Food and Agriculture Organization of the United Nations

Standard operating procedure for soil bulk density

Cylinder method

GLOSOLAN

GLOBAL SOIL LABORATORY NETWORK

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Standard operating procedure for soil bulk density by cylinder method

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SOIL BULK DENSITY
Cylinder method

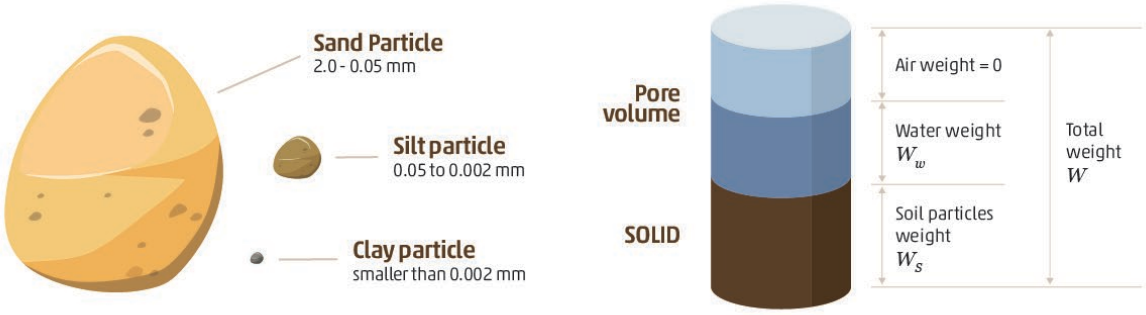
VERSION HISTORY

N°	Date	Description of the modification	Type of modification
01	15 May 2023	All comments by RESOLANs and reviewers to the draft SOP were addressed	Finalization of the SOP
02			
03			
04			

1. A brief introduction to soil bulk density

Soil is the result of rock fractioning and weathering over periods ranging from thousands to millions of years. Fractioning and weathering produce mineral fractions and particles of an extremely large range of sizes, from several metres to less than one micrometre. By definition, soil is made by the packing and assemblage of particles <2 mm, with larger particles being called “coarse material”. The way the soil is packed and the particle size determine the size and number of spaces between particles, which are called pores or voids. The fraction that the volume of these voids over the total soil is called the pore volume or porosity (Figure 1). The amount of pore volume depends on the size of the particles, as well as by their shape and packing.

Figure 1. Representation of soil particles (left); major components of soil (right)



Source: Elaborated by FAO

Approximately 10 000 years ago, agricultural practices had started using tools to loosen the topsoil layer, resulting in decreased bulk density (increasing its porosity) and facilitating water infiltration and storage, as well as soil aeration and root penetration. With the eventual development of machinery and extension of soil mechanical tillage, it was then possible to increase the ploughing depth. However, the ever-increasing weight of machinery and tractors has resulted in the intensification of mechanical pressure, thus increasing bulk density (reduced porosity) and consequently lower water infiltration and root growth. Additionally, bulk density can also vary with the differing soil structural conditions of terrain, cultivation, trampling by animals, and weather. Soil compaction is a critical component of soil degradation, and the Protocol for the Assessment of Sustainable Soil Management (FAO-ITPS, 2020) recognized bulk density as a key indicator that is recommended to monitor to assess the impact of sustainable soil management practices.

Soil bulk density is an indicator of soil compaction and soil health and is an important factor to consider when assessing the physical behaviour of soils, as it affects infiltration, root depth and restrictions, available water capacity, and soil porosity. Soil porosity controls many soil properties and ecosystem services and is consequently one of the most important soil characteristics. The pore volume can

contain air and water simultaneously. Water can be transferred in deep layers and thus recharge the groundwater table, or it can be held in the layers close to the surface by capillary forces, resulting more available for plants. The air contained in the pore volume is necessary for the functioning of plant root systems and allows for the development of trophic webs.

2. Scope

The cylinder method is generally used to characterize the bulk density of an undisturbed soil sample having a volume of between 100 and 250 cm^3.

This method is not recommended when:

- Inserting the cylinder without disturbing the arrangement of the solid particles is not possible, such as:
  - in the presence of high root density that will be driven by the cylinder, as this creates cracks inside the cylinder;
  - for excessively hard soils as the vibration of the cylinder will disturb the structure with each hit of the hammer;
  - for excessively wet soils that stick to the wall of the cylinder, causing compaction; and
  - for soil containing large amount of coarse material, where it is not possible to enter the cylinder without pushing the stones or gravel.

