4. SOIL PHYSICAL ANALYSIS

Soil physical measurements are numerous, depending on the objective of the study for agricultural purposes. These measurements generally include *soil water content, infiltration* and *hydraulic conductivity, evapotranspiration, heat, temperature, reflectivity, porosity, particle size, bulk density, aggregate stability, and particle size distribution* (Klute, 1986). However, only a few physical measurements are normally conducted in soil-plant analysis laboratories.

Soil moisture is routinely measured on field-moist samples, since all chemical analyses are expressed on oven-dry basis. As texture (e.g., whether sandy or clay) is quite important in relation to nutrient behavior, particle-size distribution is often carried out, especially if more precision is needed than provided by the qualitative physical "feel" approach for determining texture.

A common physical soil measurement, especially for irrigated soils, is the preparation of saturated paste. This provides an extract in which soluble anions and cations are measured; criteria for deficiency or toxicity of some elements are also based on soil extract element concentrations. For example, criteria for salinity tolerance, presented in **Appendix 14**, are based on a saturation extract. Similarly, criteria for boron (B) in relation to plant growth, shown in **Appendix 15**, are based on this extract.

4.1 Soil Moisture Content

As water is the most limiting factor in the CWANA region, soil moisture determination is of major significance. Soil moisture influences crop growth not only by affecting nutrient availability, but also *nutrient transformations* and soil *biological behavior*. Therefore at ICARDA soil moisture is routinely measured in most field trials. While it can be assessed in the field by neutron probe, the gravimetric approach is more flexible, as samples can be readily taken from any soil situation. All analyses in the laboratory are related to an air- or oven-dry basis, and therefore must consider the actual soil moisture content (Hesse, 1971).

Apparatus

> Electric oven with thermostat.
> Desiccator.

Procedure

1. Weigh 10 g air-dry soil (< 2-mm) into a previously dried (105°C) and weighed metal can with lid.
2. Dry in an oven, with the lid unfitted, at 105°C overnight.
3. Next day, remove from oven; fit the lid, cool in a desiccator for at least 30 minutes and re-weigh.

CALCULATIONS

$$\% \text{ Moisture in Soil } (\theta) = \frac{\text{Wet soil (g) - Dry soil (g)}}{\text{Dry soil (g)}} \times 100 \quad \text{.......} \quad (2)$$

$$\text{Dry Soil (g)} = \frac{1}{1 + \dfrac{\theta}{100}} \times \text{Wet soil (g)} \quad \text{.....................} \quad (3)$$

$$Moisture\ Factor = \frac{Wet\ soil}{Dry\ soil}\ or\ \frac{100 + \%\theta}{100} \quad .... (4)$$

4.2 Particle Size Distribution

Individual soil particles vary widely in any soil type. Similarly, as these particles are cemented together, a variety of aggregate shapes and sizes occur. For standard particle size measurement, the soil fraction that passes a 2-mm sieve is considered. Laboratory procedures normally estimate percentage of *sand* (0.05 - 2.0 mm), *silt* (0.002 - 0.05 mm), and *clay* (<0.002 mm) fractions in soils. Particle size distribution is an important parameter in soil classification and has implications on soil water, aeration, and nutrient availability to plants.

As primary soil particles are usually cemented together by organic matter, this has to be removed by H_2O_2 treatment. However, if substantial amounts of $CaCO_3$ are present, actual percentages of sand, silt or clay can only be determined by prior dissolution of the $CaCO_3$. The two common procedures used for *particle size analysis* or *mechanical analysis* are the *hydrometer* method (Bouyoucos, 1962; Day, 1965; FAO, 1974) or the *pipette-gravimetric* method.

