Lake Victoria Watershed Agroforestry Carbon Project (LV Carbon)

Climate Monitoring Plan

March 2024

Version 1.0

Table of Contents

1. Introduction

1.1 Project Overview

Trees for the Future (TREES) is a 501c (3) that provides direct agroforestry training and resources to farming communities in Africa. Through sustainable land practices, farmer participants are engaged in education about climate change and provided technical training and assistance. TREES has developed the Lake Victoria Watershed Agroforestry Carbon Project, which enables rural farmers to develop sustainable landscapes through targeted training and support. The project aims to train and equip smallholder farmers with the skills and resources to transform the landscape into productive diverse agroforestry systems. Combining applications of ecological agriculture, agroforestry, and Indigenous farming practices, TREES implements the "Forest Garden Approach" including training modules and sustainable land management support.

1.2 Methodology and Size

The project utilizes the VERRA methodology VM0042 for Improved Agricultural Land Management to generate VCUs. The grouped project is planned for implementation on 75,000 ha located in Kisumu, Homa Bay, Migori and Siaya counties in Western Kenya. There are 8,500 individual farmers included in the first three project instances (8,000 ha) for validation in this PDD.

1.3 Timeline

The project lifetime is 40 years from 2020 - 2059. Each project instance has 4 years of implementation and 24 years of crediting.

2. Methods for Measuring, Recording, Storing, Aggregating and Reporting

Detailed processes and schedules for obtaining, recording, compiling and analyzing monitored data and parameters are set out in Section 3.3.2 (Data and Parameters Monitored).

Data collection for the carbon monitoring plan will occur once every verification period. Data will be collected through a series of farmer surveys, biomass surveys and soil organic carbon sampling. The Lake Victoria Watershed Agroforestry Carbon Project is designed with specific Standard Operating Procedures (SOPs) for the surveys to maintain consistency in data collection and monitoring to determine overall impacts of program activities. The SOPs are included in the Appendices to this Monitoring Plan. These surveys help TREES determine if the program outcomes have been achieved in the program implementation timeline and prove to the Validation and Verification Body (VVB) that the program meets all VCS and CCB requirements.

2.1 Measuring Methods

2.1.1. Soil organic carbon

Soil organic carbon is estimated using a combination of soil measurements and RothC modeling. Measurements are conducted for the baseline and every five years to allow the 'true-up' of modeled estimates. Soil cores are collected to determine the carbon content and bulk density across two depth increments (at initial measurement 0-15 cm depth and 15-30 cm depths but increasing at future measurement to maintain Equivalent Soil Mass – ESM). Baseline laboratory procedures use Standard Operating Procedures of the Soil-Plant Spectral Diagnostics Laboratory of World Agroforestry Centre (ICRAF).

The key parameters derived from field measurement of soil carbon are:
BD_{corr} Corrected bulk density of the fine soil fraction (after subtracting the mass proportion of the coarse fragments); g/cm^3 AND
$OC_{n,dl}$ Organic carbon content in sample *n* from depth layer *dl*; g/kg

A detailed description of the standard operating procedures for measuring soil carbon is provided in Appendix 6.2 SOP for Soil Sampling and Lab Analysis.

Soil carbon is modeled using the RothC model. During the second sampling campaign and beyond, the project will true-up the RothC model following procedures in Section 8.6.1.3 of VM0042 v 2.0.

The key parameters derived from modeling of soil carbon are:
$f(SOC_{bsl,i,t})$ Modeled SOC stocks in the baseline scenario for sample unit *i* at time *t*, calculated by modeling SOC stock changes over the course of the preceding year; t CO_2/ha
$f(SOC_{wp,i,t})$ Modeled carbon dioxide emissions from SOC pool in the project for sample unit *i* at time *t*; t CO_2e/ha

A description of the standard operating procedures for modeling soil carbon is provided in Appendix 6.4 SOP for RothC.

2.1.2. Above and belowground biomass

Following VM0042, ex-ante (baseline) woody biomass carbon stocks will be assumed to be zero where:

1. The pre-project trees are neither harvested, cleared, or removed throughout the project's crediting period (e.g., existing trees on the baseline farms will not be removed during implementation of Forest Garden project activities).
2. The pre-project trees do not suffer mortality because of competition from trees planted in the project, or damage because of implementation of the project activity, at any time during the crediting period of the project activity.
3. The pre-project trees are not inventoried along with the project trees in monitoring carbon stocks, but their continued existence is monitored throughout the project activity's crediting period.

Where the above criteria are met, then the location of biomass is photographed and recorded to ensure that trees are not inventoried during monitoring. Additionally, the farmer must sign an attestation form that they will not clear or kill any trees present before project activities were implemented.

The biomass of trees or shrubs that were cleared in year *t* were calculated using the *CDM A/R tools Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities.* The diameter of all sampled trees was measured at breast height alongside the species and specific location. For shrubs in the baseline scenario, ocular estimates were made for shrub canopy cover, and length and starting and ending width of hedgerows was recorded. A detailed description of the standard operating procedures for baseline biomass monitoring is included in Appendix 6.2.

The parameters recorded from baseline biomass measurements were:

$C_{TREE\_BSL,t}$ Carbon stock in tree biomass within the project boundary in the baseline scenario in year t; t CO_2e

$C_{SHRUB\_BSL,t}$ Carbon stock in shrub biomass within the project boundary in the baseline scenario in year t; t CO_2e

In the project case, trees will be measured in permanent sampling plots. Forest gardens under LV Carbon have multiple components, which for the sake of precision in carbon stocks must be treated individually. Within each sampled farm the area / length of each component is recorded using GPS. Polygons of area are recorded for: timber plantations, fruit orchards (large and small), fodder production areas, and market permagardens. Alley plantings and green walls are recorded as linear features with the total length recorded for each farm. Within each component, permanent sample plots are installed and measured (and remeasured at each monitoring interval). Sample plot locations are randomly selected. Plot types differ by component as shown in Table 2.1.1.a.

Table 2.1.2.a Monitoring plot dimensions of LV Carbon Project Forest Garden elements

Garden Element	Includes trees?	Unique subplot	Plot dimensions
Timber Plantation	Yes	Yes	10 m radius circle
Fruit Orchards (large and small)	Yes	Yes	10 m radius circle
Fodder Production	Yes	Yes	10 m radius circle
Market Permagardens	Yes	Yes	10 m radius circle
Alley Planting	Yes	Yes	10 m linear
Green Wall	Yes	Yes	10 m linear with width/height recorded
Field Crop	No	No	Not measured for biomass

Where alley crop trees are encountered in orchards or fodder production zones, they will not be measured (trees will be recorded – see procedures in SOPs in appendix – to clearly indicate they are alley trees rather than fodder or orchard trees).

Figure 2.1.2.a: Generic design of LV Carbon forest garden

For trees the diameter at breast height is measured. A detailed description of the standard operating procedures for project scenario biomass monitoring is included in Appendix 6.2.

The parameters recorded from project biomass measurements were:

$\Delta C_{TREE\_PROJ,t}$ Change in carbon stock in tree biomass within the project boundary in the project scenario in year t; t CO_2e

2.1.3 Livestock

- A randomized sampling of farmers stratified by AEZ for each instance will be conducted. Survey questions are asked during an on-farm interview, while walking around and discussing practices (or what TREES technicians call 'storying');
- The survey questions are asked by TREES trained technicians who serve as trainers and agricultural extension agents for farmers. The questions are prepopulated in Taroworks, and answers are directly recorded on the mobile data collection device (smart phone or tablet). Livestock Management Questions can be found in Section 7, Q33 - Q43 in the Farm Survey in Appendix 6.4.

The parameters recorded from livestock assessment were:

$P_{bsl,l,i,t}$ Population of grazing livestock of type l in the baseline scenario in quantification unit i for productivity system P in year t

$Pop_{wp,l,i,t,P}$ Population of grazing livestock of type l in the project scenario in quantification unit i for productivity system P in year t

$AWMS_{l,i,t,P,S}$ Fraction of total annual volatile solids for each livestock type l that is managed in manure management system S in the project area, for productivity system P

2.1.4 Fertilizer

- A randomized sampling of farmers stratified by AEZ for each instance will be conducted. Survey questions are asked during an on-farm interview, while walking around and discussing practices (or what TREES technicians call 'storying').
- The survey questions are asked by TREES trained technicians who serve as trainers and agricultural extension agents for farmers. The questions are prepopulated in Taroworks, and answers are directly recorded on the mobile data collection device (smart phone or tablet). Livestock Management Questions can be found in Section 7, Q33 - Q43 in the Farm Survey in Appendix 6.4.
- Following project design, no compost is derived from beyond farm boundaries. This will be demonstrated through farmer attestation in the survey.

The parameters recorded from fertilizer assessment were:

$M_{bsl,SF,i,t}$ Mass of N-containing synthetic fertilizer type SF applied in quantification unit i in year t in the baseline scenario; tonnes

$M_{bsl,OF,i,t}$ Mass of N-containing organic fertilizer type OF applied in the baseline scenario for quantification unit i in year t; tonnes

$M_{wp,SF,i,t}$ Mass of N-containing synthetic fertilizer type SF applied in the project for quantification unit i in year t; tonnes

$M_{wp,OF,i,t}$ Mass of N-containing organic fertilizer type OF applied in the project for quantification unit i in year t; tonnes

$M\_OA_{wp,i,t}$ Mass of organic amendment applied as fertilizer on the project area from livestock type l in year t; tonnes

2.1.5 Residue Management – Biomass Burning

- A randomized sampling of farmers stratified by AEZ for each instance will be conducted. Survey questions are asked during an on-farm interview, while walking around and discussing practices (or what TREES technicians call 'storying');
- The survey questions are asked by TREES trained technicians who serve as trainers and agricultural extension agents for farmers. The questions are prepopulated in Taroworks and answers are directly recorded on the mobile data collection device (smart phone or tablet). Livestock Management Questions can be found in Section 7, Q33 - Q43 in the Farm Survey in Appendix 6.4.
- Survey will demonstrate that residue burning is not occurring through farmer attestation. If ever residue burning is recorded, then three 1 m^2 plots will be established to determine biomass burned.

