Annex E1
Soil Bulk Density Sampling for Composite Carbon Stock Calculations

For use with the CARA Composite Sampling and Bulk Density Infield Record

Purpose. This annex establishes the field and laboratory requirements for obtaining a bulk density value that can be paired with composite Total Carbon or Total Organic Carbon results to calculate carbon stock. The bulk density must represent the same sampling location, depth increment and sampling footprint represented by the composite carbon sample.

Core requirement. Complete one CARA Composite Sampling and Bulk Density Infield Record for every sampling location and depth. Select Method A or Method B before sampling and follow the selected method for every accepted core used to represent that sample.

1 Principle and calculation basis

Bulk density is the oven-dry mass of soil divided by the volume from which that soil was collected. A measured bulk density is valid only when both the soil mass and the corresponding sampled volume are known.

Core volume (cm^3) = π × (internal diameter ÷ 2)² × sampled depth

Total sampled volume = core volume × accepted-core count

Composite bulk density (g/cm^3) = estimated oven-dry composite mass ÷ total sampled volume

Measure the internal diameter at the cutting edge. Record the actual sampled depth, not only the nominal length of the corer. If equal-volume cores are combined, the resulting mass divided by their combined volume gives a volume-weighted composite bulk density for that SL and depth.

2 Selecting the bulk density sampling method

Method	When it may be used	Required sample submitted to CARA
Method A **Same soil as the analytical composite**	Use only when every analytical composite core is a complete known-volume core collected with the same recorded internal diameter and depth, every accepted core is counted, and all recovered material is retained.	One composite bag per SL and depth. The same complete sample is used for analytical subsampling and the composite bulk-density calculation.
Method B **Separate bulk density composite**	Use whenever any Method A requirement cannot be met, including unknown volume, incomplete recovery, discarded soil or uncertain core count.	Beside each analytical core, collect a separate intact known-volume core at the same depth. Combine the paired BD cores for that SL and depth in one dedicated BD bag.

3 Method A same soil as the analytical composite

The analytical composite soil may also be used to calculate composite bulk density only when every requirement below is satisfied:

- Every accepted core is collected with the same known-volume corer or sleeve.
- The internal diameter at the cutting edge is measured and recorded in Table B.
- Every core is collected to the full selected depth recorded in Table B.
- The number of accepted complete cores placed in the composite bag is recorded in Table B.
- No soil is discarded in the field. All recovered soil, roots and coarse fragments are transferred to the correct labelled composite bag.

- Incomplete, spilled or rejected cores are excluded from the accepted-core count and replaced when possible.
- Rejected cores, relocations and depth changes are documented in Table A or the comments area.
- The complete composite sample is delivered moist, cool and sealed to the laboratory.

When these conditions are met, the combined volume of all accepted cores represents the sampled volume. CARA may weigh the complete moist composite, remove representative moist subsamples for Soil Food Web and other analyses, determine moisture using a representative subsample, estimate the oven-dry composite mass and calculate composite bulk density.

4 Method B separate bulk density composite

Use Method B whenever the analytical composite cannot provide a defensible known soil volume. Method B is required when:

- The analytical cores were not collected with a known-volume corer.
- The core diameter, sampled depth or accepted-core count is unknown.
- The full depth increment was not recovered.
- Soil was spilled, discarded or divided before the complete moist mass could be recorded.
- Cores representing different depths or incompatible core geometries were mixed.

At each analytical sampling point, collect a separate intact known-volume bulk-density core beside the analytical core and at the same depth. Place all paired bulk-density cores for the same field and depth into one dedicated BD composite bag. For example, if eight analytical cores are used to represent a field, collect eight corresponding BD cores unless Method A is followed.

5 Selecting and recording the sampling depth

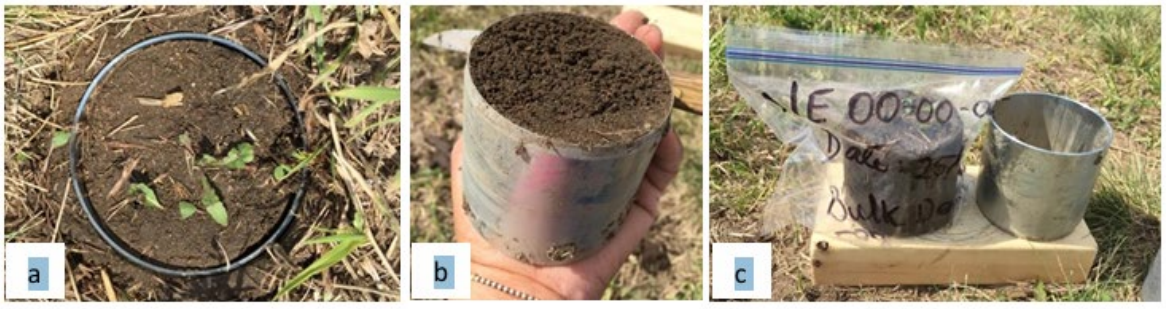
Use the compaction measurements recorded in Table A to apply the CARA depth rule:

- If 300 PSI is reached within 0-6 inches, collect separate 0-3 inch and 3-6 inch samples.
- If 300 PSI is not reached within 0-6 inches, collect one 0-6 inch sample.
- Record the selected depth and the actual core geometry in Table B.

