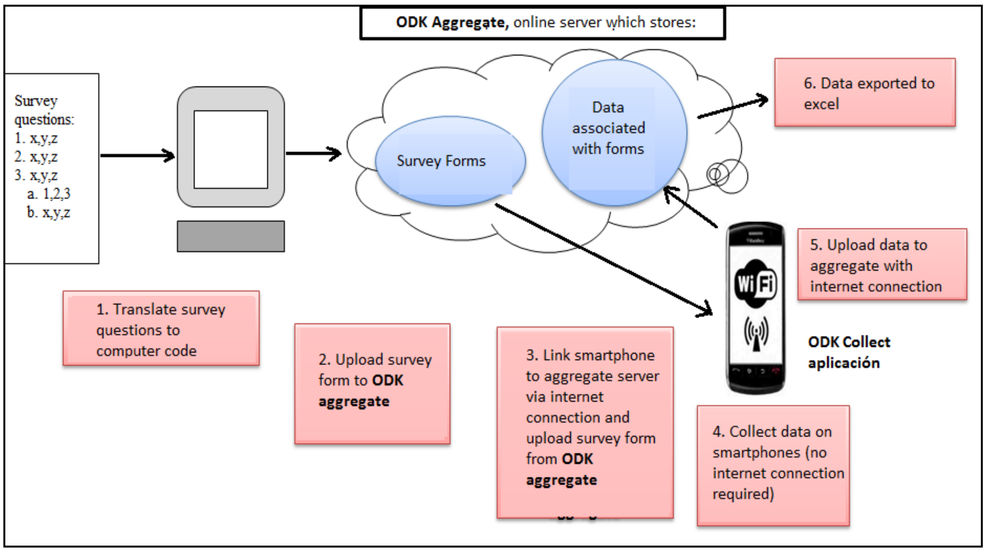

Figure 2: Diagram depicting how the ODK form was created, how the data was collected, and how an aggregate was created. (Diagram made by PYF)

3.4 FOCUS GROUP DESIGN

3.4.1 Dimensions of the sampling sub plots

The research consisted of establishing 60 circular sub plots, each with a 7 m radius (see Figure 3) within which to carry out monitoring of tree growth and health. GIS maps of each agroforestry plot were used as a means of identifying and locating each plot. The centre of the subplots was then randomly selected (see Figure 4). For agroforestry plots of 1 hectare (10,000m^2), three sub plots were delineated whereas for agroforestry plots of 0.5 hectares, only two sub plots were created. These sub plots were selected randomly within the agroforestry plots in order to ensure there bias was minimised and different parts of the plot were investigated criteria to take into account variations at the micro level.

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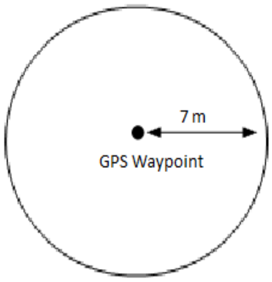


Figure 3: Sub plot dimensions

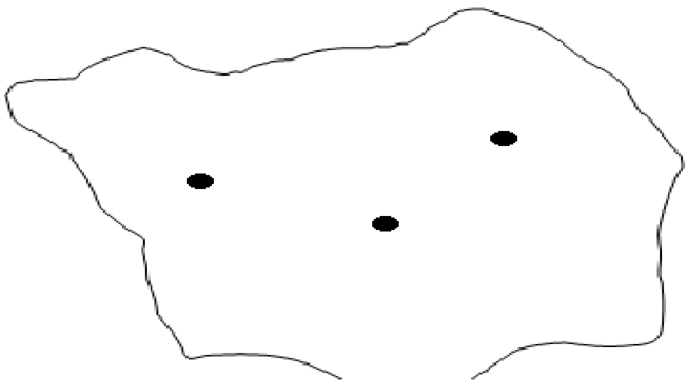


Figure 4: Agroforestry plot in which three GPS points were randomly selected.

3.4.2 Organising the monitoring teams

For the appropriate and efficient monitoring of fruit and timber trees, it was necessary to have two different teams of people. Each group consisted of three people (one PyF volunteer, one farmer and one agroforestry expert). It was crucial that each team be made up of:

- a person with knowledge on the design of the agroforestry plots, the planted species, the pests and diseases that may affect the trees, etc. This was usually the agroforestry expert who could address some of these key questions with the support of the farmers.
- a person familiar with using mobile devices and completing the form. This person was in charge of recording the data collected during the evaluations of every single tree. Initially this responsibility was held by the PyF volunteers, but, as the project developed, this was carried out by the agroforestry experts and farmers.
- a person in charge of measuring the height and the diameter at breast height of the trees; this was done by not only the experts but also by the volunteers and the farmers.

Figure 5: Farmers learning how to use the form and the mobile devices **(a)** y a farmer recording data onto a mobile device during the monitoring process (**b**). (Photo: Julio Vásquez)**.**

It is important to note that although the farmers were skilled and trained in the recording of data as well as in the measuring of the tree height and diameter at breast height, the supervision of the volunteers and/or the agroforestry experts was always necessary to ensure that the data and information was correctly registered.