The hydrometer method of silt and clay measurement relies on the effect of particle size on the differential settling velocities within a water column. Theoretically, the particles are assumed to be spherical having a specific gravity of 2.65 g/cm^3. If all other factors are constant, then the settling velocity is proportional to the square of the radius of the particle **(Stoke's Law)**. The settling velocity is also a function of liquid temperature, viscosity and specific gravity of the falling particle. In practice, therefore, we must know and make corrections for the temperature of the liquid. Greater temperatures result in reduced viscosity, due to liquid expansion and a more rapid descent of falling particles.

Apparatus

Soil dispersing stirrer: A high-speed electric stirrer with a cup receptacle.
Hydrometer with Bouyoucos scale in g/L (ASTM 152H).

Reagents

A. Dispersing Solution

Dissolve 40 g *sodium hexametaphosphate* [$(NaPO_3)_{13}$], and 10 g *sodium carbonate* (Na_2CO_3) in DI water, and bring to 1-L volume with DI water. This solution deteriorates with time and should *not* be kept for more than 1 to 2 weeks.

B. Amyl Alcohol

Procedure

1. Weigh 40 g air-dry soil (2-mm) into a 600-mL beaker.
2. Add 60-mL dispersing solution.
3. Cover the beaker with a watch-glass, and leave overnight.
4. Quantitatively transfer contents of the beaker to a soil-stirring cup, and fill the cup to about three-quarters with water.
5. Stir suspension at high speed for 3 minutes using the special stirrer. Shake the suspension overnight if no stirrer is available.
6. Rinse stirring paddle into a cup, and allow to stand for 1 minute.
7. Transfer suspension quantitatively into a 1-L calibrated cylinder (hydrom eter jar), and bring to volume with water.

A. Determination of Blank

- Dilute 60 mL **dispersing solution** to 1-L hydrometer jar with water.
- Mix well, and insert hydrometer, and take hydrometer reading, R_b.
- The blank reading must be re-determined for temperature changes of more than 2°C from 20°C.

B. Determination of Silt plus Clay

- Mix suspension in the hydrometer jar, using a special paddle carefully, withdraw the paddle, and immediately insert the hydrometer.
- Disperse any froth, if needed, with one drop of **amyl alcohol**, and take hydrometer reading 40 seconds after withdrawing the paddle. This gives reading, R_{sc}.

CALCULATIONS

Percentage **Silt** plus **Clay** in soil

$$\% \; [Silt + Clay] \; (w/w) = (R_{sc} - R_b) \times \frac{100}{Oven\text{-}dry \; soil \; (g)} \quad ....(5)$$

C. Determination of Clay

- Mix suspension in the hydrometer jar with paddle, withdraw the paddle, with great care, leaving the suspension undisturbed.
- After 4 hours, insert the hydrometer, and take hydrometer reading, R_C.

Percentage **Clay** in soil:

$$\% \text{ Clay } (w/w) = (R_c - R_b) \times \frac{100}{\text{Oven-dry soil (g)}} \quad \text{...................... (6)}$$

Percentage **Silt** in soil:

$$\% \text{ Silt } (w/w) = [\% \text{ Silt } + \text{ Clay } (w/w)] - [\% \text{ Clay } (w/w)] \quad \text{.............. (7)}$$

D. Determination of Sand

- After taking readings required for clay and silt, pour suspension quantitatively through a 50-μm sieve.
- Wash sieve until water passing the sieve is clear.
- Transfer the sand quantitatively from sieve to a 50 mL beaker of known weight.
- Allow the sand in the beaker to settle, and decant excess water.
- Dry beaker with sand overnight at 105°C.
- Cool in a desiccator, and re-weigh beaker with sand.

