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STANDARD OPERATING PROCEDURES FOR TERRESTRIAL CARBON MEASUREMENT

COCOA AGROFORESTRY SYSTEMS

INTEGRATED LAND AND RESOURCE GOVERNANCE TASK ORDER UNDER THE STRENGTHENING TENURE AND RESOURCE RIGHTS II (STARR II) IDIQ

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STANDARD OPERATING PROCEDURES FOR TERRESTRIAL CARBON MEASUREMENT
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INTEGRATED LAND AND RESOURCE GOVERNANCE TASK ORDER UNDER THE STRENGTHENING TENURE AND RESOURCE RIGHTS II (STARR II) IDIQ

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DISCLAIMER

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LIST OF ACRONYMS

ACR	American Carbon Registry
CAR	Climate Action Reserve
CDM	Clean Development Mechanism
DBH	Diameter at Breast Height
DSH	Diameter at Stump Height
GHG	Greenhouse Gas
IDIQ	Indefinitely Delivery/Indefinite Quantity
ILRG	Integrated Land and Resource Governance Task Order
QA/QC	Quality Assurance/Quality Control
SOP	Standard Operating Procedure
STARR II	Strengthening Tenure and Resource Rights II
USAID	United States Agency for International Development
VCS	Verified Carbon Standard

1.0 INTRODUCTION AND HOW TO USE THIS DOCUMENT

The active and important role vegetation and soil play in the global carbon cycle and global climate change is now internationally recognized. Vegetation and soil can act as both a net source and a net sink of greenhouse gas (GHG), depending on how the land is managed. Alterations in land use management techniques that result in changes to net GHG emissions are now a significant component to the regulatory and voluntary actions taking place globally to combat climate change.

The purpose of this document is to provide standard field measurement approaches to assist in quantifying the amount of carbon stored within the organic pools found within **cocoa agroforestry systems** (*Theobroma cacao*). This document has been adapted from the original generic Standard Operating Procedures (SOPs) for evaluating terrestrial carbon stocks across all land uses[1], tailored specifically for evaluating terrestrial carbon stocks in cocoa agroforestry systems. The methods presented in each SOP have been developed over time by foresters and ecologists to accurately and efficiently estimate carbon stocks.

This manual *does not* specify guidance on stratification, sampling design, sampling intensity, the spatial distribution of sampling points, pool measurement selection, or the methods needed to transform field measurement data into carbon stock estimates. Therefore, additional guidance is required prior to any field data collection.

The SOPs present an approach appropriate for shaded cocoa agroforestry systems in Ghana. However, all the field measurement methods presented in this document may require adaptation for the specific ecosystem, land cover, and vegetation type in the location where sampling will take place. It is therefore expected that this manual will be updated overtime as the carbon market changes and as terrestrial carbon science evolves.

The SOP manual is also *not specific* to any regulatory or voluntary market standard such as the Clean Development Mechanism (CDM), Climate Action Reserve (CAR), American Carbon Registry (ACR), Verified Carbon Standard (VCS), CarbonFix, or PlanVivo.

The SOPs should not be conducted without receiving extensive field training in the measurement methods performed by a qualified forester or ecologist.

[1] Available at: https://www.winrock.org/document/standard-operating-procedures-for-terrestrial-carbon-measurement-manual/

2.0 GENERAL SOPS

The following SOPs are used for a variety of purposes and studies. They provide general guidance on best practices and specific guidance on the use of measurement tools needed for terrestrial carbon measurement. These SOPs include:

- SOP Field Safety
- SOP Data Storage and Archiving
- SOP Plot Labeling
- SOP Quality Assurance/Quality Control
- SOP Using a Clinometer

3.0 SOP FIELD SAFETY

No matter what activities are engaged in or where they are carried out, *safety is the first priority* and all precautions must be well thought out in advance and then strictly adhered to. Planned field activities must remain flexible and allow for adjustments in response to on-the-ground assessments of hazards and safety conditions. Accordingly, field personnel must be vigilant and always avoid unnecessary risks.

Field crew members in particular must be well prepared. It is recommended that personnel engaging in field activities hold general first aid training and, if possible, training in CPR.

The following guidelines will apply to all field-based activities:

- Mandatory buddy system. Field crews will include no less than two people who must be directly accompanying each other for the entire duration of field work. Ideally field crews should include a minimum of three people; in case of an accident resulting in injury one person may leave to seek help while another person stays with the injured crew member.
- For each day in the field, specific location and scheduling information must be logged in advance with a point person who can be reached at any time during the anticipated duration of field work. While in the field, crews should check in with their designated point person once per day.
- Each independent crew must carry a radio, satellite phone, or cell phone provided by the institution. Crews should make sure to check batteries each time before entering the field.
- Trip planning will include identification of the nearest medical facility and specific directions to reach that facility. When in areas with poisonous snakes, advance communication should be made to verify that appropriate antivenins are available. Where applicable, hunting regulations should be checked with local state agencies prior to field work.
- Personnel will carry personal and institutional insurance cards with them at all times. As well, personnel will carry identification and, if possible, institutional business cards at all times.
- Field crews will carry a first aid kit with them at all times. First aid kits should contain Epinephrin/Adrenalin or an antihistamine for allergic reactions (e.g. bee/wasp stings). Sun block and insect repellent should be carried in the field.
- Where poisonous snakes are common, snake chaps are recommended. In the event of snake bite, the victim should be taken immediately to a medical facility. Conventional "snake bite kits" (e.g. suction cups, razors) have been proven ineffective or even harmful and should not be used.
- Basic field clothing should be appropriate for the range of field conditions likely to be encountered. This will include: sturdy boots with good ankle support or rubber boots, long sleeves and pants, rain gear, and gloves. Blaze orange (vest or hat) is recommended when and where hunting may be taking place. Where necessary, to avoid extended contact with plant oils, ticks, and/or chiggers, a change of clothes should be made at the end of each day in the field and field clothes should not be reworn without first laundering.
- Ensure personnel stay sufficiently hydrated and carry enough clean water for the intended activity. Carry iodine tablets or other water purification tablets in case there is a need to use water from an unpurified source.

