Soil Water Holding Capacity

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Phytotechnology with Biomass Production
CHE 650 Hazardous Waste Engineering Seminar
January 9-11, 2018

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Soil Water Retention Basics

Mass and Volume Relationships

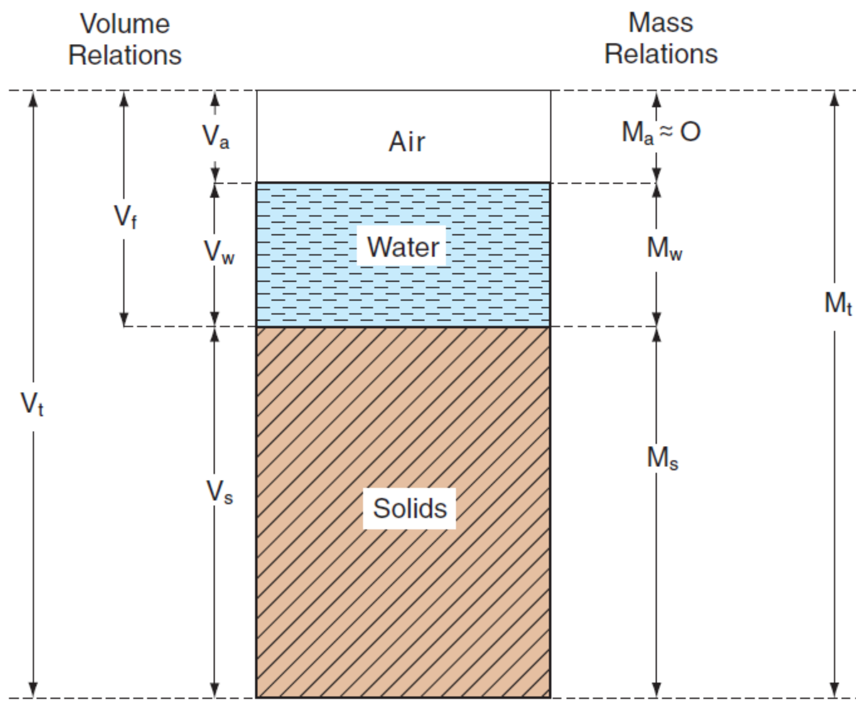

Fig. 1.4. Schematic diagram of the soil as a three-phase system.

Figure source: Hillel, D. 2005. Introduction to environmental soil physics. Elsevier Academic Press, Amsterdam.

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Soil Water Retention Basics

Soil Water Content

- Can be expressed on mass or volume basis
- Volume basis better suited for quantifying water holding capacity.
- Volumetric water content, θ [m^3 m^{-3}], is defined as

$$\theta = \frac{V_w}{V_t}$$

- Typical values for θ at saturation:
  - 0.4 m^3 m^{-3} for sandy soils
  - 0.5 m^3 m^{-3} for medium-textured soils
  - As large as 0.6 m^3 m^{-3} for clayey soils

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Soil Water Retention Basics

Soil Water Content

- For a unit area of soil, θ is also a depth ratio [m m^{-1}] that represents the depth of water per unit depth of soil.
- Thus, a water content of $\theta = 0.25$ m^3 m^{-3} can also be expressed as $\theta = 0.25$ m m^{-1}.
- Practitioners often report θ with units of inches per foot.

Unit conversion example: A soil sample is known to have a water content of $\theta = 0.25$ m^3 m^{-3}. Express this water content in units of inches per foot.

Solution: Express on a unit area basis to give $\theta = 0.25$ m m^{-1}, which is equivalent to $\theta = 0.25$ in in^{-1}. Then do standard unit conversion (i.e., multiply by 12 in ft^{-1}) to get $\theta = 3.0$ in ft^{-1}.

Soil Water Retention Basics

Energy Status of Soil Water

- It is not sufficient to simply know the water content of soil.
- Energy status (i.e., potential energy) is needed to quantify soil water flow and the availability of water to plants.
- Influenced by gravity, matric forces (capillarity and adsorption), solutes, etc.

