

01

Bulk density protocol

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Why measure this?

Bulk density tells you whether soil is compacted. Compacted soils block root growth, reduce water infiltration, and slow recovery. Bulk density is also essential for calculating soil carbon stocks – without it, soil organic carbon concentrations cannot be converted to stocks per unit area (Toro et al. 2025).

What it captures

Bulk density relates directly to soil porosity, soil compaction, erosion resistance, and water and air infiltration rates. This measurement is the weight of dry soil divided by the total soil volume. A high bulk density value restricts root growth, reduces water infiltration, and indicates compaction. Both soil bulk density and aggregate stability are negatively affected by compaction and covary with soil infiltration and water-holding capacity (Toro et al. 2025).

Sampling

See the Sampling Protocol (00) for general guidance on plot layout, replication, and timing.

Sample size: Collect from at least 5 locations per plot.

Frequency: The ideal sampling frequency is every 5 to 10 years. Standard sampling depth: 0-10 cm.

A 0-5 cm depth is also acceptable for surface compaction assessment.

Materials needed

- Soil corer of known volume (steel or PVC pipe) – 5 cm diameter, 5-10 cm height. Record the exact height.
- Knife
- Shovel
- Plastic bag
- Marker
- Ruler
- Oven-proof dish
- Oven or convection microwave
- Kitchen scale or balance (grams)
- Sieve with ~4 mm openings
- Field notebook
- Pen or pencil

Procedure

1. Scrape away leaf litter from the soil surface at the sampling point.
2. Insert the corer to its full height (not deeper) – typically 10 cm depth (or 5 cm for surface compaction assessment). Avoid twisting or compressing the core.
3. Use the shovel to excavate around the corer and lift it out. Do not yank the corer – this dislodges soil from the bottom.
4. Trim excess soil from both ends of the core with a knife or flat edge. Take care not to lose material from either end.
5. Transfer the soil into a labeled plastic bag. Mark the bag with the date, location, and sample ID.
6. Repeat steps 1-5 at each sampling location (minimum 3 per plot).



Calculating results

These calculations can be done in the field or back at the lab.

1. Measure the height and diameter of the corer in cm. Calculate the radius (diameter / 2).
2. Calculate the core volume: Soil volume = $3.14 \times \text{radius}^2 \times \text{height}$
3. Weigh the oven-proof dish (record this weight).
4. Pass the soil through the 4 mm sieve into the oven-proof dish. Set aside and weigh any rocks separately.

5. Dry the soil at 105°C to a stable weight. Use a conventional oven (minimum 24 hours) or a microwave (in 10-minute intervals, reweighing until mass stabilizes).
 6. Weigh the dried soil plus dish.
 7. Calculate the dry soil weight: Dry soil weight = (dried soil + dish weight) - dish weight
 8. Calculate bulk density: Bulk density (g/cm³) = Dry soil weight / (Core volume - Rock volume)
- **If rock volume is unknown, estimate by water displacement: submerge rocks in a graduated cylinder and record the volume displaced.*

Interpreting results

Use these ranges as rough benchmarks. Local soil type, climate, and land-use history all affect what “normal” looks like. Always compare to your reference site.

Range (g/cm ³)	Interpretation
Less than 1.0	Very loose; high organic matter content; common in surface organic horizons
1.0-1.4	Healthy range for most tropical forest soils
Greater than 1.4	Likely compacted, especially for clay soils; restricts root growth and water infiltration

During recovery, expect bulk density to decrease as organic matter accumulates and root growth loosens the soil structure.

Important considerations

- Always compare measurements to a nearby reference site on similar soil type, slope, and parent material. The reference represents the recovery target. If no suitable reference exists, establish a baseline at the restoration site before any intervention and track change over time (Toro et al. 2025).
- Bulk density typically increases with soil depth since deeper soil layers have reduced organic matter and root penetration.

References

- Toro, L., et al. (2025). Integrating belowground recovery into tropical forest restoration design and monitoring. BioScience. <https://doi.org/10.1093/biosci/biaf097>
- Anderson, J.M. and Ingram, J.S.I. (1994). Tropical Soil Biology and Fertility: A Handbook of Methods. 2nd ed. CAB International.

See also

Protocol 00 – Sampling Protocol (plot layout, replication, timing), Protocol 03 – SOM & SOC Protocol (bulk density is required to convert SOM/SOC concentrations to carbon stocks per unit area).

Useful resources

- Bulk density sampling demonstration SIPS [<https://www.youtube.com/watch?v=omnrMrA-XMQ>]
- Measuring and interpreting bulk sensitivity – Soil Health Institute [<https://www.youtube.com/watch?v=C0Wu7FVPt6I>]
- USDA NRCS Soil Quality Indicators – Bulk Density: [<https://www.nrcs.usda.gov/sites/default/files/2023-01/Soil%20Quality-Indicators-Bulk%20Density.pdf>]

Questions or Feedback?

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