When two depths are collected, determine bulk density independently for each depth. Do not apply the 0-3 inch bulk density to the 3-6 inch carbon result, or combine the depth increments before calculating carbon stock.

6 Collection procedure

1. Select the same sampling-point areas used for the analytical composite and in-field measurements. Record GPS coordinates and measurements in Table A.
2. Remove loose surface residue without removing or compressing mineral soil.
3. Insert the known-volume corer vertically to the selected depth. Avoid rocking, tilting or overdriving the corer.
4. Excavate carefully around the corer and support the bottom during removal to prevent soil loss.
5. Trim only soil outside the defined core volume. Do not discard material from inside the accepted core.
6. Transfer the entire accepted core, including recovered roots and coarse fragments, to the correct labelled bag.
7. Record the method, internal diameter, selected depth and accepted-core count in Table B.
8. Keep the sample moist, cool, sealed and protected from direct sunlight until delivery.



Picture 10. Collection of a known-volume bulk-density core: ring inserted at the selected sampling point, complete core recovered without soil loss, and all recovered material transferred to a labelled sealable bag.

7 Required field records

Infield form table	Required information
Table A Core infield records	Core number, GPS coordinates, 200 and 300 PSI depths, infiltration time, rejected cores, relocations and sampling comments.
Table B Bulk density sample information	Method selected, internal diameter at the cutting edge, selected sampling depth and number of accepted complete cores.
Table C Field completion and laboratory record	Bag and sample checks completed by the sampler; moist mass, moisture subsample, coarse fragments, total volume and calculated composite BD completed by CARA.

8 Sample labelling and submission

Every bag must identify the farmer or field, sampling location or SL, depth, selected method and accepted-core count. A Method B bag must also be clearly identified as a separate bulk-density composite. Complete Table C before submitting the samples.

Samples intended for Soil Food Web evaluation must remain moist. Do not air-dry, oven-dry or freeze them before the required biological subsamples are removed.

9 Laboratory handling

1. Confirm the sample identity, selected method, depth, internal diameter and accepted-core count.
2. Weigh and record the complete moist composite mass before removing analytical subsamples.
3. Mix the moist composite thoroughly and remove all required moist analytical subsamples, including the Soil Food Web and moisture subsamples.
4. Determine moisture content using a representative subsample and use it to estimate the oven-dry mass of the complete composite.
5. Separate, measure and document coarse fragments according to the laboratory calculation method.
6. Calculate total sampled volume and composite bulk density and record the results in Table C.

10 Matching bulk density with carbon results

Use bulk density only with the carbon concentration from the same SL and depth. The required pairings are shown below.

Carbon result	Bulk density required
Composite TOC or TC 0-3 inches	Composite BD from the same SL 0-3 inches
Composite TOC or TC 3-6 inches	Composite BD from the same SL 3-6 inches
Composite TOC or TC 0-6 inches	Composite BD from the same SL 0-6 inches
Individual core carbon concentration	BD from that core or its paired BD core

A bulk density measured at one sampling point must not be assigned to the other sampling points as though it were measured at those locations. If it is used because no other bulk-density information exists, all resulting stock values must be identified as estimates based on an assumed common bulk density.

11 Carbon stock calculation

For organic carbon stock, use the TOC concentration, the corresponding bulk density, the thickness of the depth increment and the coarse-fragment correction used by the laboratory.

Organic C stock (Mg C/ha) = TOC (%) × BD (g/cm³) × thickness (cm) × (1 - coarse-fragment volume fraction)

If coarse fragments are absent or are already incorporated appropriately in the laboratory bulk-density convention, the correction must not be applied a second time. The calculation method and the basis of the reported bulk density must be documented.

12 Quality control and rejection criteria

Do not report a measured composite bulk density when any of the following applies:

- Internal diameter, sampled depth or accepted-core count is unknown.
- A core is incomplete or soil was lost and the affected core cannot be replaced.
- Soil mass cannot be matched confidently with the recorded sampled volume.
- Different depths were mixed.
- Method A was selected but only a portion of each analytical core was retained.

The soil may still be suitable for concentration-based soil-health measurements. However, a carbon-stock value that requires bulk density should be reported only when a valid corresponding bulk-density measurement or a clearly disclosed estimation method is available.

13 Relationship to USDA NRCS guidance

This CARA annex adapts the USDA-NRCS known-volume cylindrical-core principles to CARA composite sampling. The NRCS Soil Quality Test Kit Guide describes careful removal of a known-volume core, prevention of soil loss, determination of oven-dry mass and correction for rock volume. USDA-NRCS soil carbon monitoring guidance emphasizes matching carbon results with the corresponding depth-specific bulk density and measuring fine-earth material and coarse fragments separately.

The NRCS CEMA 221 procedure analyzes and averages individual core increments without compositing. CARA Method A and Method B instead calculate a volume-weighted composite bulk density from the combined dry mass and combined known volume of accepted cores. Therefore, the CARA approach should be identified as a composite adaptation rather than described as the exact NRCS CEMA 221 procedure.

References

USDA Natural Resources Conservation Service. Soil Quality Test Kit Guide. Section I, Chapter 4, Bulk Density. Open official NRCS PDF

USDA Natural Resources Conservation Service. Soil Quality Indicators Bulk Density. Open official NRCS PDF

USDA Natural Resources Conservation Service. CEMA 221 Soil Organic Carbon Stock Monitoring. October 2023. Open official NRCS PDF