In addition, the measurements were quality-controlled and audited to guarantee a high standard of the evaluations and assessments. This auditing process consisted in two types of proofs:

- **Immediate field checks (hot check):** during the hot checks, the principal investigator of the field squad observed the monitoring teams and the measurement processes. Mistakes or misunderstandings were explained and addressed appropriately. Hot checks were repeated throughout the measurement season to ensure that incorrect measurement methods were not being adopted and that good measurement techniques were being used at all times.

- **Blind check:** blind checks were used to quantify measurement errors. This type of check required complete re-measurement of various sub plots by different people within the measurement team. The auditing team then entered the field and re-measured the sub plots thereby repeating all the measurements carried out before hand and checking their accurateness.

  Following the audits, the information was compared with that originally collected and any discrepancies were addressed. Using this method error can be expressed as a percentage of all the agroforestry plots that have been checked by the auditing team to provide a value for measurement errors.

3.4.3 Location and delimitation of the focus group sub plots

The GPS was necessary for locating the sub plots and pinpointing the centre of the sub plots (this was subsequently marked by a peg). Once the centre of the sub plot had been identified, the team proceeded to measure out a 7m radius in the north, south, east and west directions and mark out the sub plots' perimeters (see Figure 6). Doing so helped identify the trees within the area and record the number of dead trees in the sub plot.

The measurements were then carried out, starting with the most northerly located tree and then going round and evaluating the trees clockwise.

In some cases, some trees were located on the area boundary. In such cases, the tree was included and assessed if more than 50% of the trunk resided within the area boundary.

Figure 6: Placing a peg in the centre of the sub plot (**a**) and measuring the area boundary (**b**). (Photo: Valeria Saldaña)**.**

3.4.4 Measuring the diameter at breast height of the trees

Measurement of the diameter at breast height was carried out at 1.30 cm from the ground. For the trees that had diameters at breast height that were greater or equal to 7cm, a measuring tape was used, for trees with diameter at breast height less than 7 cm, a calibrator was used to avoid any measuring errors.

Several methods were considered during the measurements:

- cutting a stick 1.30 m long (breast height) and using it to determine the correct height to measure out the diameter at breast height (see Appendix 3: Photos of the criteria evaluations).
- using the measuring tape or calibrator to determine the diameter at breast height of each tree as depicted in the below drawings. If the tree branched out either twice or more (see Figure 7), the diameter at breast height needed to be measured and recorded for every branch.
- if the tree was classified as dead, its diameter at breast height was not measured.

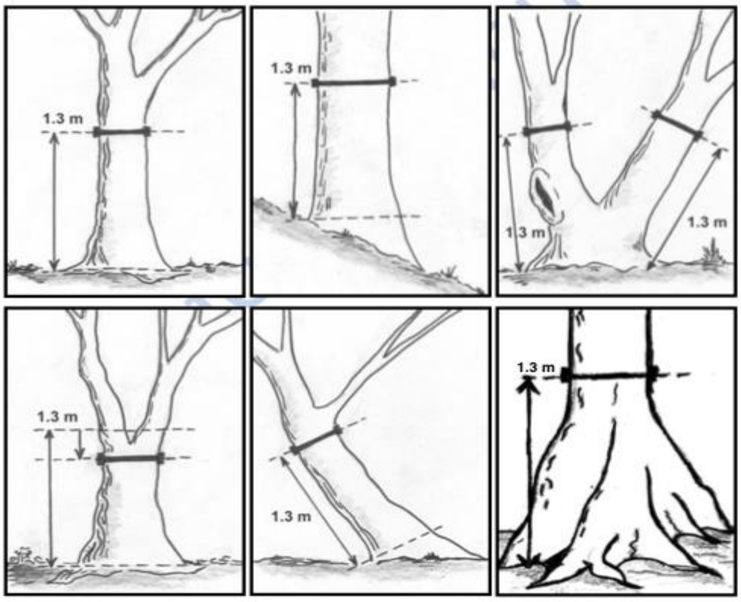


Figure 7: Instructions as to how to measure the diameter at breast height depending on the terrain and root formation of the trees (Source: Diagram taken from *Terrestrial Carbon Measurement Standard Operating Procedures*, Winrock International, 2012).

In addition to measuring the diameter at breast height, the diameter at ground level was measured for the trees that had a diameter at breast height that was less than 5cm.

3.4.5 Measuring tree height

Tree height was measured up to the tallest part of the plant. For trees more than 3 m high, a clinometer was used at a fixed distance of 15 or 20 m for observation and for trees under 3 m high metal measuring tape was used. In order to determine the total height of every tree, the angle at the peak of the tree had to be considered, as did the distance of observation and the height of the person carrying out the measurement (see Appendix 3: photos of the evaluation if the criteria).

For the appropriate measurement of tree height, the following criteria were considered:

- Find the best suited spot from which to observe the tree peak
- Have a sufficient distance between the person carrying out the measurement and the tree so that the peak was less than 90 degrees above the line of vision (distances of 15 or 20 m were used)
- Measure the total height of the tree as is depicted on Figure 8
- Use a clinometer to estimate the percentage in which the tree peak lies (a)
- Use a clinometer to estimate the percentage in which the tree base lies (b)
- Use a measuring tape to measure the distance from the person carrying out the measurement's eye to the tree ($dist_{tree}$) in metres. Ensure that the measured distance is horizontal.
- Repeat the measurements in other locations, using this methodology to measure the tree height in two areas.