The parameters recorded from biomass burning assessment were:
$MB_{bsl,c,i,t}$ Mass of agricultural residues of type c burned in the baseline scenario for quantification unit i in year t; kg
$MB_{wp,c,i,t}$ Mass of agricultural residues of type c burned in the project for quantification unit i in year t; kg

2.1.6 Nitrogen Fixing Species

- A randomized sampling of farmers stratified by AEZ for each instance will be conducted. Survey questions are asked during an on-farm interview, while walking around and discussing practices (or what TREES technicians call 'storying').
- The survey questions are asked by TREES trained technicians who serve as trainers and agricultural extension agents for farmers. The questions are prepopulated in Taroworks, and answers are directly recorded on the mobile data collection device (smart phone or tablet). Livestock Management Questions can be found in Section 7, Q33 - Q43 in the Farm Survey in Appendix 6.4.

The parameters recorded from nitrogen-fixing species assessment were:
$MB_{g,bsl,i,t}$ Annual aboveground and belowground dry matter of N-fixing species g returned to soils in the baseline scenario for quantification unit i in year t; tonnes dry matter.

2.1.7 Fossil Fuels

- A randomized sampling of farmers stratified by AEZ for each instance will be conducted. Survey questions are asked during an on-farm interview, while walking around and discussing practices (or what TREES technicians call 'storying').
- The survey questions are asked by TREES trained technicians who serve as trainers and agricultural extension agents for farmers. The questions are prepopulated in Taroworks, and answers are directly recorded on the mobile data collection device (smart phone or tablet). Livestock

Management Questions can be found in Section 7, Q33 - Q43 in the Farm Survey in Appendix 6.4.

The parameters recorded from fossil fuel assessment were:
$FFC_{bsl,j,I,t}$ Consumption of fossil fuel type j (gasoline or diesel) for quantification unit i in year t in the baseline scenario; liters
$FFC_{wp,j,i,t}$ Consumption of fossil fuel type j for quantification unit i in year t in the project scenario; liters

2.2 Sampling Design

As described in VM0042 v 2.0, a stratified random sampling design is required using area weighted approaches from the CDM guidelines as was used for baseline sampling. The precise number, and placement of plots will be determined based on variance of data in initial recorded plots. Details on plot design for tree and soil measurement is given in Appendix 6.2.

2.3 Recording Methods/Technology including Calibration

TREES utilizes the mobile application Taroworks for data collection, monitoring and reporting. TaroWorks' mobile CRM and field service app allows for offline mobile data collection, metrics analysis and operations management in last mile environments in real time. One of the key strengths of TaroWorks lies in its ability to standardize data collection forms and methods. Once records are initially set up, data collectors in the field can access records through a series of dropdown menus ensuring that data is accurately connected to the correct record. This reduces the impact of human error in misidentifying farmer participants, creating multiple records for the same famer participant, and/or having variations in the data collected. This standardization not only enhances the overall quality of the data collected but also simplifies the process of aggregating and analyzing data from various sources.

2.3.1 Storing Technology

TREES currently uses two databases for storing data for the LV Carbon project:

2.3.1.1 Salesforce Database

Salesforce serves as a central and comprehensive platform for cloud storage, organization and analytical analysis of project data received from Taroworks. It provides electronic records and data storage for all farmer data from baseline throughout the project lifetime, storage of landowner agreement data, and a permanent record for management farmer benefit share in the future.

2.3.1.2. ESRI Arc Online

This GIS platform is primarily used to store geospatial data including polygons which provide accurate location and land size. Arc Online is synced with Salesforce records to ensure all farmer data is consistent between the two platforms. Arc Online is critical in assessing:

- the project meets applicability conditions
- stratifying sample sizes for baseline measurements and each instance,
- geo spatially representing data and changes over the project longevity and

- assessing potential loss events during project permanence.

2.3.2 Aggregating and Collating Processes

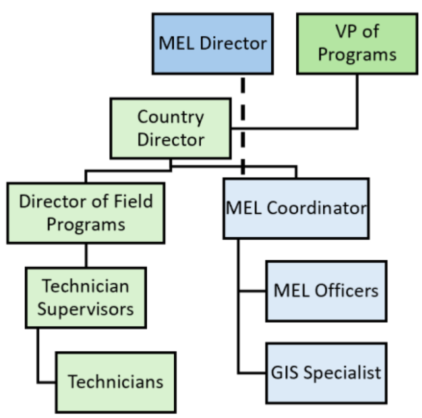
The integration between TaroWorks and Salesforce facilitates the seamless transfer of data, enabling real-time updates and ensuring that project records are consistently up to date. Salesforce allows TREES to create customized databases and dashboards, providing a unified view of project metrics, farmer participation, and overall project performance. Data from salesforce is downloaded into csv files and processed in spreadsheets that calculate that emission reductions in various fields aligned with the VM0042 methodology as indicated in Section 2.1. Data is aligned through farmer IDs, with the farmer ID being the consistent identifier across all data collected.

2.3.3 Schedule

Data collected in Taroworks is synced daily with Salesforce. During high data collection times including farmer registrations, polygons taking, annual evaluations, household surveys, baseline field areas measurements and verification events, data is reviewed daily and run through a data is checked daily for outliers and requests for checking data is sent back to field data collectors.

3. Personnel

3.1 Organizational Structure and Responsibilities/Competencies



3.1.1 Programs Department

Programs is responsible for the implementation of the Project Activities and guidance and oversight of MEL activities in line with the Theory of Change, Adaptive Management of the Project and to meet VCS/CCB baseline and continued reporting requirements for validation and Verification. The programmatic teams competencies include:

- Mastery of local language and nuances of language
- Understanding cultural norms
- Experience in organizing large field teams to complete complex tasks
- Experience in ecosystem services measurements for payments.

- BS or MS in Agriculture, Forestry, Environmental Science
- Certification in Forest Garden Specialist endorsed by UNITAR
- Training on use of Taroworks and at least 1 year experience in using Taroworks
- Training on the use of ESRI App Survey 123 and at least 1 year of experience using the App Survey 123.

The Programs Team includes:

- **The Country Director:** The Country Director has oversight of all Project activities and directly supervises the MEL Coordinator and team.
- **Director of Field Programs:** The Director of Field Programs is responsible for coordinating and sequencing project activities with 7 Technician Supervisors to ensure field programs are fully operational and staffing across programmatic field events and MEL monitoring events.
- **Field Technicians - Data Collection Staff:** TREES Field Technicians trained in the data collection methods outlined in Section 2.1 and 2.2 who conduct data collection at baseline and during verification events. Staff are trained in data collection and have BS and MS degrees in agriculture, forestry, environmental science, or natural resource management with a thorough understanding of agriculture practices. They are also adept at culturally appropriate timing and conduct when asking questions, arranging field visits and conducting field measurements.

3.1.2. Monitoring, Evaluation and Learning (MEL) Department

The MEL Department, responsible for overseeing the systematic monitoring and evaluation processes essential for assessing the impact and effectiveness of the carbon project. The MEL team is dedicated to designing and implementing robust monitoring frameworks, conducting evaluations, and facilitating continuous learning within the organization. Their work ensures that data collection methods align with project goals, allowing for informed decision-making and strategic adjustments. The MEL Department is structured as follows:

- **MEL Director:** The MEL Director is a strategic leader responsible for shaping the overall monitoring and evaluation strategy. This position oversees the development and implementation of M&E frameworks that meet most current VCS/CCB standards and align with VM0042 V2 methodology. The MEL Director has a supervisory dotted line to the MEL Coordinator for QA/QC oversight.
- **MEL Coordinator:** Supporting the MEL Director and operationalizing M&E frameworks in the field. The MEL Coordinator facilitates communication between team members, ensures the timely execution of monitoring activities, and liaises with other departments to integrate monitoring and evaluation seamlessly into project workflows.
- **MEL Officers:** Working under the guidance of the MEL Coordinator, the MEL Officers conduct trainings on data collection, perform data cleaning activities, ensure proper labeling procedures on soil sampling serve as technical support for data collection teams.
- **GIS Specialists:** The GIS Specialists bring expertise in spatial data management, analysis and mapping using Arc Online to evaluate project data in relationship to multiple other data sets

critical to ensure project applicability conditions are met and samples sizes can be determined for baseline and continued verification events for each project instance.

The MEL Team's competencies include:

- Mastery of local language and nuances of language
- Understanding cultural norms
- Experience in organizing large field teams to complete complex tasks
- Experience in ecosystem services measurements for payments.
- BS or MS in Agriculture, Forestry, Environmental Science
- Certification in Forest Garden Specialist endorsed by UNITAR
- Minimum of 2 years' experience training staff on the use of Taroworks and troubleshooting data collection issues
- Ability to train staff on Carbon Project Field Area Measurement survey requirements and potential variations and QC data as it is synced in Salesforce to identify issues in real time.
- Knowledge of and ability to train and monitor staff in using DBH tape, GPS device, clinometer, and distance measuring equipment (DME)
- A minimum of 500 hours of experience training, equipping and working with staff to trouble shooting field surveys for TREES in Forest Gardens
- A minimum of 500 hours of experience analyzing data and QA/QC of data in ESRI Arc online
- Working knowledge of TREES Salesforce database, reviewing and downloading data for QA/QC.
- Ability to run data cleaning software to search for outliers.
- Experience in adhering to standards and familiarity with VCS/CCB Standards include VM0042 Version 2.