- Heightened caution should be given while operating any motor vehicle, particularly on backcountry roads where conditions are unreliable and rights-of-way are often not designated or adhered to. All-terrain vehicles should always be operated at low speeds (<15 mph).
- Some plots may be too hazardous to sample. Situations include: plot center on a slope too steep to safely collect data (i.e., >100% slope or on a cliff); presence of bees; volcanic activity; illegal activities; etc. When hazardous situations arise, a discussion should be conducted among the team members to assess the situation.

4.0 SOP DATA STORAGE AND ARCHIVING

Recommended equipment:
Field log book/electronic field log book
Laptop computer
Desktop computer
External data storage (harddrive, cloud, usb)
Connection to network server or cloud storage services
Scanner

This SOP describes the methods for storing and archiving data in a simple yet safe and retractable way, so data can be accessed whenever necessary. Data storage and archiving is a very important and final component of the data collection process. The basic framework involving data storage and archiving follows.

DATA STORAGE IN THE FIELD

In the field, one person is responsible for storing and keeping the field data sheets; this person can also be the person who validates the data on the sheets and is one of the team leaders.

If the data entry process is being done or started in the field, these sheets will be used after which they must be returned to the person responsible for their safekeeping. These sheets are stored in a dry and safe place where they cannot be tampered with until they are transported to the office.

DATA STORAGE IN THE OFFICE

In the office, all original field data sheets shall be scanned and compiled into a document to be stored electronically. This avoids any changes to be made to the original sheets.

HARD COPY

The original data sheets are photocopied and are kept in separate location. The data sheets are placed in a special jacket folder in the filing cabinet with the location name and date written on the label. After all data has been entered into a digital format and the SOP for quality assurance/quality control (QA/QC) completed, the two sets of data sheets are then stored in secure fireproof filing cabinets in two separate locations.

SOFT COPY

The scanned data sheets are stored on a computer in the office, along with all tools with the entered data, including data entered in the field laptop. These data files are backed up on a server or cloud storage services. Folders containing data and folders containing tools should be properly named and adequately organized. All digital data collected and compiled (photos, proposal, and report for exercise) are also stored in the archive file on both the desktop in the office and on the server or cloud storage services. On the server or on the cloud, there are a few folders in which all data are placed as follows:

1. *Field Data*, in which sub folders are created and are named the same way (Location) as the hard copy folder so as to have a uniform filing system. In each sub-folder there are two folders – pictures and scanned data sheets – in which the respective pieces are placed;
2. *Data Analysis* in which all completed tools are placed after the data entry has been completed;
3. *Template* in which all tool templates and field data sheets used in the data analysis are placed;
4. *Documents* in which all documents related to the project are placed; and
5. *Field Proposal & Report* in which all field exercise proposals and report are placed.

PROCEDURE FOR DATA FILE BACKUP

Any file(s) that is updated during the data analysis will be backed up to a network server or cloud storage. This back up will be done daily on the office computer(s), and at the end of every week they **must** be saved on an external hard drive and the folder on the server or cloud, which is specifically designated for this data storage.

PROCEDURE FOR COMPILING AND MANAGING FIELD LOG BOOK OR ELECTRONIC LOG BOOK

This log book will be both of an electronic form and of the traditional bookkeeping format (a book). Both log forms will be updated simultaneously and twice for each field venture, before and after each trip. Log books will be used for recording the logistics of the field exercise and providing explanation about field campaigns (e.g. date of departure to the field and date of returning, number of plots, location, field crew, challenges etc.). Each field campaign will be given a unique reference number and each report will also be given a reference number related to that of the campaign. This is to facilitate cross referencing processes.

Upon returning to the office after field records are entered, the log books will be stored in a secure filing cabinet or placed on the network server or cloud storage via desktop computers respectively, after being updated. Upon the completion of field reports of which each report will be given a unique reference number, the log books will be revisited and the report number will be inserted for future references.

It is important to restrict access to log books and information only to users, as they alone are responsible for making changes.

5.0 SOP LABELING PLOTS

The following provides recommendations on how plots should be labeled. Proper plot labeling is important because it provides a unique signature to sampled plots as well as information about the sampling conducted. Experience has shown that plots should be named with multiple characters defining the type of sampling conducted, the area, the number of the plot and any other relevant information.

The labeling system must be finalized prior to data collection. All plots must be numbered with a unique name and number in accordance with the ECOM farm labeling system. The character denoting the number of the plot should include at least as many digits as total numbers of plots expected to be sampled. In other words, if the number of plots is expected to be greater than 100 but less than 1000, the number characters must be at least three integers e.g. 001 to 999.

The following is the recommended plot labeling format: number/letter/number/three numbers.

- Farm ID
- Group (A or B)
- Plot Number.

An example of plot numbers are:

- FarmID-A-001
- FarmID-B-001

6.0 SOP QUALITY ASSURANCE/QUALITY CONTROL

Those responsible for aspects of data collection and analysis should be fully trained in all aspects of the field data collection and data analyses. Standard operating procedures should be followed rigidly to ensure accurate measurement and remeasurement. It is highly recommended that a verification document be produced and filed with the field measurement and calculation documents that show that QA/QC steps have been followed.

QUALITY ASSURANCE

DATA COLLECTION IN FIELD

During all data collection in the field, the crew member responsible for recording must repeat all measurements called by the crew member conducting the measurement. This is to ensure the measurement call was acknowledged and that proper number is recorded on the data sheet. In addition, all data sheets should include a "Data recorded by" field with the name of the crew member responsible for recording data. If any confusion exists, the transcribers will know which crew member to contact.

After data is collected at each plot and before the crew leaves the plot, the crew leader shall double check to make sure that all data are correctly and completely filled. The crew leader must ensure the data recorded matches with field conditions, for instance, by verifying the number of trees recorded.