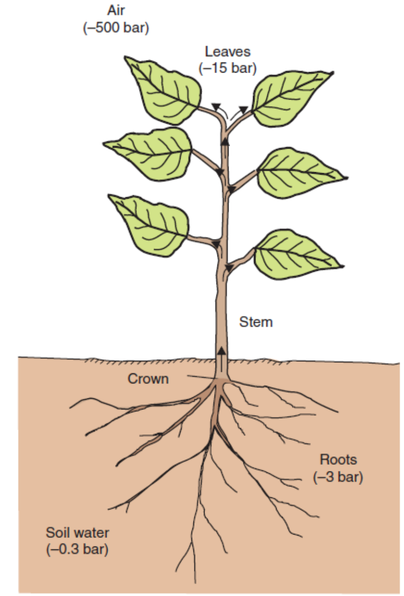

Fig. 19.6. Variation of water potential along the transpiration stream.

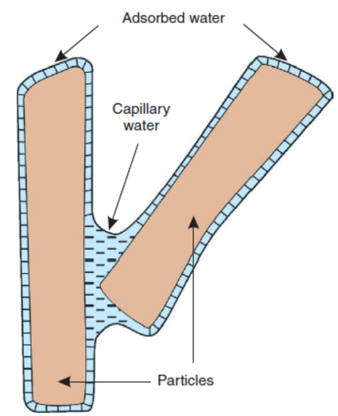

Fig. 6.6. Water in an unsaturated soil is subject to capillarity and adsorption, which combine to produce a "negative" matric potential, or a matric suction.

Figure source: Hillel, D. 2005. Introduction to environmental soil physics. Elsevier Academic Press, Amsterdam.

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Soil Water Retention Basics

Matric Potential

- Here we consider only matric forces, which bind water in the soil matrix and lower its potential energy relative to that of free water.
- This component of the total potential is called the matric potential (ψ_m or h).
- Because $\psi_m < 0$ and $h < 0$, it is often said that soil water is under <u>tension</u> or <u>suction</u>.
- We will use ψ_m [Pa] when expressed as energy/volume and h [m] when expressed as energy/weight.

$$\boxed{\frac{\text{Energy}}{\text{Volume}} = \frac{\text{J}}{\text{m}^3} = \frac{\text{Nm}}{\text{m}^3} = \frac{\text{N}}{\text{m}^2} = \text{Pa}}$$

$$\boxed{\psi_m = \rho_w g h}$$

$$\boxed{\frac{\text{Energy}}{\text{Weight}} = \frac{\text{J}}{\text{N}} = \frac{\text{Nm}}{\text{N}} = \text{m}}$$

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Soil Water Retention Basics

Soil-Water Retention Curve

- Relationship between the water content and matric potential of a soil.
- Typically measured in the lab by imposing a potential *h* and then measuring θ after achieving equilibrium.

