**CAFNET Uganda**

# Carbon in Shade Coffee Agroforestry

# Sampling Protocol

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## Rationale

The use of shade trees in coffee growing systems has been widely spread in eastern Africa, such as Uganda, although different levels of tree cover are reported. As studies from coffee agroforestry systems (CAF) other continents suggest, shade trees harbor the majority of biomass and hence carbon in such systems. AS carbon, carbon sequestration and carbon sequestration potential has been increasingly focused for their climate change mitigation potential, it is the objective of this study within the CAFNET framework in Uganda to assess the biomass, carbon and it partition between coffee and shade trees in the CAFs of *Coffea robusta* surrounding the Mabira forest.

## Summary

For a representative picture of the diverse practices and patterns in the present shade CAFs, all approx. 50 associated smallholder CAFNET/NUCAFE farmers in the Mabira forest area and their plantations will be chosen randomly following a protocol developed for the activities also involving the socioeconomic survey. These farmers will be visited and their coffee plots surveyed in the time from January to June 2010.

Focus lies on assessing the biomass of shade trees (> 5 cm dbh) in the coffee agroforestry systems. In cases where allometric equations are not readily available for shade tree species, generic equations (e.g. from Chave et al. 2005) will be applied. However, wood density measurements according to the adapted methodology by Francis (1994) will be conducted for at least 30 trees per species at breast height. All Shade trees will be assessed in terms of species, height, diameter at breast height (dbh) and crown diameter. Species specific wood density will be sampled on wood cores for 10 individuals per

species. No other destructive sampling on shade trees will be conducted. If one tree is found per species in the entire study, then wood density is obtained from that tree to represent that species.

For biomass conversion, the allometries by Tumwebaze (2008) will be applied to trees of the respective species, allometries from literature for other species where applicable and where no species specific allometries are available the moist forest equation by Chave et al. (2005) will be applied considering the species specific wood density factor.

Coffee plants will be inventoried by counting from 5 randomly selected 10x10 m subplots per hectare and measurement of all woody (=non-green) shoots of >2.5 cm diameter at 50 cm above the ground for young coffee plants (single-stemmed). For old coffee plants (old multi-stemmed), measurement of all woody (=non-green) shoots of >2.5 cm diameter will be taken above mother stool. To account for biomass of the mother stool, its diameter and length will be recorded and incorporated in the biomass calculations. In order to convert these data into biomass and ultimately carbon values, a destructive biomass harvest of selected coffee trees will be conducted to develop a corresponding and applicable allometry. At least 2-3 pure *C. robusta* plantations without shade trees should be inventoried as control sites.

In Mukono district, *C. robusta* prevails and coppicing is practiced at irregular intervals in contrast to many other coffee systems on other continents, it was deemed appropriate to additionally assess the biomass of the coffee plants. Management intensities and life spans, mainly due to the coffee wilt disease, of coffee plants vary greatly in this area and old multi-stemmed individuals are common between long and bent single-stemmed individuals. To this end, a stratified random selection of coffee bushes will be harvested destructively both for aboveground (>40 individuals) and belowground (>2 cm root diameter; >16 individuals) biomass. Additional scientific guidance for the processing of the data and development for stem/shoot-number based allometries will be provided by Dr. Susan Tumwebaze of Makerere University. This study can be developed and carried out in close cooperation with COREC (Dr. Pascal Musoli).

Intended outputs of the study are:

1. Diversity and density of shade trees.
2. Allometric equation and root:shoot ratio for *C. robusta.*
3. Comparison of carbon in coffee trees between shade coffee and open control systems.
4. Comparison of C stocks between coffee plants and shade trees.
5. Data basis for complimentary studies on drivers of shade trees and shade tree properties in CAFs in combination with results from the socioeconomic survey and proxies such as farm or plot size.

## Technical Protocol

**Choice and documentation of location**

- At any chosen farm, the area (plot) currently under coffee agroforestry (CAF) will be chosen for the assessment.