4. Quality Assurance (QA) and Quality Control (QC)

Data quality will be maximized and ensured during all aspects of the monitoring process through quality assurance and quality control procedures.

4.1 Policies for Oversight and Accountability

When data are being collected through either field measurements or surveys, consistent units are used to describe the input. For example, all areas are recorded in metric units: (hectares, cm, etc.) all dates are recorded in the same format (i.e., mm/dd/yyyy), etc. Data is collected that is relevant to the sample unit of interest. It must be noted in the data collection forms whether the survey responses and measurements are relevant to the full farm area as opposed to a sub-section where forest garden activities are being implemented. Participating farmers have records in TREES Salesforce database synchronized with the Taroworks app. When recording data, the data collector locates the farmer record on the Taroworks app by navigating through the following series: Country, Project #, Farmer Group, Farmer Name. The technician checks with the farmer to ensure that all information is correct.

Data collectors work in teams of 2-3 and record all data on mobile devices using TREES designed surveys on the Taroworks App platform which has offline capabilities. Data collected is synchronized with

Salesforce at the end of each field day to store a backup of the information on the farmer record. One data collector digitally records the data in TREES online capable Taroworks App, while the other team member indicates the information verbally. The person recording the information repeats the information, as they are recording it, to ensure the information is correct. Once the data collector has access to Wi-Fi, the Taro works data is synced with TREES Salesforce database.   All electronic data is stored in TREES Salesforce database organized by Country, Project, Farmer Group, Farmer, Farmer ID, date enrolled. The data collector's information and data collected is also automatically stored in the system.

The data collection leader is responsible for checking and verifying all measurement work. The following procedures are followed *before* the data collectors leaves the farm.

- The data collector leader makes sure *every* mandatory line in the data form is filled out. It is the data collection leader's responsibility to ensure each datasheet is completed. Any missing data point or points must be completed before leaving the farm.
- When the data collection is complete, the data collection leader double checks the Taroworks data entries including Forest Garden ID, GPS coordinates, tree DBH and tree species for obvious outliers.
- Photo attachments are verified and determined not blurry, and the coordinates are legible and recorded in the correct format (i.e., lat/lon, decimal degrees, etc.).
- To verify that the measurement/survey is complete, the data collection leader checks the Data Review Box in Taroworks.
- To verify that the measurement/survey is accurate and representative of farmer practices, the farmer must sign their name on an attestation form.

Detailed QA/QC requirements for each collected parameter are included in Section 3.3.1 and 3.3.2 and in the Appendices to this monitoring plan.

4.2 Procedures for Internal Auditing and handling non-conformance with the Validated Monitoring Plan

LV Carbon will establish a "Project Information Quality Management System". This system will log all instances of training, all instances of quality assurance checks with the associated results for field data, lab analysis, survey and data entry, as well as any additional flags to potential gaps in conformance with the validated monitoring plan or the high-quality expectations of the project. Where any non-conformance is identified this will be immediately raised to the management of the project and of TREES for the Future and a plan immediately put in place to rectify non-conformance and to ensure the same issue cannot arise again.

5. Sampling Approaches

5.1 Stratification

Project stratification, as detailed in PD section 3.1.3, is based on Kenyan Agroecological Zones (AEZ) (Figure 5.1.a and Table 5.1.a). These strata represent the sampling unit for the project with a single homogeneous "stratum" in each. This stratification is not to be confused with the fine scale practice-based differentiation which will occur on the scale of a small-fraction of a hectare within each forest garden. The fact that seven practices-based differences exist within a garden which itself may be not much more than 0.5 ha means that this differentiation is captured through the stratified sampling within each randomly selected monitored forest garden. Weighting changes by area of each practice in each forest garden allows a per garden stock and carbon stock change.

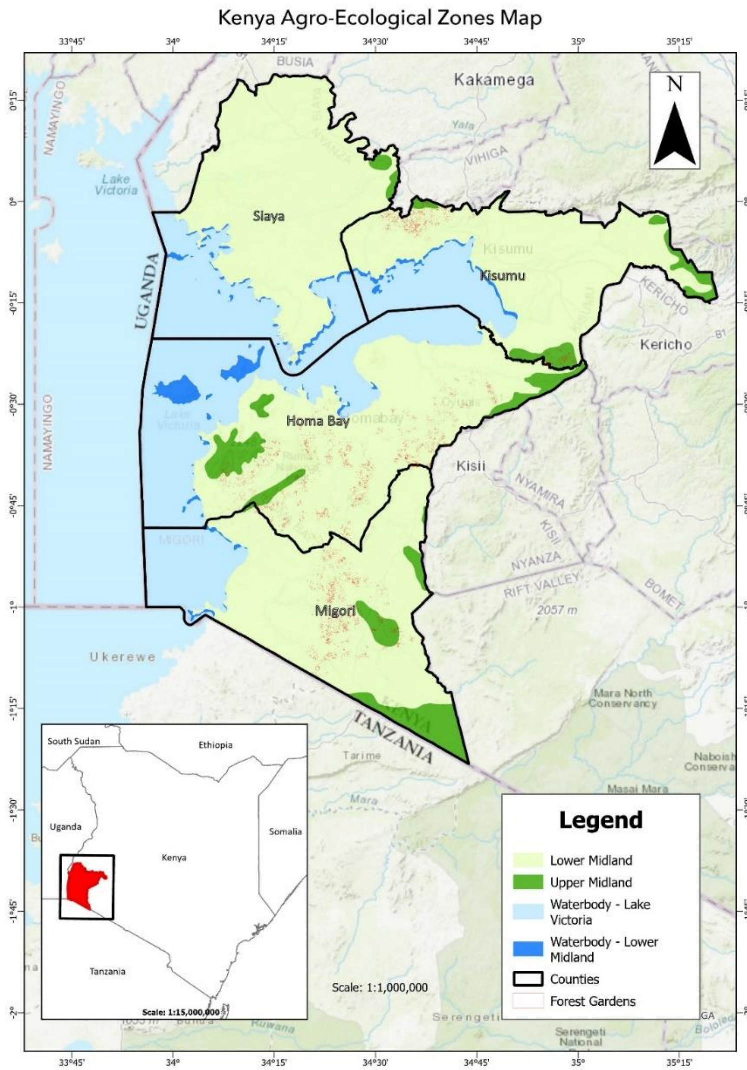


Figure 5.1.a Project region overlaid with Kenya's Agroecological Zones

Table 5.1.a: Strata and Forest Garden Farms

Agroecological Zones (AEZ)	TREES Forest Garden Farm Area (ha)	Number of Forest Garden Farms
Lower midland	5,182	6,967
Upper midland	542	883
Total	5,724	7,850

5.2 Target Precision Level

Uncertainty in measurements of biomass and soil carbon will target a precision level of 10% of the mean at the 90% confidence level.

5.3 Sample Sizes

Sample sizes will be calculated based on expected variance and the target precision level. The minimum number of plots can be calculated using the formula in Pearson et al 2005.[1] For baseline sampling, 189 plots were sampled for soil carbon. This number of plots yielded an uncertainty in soil carbon stocks of 4.3% based on a 90% confidence interval. Where a measurement event occurs and the target precision level is missed, additional plots will be added and measured and subsequently included in future measurement campaigns.

5.4 Sample Site Locations

Baseline sample sites are illustrated here in Figure 5.4.a. Sample sites for project monitoring will be included in Monitoring Reports submitted at the time of verification.

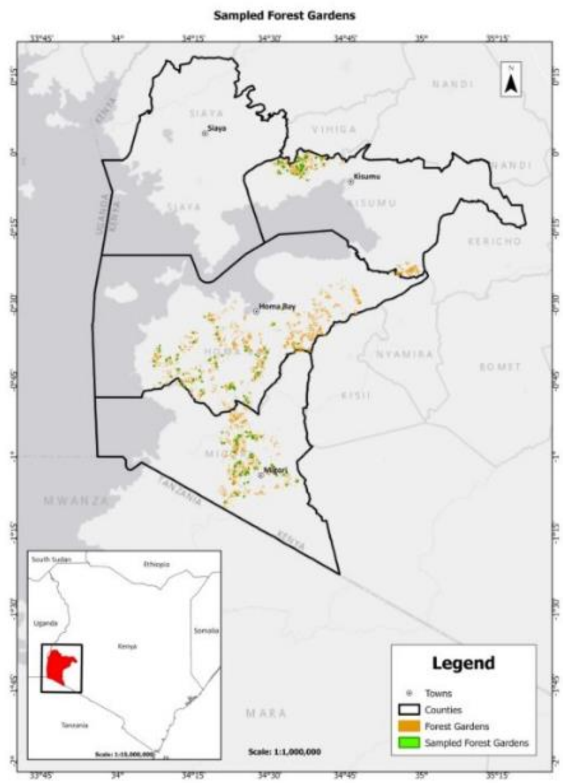


Figure 5.4.a: Sampled farms used to quantify baseline stocks and emissions

5.5 Frequency of Measurement

Measurement and analysis for reporting in the Monitoring Report will occur on the following frequency:

- Soil Measurement: Every 5 years to true-up RothC model
- Biomass Measurement: Every 2 years to coincide with verification
- Farm Sampling (for fossil fuel, fertilizer, livestock, n-fixing species and biomass burning): Every 2 years to coincide with verification

[1] Brown, Sandra; Pearson, Timothy R.H.; Walker, Sarah Lynn.
Sourcebook for land use, land-use change and forestry projects (English). Washington, D.C World Bank Group.
http://documents.worldbank.org/curated/en/285391468335978463/Sourcebook-for-land-use-land-use-change-and-forestry-projects

6. APPENDICES

6.1 Overview of GHG data collection and management system

6.1.1. Preparation Phase

Select Permanent Sampling Sites

Process Steps:

- Stratify in AEZs to ensure representative sampling.
- Select sample sites within each stratum for each instance

Considerations: Geographic diversity, crop types, and accessibility.