- Inserting the cylinder is possible but the soil does not have enough cohesion to remain in the cylinder when taken out of the ground, such as:
  - for loose or structureless soil;
  - for soil with cracks; and
  - for coarse textured soils, for which cohesion is too low due to extremely high or low water content.

3. Principle

A rigid cylinder of known diameter and height is inserted in the soil. An undisturbed soil sample that has exactly the internal dimension of the cylinder is collected and dried. The bulk density is equal to the ratio of the soil sample's dry mass divided by its volume and is expressed in grams per cubic centimetre (g/cm^3).

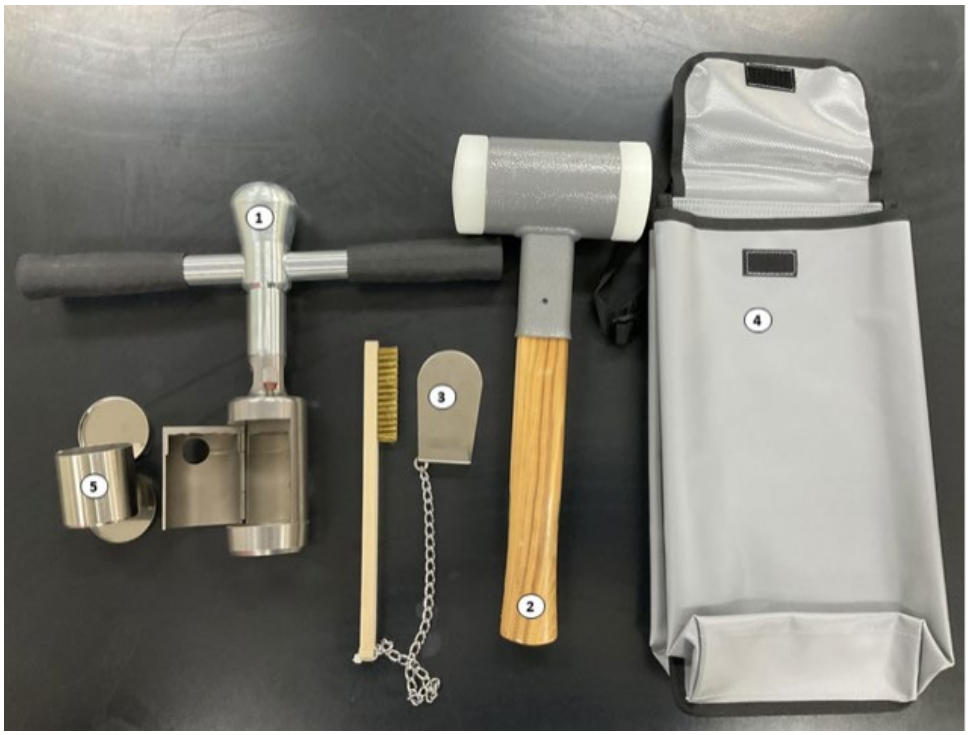
4. Apparatus

4.1. Field sampling

For field sampling (see Figure 2), the following items are recommended:

- a soil sampling kit with cylinder holder with handle and hammering head;
- an impact-absorbing hammer;
- a brush and knife set;
- a case;
- a core cylinder. (This is a stainless steel tube with a 5 to 10 cm diameter and a 7.5 to 15 cm length and sharpened on one end using an outside bevel. The most common size has a 5 cm diameter and a length of 5 cm, with two caps. A driving dolly must be made to fit inside the upper ring as shown in Figure 3, although these should be always measured prior to the calculation); and
- an auger (optional, for sampling in a deeper soil layer).

Figure 2. Field sampling set (this represents one possible device setup and others are possible, such as those with only a ring and a hammer)



Source: Elaborated by the authors

1. A soil sampling kit with cylinder holder with handle and hammering head.
2. An impact-absorbing hammer.
3. A brush and knife set.
4. A case to contain the tools.
5. A core cylinder.

4.2. Laboratory analysis

For laboratory analysis, the following items are needed:

- A drying oven (105 ˚C ± 5 °C capacity);
- a weighing balance (0.01 g precision);
- a desiccator with active desiccants; and
- a tray.

5. Materials

The materials needed are:

- a tape;
- a permanent marker; and
- a sealable plastic bag.

6. Health and safety

The procedure does not involve the use of hazardous chemicals. Take caution in handling the tray and sample from the oven as the surface will be hot.