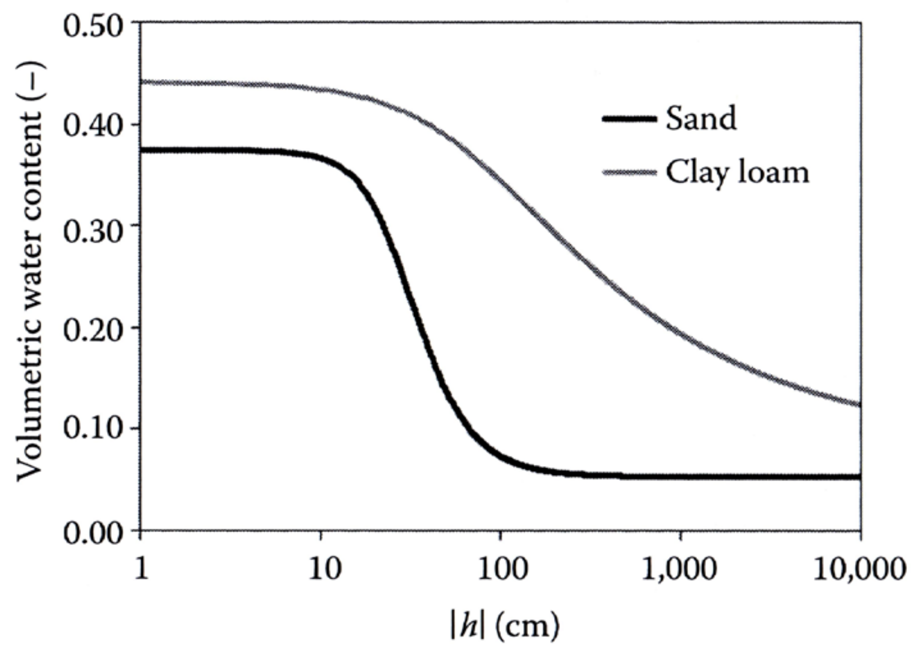

Figure source: Radcliffe, D. E., and J. Šimůnek. 2010. Soil physics with HYDRUS: Modeling and applications. CRC Press, Boca Raton, FL.

Available Water Capacity

Expression for AWC

$$\mathrm{AWC} = \theta_{\mathrm{fc}} - \theta_{\mathrm{wp}}$$

- θ_{fc} is *field capacity*
- θ_{wp} is the *permanent wilting point*
- AWC, θ_{fc} and θ_{wp} in units [$m^3\ m^{-3}$], [$m\ m^{-1}$], or [$kg\ kg^{-1}$]
- AWC, θ_{fc} and θ_{wp} are values for the entire portion of the soil profile from which roots can extract water.

Available Water Capacity

Permanent Wilting Point

- "The largest water content of a soil at which indicator plants, growing in that soil, wilt and fail to recover when placed in a humid chamber. Often estimated by the water content at –1.5 MPa soil matric potential."*
- Much criticized concept. Varies with plant type, evaporative demand, plant growth stage, rooting characteristics, etc.
- Pragmatically impossible to measure using plants
- Nearly always <u>estimated</u> from lab water retention measurements
- θ_{wp} is set to the VWC at some fixed value of ψ_m, often –1.5 MPa
- Redeeming characteristic of this estimation approach is that we have $d\theta/d\psi_m \approx 0$ for -0.8 MPa $< \psi_m < -3$ MPa

Glossary of Soil Science Terms, Soil Science Society of America

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Available Water Capacity

Field Capacity

- "The content of water, on a mass or volume basis, remaining in a soil 2 or 3 days after having been wetted with water and after free drainage is negligible."*
- Flawed and highly criticized concept, yet still widely used
- Major issue is the difficulty in defining what constitutes negligible drainage
- Especially for fine-textured soils, a week or more may be required for drainage to become negligible