DATA SHEET CHECKS

At the end of each day, all data sheets must be checked by team leaders to ensure that all the relevant information was collected. If for some reason there is some information that seems odd or is missing, mistakes can be corrected the following day. Once this is verified and potential mistakes checked, corrected data sheets shall be handed over to the person responsible for their safekeeping while the crew is still in the field. Data sheets shall be stored in a dry and safe place while in the field. After data sheets have been validated by crew leaders, the data entry process can commence.

FIELD DATA COLLECTION HOT CHECKS

After the training of field crews has been completed, observations of each field crew and each crew member should be made. A lead coordinator shall observe each field crew member during data collection of a field plot to verify measurement processes and correct any errors in techniques. It is recommended that the crew chiefs switch to a different crew to ensure data collection procedures are consistent across all field crews. Any errors or misunderstandings should be explained and corrected. These types of checks should be repeated throughout the field measurement campaign to make sure incorrect measurement techniques have not started to take place.

DATA ENTRY CHECKS

To ensure that data is entered correctly, the person entering data (whether during fieldwork or after a return to the office) will recheck all of the data entered and compare it with the original hard copy data sheet before entering another sheet. It is advised that field crew leaders either enter the data or participate in the data entry process. Crew leaders have a good understanding of the field sites visited and can provide insightful assistance regarding potential unusual situations identified in data sheets. Communication between all personnel involved in measuring and analyzing data should be used to resolve any apparent anomalies before final analysis of the monitoring data can be completed. If there are any problems with the plot data (that cannot be resolved), the plot should not be used in the analysis.

QUALITY CONTROL

FIELD MEASUREMENT ERROR ESTIMATION

A second type of field check is used to quantify the amount of error due to field measurement techniques. To implement this type of check, a complete remeasurement of a number of plots by people other than the original field crews is performed. This auditing crew should be experienced in forest measurement and highly attentive to detail. A total of 10% of plots (or clusters if clustered plots are used) should be randomly or systematically chosen to be remeasured. Where clustered plots are used, all plots within a selected cluster shall be measured. All trees shall be remeasured in each plot. Field crews taking measurements should not be aware of which plots will be remeasured whenever possible.

After remeasurement, data analysis is conducted and biomass estimates are compared with estimates from the original data. Any errors discovered could be expressed as a percentage of all plots that have been rechecked to provide an estimate of the measurement error.

For all the verified plots:

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

This error level will be included in the carbon stock reporting.

DATA ENTRY QUALITY CONTROL CHECK

After all data has been entered into computer file(s), a random check shall be conducted. Sheets shall be selected randomly for re-checks and compared with data entered. Ten percent of all data sheets shall be checked for consistency and accuracy in data entry. Other techniques such as data sorting and verification of resulting estimates shall be employed to ensure data entered properly corresponds to field sites visited. Personnel experienced in data entry and analysis will be able to identify errors especially oddly large or small numbers. Errors can be reduced if the entered data is reviewed using expert judgment and, if necessary, through comparison with independent data.

7.0 SOP USE OF A CLINOMETER

A clinometer is a piece of equipment used to measure angles. This equipment is widely used in the field for multiple reasons, among them measuring slope of the terrain, and measuring tree height. In this SOP, it is used to measure slope. Usually a clinometer has two sets of units for measuring angles, shown on either side of the measurement viewer:

- Percent (%)
- Degrees

The clinometer will indicate the units. For example, if using a Suunto® Clinometer, look into the clinometer and tilt your head back to look all the way up. The right side will say %.

To measure slope using a clinometer:

1. Two team members of approximately the same height should be selected to complete slope measurement.
2. One team member should stand in the center of the subplot with the clinometer and the other member should go to the edge of the larger nested subplot (i.e., the 40x40m plot).
3. The team member at the center of the subplot should hold the clinometer string and bring it up to his/her dominant eye (the string on the clinometer should be below the eye piece, stretching downward) Keeping both eyes open, the team member at the center of the subplot should aim the clinometer at the eye-level of the team member at the edge of the larger sub-plot.
4. Record the % at the point that crosses the eye level of the team member standing at the edge of the large subplot. In the cases of very steep slopes, it can be recorded as degrees, making sure to note the unit used in the data sheets.

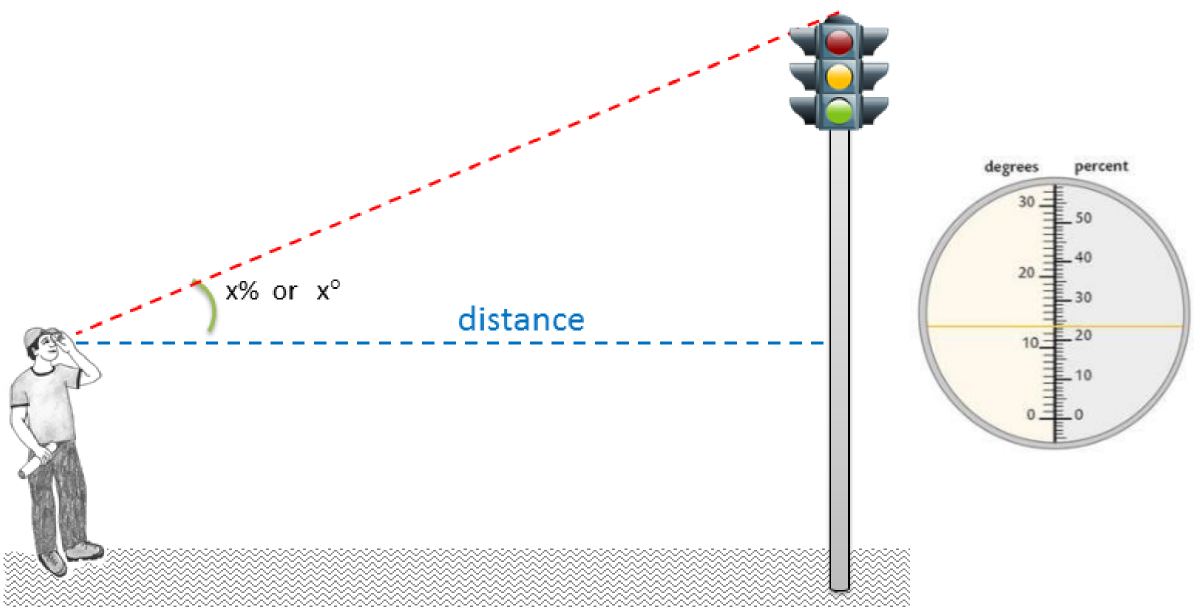


Figure: Measuring angle degrees or % using clinometer (for height or slope). For slope, the clinometer would be directed toward the eye-level of a team member standing at the high end of the plot being measured, rather than the top of a tree (or light post as pictured)