Communicate Sampling Protocol and Timeline

Process Steps:

- Develop communication materials (guidelines, schedules).
- Engage with farmers and local communities and document
- Document feedback and adjust plans as necessary, finalize sampling plan

Considerations: Clear, understandable communication; local languages and channels.

Acquire and Prepare Equipment

Process Steps:

- List required equipment for sampling and data collection.
- Acquire and calibrate equipment.
- Train trainers in equipment use.

Considerations: Technical specifications, calibration standards.

6.1.2 Planning and Development Phase

Develop a Field Monitoring Plan and Schedule

Process Steps:

- Define objectives and metrics for monitoring.
- Schedule field visits and data collection periods.

Considerations: Seasonal factors, crop growth stages.

Develop Survey Tools

Process Steps:

- Design questionnaires and data recording formats.
- Test tools for comprehensiveness and usability.

Considerations: Clarity, relevance, and ease of use.

Train Trainers on SOPs and Survey

Process Steps:

- Develop Standard Operating Procedures (SOPs) for data collection.
- Conduct training sessions for trainers.

- Field test SOPs and survey tools.

Considerations: Ensuring consistency and reliability in data collection.

6.1.3 Execution Phase

Train Data Collection Crews

Process Steps:

- Train crews on the use of tools, survey, and SOPs.
- Conduct field tests with teams.
- Review and refine tools and SOPs based on feedback.

Considerations: Practical challenges, team feedback.

Field Data Collection

Process Steps:

- Execute data collection according to plan.
- Implement QA/QC reviews between collection days.
- Continuously refine processes and tools.

Considerations: Data integrity, adherence to SOPs.

6.1.4 Analysis and Reporting Phase

Analyze Data

Process Steps:

- Compile and clean collected data.
- Perform statistical and spatial analyses.
- Interpret results and draw conclusions.

Considerations: Analytical methods, software tools.

Report Findings in accordance with Verra VCS/CCB Verification Reporting Template

Process Steps:

- Ensure adequate consulting support for calculations in accordance with Verra VCS/CCB Verification Reporting Template and VM0042 standards
- Ensure ability to have Module calibration for IME review

Considerations: high quality QA/QC so all farms align with data, strong database management over time, Verra updates that are frequently changing data needs.

6.2 Standard Operating Procedures (SOPs) Manual for Carbon Measurement under LV Carbon (Version March 2024)

6.2.1 How to use this document

The purpose of this document is to provide standard operating procedures (SOPs) for field measurement approaches to assist TREES for the Future in quantifying the amount of carbon stored within the forest gardens under the Lake Victoria Watershed Agroforestry Carbon Project (LV Carbon) in Kenya. These SOPs should not be implemented without receiving extensive field training in the measurement methods and protocols.

6.2.2 General SOPs

The following SOPs provide general field sampling guidance:

Data Collectors

Field teams are responsible for data collection and should be comprised of TREES staff, interns or volunteers and other local community members. Teams should have a minimum of three people, two measuring and recording biometric data and one team leader overseeing and supporting the work. The following field crew composition (and their associated responsibilities) is recommended:

Field Coordinator (will also often function as a Team Leader):

- Organize and prepare for fieldwork, including planning work schedule and plots to sample and re-sample each day, coordinating team member logistics, and monitoring progress.
- Direct all fieldwork, including quality assurance during data collection and take notes of measurements/observations.
- Input collected data and take data backups.
- Maintain team spirit, relationships with communities, and relationships with local authorities.

Team Leader:

- Lead specific teams in the field, overseeing other team members and assuring SOPs are followed.
- Direct team's fieldwork, including quality assurance during data collection, and take notes of measurements/observations.
- Participate in QA/QC across teams. This includes reviewing plots data collected before leaving the site to ensure no illogical data has been collected, and direct re-sampling as needed.

DBH/DME Measurement Person 1**:**

- Collect any necessary biomass samples and measure and/or assess tree attributes, and other items from SOPs, following guidance from the team leader.

DBH/DME Measurement Person 2**:**

- Same as above.

Team composition can and should be adjusted from the above based on the specific skills of the team members to optimize data collection quality and efficiency. A TREES for the Future staff member should act as field coordinator (and may also be one of the team leaders), responsible for fieldwork logistics, obtaining access to the field and the sampling plots, engaging with farmers granting access to the sites, communicating between field crew teams, and collating all data collection forms after the field campaign. At least one of the measurement personnel should have experience with forest garden species identification.

Using and calibrating field equipment

Distance measuring equipment (DME) - Distance measuring equipment (DME) is used to set up plot boundaries in circular plots. The DME includes a measuring unit and a transponder, which use ultrasound waves to estimate the distance between the two components (Figure 6.2.2a). The team leaders and the field coordinator must review the DME instructions and practice use before going into the field.

Figure 6.2.2a Distance Measuring Equipment (DME)[2]

Briefly, the steps to use the DME are:

1. **Expose the DME to the air before use:** The speed of waves used by the DME varies slightly depending on humidity and temperature, e.g., they will travel faster in a dry environment. The DME therefore needs to be calibrated before use in every plot or it will produce inaccurate estimates. The DME needs to adjust to local conditions for at least 10 minutes before use. Do not keep the DME in its box or in someone's pocket directly before using it – instead, expose it to the air for at least 10 minutes before use. The DME could be carried on a neck strap during this calibration period.
2. **Calibrate the DME:** The DME should be calibrated daily. To calibrate the DME, one team member should hold the transponder in one hand and measuring tape in the other while the team leader takes the measuring instrument in one hand and measuring tape in the other. The team leader should go to a point 10 m away, holding the measuring tape tautly and not allowing it to drape to the ground. Make sure that the transponder, measuring instrument, and measuring tape are parallel to each other. The team leader should follow the specific instructions from the DME manual, but this will typically include holding still, pointing the measuring unit at the transponder, and applying the calibration protocol for the device until 10 m is shown on the screen. Repeat this step until 10 m is shown.
3. **Put the transponder in the plot center:** Use a tripod or staff on the rod at the center of the plot so the transponder can be directly above the plot center. It is recommended to put a piece of brightly colored tape above or near the DME to increase visibility throughout data collection. It will be very important to ensure the DME is very stable so that no risk exists of the DME falling.
4. **Record distances to set plot boundaries.** Make sure that the unit displayed on the screen is in meters (not feet) for consistency across field measurements and greater precision. Check the DME manual to confirm how to change the unit on the measuring unit screen.

[2] Source: www.forestry-suppliers.com

Using a diameter tape for DBH

DBH is best measured using a specially calibrated diameter tape that shows the diameter of the tree trunk when wrapped around it. The tape must be wrapped straight and tight around the tree at the DBH height, i.e., 1.3 m from the ground. Instructions on how to measure DBH in irregular trees are provided in the Field Measurement SOPs volume. For quick measurements where there is an identifiable tree trunk at breast height, it is often useful to bring a 1.3 m pole (e.g., a PVC pipe, as shown in Figure 6.2.2b) to the field to quickly find the tree DBH height rather than using a regular measuring tape.

Figure 6.2.2b. Using a DBH tape and a pole to measure the tree diameter[3].

Data storage

Data storage and archiving is important for the long-term success of a project and is a vital last step of data collection. In the field, data are recorded using Taroworks. Taroworks allows for seamless collection and storage of data. See Section 2.3 discussing data storage in Taroworks.

Logbooks: A logbook should be kept that records information about each field day (e.g., time of departure to the field and date of return, number of plots, location, field crew and leader, challenges, purpose of the campaign, etc.). Each field campaign should be given a unique number.

6.2.3 Quality Assurance and Quality Control SOPs

Quality assurance (QA) and quality control (QC) SOPs must be followed closely to ensure accurate carbon stock measurements. QA/QC across different steps in data collection are outlined below. This section reviews the QA/QC procedures for field sampling, lab analysis, remote sensing analysis, and data entry.

Quality assurance

Training: A trained member of TREES MEL Department will lead training for data collectors on all SOPs and clearly impart the importance of accurately, carefully, and completely collecting data. After training, each field crew member should be evaluated and provided with immediate feedback to correct any errors in measurement techniques before field sampling occurs. Any errors should be clearly explained.

[3] Walker, SM, TRH Pearson, FM Casarim, N Harris, S Petrova, A Grais, E Swails, M Netzer, KM Goslee, S Brown and G Sidman. 2018. Standard Operating Procedures for Terrestrial Carbon Measurement: Version 2018. Winrock International.

If there is more than one field team, it is recommended that field team leaders switch between field teams to ensure techniques are uniform across teams. Training should be repeated before each field campaign to refresh staff on SOPs. A record must be kept of all training and retraining that occurs with all participants signing to document their participation.

Field measurements: For all data points, the team leader (or other data collectors designated by the team leader) that is recording data must verbally repeat the measurement called out by the crew member who conducted the measurement to ensure the correct numbers are recorded in the Taroworks App. Before leaving the site and after all data has been collected, the team leader should double-check all Taroworks data for completeness, accuracy, coherence, and legibility. All measured trees should be permanently marked and before leaving the plot data collectors should verify all trees are tagged. If any information is missing or appears incorrect, mistakes should be corrected before leaving the site with a clear record when changes have been made.