*_Glossary of Soil Science Terms, Soil Science Society of America_

Available Water Capacity

Field Capacity – Leaky bucket issue

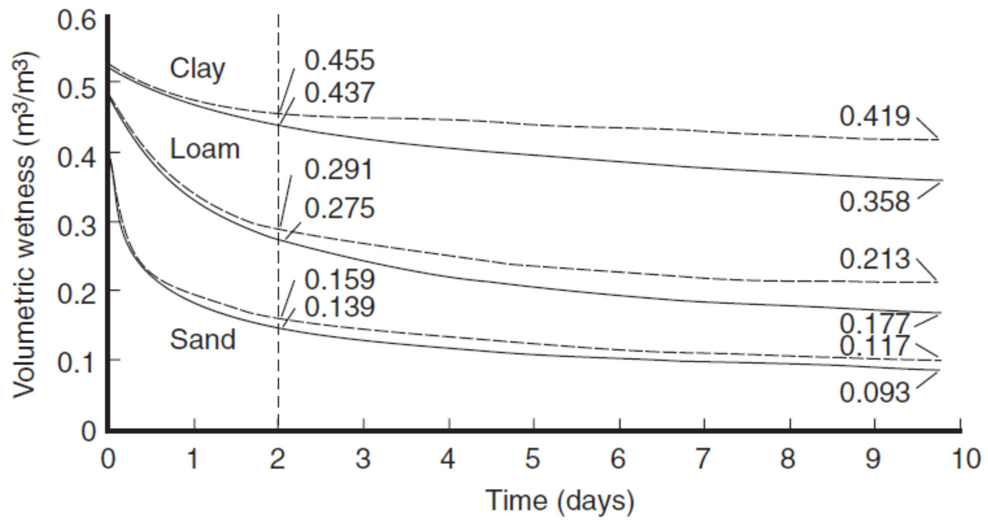

Fig. 16.3. Volumetric wetness at depth 0.41 m as function of time in initially saturated uniform profiles of sand, loam, and clay. Dashed lines, drainage without evaporation; soild lines, simultaneous drainage and evaporation. (After Hillel and van Bavel, 1976.)

Figure source: Hillel, D. 2005. Introduction to environmental soil physics. Elsevier Academic Press, Amsterdam.

Available Water Capacity

Field Capacity – Leaky bucket issue

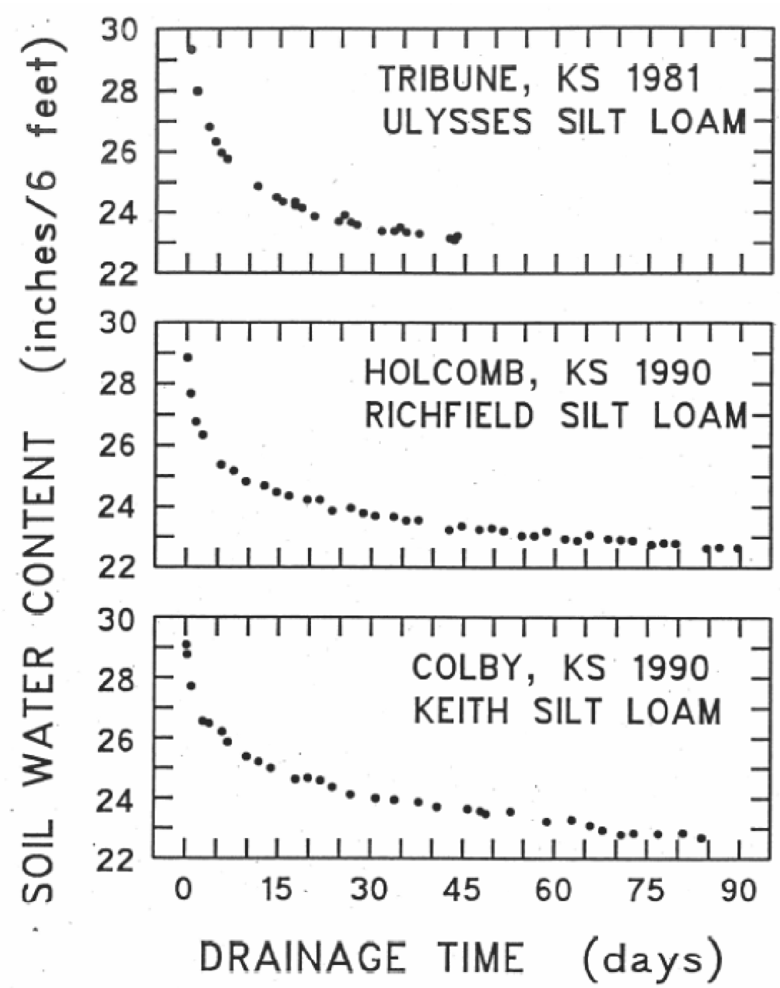

Figure source: Dr. Loyd R. Stone, Professor Emeritus, Department of Agronomy, Kansas State University

Available Water Capacity

Field Capacity

- In situ measurement of θ_{fc} can be achieved using the field method described in the chapters listed below
- There currently is ***no*** good alternative for measuring θ_{fc}
- In practice, usually estimated from lab water retention measurements:
  - Sandy texture: θ_{fc} is VWC at $h \approx -100$ cm
  - Medium texture: θ_{fc} is VWC at $h \approx -350$ cm
  - Clayey texture: θ_{fc} is VWC at $h \approx -500$ cm

Cassel, D. K., and D. R. Nielsen. 1986. Field capacity and available water capacity. p. 901–926. *In* A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Romano, N., and A. Santini. 2002. Water retention and storage. p. 721–738. *In* J. H. Dane and G. C. Topp (ed.) Methods of soil analysis. Part 4. SSSA Book Ser. 5. SSSA and ASA, Madison, WI.