Percentage **Sand** in soil:

$$\% \text{ Sand } (w/w) = \text{Sand weight} \times \frac{100}{\text{Oven-dry soil (g)}} \quad \text{............ (8)}$$

Where: Weight of sand follows from:

$$Sand\ weight(g) = [Beaker + Sand\ (g)] - [Beaker\ (g)]\ \dots\dots\dots\dots\ (9)$$

Note
1. If possible, all hydrometer jars should be placed in a water bath at constant temperature (20°C); in that case, temperature corrections are not needed.
2. For temperature correction, use a value of 0.4 for each degree temperature difference from 20°C. Add or subtract this factor if the temperature is more or less than 20°C, respectively.
3. All results of mechanical analysis should be expressed on the basis of oven-dry soil (24 hours drying at 105°C).
4. In the above procedure, carbonates and organic matter are not removed from the soil.
5. The Hydrometer method, as described in this section, cannot be applied to soils that contain free gypsum (gypsiferous soils). For gypsiferous soils, see Hesse (1971).
6. Sum of % silt and clay + % sand should be 100 %. The magnitude of deviation from 100 is an indication for the degree in accuracy.

Soil Texture

Once the percentage of sand, silt, and clay is measured, the soil may be assigned a textural class using the USDA textural triangle **(Fig. 4)**. Within the textural triangle are various soil textures which depend on the relative proportions of the soil fractions.
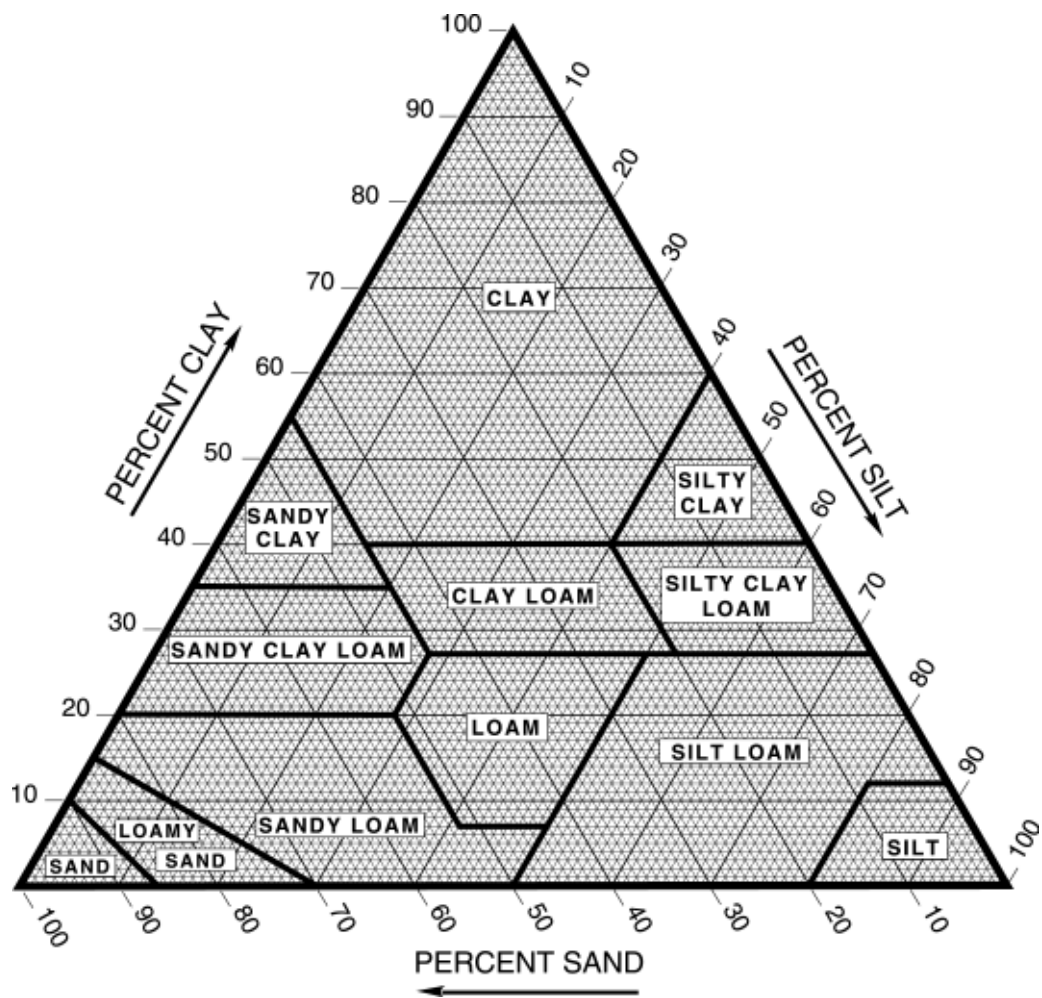
Fig. 4. The USDA Soil Textural Triangle.