When the data has been reviewed and validated by the team leader, they will check the box in Taroworks indicated that the data has been reviewed and enter their name. The name of the data recorder and the date are automatically captured in Taroworks. Any issues that were found should be detailed in the notes section in Taroworks on the record so they can be addressed and avoided in the future. Date should be synced at the end of each day to be permanently captured in the Salesforce database.

On the first sampling day, the team leader should take measurements alongside the field team to correct any mistakes during data collection. Five percent of farms should be remeasured in a blind measurement. Full data should be recollected with no access to the results of the prior measurement.

Data entry: Immediately before leaving the farm, the crew chief should assess the collected data and ensure that there are no non-sensical data points (i.e., numbers that are too large or too small or biophysically impossible), in such cases the relevant tree should be revisited and remeasured. During data analysis, if there are any significant issues with the plot data that cannot be resolved with clarifications from the field team leader or other team members, the plot data should not be used in the analysis. For details about procedures to follow during data analysis, see Section 6.2.6 for Data Analysis SOPs.

Quality Control

Field measurement and error estimation will rely on blind checks. Five percent of plots will be remeasured for quality control. Biomass estimates from remeasured plots should be compared with the original measurements, and an error should be estimated using the following formula that will be reported with carbon stock estimates:

$$\text{Measurement Error (\%)} = \left| \frac{t\ C\ per\ ha\ of\ measured\ plot - t\ C\ per\ ha\ of\ remeasured\ plot}{t\ C\ per\ ha\ of\ remeasured\ plot} \right| \times 100$$

6.2.4 Fieldwork Planning SOPs

This section describes the steps to develop a field measurement plan, including the considerations and decisions to be made during the design process. This section also provides guidance on how to determine the minimum number of plots to meet precision requirements, how to locate them across farms and label them consistently.

Developing a measuring plan: The measuring plan must be developed before field data is collected and shared transparently with the field crew. The goal of the measuring plan is to be cost-effective in the collection of data, consistent, and transparent. The following aspects should be considered in the development of a measuring plan:

- **Area boundaries**: The LV Carbon project occurs over thousands of farms in four counties in Kenya.
- **Stratification**: The forest gardens have been stratified into Kenya's national AEZ classifications.
- **Carbon pools:** The field inventory will assess soil carbon stock and living biomass of trees, while other emission sources will be assessed via farmer surveys.
- **Plots:** Permanent circular plots will be randomly allocated in each area of timber plantation, fruit orchard, intensive fodder zones, and market permagardens within each forest garden to measure tree biomass. Permanent linear plots will be established along alleys and green walls.
- **Sampling frequency**: Biomass carbon stock estimates will be updated for each monitoring period (every two years, or less or more frequently depending on project monitoring frequency). Soils will be monitored with every true-up, at least every five years.

Determining number of plots needed: To determine the number of plots needed, follow these steps:

1. **Set the desired precision level.** The project will aim for carbon stocks within 10% of the true value of the mean at the 90% confidence level.
2. **Examine preliminary data to estimate variance.** Initial sampling across pre-existing forest gardens, and baseline soil carbon measurements will give an estimate of variance. The higher the variance the more plots will be needed.
3. **Calculate the required sample plot number.** The minimum number of plots can be calculated using the formula in Pearson et al 2005[4]. The calculated minimum sample size should be increased by approximately 20% to allow for plots that need to be dropped during field sampling due to inaccessibility or other circumstances. The calculated minimum sample size should be increased by approximately 20% to allow for plots that need to be dropped during field sampling due to inaccessibility or other circumstances.

Laying out random plots: Sample farms should be assigned randomly using GIS throughout the focus instance and stratum within the project area and should not be biased based on known local conditions or forest garden composition. These should be assigned using the random function in GIS. Within each farm separate subplots will be established for: a) timber plantation; b) large tree orchard; c) small tree orchard; d) intensive fodder production; e) market permagarden; f) alley trees; g) green wall. The random location of these subplots is determined once the team is at each farm as described below in the field measurement SOPs.

[4] ibid

Labeling plots and trees: Plot labels provide a unique identifier and information about the sampling point. Every plot should have a label comprised of multiple components that identify the type of sampling, the area, the number of the plot, the subplot, and any other relevant information. The plot number should have as many digits as the total number of plots expected to be sampled in the field campaign, i.e., three digits if more than 100 but fewer than 1,000 plots will be sampled, two digits if more than 10 but fewer than 100 plots will be sampled, etc.

Plot labels should include:

- Kenya county code (K – Kisumu; H – Homa Bay; M – Migori; S – Siaya)
- Instance: should be two numbers for the year of the instance (instance year is determined by year of first outplanting), e.g., 21 for 2021
- Stratum: should be one letter, e.g., U for Upper Midland or L for Lower Midland
- Plot number: Unique number for specific plot.
- Subplot number: Specific subplot (i.e., TP - Timber plantation; LO - Large tree orchard; SO - Small tree orchard; IF - Intensive fodder production; MP - Market permagarden; AT - Alley trees; GW - Green wall

For example, the green wall in a farm in the 2021 instance in the Lower Midland stratum in Homa Bay could be labelled H-21-L-013-GW.

6.2.5 Field Measurement SOPs

These SOPs describe the steps to collect live biomass and soil carbon data that will be used to estimate with an accuracy above 90% the carbon stock contained in forest gardens in the LV Carbon project area in Kenya. Topics covered in these SOPs are:

- Equipment needed for fieldwork
- Determining subplot locations
- Establishing permanent plots and marking trees
- Measuring biomass of trees
- Collecting soil carbon samples

Equipment needed for fieldwork

General

- Data collection device with Taroworks installed.
- Measuring tape (at least 30 m) for transect distance measurements, for calibrating the DME and as a backup approach.

Navigation

- GPS device
- Backup batteries for GPS or second GPS device

Setting up plot boundaries

- DME (box, measuring unit, transponder, and neck strap if using one)

- Tripod or rod for the center of the plot (usually supplied with the DME, otherwise another one will be needed)
- Measuring tape

Measuring tree diameters

- Range finder
- Measuring tape
- DBH tape

Collecting soil samples

- Soil corer or probe
- Non-breakable rod (Used to remove soil from corer/probe)
- Rubber mallet
- Small bucket
- Cloth or plastic bags (bags must be large enough to accommodate soil samples)
- Labels

Other plot measurements

- Digital cameras/smartphones with cameras, plus backup batteries, or portable chargers
- Clinometer

Plot and tree marking supplies.

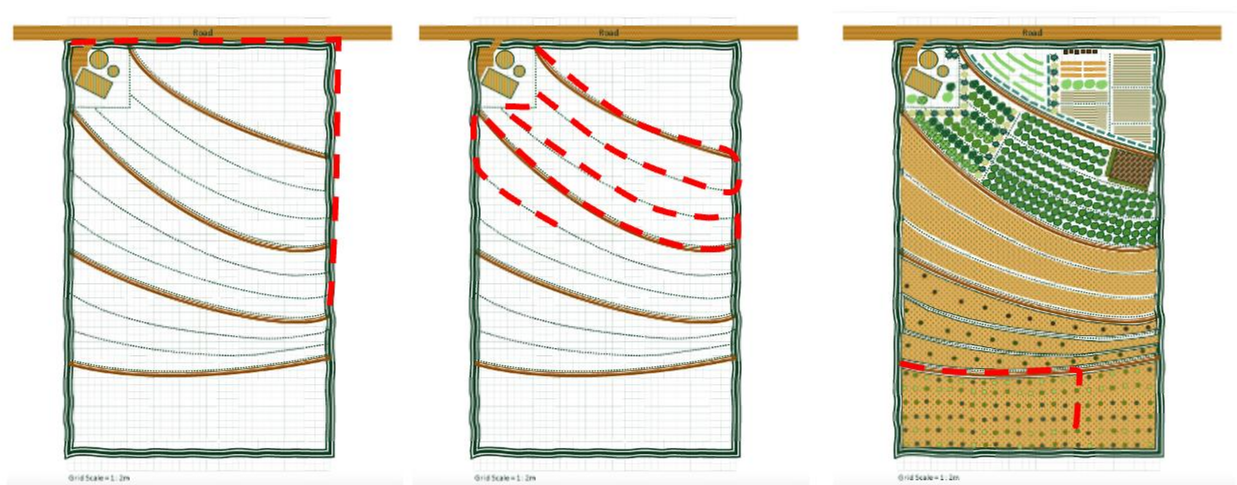
- Aluminium identification tags (with pen or pencil to write on / emboss)
- PVC ribbon and scissors to cut ribbon.
- Rebar (30 cm) and PVC tubes (1.5 m) for plot center
- Small hammer or mallet
- Permanent marker

<u>Determining subplot locations</u>

When the team arrives at the sampling farm, start up the GPS. The longer the GPS is in one location, the more data it can acquire from satellite signals and the more accurate it will be. The center of the other subplots should be recorded in the same manner. The team lead must know how to operate the GPS device and ensure it functions properly and is fully charged, bringing backup batteries or even a second GPS. At least two members of each field team must understand how to use the GPS. One person will be responsible for carrying the GPS and always having it in sight while doing fieldwork.

The next step is to walk the boundaries of the forest garden elements. Polygon elements that should be fully walked round are timber plantation, fruit orchards (large and small), intensive forage production zone, and market permagarden. The linear features that should be walked from one end to the other are: alleys and green wall (note the alleys will have multiple linear features while the green wall will be continuous).