Available Water Capacity

Example Calculation

When estimating AWC from water retention data, we use the expression

$$\mathrm{AWC} = \frac{\sum_{i=1}^{N} d_i \times \mathrm{AWC}_i}{\sum_{i=1}^{N} d_i}$$

where d_i and AWC_i are the depth and available water capacity of layer i, respectively, and N is total number of soil layers.

Available Water Capacity

Example Calculation

Problem: Use the soil data in the table to calculate available water capacity for a scenario where the depth of rooting is known to be 110 cm.

Soil horizon	Horizon thickness	θ_{fc}	θ_{wp}
	cm	cm^3/cm^3	cm^3/cm^3
A	30	0.40	0.15
B	40	0.40	0.20
C	80	0.20	0.05

Solution: The first two layers coincide with the A and B horizons; the third has properties of the C horizon but must have a depth of d_3 = 40 cm to yield a total depth of 110 cm.

$$\text{AWC} = \frac{(30\text{ cm})(0.25) + (40\text{ cm})(0.20) + (40\text{ cm})(0.15)}{30\text{ cm} + 40\text{ cm} + 40\text{ cm}} = 0.195\text{ cm}^3/\text{cm}^3$$

Depth of plant available water in rooting zone is 0.195×110 cm = 21.5 cm

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Available Water Capacity

Data Sources for AWC Determination

Available Water Capacity

Basic Soil Properties that Influence AWC

- AWC controlled to a large extent by water retention properties
- Capillary region: Curve shape determined by texture and structure. Indirect organic matter effect via its influence on structure.
- Adsorption region: Curve shape determined by clay content, mineralogy of clay fraction, and organic matter content.
- Major control on AWC is texture

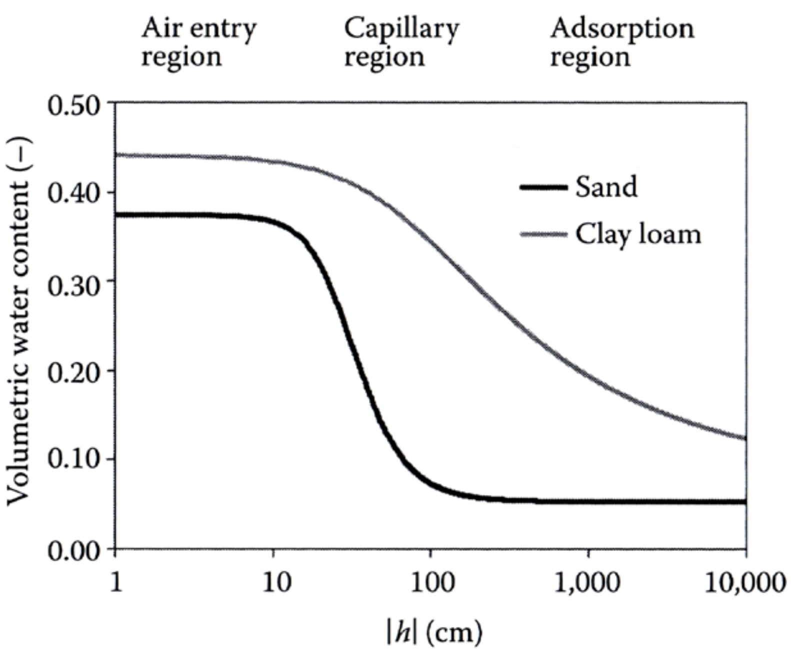
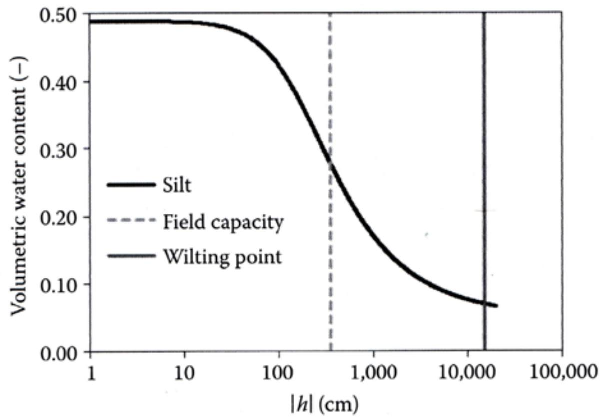
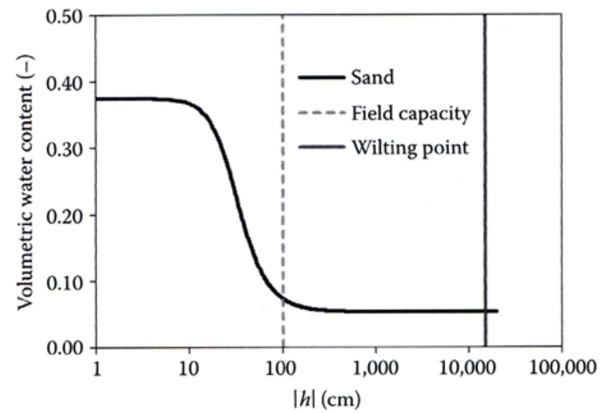