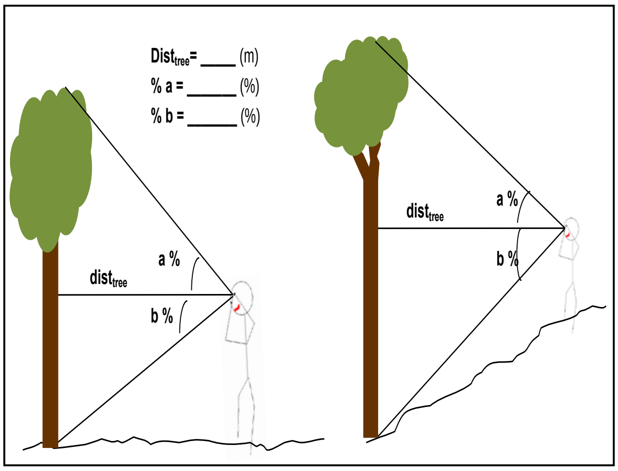


Figure 8: Measuring the tree height (m) with a clinometer. (Source: Diagram taken from *Terrestrial Carbon Measurement Standard Operating Procedures*, Winrock International, 2012).

The equation to measure tree height (h) using distance from trees of which height it known:

$$h = (\% \text{ peak}/100 \times d) + (\% \text{ base}/100 \times d)$$

Where:

h : Total tree height

d : Observation distance

IV. RESULTS

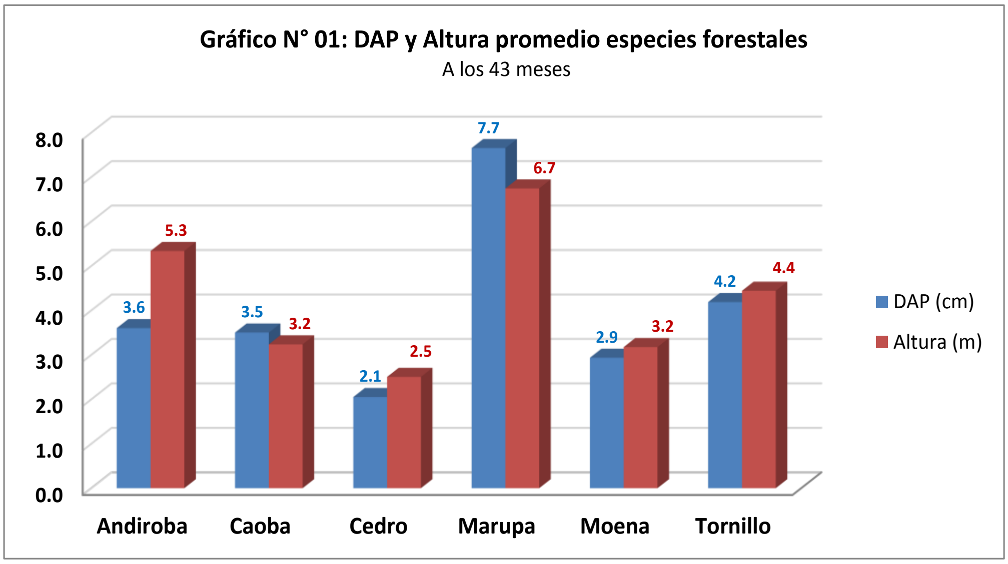
4.1 GROWTH OF FRUIT AND TIMBER TREE SPECIES

The growth of the fruit and timber tree species was determined by the tree measurements, including that of the diameter at breast height and the tree height. These measurements were carried out in the agroforestry plots of the project's first stage (in which trees were planted 43 months prior, and in the project's second stage, in which trees were planted 20 months earlier (See Appendix 4: Design of the agroforestry plots – first and second stages).

The following results were obtained:

- **Diameter at breast height and the average tree height of timber species in agroforestry plots established 43 months ago (during the project's first stage)**