AREA CORRECTION DUE TO SLOPE – CONDUCTED DURING DATA ANALYSIS

Carbon measurements are reported on a horizontal-projection basis, thus, plots established on sloping lands must use a correction factor. This correction factor accounts for the fact that when distances measured along a slope are projected to the horizontal plane, they will be smaller. If the plot falls on a slope greater than 10 percent, then slope angle should be measured using a clinometer so that an adjustment can be made to the plot area at the time of analysis. If the slope is less than 10 percent, correction is not required. The calculation of area correction is done during data analysis. In the field, only the average slope measurement is taken.

Following data collection, the slope will be used to estimate the projected horizontal area of the plot (see Figure below). It is recommended this be done as part of data analysis within computer spreadsheet.

$$L_{horixaontal} = L_{field} * \cos(slope)$$

Where:

$L_{horizontal}$	True horizontal length; m (For square/rectangular plots, this will be the side parallel to the slope)
L_{field}	Length measured in the field, parallel with the slope; m (For square/rectangular plots, this will be the side parallel to the slope)
Slope	Slope, measured in degrees
Cos	the cosine of the angle

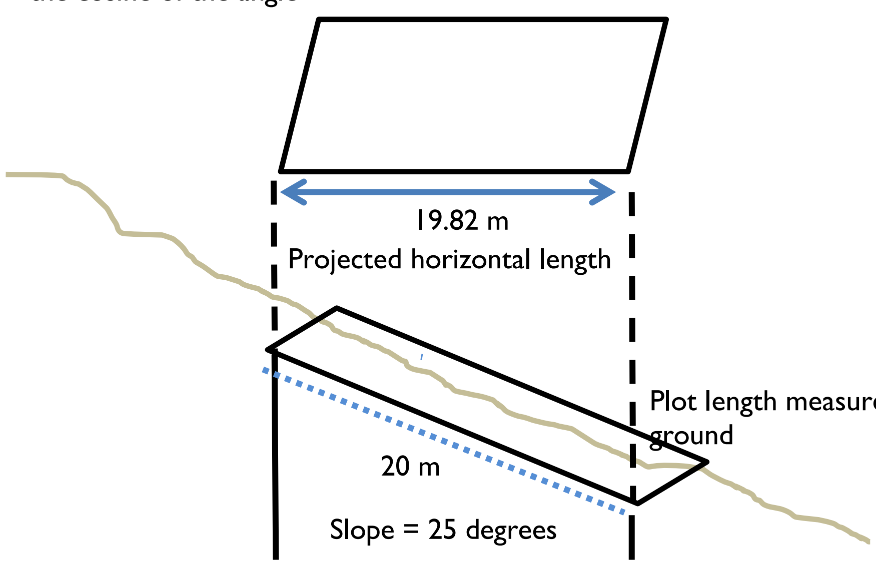


Figure: Plot measurement on ground and projected horizontal size of plot. In this example, with a slope of 25 degrees, although the plot length on the ground is measured as 20 m radius, the projected horizontal size of the plot has a length of 19.82 m (20 m * cos(25 degrees) = 19.82 m).

8.0 STOCKS OF CARBON POOLS SOPS

The following set of SOPs can be used to establish plots to estimate the standing carbon stock of cocoa agroforestry systems. These SOPs may need to be altered based on the specific methods used by the field campaign.

- SOP Plot Design and Layout
- SOP Establishment of Plots
- SOP Measurement of Trees
- SOP Standing Deadwood

9.0 SOP PLOT DESIGN AND LAYOUT

This SOP describes the methods to determine the sampling layout and shape of sampling plots. This SOP must be implemented prior to field data collection.

The sampling design must address where sampling will be conducted, how it will be carried out, and what elements will be sampled. The size and shape of the area to be sampled to estimate tree biomass is a trade-off between accuracy, precision, time, and cost for measurement. The most appropriate size and shape should depend on the vegetation type found in the sampling area. For estimating the biomass in cocoa agroforestry systems, the following is suggested.

PLOT LAYOUT

SIZE AND SHAPE OF TREE PLOTS AND SUBPLOTS

Plots can be circles, squares, or rectangles, but for the evaluation of biomass in cocoa agroforestry systems, plots will be established in a **square shape**.

NESTED TREE PLOTS

In homogenous systems with low structural variation (e.g., single species, even-aged plantations or areas without trees) a single plot can be effectively used. Yet experience shows that in systems with lots of diversity benefits adopting a nested structure for sampling tree plots is cost efficient and scientifically robust. Nested plots are divided into sub-units varying in size that each measure distinct tree classes such as trees within specific diameter at breast height (DBH) ranges or species. Nested plots are typically composed of several plots (typically 2 to 4, depending upon forest structure) and each plot in the nest should be viewed as being a separate plot.

For terrestrial carbon stock evaluation for cocoa agroforestry systems, nested rectangular plots are suggested, where cocoa trees (*Theobroma cacao*) are measured in a smaller nested plot and other shade trees in the larger plot (inclusive of shade trees occurring in the smaller plot). This is outlined below.