7. Soil sampling

7.1. Field sampling

The sample to be used in the analysis should be undisturbed soil collected from the field. The collected soil can be kept in the cylinder, or if needed, transferred into a plastic bag and the cylinder reused (after cleaning) to collect more samples.

Sampling must be done in replicates to assess the variability of the field, considering the field heterogeneity within the planned sampling area.

The cylinder method uses a core cylinder of known volume: a 1 mm thin-walled stainless steel cylinder chamfered on the outer ring of one end to give a cutting edge (Figure 2). The standard dimensions are approximately 5 cm height by 5 cm diameter. The cylinder is pressed vertically until the end is flush the surface of the soil and carefully removed after digging around the cylinder. The excess soil of the sample is trimmed to match the cylinder's edges and brought to the laboratory for subsequent weighing and drying. For extra information on the use of the sampler kit in the field, please refer to Figure 3.

Surface sampling

1. Clean the soil surface by removing vegetation and stones.
2. Clean the core sampler, the core, and the caps.
3. Assemble the core sampler by inserting a core of suitable length inside and tightening the handle with an appropriate rod.

3. Insert the core sampler into the soil with gentle hammering. Excessive hammering should be avoided as not to induce artificial soil compaction through the sampling procedure. Compression can be observed by comparing the soil elevation inside the cylinder with the original soil surface outside the cylinder. Dry or hard soils often shatter when hammering the cylinder into the soil. Pressing the cylinder into the soil reduces the risk of shattering the sample.
4. Remove the sampler carefully and dismantle the assembly.
5. Remove the core out of the sampler, and trim from either side to remove excess soil and fix both caps.
6. Seal each cap tightly using masking tape.
   Alternatively, place the cylinder in the sealable plastic bag with a label.
7. Label the core with the date of sampling, location, horizon depth, topography, and sample number/code.
8. Bring the sample to the laboratory.

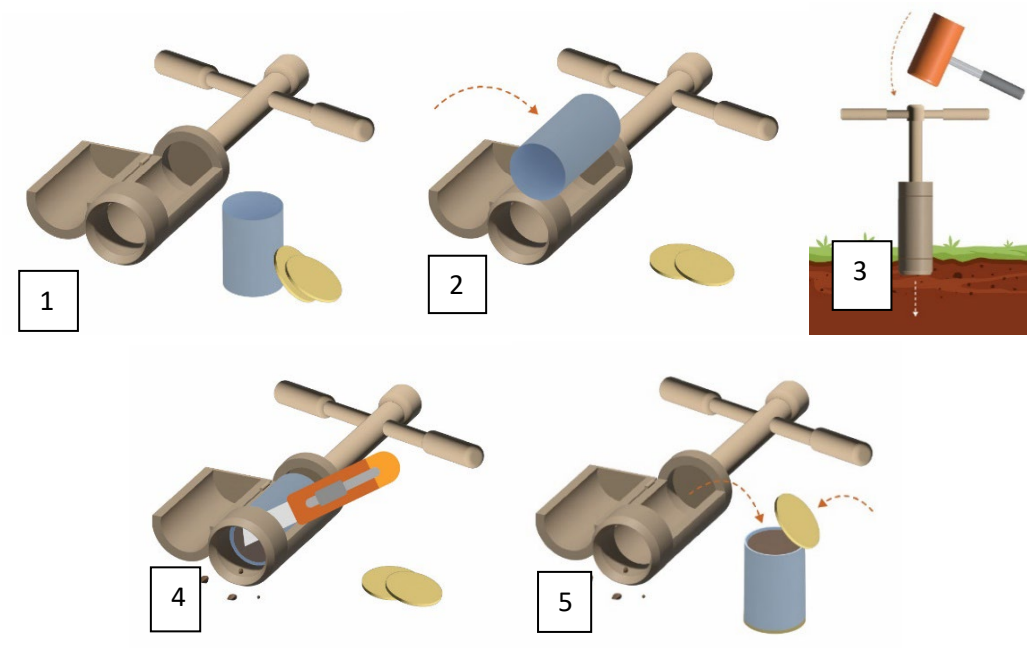
Deep-layer sampling

1. When sampling in deep soil layers, a sampling kit with a soil auger is used. The auger is used to drill a hole until reaching the depth of soil from where it is planned to take a soil sample.
2. Excess soil is removed by the auger.
3. The ring is pressed into the soil in, for example, 1 m depth of soil with a ring holder and handle with a hammering head.
4. The excavation method is best when sampling at sites with many coarse fragments, exceeding 25 percent of its volume.
5. Bring the sample to the laboratory.