- Record name of farmer and location.
- Record age of CAF plot.
- Using the GPS in tracking mode, walk around the perimeter of the CAF plot to determine the area size which will later serve as basis for computing the stem density and specific basal area for both shade trees and coffee plants.
- Based on the area size, determine how many of the 10x10 m coffee subplots are to be established (2 per acre = 5 per ha).
- As this exercise is currently not considered to be repeated a permanent numbering of all shade trees is not considered.
- Measure and record the dbh, height and crown diameter for all trees dbh >5 cm (see below).
- Take 3 wood density cores for 10 individuals per shade tree species encountered (see below).
- Count coffee bushes and record diameter of all woody vertical shoots with a diameter >2.5 cm at 50 cm above ground (see below).
- Coffee plants will be inventoried by counting from 5 randomly selected 10x10 m subplots per hectare) and measurement of all woody (=non-green) shoots of >2.5 cm diameter at 50 cm above the ground for young coffee plants (single-stemmed). For old coffee plants (old multi-stemmed), measurement of all woody (=non-green) shoots of >2.5 cm diameter will be taken above mother stool. To account for biomass of the mother stool, its diameter and length will be recorded and incorporated in the biomass calculations.
- Destructively harvest aboveground biomass of 10 coffee shrubs per shoot number class (see below).
- Destructively harvest belowground biomass of 4 coffee shrubs per shoot number class (see below).

*Constraints and opportunities*

- Permission by owners for cutting and uprooting coffee bushes.
- Scale of compensation.
- Destructive harvest of both aboveground and belowground biomass could also be facilitated by COREC staff and facilities providing *C. robusta* plants of different ages for scientific purposes.

**Shade Trees**

- Number each with dbh >5 cm tree separately consecutively and with an unequivocal code.
- Determine and record species (if unsure, retain sample for identification).
- Record position with GPS.
- Trees branching the below breast height are measured as >1 tree given that dbh of each is >5 cm.
- Determine height using clinometer (degree scale) to determine angle from viewer to foot ant top of tree (interpolating the highest point directly over the trunk axis, see graphic below) and measuring distance from the observer's chest to the tree.

- *Note the potential measurement bias for interpolating the highest point directly over the foot of the tree! It is therefore advisable to have height measurements done always by the same person, ideally the recording person.*

- Using the breast height pole, determine DBH with cm-tape (circumference) and/or caliper (2x cross-wise), if dbh < 5 cm. Note any irregularities

- Determine largest extension of the crown:
    - Ensure with inclinometer (90 degrees) that the observer is directly under the crown boundary
    - Measure distance from shoulder to shoulder of observers with a measuring tape or with the vertex. If on sloped ground, additionally note the inclination.
    - Repeat these measurements directly opposite (180 deg) of the maximum extension and perpendicularly (90 deg) to the left and right from it.
- Conduct wood density sampling as described below.

**Coffee shrubs**

- Determine number of 10x10m coffee subplots required from the size of the overall plot (2 per acre = 5 per ha).
- Determine their randomized location:
    - Start at the SW corner of the plot.
    - Roll a dice 3 times and multiply the sum of the eyes by 2 (e.g. (1+5+6)*2= 24 m) and advance by that distance strictly northward.
    - Roll a dice 3 times and multiply the sum of the eyes by 2 (e.g. (2+2+4)*2= 16 m) and advance by that distance strictly eastward.
    - You have reached the center of a 10x10 m plot.
    - Measure 7.1 m (=sqrt(100+100)/2) to the N, S, E, and W from the centre to mark the corners of the plot with marking tape.
    - In case the plot protrudes beyond the obvious plot boundaries, move it, so it lies at least by 1 m within the plot.
    - From this center repeat the above exercise to reach the next subplot, etc.
    - If arrived at the northern or eastern boundary of the plot, subsequent directions would be inverse (e.g. southward and westward).
    - In case the plot overlaps with a previous plot, move it, so there is 1 m of space between both plots.
- Within the plot assess each coffee plant by recording the diameter of all woody vertical shoots with a diameter >2.5 cm at 50 cm above ground with a caliper.

**Aboveground Biomass**

- Establish coffee shoot number classes (SNC) as plants with 1, 2-3, 4-6, 7+ amounts of woody (non-green) stems with a diameter >2.5 cm at 50 cm above ground.

