Protocol for Soil Carbon Sampling in ForestGEO Census Plots

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1. SOIL PROFILE PITS

Soil pits are excavated to 2 m depth (or to bedrock if < 2 m deep) around the outside of the plot – see *Protocol for Soil Profile Pits* for details. Samples are taken from the pit walls to determine bulk density and physical and chemical parameters related to soil classification (e.g., texture, amorphous metals, total element concentrations, exchangeable cations, etc.).

2. FIELD WORK

Personnel

Field work requires 2–3 people for 8–12 weeks, depending on local conditions (e.g., distance to the plot, nature of the soil, interruption by bad weather, etc).

Equipment List

- Coring equipment (NC fittings): (i) split-core sampler (2.5" diameter x 6" length), (ii) extension rod (3'), (iii) rubber-coated cross handle, (iv) replacement tip (optional).
- Auger equipment (Quick Connect fittings): (i) Dutch auger (2" diameter), (ii) mud auger (2 ¾" diameter), (iii) regular auger (2 ¾" diameter), (iv) rubber-coated cross handle, (v) extension rods (3') x 5.
- Long-handled spoon (x 2)
- Rubber mallet
- Retractable tape measure
- Electrical tape
- Knife (removing clay soils from corers)
- Secateurs (for cutting roots)
- Large plastic bucket/plastic sheet for mixing soil in the field
- Waterproof marker pens (x 10)
- Waterproof notebook (e.g., *Rite in the Rain*) and pencils

Note: all coring equipment is available from AMS (Idaho, USA) or Forestry Supplies. Purchase of a replacement tip is recommended in case of damage in the field.

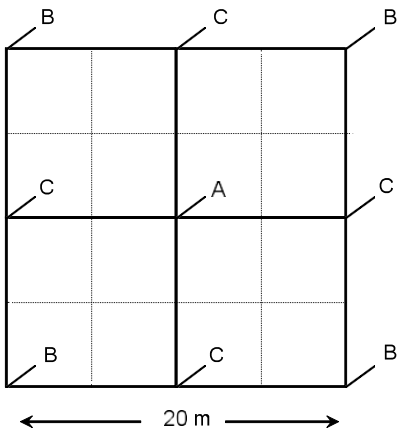
Sampling Strategy

Sample locations are on a systematic grid in the 20 m x 20 m square in the center of each hectare. See *50 ha Plot Sampling Locations* for details of precise sampling locations. Samples are taken to the following depths:

A = 0-10 cm
10-20 cm
20-50 cm
50-100 cm
100-150 cm
150-200 cm
200-250 cm
250-300 cm

B = 0-10 cm
10-20 cm
20-50 cm
50-100 cm

C = 0-10 cm
10-20 cm



Thus, there are nine samples of 0-10 cm, nine of 10-20 cm, five of 20-50 cm, five of 50-100 cm, and one each of 100-150 cm, 150-200 cm, 200-250 cm, and 250-300 cm. The maximum number of samples for a 50 ha plot is therefore 400 (8 depths per hectare x 50 hectares).

Soil Coring Procedure

1. Mark the corer with electrical tape at 10 cm and 20 cm. The base of the tape should correspond to the required depth. Mark the augers with tape at 50 cm, 100 cm, etc. Note that this requires using the extension rods in a systematic order.
2. For each sampling point, find the required marker post and then move two meters in a north-easterly direction to take the core. This is because researchers usually walk to the area around the marker posts, which can disturb the soil surface.
3. Prepare the sampling point by removing leaves, including decaying but recognizable leaves, from the surface (see below). These may be retained for subsequent drying and determination of total elements (C, N, P, etc).
4. Start in the center of the hectare. Sample surface soil (0-10 cm and 10-20 cm) using the constant volume corer. These samples should be taken to the exact depths, because the samples will be used to calculate bulk density (and therefore mass of carbon).
5. Next, use the auger to sample soil from 20-50 cm, 50-100 cm, 100-150 cm, 150-200 cm, 200-250 cm, and 250-300 cm from the same bore hole as for the surface samples.
6. If augering is stopped by stones, plinthite, or bedrock, then measure the exact depth using the tape measure and recorded. Also note any prominent changes in color to grey (gleyed) soil. If you are unable to pass 100 cm at the center pin then the deep (A) samplescan be continued from another point (note the change in location).
7. Samples are placed in ziplock bags for transport to the laboratory. Each bag is labeled with the plot name, location in the hectare (e.g. 01, 02) and the depth of the sample.

8. At the corners of the center 20 x 20 m square, use the constant volume corer to sample 0-10 cm and 10-20 cm, and the auger to sample 20-50 cm and 50-100 cm.
9. At the sides of the center 20 x 20 m square, use the constant volume corer to sample 0-10 cm and 10-20 cm.
10. For each hectare, all samples from the same depth can be combined into a single bag in the field (e.g., place all 0-10 cm cores in the same bag). This is not possible for 50-100 cm as the samples are too big. These samples can be mixed in the field using a large bucket, with a subsample of approximately 1 kg taken for laboratory analysis.