Sample storage

Samples must be kept within 15 to 25 °C room temperature with less than or equal to 60 percent relative humidity. The alarm limits for room temperature are <14 °C and >26 °C, and <10 percent and >75 percent for relative humidity. Environmental conditions are monitored using a calibrated thermohygrometer. Minimize sample handling to avoid losses of sample mass.

Figure 3. Use of sampler kit in the field



Source: Elaborated by FAO
1. Loosen the bolt that is located on the top of the sampler, open the sampling tube cover. Set the cylinder in the sampler. Close the cover and tighten the bolt.
2. Set the soil sampler straight to the ground. Beat the head little by little with a hammer. After beating to the depth of sampling, pull it up slowly, turning the handle to one direction.
3. Place the sampler in the ground and cut the bottom of the cylinder with the attached knife.
4. Remove the cylinder slowly.
5. Put the lids on the top and bottom of the cylinder and seal them with tape.(Note that this represents one possible device setup. Others are also possible, such as those with simply a ring and a hammer).

8. Procedure

The procedure is as follows:

- Remove one cap of the cylinder with the sample (for bulk density with moisture content, take the fresh mass of the cylinder with the sample before oven drying).
- Place the sample on the tray. Transfer to the oven and dry at 105 °C ±5 °C for 24 hours or until the constant weight is achieved.
- Fit the cap back to the cylinder and place the sample inside the desiccator until room temperature is achieved, then weigh its oven-dried mass and record it.

- Calculate the bulk density (BD or ρ_b) following the computation in Section 9 and report to the nearest 0.01 g/cm^3 (two decimal digits).

9. Calculation

$$\text{Bulk density} = \frac{(\text{dry soil mass} + \text{cylinder mass}) - \text{cylinder mass}}{\text{volume of the cylinder}} \times 100$$

$$\text{BD} = \frac{\text{dry soil mass (g)}}{\text{volume of cylinder } (\text{cm}^3)} \times 100$$

The volume of the cylinder is:

$$V = \pi \times r^2 \times h$$

Where:

π = 3.1416;

r = radius (half of the diameter) (cm); and

h = height of the cylinder (cm).

Starting from the measurement of bulk density, several other soil parameters can be derived. For example, if particle density is known (or assumed), porosity can be calculated as:

$$\varphi = \left(1 - \frac{\text{BD}}{\text{PD}}\right) \times 100$$

Where:

φ = porosity

BD = bulk density

PD = particle density

10. Interpretation of results

Soil bulk density is dependent on soil texture, and is used as an indicator of compaction and relative restrictions to root growth (Table 1). Typical values for soil bulk density range from 1.0 to 1.7 g/cm^3 (Arshad, Lowery and Grossman, 2015). Sandy soils have relatively high bulk density since total pore space in sandy soils is less than that of silt or clay soils. Finer-textured soils that have good structure, such as silt and clay loams, have higher pore space and lower bulk density compared to sandy soils.

Table 1. General relationship of bulk density to root growth based on soil texture

Soil texture	**Ideal bulk densities** (g/cm^3)	**Bulk densities that may affect root growth** (g/cm^3)	**Bulk densities that restrict root growth** (g/cm^3)
sands, loamy sands	< 1.60	1.69	>1.80
Sandy loams, loams	< 1.40	1.63	>1.80
Sandy clay loams, loams, clay loams	<1.40	1.60	>1.75
Silts, silt loams	<1.30	1.60	>1.75
Silt loams, silty clay loams	<1.40	1.55	>1.65
Sandy clays, silty clay loams, some clay loams (35–45% clay)	<1.10	1.49	<1.58
Clays (>45% clay)	<1.10	1.39	>1.47

Source: **NRCS (National Resources Conservation Service).** 2001. *Soil Quality Test Kit Guide*. USDA Natural Resources Conservation Service, Washington, DC.

The presence of organic matter in a soil directly affects the values of the bulk density. Organic soils have lower bulk density compared with mineral soils. As such, the bulk density of Histosols (soil containing more than 20 percent of organic matter) ranges from about 0.1 g/cm^3 for Fibrists, 0.2 to 0.3 g/cm^3 for Hemists and Saprists. In wetland mineral soils, bulk density ranges from 0.5 to 1.5 g/cm^3. Likewise, volcanic ash soils (Andosols) are characterized by a bulk density of less than 0.85 g/cm^3. Humus-rich allophanic Andisols tend to be lower than those of humus-poor allophanic Andisols.