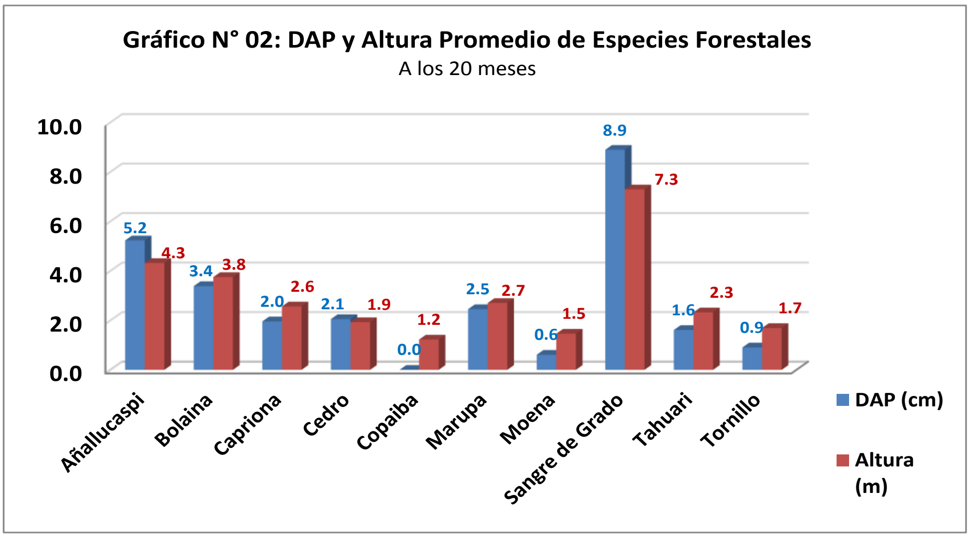
  Graph 1 shows the timber species with greatest average height and diameter at 43 months. The species that stand out are: Marupa (6.7 m height; 7.7 cm diameter), Andiroba (5.3 m; 3.6 cm) and Tornillo (4.4 m; 4.2 cm). To this date, these species have proved to have initially strong growth in these low fertility soils (defined as exceedingly to very acidic – 4.1 to 4.6 – but well drained).



- **Diameter at breast height and the average tree height of timber species in agroforestry plots established 20 months ago (during the project's second stage)**

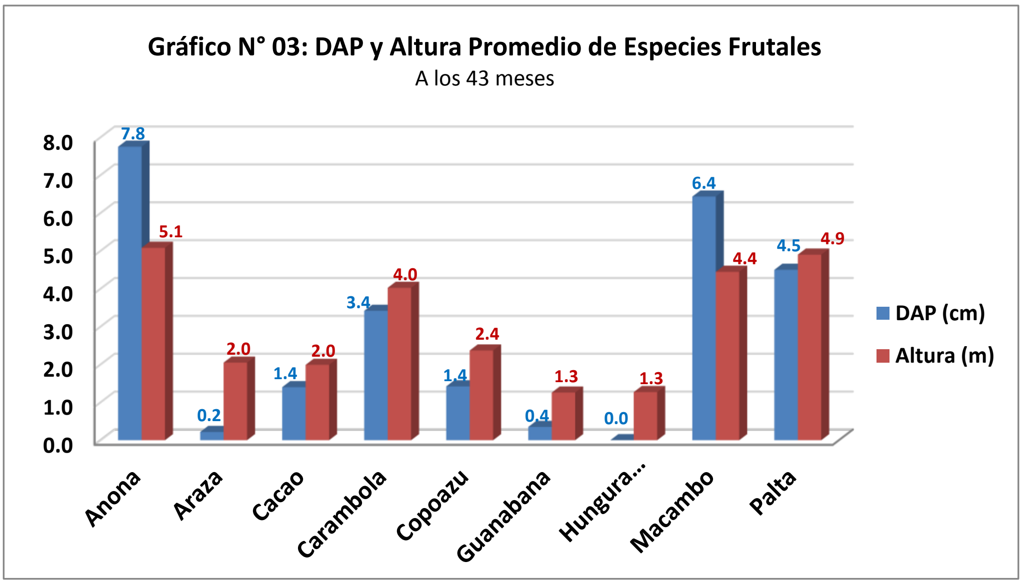
  Graph 2 shows the timber species with greatest average height and diameter at 20 months. The species that stand out are: Sangre de Grado (7.3 m height; 8.9 cm diameter), Añallu caspi (4.3 m; 5.2 cm) and Bolaina (3.8 m; 3.4 cm). To this date, these species have proved to have initially strong growth in these low fertility soils (defined as exceedingly to very acidic – 3.6 to 4.7 – but well drained). Other tree species that have done well under these conditions are Marupa (2.7 m height; 2.5 cm diameter) and Capirona (2.6 m; 2.0 cm).

When considering the exceptional results that have been demonstrated by Sangre de Grado and Bolaina species it is important to note that these species are among those that grow the fastest in any case so they would be expected to out strip other species at this stage. It is therefore not surprising that these species would have obtained such results.



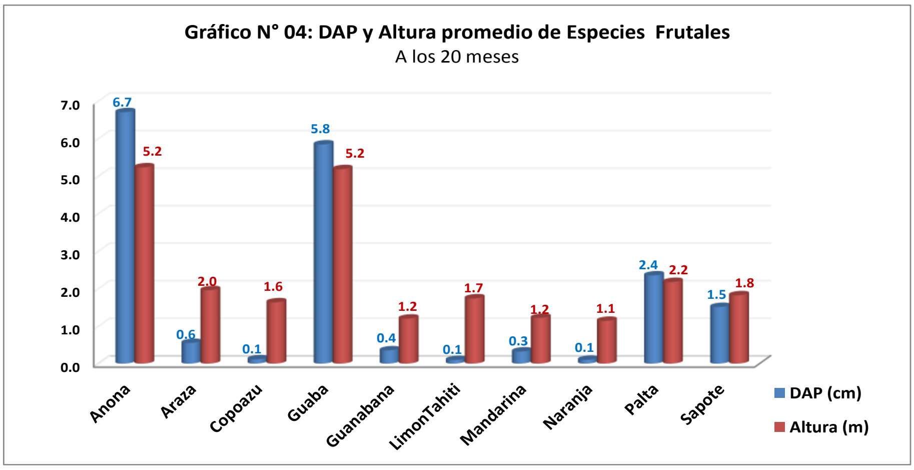
- **Diameter at breast height and the average tree height of fruit species in agroforestry plots established 43 months ago (during the project's first stage)**