4.3 Saturated Paste

The use of an extract from a saturated paste is advantageous for characterizing saline soils since it closely approximates salinity in relation to plant growth. One can also obtain soluble cations and anions by this method and estimate other important parameters such as Sodium Adsorption Ratio (SAR) which, in turn, predicts Exchangeable Sodium Percentage (ESP). Criteria for boron (B) toxicity tolerance by various plant species have been also developed for such an extract (Richards, 1954).

Thus, a saturation extract is routinely used where salinity is a concern. However, in dryland areas, which constitute major part of the CWANA region, it is seldom used. Nevertheless, with encroachment of supplementary irrigation in traditionally dry areas, increased use is likely to be made of saturation extracts in soil analysis.

The cations analyzed in saturation extracts are Ca^{++}, Mg^{++}, K^+, and Na^+, while the anions are SO_4^{--}, CO_3^{--}, HCO_3^-, and Cl^-. Boron in saturation extracts is often measured where its toxicity is suspected.

Apparatus

Porcelain dishes.
Spatulas or mixing spoons.
Vacuum filtration system.

Procedure

1. Weigh 200 - 300 g air-dry soil (< 2-mm) into a porcelain dish.
2. Slowly add DI water, and mix with a spatula until the paste glistens and flows slightly as the porcelain dish is tipped; it should slide off the spatula without collection of any free water on the surface of the paste.
3. Allow the paste to stand for 1 hour, then re-check the criteria for saturation by adding more DI water or soil, as needed.
4. Leave the paste for 6 to 16 hours, and then filter with a vacuum filtration system using a Buchner funnel fitted with Whatman No. 42 filter paper.
5. Collect filtrate in a small bottle and keep it for subsequent measurements. If the initial filtrate is turbid, re-filter.

4.4 Field Capacity Moisture and Permanent Wilting Point

Principle

Soils are equilibrated with water at various tensions and moisture content is determined. The ability of soil to retain water depends on several factors, e.g., texture or particle-size distribution, organic matter content (due to its hydrophilic nature), nature of mineral colloids, and soil structure or arrangement of particles.

A. Low Range: moisture at 0 - 100 kpa (0 - 1 bar) pressure

Apparatus

One-bar pressure plate extractor

One-bar ceramic plates.

Rubber rings (5-cm diameter, 1-cm height).

Compressed air source with a manifold, regulator, and gauge.

Balance.

Drying oven.

Disposable aluminum dishes or soil-moisture cans.

Desiccator.

Procedure

1. Submerge the ceramic plates in water for 24 hours to saturate.
2. Place plates on a workbench.
3. Place labeled rubber rings in order on the plate (each plate accommodates 12 samples).
4. Fill ring with 2-mm air-dry soil using a spatula (about 20 g sample). In order to avoid particle-size segregation, place entire soil sample into the ring.
5. Level, but don't pack, the sample in the ring.
6. Cover plate with water to wet sample from below. Add water between the rings until there is an excess of water (at least 3-mm deep) on the plate.
7. Cover samples with wax paper or a plastic sheet.
8. Allow samples to stand overnight.

9. The next morning, remove excess water from the plate with a syringe, disposable pipette, or siphon.

10. Place the triangular support in the extractor vessel on the bottom.

11. Install plate with samples in the lower-most position in the extractor. Then install the middle and top plates (the plastic spaces should be placed between plates).