Table: Tree stem diameter classes and nested plot sizes

Plot	Stem diameter	Side lengths	Diagonal lengths
Cocoa	≥ 3 cm dbh	10 m x 10 m	14.14 m
Shade trees	≥ 5 cm dbh	40 m x 40 m	56.57 m

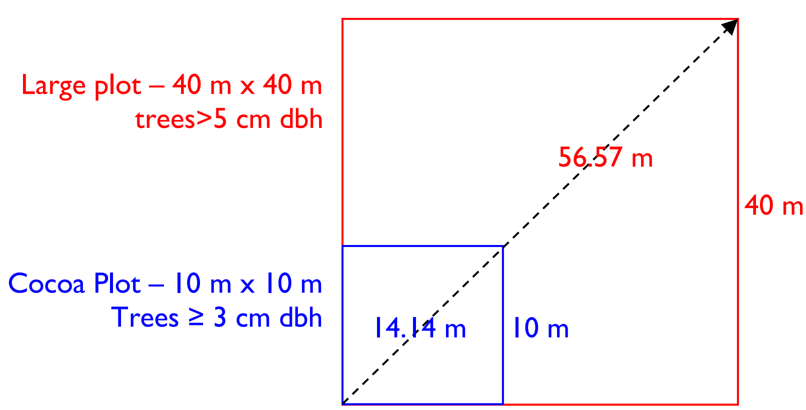


Figure: Schematic diagram of nest-rectangular sampling plots

10.0 SOP ESTABLISHMENT OF TREE PLOTS/SUBPLOTS

Required equipment:
All Tree Plots
GPS
PVC tubing (~1m in length for marking plot anchor point)
Flagging tape
Rope
Clinometer (to measure slope)
Measuring tape >50m
Ropes >50m long
Stakes (~30cm in length for marking plot corners)

PRIOR TO FIELD SAMPLING

Where rope or other materials are used to measure plot boundaries, extreme care must be taken to ensure the rope length is equal to the measurement required. Such rope should be measured repeatedly as many types of rope will lengthen or contract over time and under various field conditions, such as when wet.

ESTABLISHING INITIAL PLOT CORNER/ANCHOR POINT

It is important to have a standard procedure for establishing the plot starting corner that helps avoiding bias in plot location selection. The following steps should be followed once the field crew reaches the sample location (i.e., farm):

1. Walk 10 steps into the farm following the direction of the azimuth established by the hour arrow of a hand watch. Upon counting 10 steps, stand with back facing the farm and front facing the exit route, and throw a rock (or water bottle) within visible distance to stablish the anchor point.
2. The location where the rock rests determines the initial corner of the plot (i.e. anchor point). From this point, plot edges should be laid out ensuring the entire plot (10x10m and/or 40x40) is within the targeted cocoa farm.
3. To establish the second nested plot, a second anchor point should be established at approximately 100 steps from the first anchor plot. The direction to walk the 100 steps should be determined by the direction the coca farm is laid on the land, thus ensuring the entire next plot is within the targeted cocoa farm.
4. The two plots should not overlap nor be adjacent to each other, so adjustments may need to be made in the field to the 100-step rule, depending on the size of the farm.

Label the Anchor Point plot based on SOP Labeling Plots.

PERMANENT PLOTS

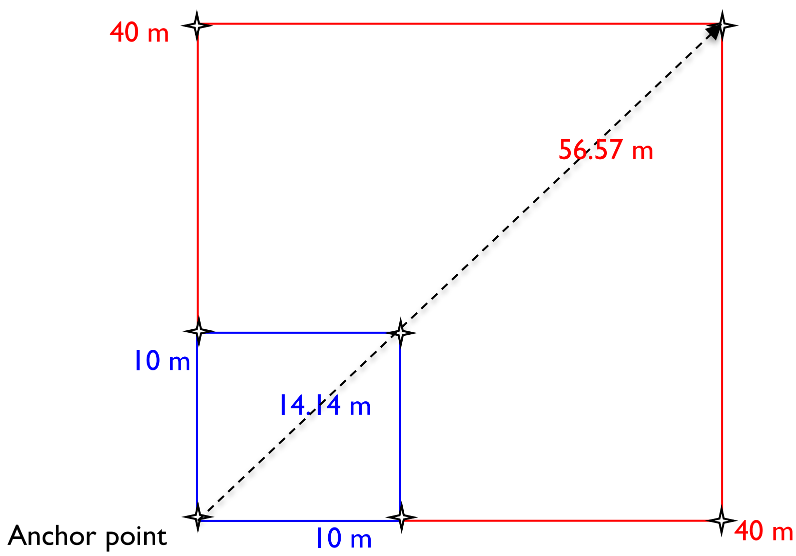
Permanent plots shall be marked using materials that will last longer than the project lifetime. Mark the anchor point with PVC tubing, and all other corners with wooden stakes. Using flagging ribbon to help visually identify the anchor point and the other four corners.

Note: Elaborate description of directions taken to arrive in anchor point are encouraged to be written in "notes" field of data sheet, so that in the future, crew can find the PVC tubing establishing the anchor point for re-measurement of the exact same plot.

SQUARE PLOTS

a. With PVC tubing, mark the anchor point.

b. Determine a random compass direction (Select random number using second hand on watch and multiply this number by six.). Using this compass direction, measure to second corner. Mark the corner for each nest with a wooden stake. Return to first corner, using a right angle and a compass, measure to the opposite corner. Mark the corner for each nest with a stake. Returning to the first corner, use compass to measure out the length of the diagonal. Mark the final corner with a stake. Mark the corner for each nest with a stake. (See figure below as example). If desired, rope marked with nest plot lengths can be repeatedly used for each plot. However, the length of the rope and markings should be checked daily to make sure the rope has not stretched.