High soil bulk density results from repeated ploughing at the same depth, equipment traffic on wet soil, limited crop rotations, the burning of crop residues, overgrazing on forage plants and using heavy equipment for land smoothing and levelling. The risk of high bulk density and compaction can be reduced by maintaining or increasing soil organic matter, reducing the number of trips across the area, having designated field roads for equipment traffic and minimizing soil disturbance. Meanwhile, conservation practices which result in favourable bulk density for soil functions include the use of cover crops, conservation crop rotations, prescribed grazing and tilling management.

Table 2. General effects of bulk density to water infiltration and plant growth

Soil bulk density (g/cm^3)	**Interpretation**
1.1–1.3	Can cause damage to canals, laterals and farm distribution systems.
1.3–1.6	Favourable for irrigation and for root penetration and development.
1.7–1.9	Very low hydraulic conductivity (permeability and has a poor drainage.
>1.89	Plant roots hardly penetrate soil horizons.

Source: **Department of Agriculture - Bureau of Soils and Water Management**. 1988. *Methods of Soil, Plant, Water and Fertilizer analysis for Research, Vol. 1.* Manila, the Philippines.

11. Quality assurance/quality control

11.1. Accuracy test

The accuracy test refers to how close a specific measurement is to the true or accepted value. This can be done by performing a replicate analysis of certified reference material (CRM) and participating in proficiency testing (PT).

Procedure:

- Perform a replicate analysis of CRM or participate in a PT programme at least once a year.
- Compare the results with other laboratories as provided in a PT analysis report, or CRM certificate. The result is considered accurate when it falls within the reported 95 percent confidence interval or the target value.
- Check the result of the PT sample and if its z-score is within the acceptance criterion as evaluated by the PT scheme provider using its stated protocol.

11.2. Precision test

When collecting replicate samples, make sure to sample cylinders next to each other to minimize field variability. This will be used as a quality control material (QCM) to set an acceptance criterion. The acceptance criteria are determined from the analysis of the 20 batches of the control material.

Procedure:

- Perform a duplicate analysis of the QCM in a batch test.
- Calculate for the standard deviation to determine if the analysis of QCM is within the acceptance criteria.

The equation is as follows:

$$SD= \sqrt{\frac{\Sigma(Xn-\bar{X})^2}{n-1}}$$

Where:

SD = standard deviation; and

$\Sigma(Xn-\bar{X})^2$ = the sum of the squares of differences between individual quality control values and the mean.

11.3. Control chart

Procedure:

- Analyse at least one duplicate of the QCM for every batch analysis.
- Plot the result in the control chart, and monitor for any results out of the specified limits. If any results out of a specified limit are observed, identify the root cause, perform corrections, develop a corrective action plan, and address the problem.
- Record the actions taken.

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Appendix I: Acknowledgements

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13. Appendix III: Contributing laboratories

GLOSOLAN thanks the following laboratories for completing the GLOSOLAN form on the method and providing information on their standard operating procedure for soil moisture content by the gravimetric method. This information was used as a baseline for global harmonization.

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- Manaaki Whenua Landcare Research, **New Zealand**
- Landcare Research, Palmerston North, **New Zealand**
- Department of Environment and Science (DES), Science Division, Chemistry Centre, **Australia**
- Fiji Agricultural Chemistry Laboratory, **Fiji**

The Global Soil Partnership (GSP) is a globally recognized mechanism established in 2012. Our mission is to position soils in the Global Agenda through collective action. Our key objectives are to promote Sustainable Soil Management (SSM) and improve soil governance to guarantee healthy and productive soils, and support the provision of essential ecosystem services towards food security and improved nutrition, climate change adaptation and mitigation, and sustainable development.

GLOSOLAN
GLOBAL SOIL LABORATORY NETWORK

GLOSOLAN is a Global Soil Laboratory Network which aims to harmonize soil analysis methods and data so that soil information is comparable and interpretable across laboratories, countries and regions. Established in 2017, it facilitates networking and capacity development through cooperation and information sharing between soil laboratories with different levels of experience. Joining GLOSOLAN is a unique opportunity to invest in quality soil laboratory data for a sustainable and food secure world.

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