For each sample farm, the team must have a random number for each farm element between 0 and 199. These numbers can either be preallocated and carried into the field or a random number table can be taken into the field and numbers sequentially used and crossed off. For each element, begin at the position on the boundary of the element that is nearest to the entrance to the forest garden (i.e., break in the green wall used by the farmer to enter the forest garden). If there are multiple entrances or it is unclear, start at the position on the boundary of the element that is the northern-most point of the boundary. From this point travel in a clockwise direction the number of meters equal to the generated random number - if the random number between 0-199 exceeds the number of meters in the boundary, continue walking along the boundary (i.e., do a full loop and continue onwards) until the number is reached. For the linear elements, this point will represent the beginning point of the plot transect. For the polygon elements of the garden, travel 12 meters perpendicular to the edge into the element and at this point establish the plot center. Illustrations of this process with examples are shown below.



Example of plot initiation point in green wall, with clockwise navigation of 90 m.

Example of plot initiation point in alleys, with clockwise navigation along sequential alleys of 150 m.

Example of plot initiation point in timber plot, with clockwise navigation along sequential alleys of 25 m, then entry into the forest garden component (i.e., timber plot) 12 m perpendicular to the edge.

Figure 6.2.5a. Example of determining sample points for different forest garden components.

Establishing permanent plots

Permanent plots will be used to measure biomass carbon stocks. Permanent plots will take the form of fixed 10 m radius circles for: timber plantations, large tree orchards, small tree orchards, intensive fodder production zones, and market permagardens. For the linear elements (alleys and green wall) permanent sampling will consist of a 10 m transect.

Once at the plot initiation point, the team lead will capture a GPS reading and take photographs in the four cardinal directions in the order (N, E, S, W). On the first visit the plot initiation point must also be marked and labelled. To mark the point the 0.3 m length piece of rebar should be hammered into the soil so that only 5 cm remains visible above the soil surface, the PVC tube then should be sunk over the rebar down approximately 20 cm. The aluminium tag should be labelled with the plot identifier and tied around the base of the tube and the same identifier must be written on the tube with a permanent pen. In addition, on first visit a careful measurement must be taken and recorded on Taroworks with a clinometer of any plot slope.

Measuring biomass

In the circular plots, trees must be measured clockwise from North with the team leader situated at the plot center calling out trees to be measured (see Figure 6.3.a).

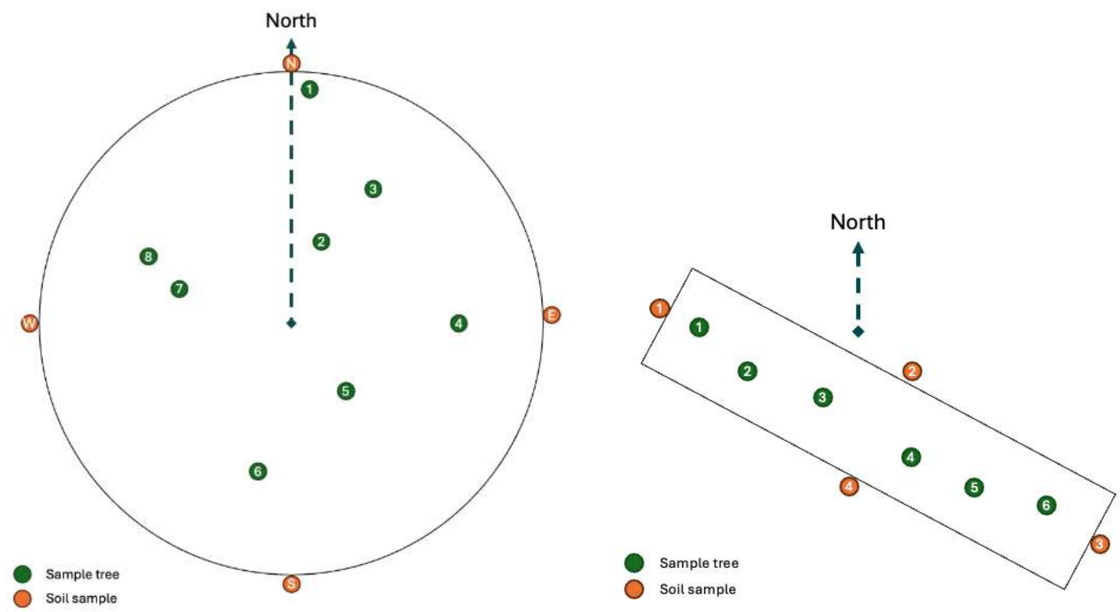


Figure 6.2.5b Diagram showing tree and soil sample locations within example plots.

The person measuring the tree must call out the tree identifier (i.e., the tree number), the DBH and species of each tree. On first measurement, trees must be labelled. As DBH measurements are taken and recorded, the field member must mark every measured stem with chalk facing the plot center consistently to facilitate finding the mark, numbering the trees immediately after measurement.

Trees should be numbered sequentially in each plot and labelled with the subplot type and tree number written on an aluminium tag, so for example the 6th tree measured in the Large Orchard of a specific forest garden would be labelled LO – 006. Labels should be tied around the base of the tree with PVC ribbon.

For the alleys the team leader walks beside the person measuring trees from the plot initiation point to the end of the transect. Every tree meeting the diameter minimum (5 cm) forming part of the alley must be measured. Where an alley crosses a circular plot (in an orchard, permagarden or fodder area), the alley tree must be noted in the field data but must not be labelled and measured as part of the circular plot.

Each tree present that meets the DBH minimum must be measured. Basic data to record for each tree are:

- **Species**
- **Stem diameter at breast height (DBH)** - 1.3 m above the ground level
- **Additional notes**: taken as needed, along with plot pictures, to help understand data collected and decisions made during sampling.

Seedlings (trees with a DBH that does not reach 5 cm) and standing or lying deadwood will not be measured in the plots.

These measurements will provide the data needed to estimate aboveground tree biomass. Belowground tree biomass (i.e., underground roots) is calculated using equations that use aboveground biomass parameters such as DBH or total aboveground biomass. These equations are provided in the *Data Analysis SOPs*. DBH or any stem diameter is always measured with a DBH tape – the DBH tape must never be made of a stretchable material.

For the green wall, the width and height of the green wall must be measured every 2.5 meters at each measurement. Measurements will be taken at 0 m, 2.5 m, 5 m, 7.5 m, 10 m. In the green wall there is no specific measurement of trees or shrubs but instead a factor applied to the measured volume of the wall.

<u>Collecting Soil Samples</u>

Soil carbon is estimated by collecting soil to a certain depth and then analyzing it in a laboratory for carbon content. This information is then combined with a collected bulk density measurement to estimate the average mass of carbon within the soil to a certain depth. Soil samples are collected every five years to true-up the RothC model.

1. Determine sampling location. Sampling for soil occurs at four locations at each vegetation subplot. These locations shall be immediately outside the measurement plot boundaries, north, south, east and west from the subplot center (see Figure 6.2.5b above). If the sample outside the circular plot falls within an alley, move 2 m clockwise around the circular plot until the sample location is outside of the alley. In linear plots, sampling points would occur just outside the linear plot, with two points halfway along on the long side and two halfway along on the short sides of the linear plot.
2. Remove all vegetation and litter from the sampling location. Because the carbon concentration of organic materials is much higher than that of the mineral soil, including even a small amount of surface material can result in a serious overestimation of soil carbon stocks.
3. Sampling forest soils with a standard soil corer can often present difficulties as the corer can hit roots frequently, which makes it difficult to extract a full core.
    a. Determine two depth increments for collection. For initial sampling to 30 cm these increments are 0-15 cm and 15-30 cm. Over time depth will increase to ensure that sufficient depth is included to capture Equivalent Soil Mass (ESM). At second sampling total depth will be 40 cm with increments 0-20, 20-40; and at all subsequent measurements total depth will be 50 cm with increments of 0-30, 30-50.
    b. Insert the soil corer/probe steadily to depth of first increment.
    c. If the soil is compacted, use a rubber mallet to fully insert. If the probe will not penetrate

to the full depth, do not force it as it is likely that a stone/root is blocking its route and if forced the probe will be damaged. If blocked withdraw the probe, clean out any collected soil, and insert in a new location.

   d. If depth of soil at sampling point at any point is less than depth measured, then the depth of the soil sampled must be recorded.
   e. Carefully extract the probe and put soil into a cloth or plastic bag.
   f. Insert probe a second time into the same hole collecting a sample up to the second increment depth, and repeat collection steps in d.
   g. To reduce variability, repeat steps a-e at a total of four points as per Step 1 above, but using the same bag for each increment within the plot (e.g., all 0-15 cm increments in the same bag, and all 15-30 cm increments in the same bag).
   h. Mix all four samples of each increment thoroughly to a uniform color and consistency. It is important to take special care to remove pieces of litter and charcoal from samples at any sites.
   i. Place one thoroughly mixed subsample into a labelled sample bag. Assign bag a unique ID number – the plot ID, I1 or I2 for the increment plus the two digits for year e.g. PLOT ID-I1-25 for a 0-15 cm sample collected in 2025. Ensure total weight of soil in bag is greater than the minimum soil weight required by the soil laboratory (if soil is very wet, this should be taken into consideration in determining mass of soil contained in soil sample bag).
   j. At each sampling location, take two additional cores for determination of bulk density at locations immediately outside the measurement plot boundaries, in northeast and southwest directions from the subplot center. When taking cores for measurements of bulk density, care should be taken to avoid any loss of soil from the cores.
   k. Each sampling plot will have five soil samples: 2 bags for soil carbon estimation (1 for each depth increment), and 4 bags containing soil for bulk density determination (2 for each depth increment).