EXTRAPOLATION TO HECTARE – CONDUCTED DURING DATA ANALYSIS

Following field data collection, during data analyses, any measurements taken at the plot level are extrapolated to the area of a full hectare to produce carbon stock estimates on a 'per hectare' basis. Extrapolation is done by the use of scaling factors that are calculated as the proportion of a hectare (10,000 m^2) that is occupied by a given nested plot or clip plot:

$$Scaling\_factor = \frac{10{,}000 m^2}{Horizontal\_Area\_of\_nest\_(m^2)}$$

11.0 SOP MEASUREMENT OF TREES

Required equipment:
All Tree Plots:
GPS
Tree name list

For measuring DBH:
Diameter tapes
Flagging tape
Tree poles: Small-diameter PVC piping cut the exact length 1.3m (for DBH measurements)
Spray paint
Portable retractable ladder (3 m)

For permanently marking trees:
Aluminum nails and/or fishing line or aluminum wire (determine most appropriate material given local conditions. Aluminum nails are not recommended for young trees <5cm)
Tree tags with unique sequential numbers
Hammers and/or wire cutters

PRIOR TO FIELD SAMPLING

ALLOMETRIC EQUATION(S) SELECTION

The biomass of live trees is usually estimated using an allometric equation that relates tree biomass with one or more specific directly measured tree variables such as tree species, diameter at breast height (DBH) diameter at stump height (DSH), total tree height, and/or wood density. Depending on the allometric equation chosen, the appropriate tree variable(s) are measured in the field and then used to calculate biomass during data analysis.

For the evaluation of tree biomass in cocoa agroforestry systems, the allometric equations developed by Mohammed et al. (2016)[2] will be applied for cocoa trees (*Theobroma cacao)* and Chave et al. (2015)[3] for other shade trees. In accordance with the DBH ranges used to develop these allometric equations, the minimum sized tree to be measured are described in the table below.

Table: Class tree size dimensions, allometric equation, and nest

Class	Dbh range	Source of allometric equation	Nest
Cocoa	≥ 3 cm dbh	Mohammed et al. (2016)	Small (10m x 10m)
Shade trees	≥ 5 cm dbh	Chave et al. (2005)	Large (40m x 40m)

Prior to field data collection, a standard list of tree names shall be developed. Depending on the biomass regression equation(s) used, the tree names may relate to actual tree species, tree genus, or tree family.

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[2] Mohammed, A. M., Robinson, J. S., Midmore, D. and Verhoef, A. (2015) Biomass stocks in Ghanaian cocoa ecosystems: the effects of region, management and stand age of cocoa trees. European Journal of Agriculture and Forestry Research, 3 (2).pp. 2243.ISSN 20546327.Available at http://centaur.reading.ac.uk/67347

[3] Chave, J., et al. 2015. Improved allometric models to estimate the aboveground biomass of tropical trees. *Global Change Biology*. 20, 3177–3190, doi: 10.1111/gcb.12629

A standard tree name list and tree name abbreviation list shall be created and brought to the field for reference and for filling out data sheets.

For permanent plots, only trees measured shall be tagged with an aluminum numbered tag and nail.

FIELD MEASUREMENTS

The design and establishment of plots shall be determined following SOP Plot Design and SOP Establishment of Plots. The instructions here assume these SOPs have already been followed.

1. Assign one person to record the data and all others should be measuring and marking trees. The recorder should stand in the center of the nested plot being measured. He or she should track those measuring the trees and should try and ensure that no trees are missed.

2. To avoid either missed trees or double recording, measurement should begin to the north and the first tree should be flagged. After a tree is measured, a chalk mark facing the center of the plot should be placed on tree to allow the person recording the data to track measured and unmeasured trees.

3. All shade (non-cocoa) trees of appropriate sizes should be tagged with the placement of an *aluminum* numbered tag and nail or alternatively fishing line or wire (see Figure below). The risk of theft of these materials must be considered and appropriate locally available alternatives may be used instead. The steps are as follows:

    a. To avoid any errors in the measurements due to the development over time of a bump at the site of the nail, it is recommended that the nail and tag be placed 10 cm below DBH (see item iv below for more details). See detail instructions on where to measure the DBH below.

    b. In future inventories DBH will be measured 10 cm up from the nail.

    c. If the trees in the project area will be subjected to some kind of harvest in the future, the nail and tag may be placed at the base of the tree to avoid any chainsaw or other equipment accidents. Be sure the nail is placed *well below* the height of future cutting, as it is very dangerous for a chainsaw to hit a nail. Chainsaws *can* cut through aluminum, but contact between the nail and chainsaw or other equipment should be avoided to prevent the possibility of accidents. Alternatively, tags may be attached to trees with fishing line or metal wire as shown below.

    d. Each plot should contain a description of what approach was used so that future measurements can be completed efficiently and accurately.

    e. Do not insert the nail fully so that there is room for the tree to grow, however, insert it deep enough to hold the tag firmly.

    f. Aluminum nails are preferred as they do not rust.

Figure. Examples of tagged tree using fishing line (left) and a nail (right).

4. For all cocoa and shade trees of the appropriate size, measure the tree parameters required for the allometric equation to be used (i.e., diameter at breast height (DBH)) for all trees of appropriate sizes for each nested plot. Steps for measuring DBH for each nested plot are described below. It is important that the diameter tape is used properly using the following steps to ensure consistency of measurements:

    a. Record the name of the tree. Common tree name can be used when scientific names are unknown. Common names can later (in data entry and analysis) be associated with scientific name through literature research, and online search.

       Note: Tree species identification is strongly recommended, whether it may be using common or scientific names, for two main reasons: 1) it improves the accuracy of biomass estimation when using Chave et al. (2005) allometric equation as one of the required inputs of this equation is wood density, and wood density varies per species; 2) it provides an indicator of site biodiversity, as an additional metric of possible interest when analyzing field collected data.

    b. Tree pole placement: For each tree, place the tree pole (e.g. 1.3 m plastic pole) against the tree to indicate the location of measurement (e.g. DBH). Placement of the tree pole depends on the slope of the ground, leaning angle of the tree, and shape of the tree bole (see Figure below for correct placement of diameter tape).

        i. **Slope:** Always place tree pole and measure diameter on the *upslope* side of the tree

        ii. **Leaning tree**: Always measure the height of a measurement (e.g. 1.3 m) parallel with the tree, *not* perpendicular to the ground. Therefore, if the tree is leaning, measure underneath the lean, parallel with angle of tree. If a tree is not straight, a tape measure must be used to measure the bole distance from ground to location of measurement (e.g. DBH).

        iii. **Multi-stem tree**: If the tree is multi-stemmed with forking below the point of measurement (eg 1.3 m), measure the diameter on each stem and tag the stems that exceed the minimum diameter for the nest. Record it as if each stem were a different tree on the data sheet, but with a note that the stems make up one tree.