Figure source: Radcliffe, D. E., and J. Šimůnek. 2010. Soil physics with HYDRUS: Modeling and applications. CRC Press, Boca Raton, FL.

Available Water Capacity

Effect of Texture





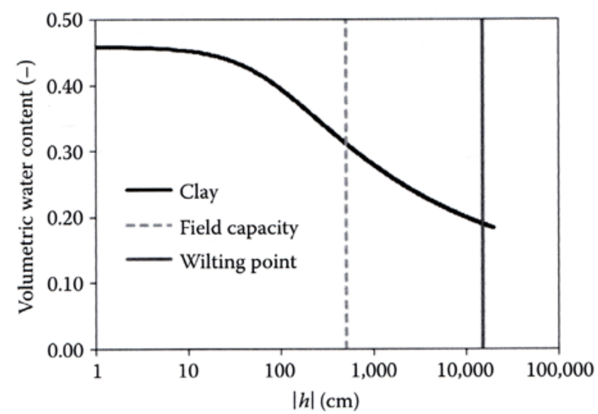
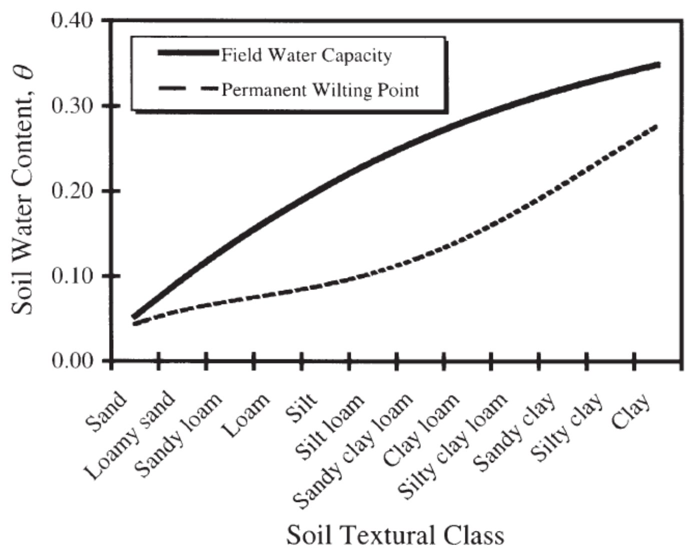


Figure source: Radcliffe, D. E., and J. Šimůnek. 2010. Soil physics with HYDRUS: Modeling and applications. CRC Press, Boca Raton, FL.

