Field Measurement of Soil Moisture

Brian Hornbuckle

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

crop water

soil moisture
Soil is a porous medium.

Soil bulk density vs. soil particle density

3.1. The approximate proportions of various phases by volume in a moist surface soil.

3.2. Enlarged view of a cross section of a sandy soil.

- Soil air
- Soil minerals
- Soil water
- Humus

soil bulk density ~ 1.3 g cm$^{-3}$

density of mineral particles ~ 2.6 g cm$^{-3}$
Soil moisture (soil water content) varies.

There are two ways to quantify soil moisture.

- **Gravimetric soil moisture**
  \[
  \theta_g = \frac{\text{water mass}}{\text{dry soil mass}}
  \]

- **Volumetric soil moisture**
  \[
  \theta_v = \frac{\text{water volume}}{\text{soil volume}}
  \]

**Dry soil mass** = mass of soil after drying at 105 °C for a couple days

**Water mass** = fresh mass – dry soil mass
Why volumetric soil moisture?
Why volumetric soil moisture?

$P + I = Q + E + D + S$

precipitation + irrigation = runoff + evapotranspiration + drainage + storage
Volumetric soil moisture and equivalent depth.

\[ \theta_v = \frac{d}{D} \]

\[ d = \theta_v \ D \]

\[ d = \text{water depth} \]

\[ D = \text{total depth} \]

\[ d = 0.30 \text{ m}^3 \cdot \text{m}^{-3} \times 5.0 \text{ cm} = \]
Volumetric soil moisture and equivalent depth.

\[ \theta_v = \frac{d}{D} \]

\[ d = \theta_v \cdot D \]

\[ d = \text{water depth} \]

\[ D = \text{total depth} \]

d = 0.30 \text{ m}^3 \cdot \text{m}^{-3} \times 5.0 \text{ cm} = 1.5 \text{ cm} = 15 \text{ mm} = 15 \text{ kg} \cdot \text{m}^{-2} \]
Importance of soil bulk density.

Volumetric soil moisture ($\theta_v$) is what we want, but gravimetric soil moisture ($\theta_g$) is easy to measure in situ. They are related by soil bulk density.

$$\theta_v = \frac{\rho_b}{\rho_w} \theta_g$$

$\rho_b = \text{soil bulk density}$

$\rho_w = \text{liquid water density}$

$$\theta_g = \frac{\text{water mass}}{\text{dry soil mass}} \quad \theta_v = \frac{\text{water volume}}{\text{soil volume}}$$
Importance of soil bulk density.

Volumetric soil moisture ($\theta_v$) is what we want, but gravimetric soil moisture ($\theta_g$) is easy to measure in situ. They are related by soil bulk density.

$$\theta_v = \frac{\rho_b}{\rho_w} \theta_g$$

$\rho_b$ = soil bulk density
$\rho_w$ = liquid water density

$$\theta_g = \frac{\text{water mass}}{\text{dry soil mass}}$$

$$\theta_v = \frac{\text{water volume}}{\text{soil volume}}$$

How is $\rho_b$ defined?
Importance of soil bulk density.

Volumetric soil moisture ($\theta_v$) is what we want, but gravimetric soil moisture ($\theta_g$) is easy to measure in situ. They are related by soil bulk density.

$$\theta_v = \frac{\rho_b}{\rho_w} \theta_g$$

$\rho_b$ = soil bulk density

$\rho_w$ = liquid water density

$$\rho_b = \frac{\text{mass of dry soil}}{\text{soil volume}}$$
Soil bulk density can change in space, time.
Soil bulk density can change in space, time.

3.6. A textural triangle shows the limits of sand, silt, and clay content of the various texture classes.

- Sand: 2 to 0.05 mm
- Silt: 0.050 mm to 0.002 mm
- Clay: < 0.002 mm = 2 um
Soil bulk density can change in space, time.

answer: soil horizons

“mineral soil” vs. “organic soil”
Soil bulk density can change in space, time.

answer: soil management

3.9. The zone of compaction has a higher bulk density and lower permeability.

Compaction zone
Instruments for in situ volumetric soil moisture.

- Impedance probe
- Time-domain reflectometry
- Soil water potential
Instruments: impedance probe.

\[ V = \left( n_{\text{soil}} - 1.1 \right) / 4.44 \]

\[ n_{\text{soil}} = \sqrt{\epsilon_{\text{soil}}} \sim \text{volumetric soil moisture} \]

100 MHz frequency
Instruments: time-domain reflectometry.

From Binayak Mohanty presentation yesterday.

Distance or time

Signal level

Wave speed = \( \frac{c}{n_{\text{Soil}}} \)
We want in situ volumetric soil moisture, but gravimetric soil moisture is easiest to measure.

Volumetric and gravimetric soil moisture are related by soil bulk density.

Soil bulk density is the mass of dry soil per volume. It varies in space and in time.

Impedance probes and time-domain reflectometry are the most common methods of automated in situ soil moisture measurement.
All numbered figures from *Soil Science Simplified, Fourth Edition* by Harpstead, Sauer, and Bennett, with illustrations by Mary C. Bratz.
Instructions for field activity...

soil bulk density

“USDA method”

“soil scoop”

Download instructions: Google “Brian Hornbuckle Iowa State” then go to “Teaching.”