Notes on coring:

1. If roots interrupt coring using the bulk density corer for the 0-10 cm sample then start again nearby (within 50 cm). If roots interrupt the 10-20 cm sample, attempt to cut them with a sharp knife or secateurs. A large rubber mallet can be used to hammer the corer through large roots, but care is needed to avoid damaging the core tip on stones.
2. The weight of soil for the 0-10 cm and 10-20 cm samples taken with the constant volume corer is used to calculate bulk density, so it is of critical importance that the sample is taken to the exact depth and that (to the extent possible) the entire sample is recovered from the corer.
3. A small amount of soil occasionally drops back into the bore hole when sampling the 0-10 cm depth. This is evident if some soil is missing from the base of the core sample. This problem can usually be prevented by keeping the corer straight when removing from the hole. If soil is left in the hole, it can be recovered using a long-handled spoon.
4. Take care to minimize soil from the surface, which is rich in carbon, falling into the coring hole and contaminating deeper samples. It is usually clear if dark material has fallen into the hole as it will sit at the top of an auger sample and can be removed easily (e.g. by removing the top 2 cm of soil from the core sample) before placing the remaining sample in the bag.
5. Some sites (e.g., Pasoh, Malaysia) have a thin ‘mat’ of very fine roots that lie on the soil surface, but underneath the leaves. Prior to sampling, remove decaying leaves by hand but leave the fine roots on the surface – these should be included in the sample.
6. Most lowland tropical sites do not have a pronounced organic surface horizon. However, montane or temperate forests often have thick organic horizons, which should be sampled separately.
7. If the water table is encountered, continue sampling until it is impossible to bring the soil to the surface (i.e., the soil is so wet that it falls from the auger before reaching the surface).
8. If there is a sign of soil disturbance (track, wild boar activity, termite nest) at site of sampling then move to an undisturbed area as close as possible to the sampling point. Record the distance from the pin and compass bearing of the new sampling location.

3. LABORATORY WORK

Personnel

Laboratory work requires 1–2 people for 8–12 weeks, depending on the rate of soil sampling in the field.

Equipment Required

- Analytical balance weighing to approximately 4 kg with one decimal place precision
- Medium drying oven capable of at least 100°C.
- Large plastic bowls (e.g. washing up bowls) (x 2)
- Large plastic trays or plates for air-drying soils (x 50)
- Sealable plastic bags (e.g. ziplock) (400 x 1 gallon and 600 x 1 quart)
- Tweezers (x2) (for removing roots)
- 250 micron sieve (root washing)
- Paper envelopes (x 500)
- Latex gloves

Sample Handling Procedure

1. Weigh all samples immediately upon return to the laboratory to obtain a total fresh weight. Record the value: Fresh Weight.
2. Homogenize each sample as follows. Place a sample in a large plastic bowl and mix thoroughly to ensure an even color. Break up large aggregates by hand. Ensure that hands are clean, and preferably use disposable plastic gloves. Clean the bowl well between samples by washing with water and then drying thoroughly. This is a critical step in the process!
3. Determine the water content of the samples as follows. Weigh a clean, dry aluminum dish and record the value: Dish weight. Zero the balance with the dish and add approximately 200 g of soil. Record the weight: Fresh Soil for Dry Wt. Carefully remove roots from the sample and add them to the roots from the rest of the sample (see below). Place the dish plus soil in the oven at 105°C for 24 hours. Reweigh the soil plus dish and record the weight: Dry Soil + Plate. The soil can then be discarded. Record all soil weights to the nearest 0.1 g.
4. Exhaustively remove all roots from the remainder of the fresh sample and add to the roots removed from the 105°C sample (above). Separate the roots into < 2 mm and > 2 mm size classes while fresh. Clean the roots by washing on a 250 micron sieve under tap water. Place the roots in paper envelopes and dry at 60°C for 3 days. Weigh the dry roots to the nearest 0.01 g and record the weights: Roots < 2 mm and Roots > 2 mm. Record the weight of stones and Other Material.
5. Weigh a 500 g sample of root-free soil onto a large plastic tray and leave to air-dry on the laboratory bench under a fan or an air-conditioned room. A minimum of two days is necessary, but 5 days is preferable to ensure the sample is thoroughly air-dried. This can be checked by repeated weighing until the weight does not change.
6. Place 50 g of air-dry soil in a labeled bag – this is for carbon analysis in Panama.
7. Place approximately 250 g of air-dry soil in a labeled bag – this is for archiving at the site.

8. The remaining sample can be discarded.

4. SAMPLE ANALYSIS

1. Samples are sieved (< 2 mm) to determine the weight of fine stones, ground to a fine powder in a ball mill, weighed into tin capsules, and analyzed for total carbon and nitrogen using gas chromatography and thermal conductivity detection on a Thermo Flash 1112 Analyzer.
2. Additional analyses can be performed (total phosphorus, exchangeable phosphorus and cations, pH, texture, etc).