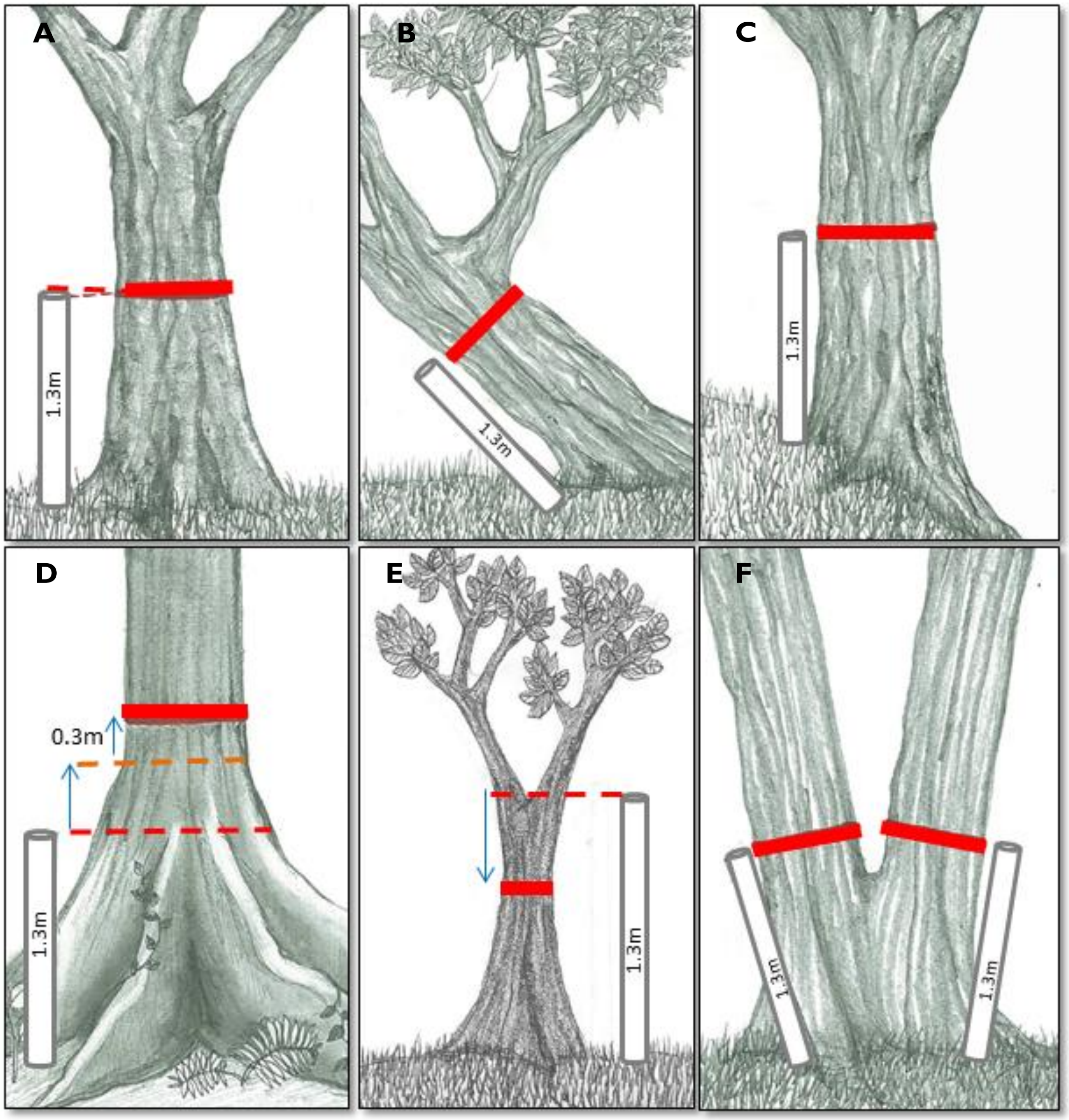

Figure: Proper placement of diameter tape when allometric equation used requires measurement at DBH (1.3 m)

iv. Tree with a lump or burl

1. If there is a lump on the tree at DBH height, a decision will have to be made to measure DBH immediately above or below the lump. This decision will need to be clearly conveyed to the entire team to ensure measurement is consistent across all trees and plots with this feature.

v. Buttressed tree

1. If the buttress roots are below 1.3 measure the diameter at the standard height (i.e. 1.3 m).

2. If the buttress roots are taller than 1.3 m, measure the diameter at 30 cm above top of buttress as shown in example D in the figure above. In cases where the buttresses are too tall and out of reach, the following procedure shall be followed:

   i) Use portable retractable ladder and lean ladder against tree to allow for measurement of DBH 30 cm above from the top of the buttress.

   ii) If ladder is unavailable, and taking into consideration the safety of field crew, climb the tree to take measurement 30 cm above the top of the buttress. In fluted buttress, it is possible to carve steps on the buttress itself to allow climbing to top of buttress. Extreme caution should be employed and climbing should only be performed when conditions are deemed safe by field crew leader.

   iii) If ladder is unavailable, and climbing is considered unsafe, retractable poles should be use. Poles shall be placed against the tree, at the edge of its circumference, projecting the diameter at exactly 30 cm above top of buttress down to the ground. An observer is required to ensure poles are properly placed at the very edge of tree's circumference in a way that linear distance between poles represents the diameter of tree at 30 cm above end of buttress. The **linear distance** between the two poles shall be measured. At least two measurements shall be taken on opposite sides of tree using this method, and then averaged to estimate tree DBH.