- On different farms if possible and necessary choose a minimum of 1 coffee shrubs representing each SNC.
- Conduct a destructive biomass harvest for each of them.
- Allocate an unequivocal sample code to the individual coffee plant.
- Extract all shoots that meet the above criteria at their base.
- Cut the remaining woody base (=stump) of the plant with all unidentified small shoots.
- Measure basal diameter and diameter at 50 cm above ground with calipers.
- Measure maximum length for each shoot with a measuring tape.
- Remove foliage and collect jointly in a standardized ugali bag.
- Using the hanging scale, measure the fresh weight of leaves and each extracted shoot individually.
- Weigh the stump together with all wood chips from the cutting.
- Collect one 2 cm thick disk from each shoot and a piece of the base and label them.
- Determine the fresh weight of these subsamples to the nearest 0.1 g and store them in labeled, airtight zip-lock sample bags.
- Remove about 100 g of leaves, determine their fresh weight to the nearest 0.1 g and store them in labeled, airtight zip-lock sample bag.

**Belowground Biomass**

*Note:* not each coffee tree needs to be unearthed. It is advisable though to do so for at least four individuals per stem number class.

- Record sample number of aboveground biomass measurements including the number of stems measured.
- Determine thickness of remaining (above-ground) stump (i.e. before it 'disperses' into roots) and its diameter.
- Unearth the full portion of the root system where possible.
- Alternatively for large bushes, use a portion such as a quarter section with a radius of 2 m and depth of at least 1 m will to assess the coarse roots (>2 cm diameter). (1 cm is possible as threshold and should be determined/adapted on the first experiment depending on the proportion of 1 cm roots compared to 2 cm roots. Practically, 1 cm roots may suffer already from the digging process.
- If a tap root can be accessed, add it to the harvested below ground biomass. Attempt at least to determine its maximum diameter.
- Note the maximum depth attained.
- Determine the fresh weight of the extracted coarse roots including all sizeable wood chips from the chopping with the pangas that can be retrieved.
- Cut from the largest root four disks (distributed over the length) of at least one cm thickness as subsamples to account for large differences in water content along the root length.
- Determine the weight of the fresh subsample and store it in a labeled sample bag.

**Wood Density Measurements** (cf. Francis 1994)

*Density measurements on shade trees* should be done for at least 10 individuals (ideally spanning the entire dbh range from small to very large) per species.

- Using a carpenters auger and 2.5cm drill bit (ideally with drill bit welded **straight** into auger!)
- Identify standard depth to core as the tree radius at breast height to a maximum of 10 cm.
- Identify the point at breast height to sample preferably where the bark is thinnest.
- Prepare a preparatory hole, by boring in carefully until the dead and living bark are penetrated, getting to the start of the sapwood. Brush out the hole to remove any wood chips. Then measure its depth of the hole with a ruler to the nearest mm and record this as the start depth.
- Discard chips produced in boring the preparatory hole and clean the auger bit.
- Tug and tie a plastic bag underneath the identified point to sample from.
- Mark the target depth (coring depth + starting depth) on the drill bit (masking tape or similar).
- Continue augering into the tree until you reach the target depth.
- Withdraw the auger by turning the brace in anti clockwise direction.
- After the auger is withdrawn, the chips remaining in the hole are collected using a flattened stick or thin spatula and added to the sample.
- All chips must be removed from the hole and the auger bit without losing any sample.
- The end depth of the hole is then measured to the nearest mm.
- Place the wood chips into a labeled paper bag and store in a cool box.
- Take a further two samples from each tree, spaced about 10 cm above and below the original hole. Keep the replicate sample separate.
- In the laboratory, oven dry the samples spread out openly at 100 degrees C for 24 hours.
- Remove each sample from the oven and empty into a tared sample container. Record the weight of the sample to the nearest 0.01 g.