12. Connect outflow tubes.

13. Close extractor and tighten, ensuring that the "O" ring is in place and all nuts are uniformly tightened. Apply desired pressure in the 0 - 100 kpa (0 - 1 bar) range. Build up the pressure in the vessel gradually.

14. Place a beaker to collect water from the outflow tubes.

15. Maintain pressure until no more water is being released (generally 18 - 20 hours, but for some soils 48 hours or even longer).

16. Release pressure from extractor (remove outflow tubes from water before turning instrument off).

17. Open extractor.

18. Without undue delay, transfer moist soil sample from ring with a wide-bladed spatula to a tarred dish. (It is not necessary to make a quantitative transfer of the entire soil.)

19. Immediately weigh wet sample (accuracy 0.01 g) and place in drying oven at 105 °C for 24 hours.

20. Place sample in desiccator, cool, and weigh.

CALCULATION

$$\% \ Moisture \ (\theta) \ = \ \frac{Wet \ soil \ (g) - Dry \ soil \ (g)}{Dry \ soil \ (g)} \times 100 \ ....(10)$$

B. High Range: moisture at 100 - 1500 kpa (0 - 15 bar) pressure

Apparatus

Fifteen-bar ceramic plate extractor.
Fifteen-bar ceramic plates.
Rubber rings.
Balance.
Drying oven.
Weighing dishes (disposable aluminum dishes or tarred soil-moisture cans)
Burette.
Desiccator.

Procedure

1. Use 15-bar ceramic plates and follow Steps 1 - 12 of the previous method, applying 1 - 15 bar pressure (100 - 1500 kpa).

2. Place beaker to collect water from outflow tubes.

3. Leave overnight.

4. Connect outflow tube to burette partially filled with tap water.

5. Samples should stay in extractor until flow has ceased from all samples on plate and the soils have reached equilibrium (24 - 48 hours for most soil; however some fine textured and organic soils may needs up to 120 hours). No change in reading on burette would indicate that flow has stopped from all samples and equilibrium has been attained.

6. Disconnect burette to prevent backflow of tap water.

7. Release pressure from extractor.

8. Follow Steps 17 - 20 of the previous method.

CALCULATION

$$\% \textit{ Moisture } (\theta) \;=\; \frac{\textit{Wet soil (g) - Dry soil (g)}}{\textit{Dry soil (g)}} \times 100 \quad .... \; (11)$$

Note

1. If the outlets of the plates continue to bubble after a few hours of applied pressure, the plates are probably defective and should be replaced.

2. Pressure should not be allowed to fluctuate during a run. It should be checked after every 2 - 3 hours (and adjusted if necessary). If the pressure fluctuations are within the specified tolerance of the regulator, then no adjusting is needed.

3. Never remove extractor lid with pressure in the container.

4. The height of the sample in the ring should be as small as possible to reduce the time required to reach equilibrium, which is proportional to the square of the height of the sample in the ring.

5. ***Available water (AW) or available water capacity (AWC) approximation:*** Available water capacity is the amount of water retained in the soil reservoir that can be removed by plants. It is estimated by the difference in the soil water content between **field capacity (FC)** and **permanent wilting point (PWP).**

CALCULATION

$$\% \ AWC = FC \ (\%) \ - \ PWP \ (\%) \ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \ (12)$$

6. ***Field capacity approximation***: Field capacity is commonly estimated by measuring the moisture retained at the following pressure:

Coarse-textured Soils	10 KPa	(1/10 bar)
Medium-textured Soils	33 KPa	(1/3 bar)
Fine-textured Soils	50 KPa	(1/2 bar)

7. ***Permanent wilting point approximation***: Wilting point is commonly estimated by measuring the 1500-kpa (15-bar) percentage. It varies according to plant species and stage of plant growth, ranging 10 to 25 bars for mesophytic plants.