   Note: The distance between poles shall be measured linearly, and thus proper measuring tape shall be used. Poles can be made from tall saplings found outside the sampling plot in the forest or by linking Tree Poles together (e.g. with PVC connectors).

c. Diameter measurement: Tree diameter should be measured to the nearest 0.1 cm (e.g. diameter of 10.2 cm *not* 10 cm).

   i. If the diameter tape has a hook, push the hook into the bark of the tree slightly to secure it and pull the tape to the right. The diameter tape should always start left and be pulled right around the tree, even if the person taking the measurement is left-handed. As the diameter tape wraps around the tree and returns to the hook the tape should be above the hook. The tape should not come around the tree below the hook. The tape should not be upside down; the numbers must be right side up. (see Figure below)

   ii. If a liana or vine is growing on a tree that is going to be measured, do not cut the liana to clear a spot to measure the tree's diameter. If possible, pull the liana away from the trunk and run the diameter tape underneath. If the liana is too big to pull away from the trunk, estimate the diameter of the liana and subtract from total tree diameter. Cutting a liana from a tree should only be done if there are no other options. The same standard should be followed for any other type of natural organisms (mushrooms, epiphytes, fungal growths, termite nests, etc.) that are found on the tree.

   iii. Place chalk mark on the tree to indicate to crew members that the tree has been measured.

Figure: Measurement of diameter using a diameter tape and tree pole

d. Boundary trees: Occasionally trees will be close to the border of the plots. The plots are relatively small and will be expanded to estimate biomass carbon on a per hectare basis. It is therefore important to carefully decide if a tree is in or out of a plot. To definitively determine whether the tree is in or out of the plot, use a tape measure to measure out from the plot center (or plot corner) to the base of the boundary tree. If the plot is on sloped ground, make sure the measurement follows the slope. If more than 50% of the base of the trunk is within the boundary of the nest, the tree is in. If more than 50% of the base of the trunk is outside of the boundary, it is out and should not be measured. If it is exactly on the border of the plot, flip a coin to determine if it is in or out.

5. When all of the trees in the plot have been measured, there should be a double-check to see that all of the trees have been measured

12.0 SOP MEASUREMENT OF STANDING DEAD WOOD

Required equipment:
All Tree Plots
DBH tape
Clinometer
Measuring tape

Standing dead wood refers to trees that have died but are still upright. Usually the minimum size class of dead trees measured is the same as the minimum live tree measured (i.e., trees greater than 5 cm DBH and taller than 1.3 m).

Standing dead wood can be measured within the permanent plots used to measure live trees. Generally, measurements of standing dead wood take place concurrently with live tree measurements. Dead trees should be measured in their respective nest size (e.g. cocoa dead trees measured in the small nest, while shade dead tree measured in the large nest). Each standing dead trees should be classified into two classes (see Figure below):

Class 1: Dead tree with branches and twigs and resembles a live tree except for absence of leaves (make sure tree is dead and not deciduous)

Class 2: Dead trees containing large branches or no branches at all, including stumps.

By classifying trees into these two simplified classes, a conservative estimate of biomass will be taken.

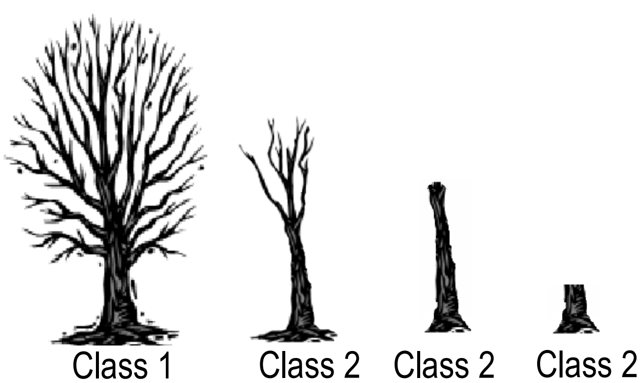

Figure: Example of trees in Class 1 and Class 2

FIELD MEASUREMENTS

The design and establishment of plots shall be determined following SOP Plot Design and SOP Establishment of Plots. The instructions here assume these SOPs have already been followed.

Class 1 trees:

1. Follow the same measurement protocols as for the measurement of live trees, including the measurement of tree variables (i.e. species and DBH) (see SOP Measurement of Trees). Class 2 trees (see Figure below):

2. The biomass of these trees is based on estimating the volume of the remaining tree and multiplying the volume by the wood density.
3. Measure DBH using methods consistent with live trees measurements.

REFERENCES

Chave, J., et al. (2015). Improved allometric models to estimate the aboveground biomass of tropical trees. *Global Change Biology*. 20, 3177–3190, doi: 10.1111/gcb.12629

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Nelson, D.W., and L.E. Sommers. (1996). Total carbon, organic carbon, and organic matter. p. 961-1010. In: D.L. Sparks et al. (eds.) Methods of soil analysis. Part 3.Chemical methods.SSSA, Madison, WI.

ANNEX 1: DATA SHEET

Plot ID:	Location:	Crew Chief:
Data Recorded By:	Date:	Start Time: End Time:
Total Time:	Slope %	Photo #:

Notes:

Nested Plot Dimensions (m): small: 10 x 10 large: 40 x 40

Nested plot tree diameter sizes (cm): small: Cocoa DBH≥3 cm large: Shade DBH≥5 cm

Deadwood

Tree #	Species	DBH (cm)	Tree #	Species	DBH (cm)	Tree #	Class (1 or 2)	DBH (cm)

Plot ID:	Location:	Crew Chief:
Data Recorded By:	Date:	Start Time: End Time:
Total Time:	Slope %	Photo #:

Notes:

Nested Plot Dimensions (m): small: 10 x 10M large: 40 x 40 M

Nested plot tree diameter sizes (cm): Cocoa DBH≥3 cm large: Shade DBH≥5 cm

Deadwood

Tree #	Species	DBH (cm)	Tree #	Species	DBH (cm)	Tree #	Class (1 or 2)	DBH (cm)

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