Graph 3 shows the fruit species with greatest average height and diameter at 43 months. The species that stand out are: Anona (5.1 m height; 7.8 cm diameter), Palta (4.9 m; 4.5 cm) and Macambo (4.4 m; 6.4 cm). To this date, these species have proved to have initially strong growth in these low fertility soils (defined as exceedingly to very acidic – 4.1 to 4.6 – but well drained). Other tree species that have done well under these conditions are Carambola (4.0 m height; 3.4 cm diameter), Copoazu (2.4; 1.4) and Cacao (2.0 m; 1.4 cm).



- **Diameter at breast height and the average tree height of fruit species in agroforestry plots established 20 months ago (during the project's second stage)**

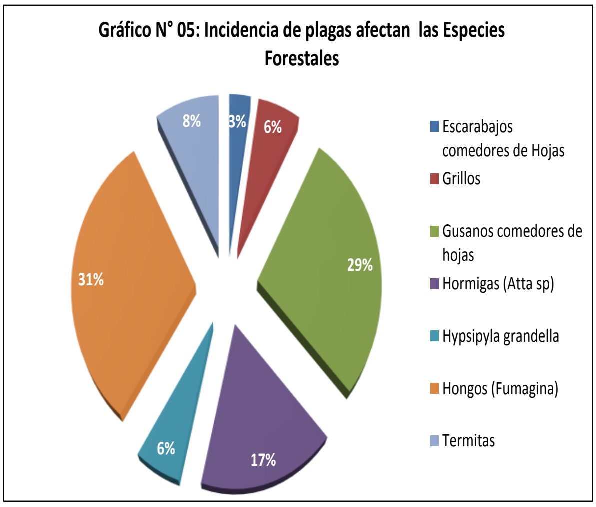
Graph 4 shows the fruit species with greatest average height and diameter at 20 months. The species that stand out with strong growth at this stage are: Anona (5.2 m height; 6.7 cm diameter), Guaba (5.2 m; 5.8 cm) and Palta (2.2 m; 2.4 cm). Other tree species that have done well under these conditions are Arazá (2.0 m height; 0.6 cm diameter), Sapote (1.8 m; 1.5 cm) and Limón Tahití (1.7 m; 0.1 cm).

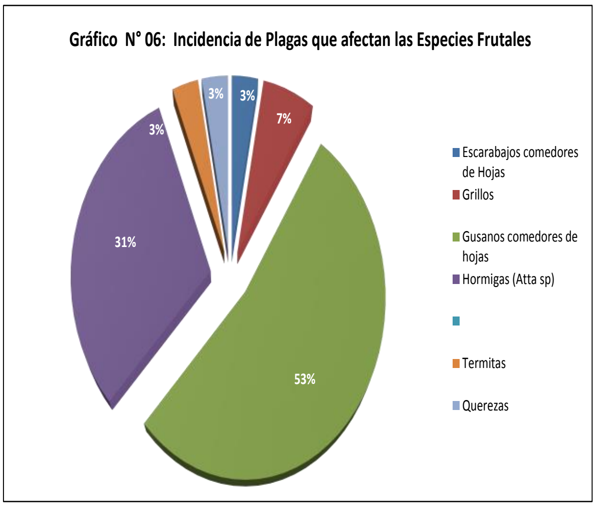


4.2 PHYTOSANITARY STATE OF THE PLANTS

The data registered during the monitoring evaluations was used to determine what has caused the greatest number of infestations in both timber and fruit tree species (See Graphs 5 and 6). The worst offenders were leaf-eating worms (lepidoptera larvae) and leaf-eating ants (Atta sp.), followed by termites, dotted worm (*Hypsipyla grandella)* and crickets.

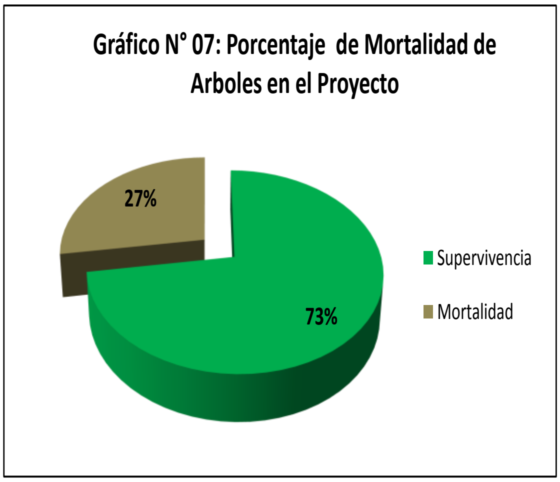
Although the incidence of leaf-eating worm infestations was greater in both cases (42-53%) the attack was minor and is not evidenced by any significant damage in the foliage or development of the plants. However, it was observed that Atta sp. and *Hypsipyla grandella* are the pests that cause the most damage to the trees, with the most susceptible species being the citric trees (lemon, orange and mandarin); the Capirona species is most vulnerable to Atta sp. attacks and the Caoba and cedar trees are most prone to *Hypsipyla grandella* damage.