*Density measurements on coffee shrubs*:

- Use harvested subsample disks.
- Use the fresh disks for determining green volume using the submersion technique (e.g. http://chestofbooks.com/home-improvement/woodworking/Mechanical-Properties-of-Wood/Volumetric-Shrinkage-And-Specific-Gravity-Specimens.html or http://www.hartnell.cc.ca.us/physics/labs/2a/densityandarchimedesprincipal.pdf):
- Measure diameter and thickness to the nearest mm and record.
- Use a large jar / bucket filled halfway with water capable of receiving the disks without overflowing
- Place the water container onto a fine scale (+/- 0.01g preferably) and tare.
- Place the fresh coffee disk into the container and use a pointed object to completely submerge the disk.
- When the disk is just submerged, read the balance, take three readings.
- Remove from water, drip off and dry at 105 degrees C for 48 hours.
- Once oven dry, weigh to the nearest 0.01 g.

**Sample Processing in the Lab**

- Wood samples in the lab are immediately removed from the sample bags and unequivocally labeled

- Original fresh weight to the nearest 0.01 g should be noted in the data files and on the sample if not already done in the field.
- Determination of coffee disk volumes as described above.
- If need be the samples must be mechanically disintegrated to fit the oven and maximize the surface area
- Drying occurs on paper plates (or equivalent) for at least 24 h (wood density cores) and 48 h (coffee disks) at 105 deg C.
- After drying, the samples are weighed again to the nearest 0.01 g and entered into the database.
- It would be an additional asset to submit a random subsample of both the dried wood density chips per species and from the coffee disks to a carbon element analysis to arrive at verifiable values of C-content.

**Field Data Sheets**

- The field data sheets are supplied as drafts to be transferred into practical layouts and adapted corresponding to the actual practical requirements in the field by NaFORRI staff.

**Database**

- The database should accommodate all recorded field data and should be simple and user friendly. Some excel templates are provided.
- It is advisable to have some parameters (such as circumference → diameter) directly and automatically processed from raw data and subjected to real-time visualization (e.g. dbh/height relationships).
- Data screening during the process is essential.
- It must be maintained, regularly backed up and data progress should be shared with every two weeks with Johannes Dietz.

**Parameters to be calculated**

- *Crown diameter:* Add 0.5 * DBH to all radius measurements, average all 4 readings and multiply by 2.
- *Harvested biomass:* Separate for leaf, branch, stem and belowground (upscaled to 100% when only a fraction had been sampled), the oven dry biomass for each tree will be calculated from the fresh weight and the reduction in weight from drying of the subsamples.
- *Allometric Equation:* Collected data from the biomass harvest will be used separately for each identified shoot, which includes the proportional, diameter-based addition of the remaining stump biomass. An allometry will be sought according to the shoot diameter irrespective of each length. Ultimately, a sufficiently solid correlation will be sought between biomass and number of relevant shoots for ease of field measurement.
- *Wood density:* Wood density will be derived from the dry weight/ green volume in g/cm3.
- *Root shoot ratio:* For coffee shrubs where above ground and below ground biomass has been established the root:shoot ratio will be calculated.

- *Shade tree biomass:* Wood volume from allometric equations by Tumwebaze (2008), other regional literature or Chave et al. (2005) –moist forest. Using wodd density measurements conversion of Volume to biomass and consequently using C content to C stocks per shade tree, later tallied at plot level.
- *Coffee biomass:* Based on the attained allometry, the sample results from the subplots will be converted to biomass and C stocks (including C-content analysis results) and ultimately upscaled to plot level.

**Equipment required**

- 2x Clinometers (90 deg)
- 1x Compass
- GPS
- Tripod and digital camera with 180deg fisheye lens ($2000)
- 2x inclinometers (90degrees) ( $ )
- 2x 50 m measuring tape
- 2x 2m measuring tape (cm) (alternatively diameter tape)
- 1x large caliper (shade trees)
- 3x small caliper (coffee)
- 3x clip boards
- 1x large hanging balance (20 kg +/- 0.1 kg)
- 1x small battery balance (2 kg +/- 0.001 kg)
- 1x Large (0.5”) plywood board (3’x3’) as weighing station/base
- 2x roll of marking tape
- 1x 1.3m breast height pole
- 1x ropes
- 1x ugali sacks
- Sample bags
- Markers
- Field data sheets
- Sample bags

- Panga/pick/shovel with operator