Available Water Capacity

Effect of Texture

- AWC smallest in coarse-textured soils
- AWC greatest in medium-textured soils



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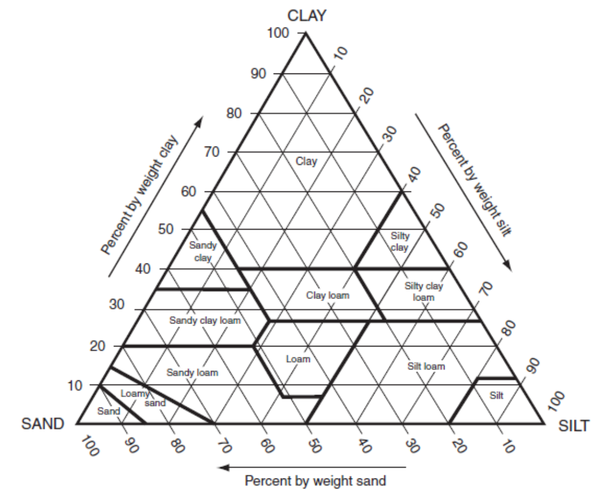

Fig. 3.3. Textural triangle, showing the percentages of clay (below 0.002 mm), silt (0.002–0.05 mm), and sand (0.05–2.0 mm) in the conventional soil textural classes.

Figure source: Hillel, D. 2005. Introduction to environmental soil physics. Elsevier Academic Press, Amsterdam.

Available Water Capacity

Effect of Texture

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Available Water Capacities in Centimeters per Centimeter of Soil [1] [2]

Soil Texture Classes	Greater than or equal to 3 percent OM	0.5 to 3 percent OM	Less than 0.5 percent OM
Coarse sand and gravel	0.04-0.06	0.03-0.05	0.02-0.04
Sands	0.07-0.09	0.06-0.08	0.05-0.07
Loamy sands	0.10-0.12	0.09-0.11	0.08-0.10
Sandy loams	0.13-0.15	0.12-0.14	0.11-0.13
Fine sandy loams	0.16-0.18	0.15-0.17	0.14-0.16
Loams and very fine sandy loams	0.20-0.22	0.17-0.19	0.17-0.19
Silt loams	0.22-0.24	0.20-0.22	0.20-0.22
Silty clay loams	0.21-0.23	0.18-0.20	0.18-0.20
Sandy clay loams	0.18-0.20	0.16-0.18	0.15-0.17
Clay loams	0.17-0.19	0.15-0.19	0.14-0.16
Silty clays	0.12-0.14	0.11-0.13	0.10-0.12
Clays	0.11-0.13	0.09-0.11	0.08-0.10
Sapric horizons	0.35-0.45		
Hemic horizons	0.45-0.55		
Fibric horizons	0.55-0.65		

[1] Use the column above most applicable for the OM in each layer.

[2] Rule of Thumb: Reduce available water capacity by 75 percent in fragipan layers and below. Use same rule for dense tills.

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Available Water Capacity

Summary

- AWC can be estimated from the difference $\theta_{fc} - \theta_{wp}$
- Approach is flawed but widely used
- (Some) additional issues:
  - Evaporation losses
  - Restrictive layers and layering in general
  - Presence of a water table
  - Time dependence of AWC due to root growth
  - Water between limits not equally available
  - Reduced availability in saline soils
- Approach should be used with caution
- Research continues on improved approaches
- Conductivity needs to be taken into account

Available Water Capacity

Summary

- Controlled primarily by texture
- Coarse-textured soils have smallest AWC
- AWC is greatest in medium-textured soils
- Rooting depth needs to be taken into account to get a complete picture
- Usually not possible to alter texture and clay mineralogy in a typical field setting
- AWC can be enhanced via practices that improve soil structure and increase organic matter content

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