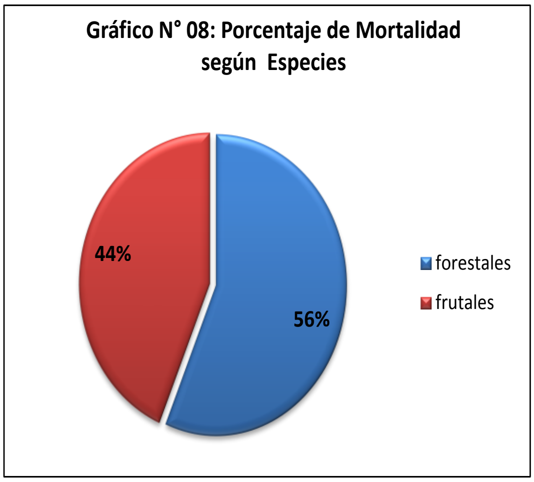




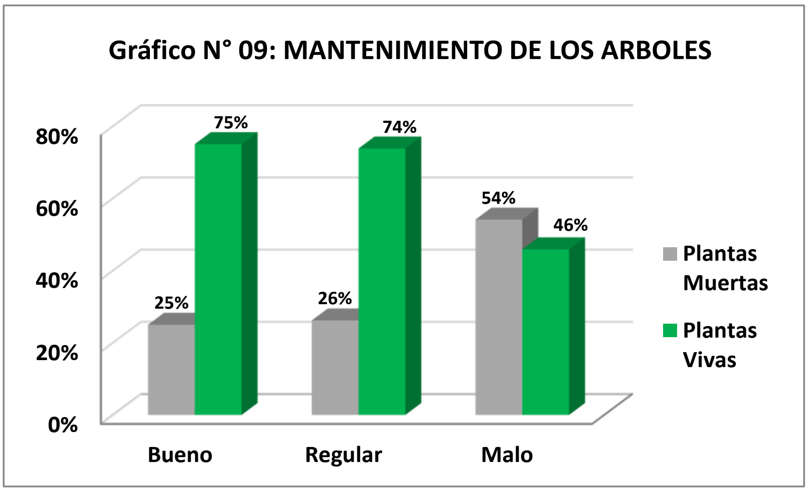
4.3 MORTALITY AND SURVIVAL OF THE TREES

- **Mortality percentage of the project's trees**
  Graph 7 depicts the mortality percentage of the project's trees. This percentage was low (27%) with a survival percentage of 73%. This survival percentage is similar to that presented in the FAO's Assessment of Forest Resources, 2000 (66.67%). The timber tree species suffered greater mortality than the fruit tree species (56% compared to 44% - a difference that is relatively insignificant- see Graph 8).

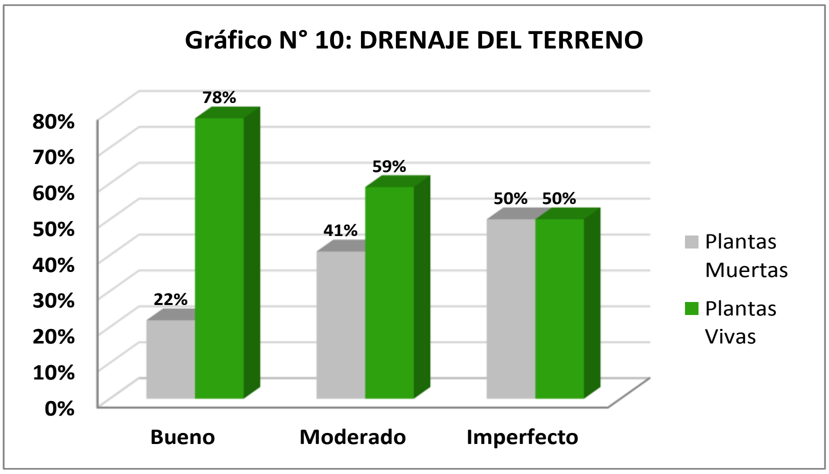




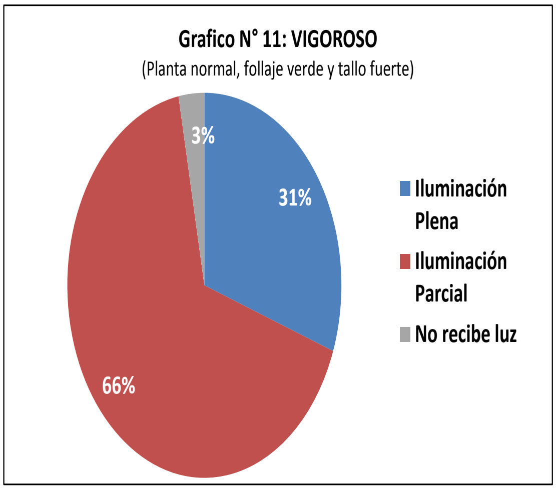
- **Mortality in relation to the maintenance of agroforestry plots**
  The survival percentage of the plants is directly related to the way the farmers maintain the plants (Graph 9). Mortality is low in cases of good and regular maintenance (this includes weeding, pest checks and appropriate control and pruning). In instances when agroforestry plots were not well maintained, mortality rates increased considerably.