4. It is allowable for there to be a delay between field data collection and laboratory analysis. However, this delay may not exceed 5 days and sample bags must be placed in a refrigerator as soon as they are returned from the field after the day of sampling.
5. Promptly send soil samples to a professional lab for analysis.

<u>Summary of steps to follow during field sampling</u>

Before fieldwork

1. On first sampling in a specific instance randomly select forest gardens to be included in the monitoring plan and create a monitoring forest garden id code
2. Confirm accessibility conditions (agreement of farmer to enter and mark and label plots and trees)
3. Develop a field measurement plan
   a. How many crews of how many people, and what will be the crew roles?

    b. Will soil samples be collected? (soil only collected every 5 years)?
    c. How many days?
    d. How many forest gardens per day?
4. Gather all field supplies and documentation, confirm equipment is in good working condition, and confirm documentation is correct and complete
5. Train or retrain field crew on the SOPs, and discuss the field measurement plan with them

On every fieldwork day

1. Confirm forest gardens planned for the day, accessibility, and schedule
2. Confirm all necessary supplies and equipment are packed and in good working condition
3. Confirm roles of the field crew members
4. Travel to first forest garden and confirm agreement with farmer to work in the garden
5. If the first visit to a forest garden for monitoring, using the GPS walk the boundaries of each forest garden element (Timber plantations; Large tree orchards; Small tree orchards; Intensive fodder production zones; Market permagardens; Alleys; Green wall) in a clockwise direction carefully recording full dimensions. Subsequently the plot initiation points must be established (as described above), marked and labeled. Record any plot slope using a clinometer
6. Make sure both GPS and DME are set with the right units (e.g., the DME in meters) and placed safely and securely. Take the subplot photographs (North, East, South and West from the plot initiation point)
7. Collect data (species, DBH, and distance from plot center or distance along transect) of all trees over 5cm DBH within 10 m of the plot center or within the 10m transect as relevant (noting these measurements are not relevant to green wall plots. In green wall plots record the height and width of the hedge at the following points on the 10 m transect: 0m, 2.5m, 5m, 7.5m and 10m. Take photographs of the trees as needed to document changes or unusual circumstances. Label new trees recorded.
    a. At least one person measures and reads the data. Confirm units before reading measurements
    b. One person records data on the sheet confirming read before noting it down
8. Confirm all necessary data has been collected
9. (where relevant) Collect soil samples for both carbon and bulk density (total of 1 composite bag for soil carbon and 2 bags for bulk density at each soil sampling depth increment in each plot)
10. Move on to the next subplot and repeat process
11. When all subplots are covered, pack all supplies and materials brought to the subplot, including the DME and GPS, and confirm the crew is ready to leave the forest garden
12. Move to the next forest garden of the day, and repeat the process

After every fieldwork day

1. Have a check-in with the field crew
2. Review field data for completeness, consistency, and legibility
3. Reach out to the crew member(s) as needed if something needs clarification
4. Confirm all field supplies and equipment is in good working condition

5. (where relevant) Ensure all soil samples are correctly labeled and either stored in a refrigerator or packed and sent to the laboratory
6. If there is another field day the next day, start the "before fieldwork" steps

After every field campaign

1. Gather all field supplies and documentation, confirm equipment is in good working condition, and confirm documentation is correct and complete
2. Store supplies and documentation in a safe space and upload all electronic copies of the sheets and plot pictures to the cloud, following the standardized data archiving protocol
3. Enter all field data into excel for data analysis
4. Check of data entry and review the finalized excel for consistency, coherence, and completeness
5. (where relevant) Ensure all soil samples have been sent to the laboratory

Reviewing biomass field data before data analysis

The electronic database of tree field data should include every note and parameter collected in the field following the field data collection templates. Each row would represent an individual tree measured in the field with its unique ID number. Once data has been exported to the data analysis software (MS Excel) following the data entry QA/QC procedures described in the volume *Quality Assurance/Quality Control SOPs*, the steps below are followed to prepare data for analysis:

1. Confirm the completeness of the data by going through each row (individual tree) to verify no gaps exist. If any gaps, errors, or unrealistic numbers are found, reach out to the field team lead to discuss the issue.
2. Confirm there are 7 subplots in each forest garden, and that trees within a subplot are numbered consecutively without repetition.
3. Check the distance to the plot center of trees.
4. Unless there is a confirmed data entry error, corrections or changes made to the database must be discussed first and agreed upon. In the odd case that a change is indeed needed anywhere in the database (e.g., if trees need to be discarded due to deviations from SOP instructions), the change must be clearly documented and justified on the Biomass Inventory Excel.
5. The biomass inventory for LV carbon includes QA/QC forest gardens where biomass is resampled following these SOPs. The number of individuals and their dimensions in the QA/QC plots must be compared to their corresponding non-QA/QC plots, to determine potential errors associated with data collection. If a given QA/QC and non-QA/QC plot shows a different number of trees, field sheets need to be reviewed to confirm both QA/QC and non-QA/QC data were entered correctly.

6.2.6 Data analysis SOPs

Equations and default factors to estimate living biomass stocks

The living biomass stock of a tree refers to the sum of the aboveground and belowground biomass stocks. Above- and belowground biomass components are estimated based on the field data collected, using the equations described below.

Allometric equations for aboveground biomass:

1. **Trees:** For trees specific equations are included for *Acacia* and *Grevillea*, in all other cases an agroforestry equation for western Africa is used from Kuyah et al. (2012).

Species planted in project scenario	Allometric equation to use	Source	Notes
Acacia polyacantha	**$AGB = 0.5099 * DBH^{1.9141}$**	[5]	54 acacia trees, including polyacantha sampled
Leucaena leucocephala	**$AGB = 0.091 \times DBH^{2.472}$**	[6]	Agricultural mosaic in western Kenya
Grevillea robusta	**$AGB = 1.384*DBH^{(1.665)}$**	[7]	MRE 3.2 R2 0.98, SEE 0.99
Other including: *Leucaena leucocephala* *Leucaena trichandra* *Calliandra calothyrsus* *Moringa oleifera* *Casuarina equisetifolia* *Terminalia brownii* *Albizia coraria* *Markhamia lutea* *Croton megalocarpus* *Podocarpus falcatus* *Cordia africana*	**$AGB = 0.091 \times DBH^{2.472}$**	[8]	Agricultural mosaic in western Kenya

[5] Aneseyee, Abreham Berta, Teshome Soromessa, Eyasu Elias, and Gudina Legese Feyisa. "Allometric Equations for Selected Acacia Species (Vachellia and Senegalia Genera) of Ethiopia." Carbon Balance and Management 16, no. 1 (November 2, 2021): 34. https://doi.org/10.1186/s13021-021-00196-1.

[6] Kuyah, Shem, Catherine Muthuri, Ramni Jamnadass, Peter Mwangi, Henry Neufeldt, and Johannes Dietz. "Crown Area Allometries for Estimation of Aboveground Tree Biomass in Agricultural Landscapes of Western Kenya." *Agroforestry Systems* 86, no. 2 (October 2012): 267–77. https://doi.org/10.1007/s10457-012-9529-1.

[7] Owate, Omamo Augustine, Mugo Joseph Mware, and Mwangi James Kinyanjui. "Allometric Equations for Estimating Silk Oak (Grevillea Robusta) Biomass in Agricultural Landscapes of Maragua Subcounty, Kenya." International Journal of Forestry Research 2018 (October 2, 2018): 1–14. https://doi.org/10.1155/2018/6495271. As cited in Saskia Reppin et al., "Contribution of Agroforestry to Climate Change Mitigation and Livelihoods in Western Kenya," Agroforestry Systems 94, no. 1 (February 2020): 203–20, https://doi.org/10.1007/s10457-019-00383-7.

[8] Kuyah, Shem, Catherine Muthuri, Ramni Jamnadass, Peter Mwangi, Henry Neufeldt, and Johannes Dietz. "Crown Area Allometries for Estimation of Aboveground Tree Biomass in Agricultural Landscapes of Western Kenya." *Agroforestry Systems* 86, no. 2 (October 2012): 267–77. https://doi.org/10.1007/s10457-012-9529-1.

Vitex keniensis *Azadirachta indica* *Carica papaya (papaya)* *Mangifera indica (mango)* *Persea americana (avocado)* *Citrus spp.*			

2. **Hedgerow (Green Wall)**

Green wall biomass is derived from the study of Henry et al. 2009 for biomass in smallholder farming systems in western Kenya[9]. In the study biomass is derived from the volume of hedgerow in three density classes.

The paper includes a range of species and densities. To be conservative here a value is applied per cubic meter of green wall volume that is equal to the mean minus the standard error of the available hedgerow models for the medium density class. Thus, green wall biomass = 1.03 kg dry matter per cubic meter of green wall.

Calculation of belowground biomass: A root: shoot ratio of 0.232 is used derived from the 2019 IPCC Guidelines, Volume 4, Chapter 4, Table 4.4 [10]value for tropical moist Africa derived from Mokany et al., 2006[11].

Calculating biomass stock: To convert individual tree dry mass to a mass per area (stock), calculate the area of the plot assigned to the tree, and convert it to hectares OR the length of the linear feature and convert to biomass per meter.

Carbon stock of living biomass at the subplot and plot level: To convert biomass to carbon, the biomass is multiplied by the default factor of 0.47. The total living biomass carbon stock (t C/ha or t C/m) of each subplot is the sum of the total living carbon stock of each tree in the subplot.

Within each garden the area or length of each garden element must be multiplied by the per area or per length calculated factor to determine the total estimated garden biomass. This is then divided by the total area of the garden to result in a single t C/ha for each forest garden.