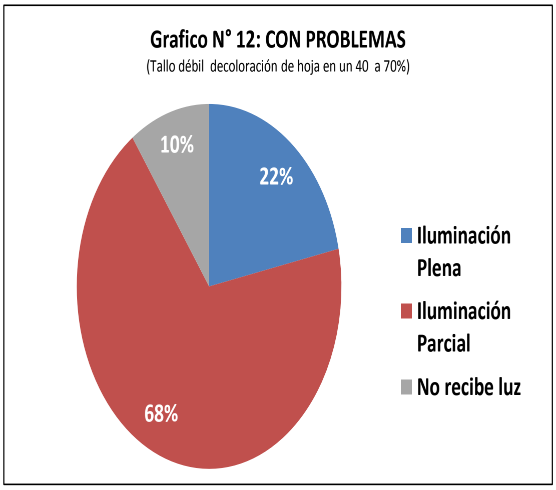


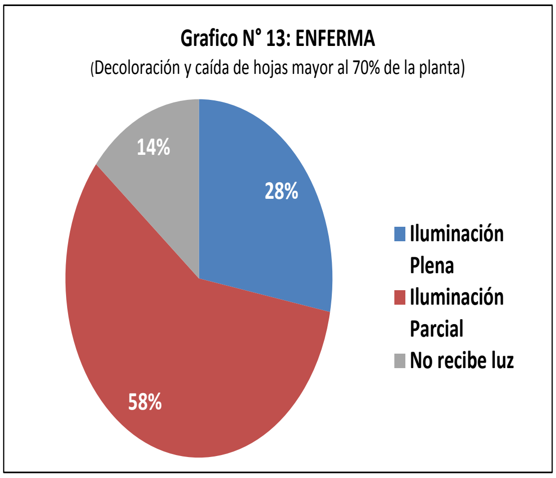
- **Mortality in relation to drainage effectiveness within agroforestry plots**
  Graph 10 shows that mortality rates are lowest when drainage systems in the fields are efficient (22%). On the other hand, moderately to imperfect drainage systems seem to be related to a considerable augmentation in mortality percentage (41-50%)

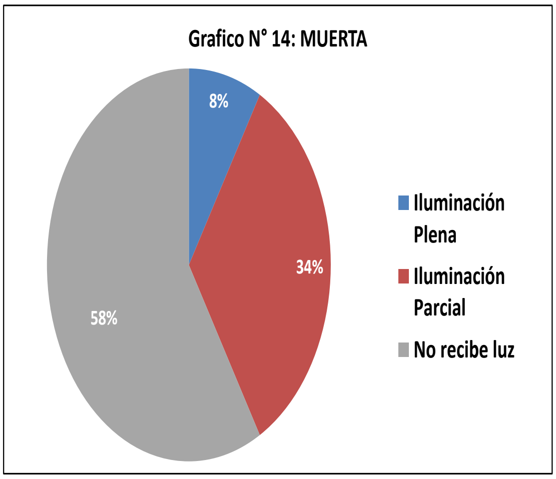


- **Plant vigour and health in relation to lighting**
  As shown in Graphs 11-14, plant health correlates to exposure to light. The healthiest trees are those that are exposed to full and partial lighting. Of the trees that were found to be dead (58%), the majority did not receive sufficient light before the focus group evaluations. This was often due to a lack of maintenance which suggests that the lack of light increases mortality rates of the plants.









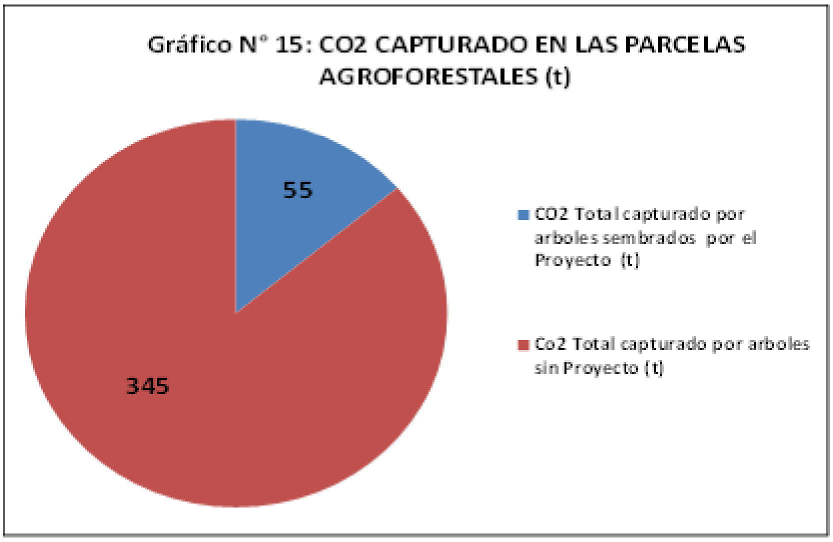
4.4 CO_2 CAPTURED IN THE AGROFORESTRY PLOTS

The study included initial evaluations to determine the quantity of captured carbon by trees in the agroforestry plots.

To calculate the biomass of the trees (and from that carbon sequestration), the Chave allometric equation was applied, using the DBH values which were measured. The Chave[1] equation for moist forest stands was selected to be the most applicable. 'Moist forest' is defined in the paper as forests where evapotranspiration exceeds rainfall during more than a month, but less than 5 month as a marked dry season, sometimes with semi-deciduous canopy, and corresponding to ca. 1,500-3,500 mm/year in rainfall for lowland forests. A root to shoot ratio was then additionally applied to include an estimate of root biomass. The biomass was calculated for the trees with diameter at breast height above 5 cm and palm trees were not included. Many trees were below 5 cm DBH which meant the carbon they capture could not be estimated, as the equation is not applicable. More details of the carbon estimations are available on request, and follow the methodology presented in Plant your Future 2015 approved VCS Project Description entitled "Planting for the Future: Financially Sustainable Agroforestry Systems and Payments for Ecosystem Services."

The total CO_2 captured in the project's 20 hectares amounted to 400 t. Only 14% of this amount was captured by the trees planted for the project. 86% was captured by trees that were planted before the project began.

It's important to note that of the 655 trees that were evaluates (trees planted for the project) only 108 were considered in the biomass calculated; these were trees with diameter at breast height that was equal to or greater than 5cm.



[1] Chave, 2005, Tree allometry and improved estimation of carbon stocks and balance in tropical forests, Oecologia 145: 87-89

V. CONCLUSIONS

- The **timber tree species** that stand out and show fastest initial growth in these low fertility soil conditions (defined as exceedingly to very acidic but with efficient drainage systems) are Sangre de *grado (Croton lechleri),* Añallu caspi *(Cordia ucayaliensis*), Marupa *(Simarouba amara)*, Andiroba (*Carapa guianensis*) and Bolaina *(Guazuma crinita*). Other adaptable species worth mentioning are Tornillo *(Cedrelinga catenaeformi),* Capirona (*Calycophyllum spruceanum*) and Tahuari (*Tabebuia impetiginosa*)

- The **fruit tree species** that stand out and show fastest initial growth in these low fertility soil conditions (defined as exceedingly to very acidic but with efficient drainage systems) are Anona *(Rollinia mucosa),* Guaba *(Inga edulis Mart*), Macambo *(Theobroma bicolor*) and Palta *(Persea americana*). Other adaptable species worth mentioning are Carambola (*Averrhoa carambola*), Arazá (*Eugenia stipitata*), Cacao (*Theobroma Cacao*) and Copoazu (*Theobroma grandiflorum*).

- The greatest incidences of infestations that are recorded on both timber and fruit tree species were caused by leaf eating worms (lepidóptera larvae) and leaf-eating pants (Atta sp.), termites, dotted worms (*Hypsipyla grandella*), crickets, leaf scale eating snails. Those that cause most damage are leaf-eating ants (*Atta sp*.) and dotted worms (*Hypsipyla grandella*), both of which severely affect trees, and particularly citric trees (lemon, orange, mandarin); the Capirona species is most vulnerable to Atta sp. attacks and the caoba and cedar trees are most prone to *Hypsipyla grandella* damage.

- Survival rate of the trees is an estimated 73%, a percentage that is similar to the Global Average presented by the FAO Assessment of Forest Resources, 2000 – 66.67%. Timber species expressed greater mortality rates than the fruit species (56% to 44%).

- Tree mortality is directly related to maintenance, drainage systems and lighting with the lowest mortality rates occurring in agroforestry plots that were well maintained with efficient drainage systems and adequate lighting.

- The carbon captured in the 21 agroforestry plots amounts to 400 t. However only trees with DBH great than 5cm are included as the Chavez equation is not applicable below this.

- A customised ODK form, that is both efficient in the field and user-friendly; that technically does not present any problems either with regards to the use of mobile devices or in the ease of uploading information; and that is easily modifiable and can be adapted by local personnel for future evaluations and assessments was developed.

- Seventeen farmers were trained in the evaluation of agroforestry plots (measurement of diameter at breast height and tree height, identification of infestations, etc.). Three farmers (Eric Putpaña, Carlis Putpaña y Roger Icahuate) were also trained in the use of mobile devices and the correct registration of data and information.

VI. RECOMMENDATIONS

- Continue and progress PyF's technical work in order to incentivise farmers to focus their efforts on the maintenance of agroforestry plots, which has been proven to be one of the criteria that most significantly influences the growth and mortality of the plants, at least in the first two years of growth.

- Species selection, which will determine those planted in future plots, should consider important criteria such as rapid growth, survival rates, adaptability, low infestation incidence, quality of timber, economic value of both timber and fruit produce, market demand, and farmer preferences.

  It is recommended that in future evaluations, the number of focus group agroforestry plots be increased and that specific tree species be assessed to be able to yield more significant data.

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