After estimating living biomass, review biomass stock results at the subplot and plot level to assess if they are within reasonable ranges and with reasonable uncertainty or variability. Seemingly odd numbers must be traced back to the original data to understand what drove the result. If biometric data

[9] Henry, M., P. Tittonell, R.J. Manlay, M. Bernoux, A. Albrecht, and B. Vanlauwe. "Biodiversity, Carbon Stocks and Sequestration Potential in Aboveground Biomass in Smallholder Farming Systems of Western Kenya." Agriculture, Ecosystems & Environment 129, no. 1–3 (January 2009): 238–52. https://doi.org/10.1016/j.agee.2008.09.006.

[10] "2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories." Agriculture, Forestry, and Other Land Use. Switzerland.: IPCC, 2019. https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch04_Forest%20Land.pdf

[11] Mokany, Karel, R. John Raison, and Anatoly S. Prokushkin. "Critical Analysis of Root: Shoot Ratios in Terrestrial Biomes." Global Change Biology 12, no. 1 (January 2006): 84–96. https://doi.org/10.1111/j.1365-2486.2005.001043.x.

suggests there might be an error in the dimensions of a tree, field sheets must be checked to confirm the data entered reflects what was recorded in the field.

Change in carbon stock of living biomass at the subplot and plot level: The sequestration achieved by the LV Carbon project is the gain achieved between two monitoring intervals. Using permanent plots, this gain is estimated at the tree level. In analysis the biomass of each tree is estimated, and the previous biomass is subtracted to result in an estimate of gain in biomass which is summed across trees to give a total gain in each subplot / forest garden element (t C/ha or t C/m).

As with stocks the area or length of each garden element must be multiplied by the per area or per length calculated factor to determine the total estimated garden biomass. This is then divided by the total area of the garden to result in a single t C/ha gain for each forest garden.

Stock variability and uncertainty of the mean: Variability and uncertainty can be estimated at the instance and the entire project area level represented by the sampled forest gardens. Variability is represented by the standard deviation of the data and the half-width of the 90% confidence interval. Both can be calculated in Excel with the STDEV and the CONFIDENCE.NORM functions. The % uncertainty to the mean is then the result of the half-width of the 90% confidence interval divided by the mean.

6.3 Data Collection – SOPs for Farm Survey

Data is collected and quality controlled as indicated in Section 4.1 above.

Step 1: Identify the Forest Garden Boundary with the farmer, ask the farmer about trees that will be cleared due to forest garden implementation.

- Record the GPS points of existing trees that will not be cleared.
- Measure per the survey existing trees that will be cleared (this should only be invasive species, shrubs or Eucalyptus that were planned for harvesting).

Step 2: Complete the Farmer Field Area Measurement Survey (FAM) using prepopulated Taroworks questions in the surveys listed below regarding:

Field Area Measurement Survey Questions[12]

- Tillage and Irrigation
- Crop History
- Livestock Management
- Fertilizer Use
- Nitrogen Fixing Species
- Fossil Fuel Use
- Agriculture Residues

Step 3: Perform QA/QC and review data

[12] Exhibit 57- Field Area Measurement Survey Questions

- Data collected is downloaded and organized in spreadsheets for easy viewing and calculation.
- Weights and dry weights for different volume measurements are measured in the field to use for conversions.
- Data in each category is compared with known data sources where available and checked for anomalies. Crop data is compared with County level crop data, while livestock management, fertilizer use, tillage and irrigation data are reviewed against other FAM data to identify outliers. Any outlying data is checked with data collector and the farmer
- Ensure that all GPS points, pictures, and additional notes have been recorded.

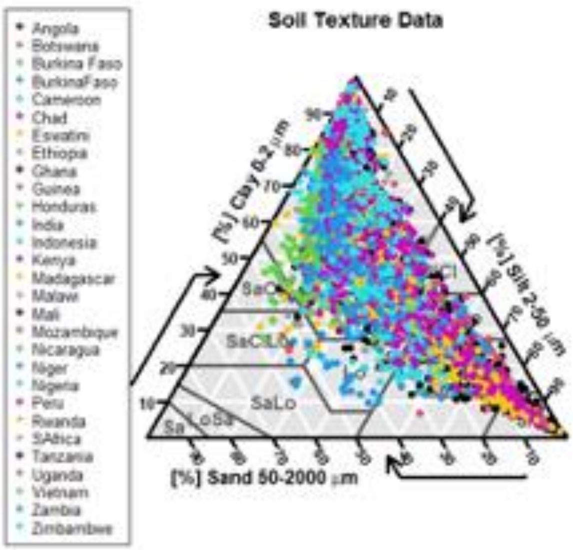
6.4 Data Collection – SOPs Lab Analysis

Soil spectroscopy tools are used in this project to assess SOC content from different sampling points. The SOPs for sample processing includes drying and sieving samples to remove any particles greater than 2 mm in diameter. Consistent with the method-specific criteria given by Table 9 in VM0042 v2.0, all protocols follow the Standard Operating Procedures of the Soil-Plant Spectral Diagnostics Laboratory of Worlds Agroforestry Centre (ICRAF).[9] ICRAF has also published SOPs for Sample Reception, Processing, Log-in, Shipping, Archiving, and Disposal, which are followed for this project.

The soil samples for the project will be analyzed using the Bruker HTS-XT Fourier Transform Mid-Infrared Spectrometer, which covers a 7,500 cm^{-1} to 600 cm^{-1} range. ICRAF has published SOPs regarding the use of this technology and instrument and their SOPs also describe all pretreatment and preprocessing methods to analyze data.[10] For the processing of baseline data, the methodology used, and results are outlined in the ICRAF MIR Spectroscopy Prediction Report provided as a supporting document in the Appendix to the Project Description.

The models are fitted using Bayesian Regularization for Feed-Forward Neural Networks (BRNN) and Random Forest (RF) algorithms. Model performance was based on a 30% hold-out validation set. The calibration and validation data used are representative of the project area, as is demonstrated in Figure 1 of the ICRAF MIR Spectroscopy Prediction Report[13]. The data used in the spectroscopy model cover a wide range of soil texture, pH, Mg, and carbon content including those of the project area (see figure 6.6a and Summary_properties csv[14] from ICRAF summarizing data used in the model).

[13] Exhibit 71 – ICRAF MIR Spectroscopy Prediction Report
[14] Exhibit 73 – Summary Properties



The goodness-of-fit metrics and descriptive statistics from the dataset are available in the ICRAF MIR Spectroscopy Prediction Report.

Posterior predictive distributions (PPDs) will be used to propagate error from the spectroscopy model to calculations of the uncertainty deduction, which will be determined before project verification. All samples will be chosen through stratified random sampling approach as is explained above. A Monte Carlo simulation will be used to estimate error before verification due to the use of spectroscopy to estimate SOC.

Figure 6.6a. Soil texture of data used in spectroscopy calibration/validation dataset, by country (shared by ICRAF in correspondence)

6.5 RothC SOPs

All processes to run RothC will follow those outlined in the RothC user guide available for download here on the RothC website.[15] This guide outlines the data requirements, model structure, steps to install and run the interface, and steps to create scenarios and run the model. All model runs will be completed using the R program.

RothC at the baseline will be initialized to SOC stock measurements by iteratively adjusting plant residue carbon inputs and running the model to equilibrium until a C input estimate is reached where steady-state SOC model output (i.e., post-equilibrium run) is +/- 0.5 t C ha-1 of an observed value to which the model is being initialized. This is an important QA/QC step and ensures the model is initialized to the project area.

In future model runs the same initial SOC stock based on steady-state SOC stocks calculated in the baseline scenario will be applied for project modelling. Inputs to the RothC model, their recording frequency, and their sources are described in the table below. Model true ups will follow the steps outlined in VMD0053.

Description of RothC input	**Unit**	**Recording frequency**	**Source**
Baseline areas in cropland with management practice	ha	Project start	Areas will continue to be estimated for each farm participating in the project as part of setting baseline.

[15] Rothamsted Carbon Model (ROTHC): Understanding Soil Carbon Dynamics, Rothamsted Research, www.rothamsted.ac.uk/rothamsted-carbon-model-rothc. Accessed 28 Mar. 2024.

Forest Garden project area	ha	Project start and every verification event	Areas will continue to be estimated for each farm participating in the project as part of setting baseline.
Soil organic carbon density, to a depth of 30 cm, at equilibrium for cropland based on measurements of bulk density and %C	t C/ha	Project start	These have been estimated by the ICRAF soil lab, derived from soil cores sampled in project farm areas.
Monthly soil cover (bare or vegetated)		Project start and at every monitoring event	Determined from farmer surveys.
Average temperature per month	°C	Project start, and according to FAO guidelines Chapter 6.1, 6.7.	Data will continue to be compiled from TerraClimate.
Average precipitation per month	mm	Project start, and according to FAO guidelines Chapter 6.1, 6.7.	Data will continue to be compiled from TerraClimate.
Average evapotranspiration per month	mm/day	Project start, and according to FAO guidelines Chapter 6.1, 6.7.	Data will continue to be compiled from TerraClimate.
Clay content of the soil	%	Project start and every five years at model true-up	At project start these were estimated by the ICRAF soil lab, derived from soil cores sampled in project farm areas (see description in Section 3.2.1) Clay content will also be estimated by the ICRAF soil lab for samples taken to true-up the model.
Monthly input of plant residues	t C/ha	Project start and at every monitoring event	Determined from farmer surveys.
Monthly input of farmyard manure	t C/ha	Project start and at every monitoring event	Determined from farmer surveys.