8.3 Classification of Soil Water

Definitions

Saturated soil: Soil that contains the maximum amount of water possible. In such soils, all the pores are filled with water.

Gravitational water: The water that moves into, through, or out of the soil by gravity.

Capillary water: Water that is left in soil, along with hygroscopic moisture and water vapor, after the gravitational water has drained off. Capillary water is held by surface tension as a film of moisture on the surface of soil particles and peds, and as minute bodies of water filling part of the pore space between particles.

Hygroscopic water: Water absorbed from the atmosphere and held very tightly by the soil particles, so that it unavailable to plants in amounts sufficient for them to survive. It is the water lost from an air-dry soil when it is heated to 105°C.

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.

Permanent wilting coefficient: 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 –1500 kPa (-1.5 Mpa) soil matric potential.

Hygroscopic coefficient: The hygroscopic coefficient is the boundary between moist-appearing and dry-appearing soil. This boundary is not sharp. Its arbitrary value is -3100 kPa (-3.1 Mpa) soil matric potential.

Oven-dry: A soil sample that has been dried at 105 °C until it reaches constant mass.

Soil water: Soil water is understood to be the equilibrium solution in the soil; pure water refers to the chemically pure compound H_2O. Water in soil is subject to several force fields originating from the presence of the soil solid phase, the dissolved salts, the action of external gas pressure, and the gravitational field.

Soil water potential: The difference between the energy of water in soil and of pure, free water at the same temperature. The water potential of pure water is zero, so that of a solution will be negative.

Matric potential: That portion of the total water potential due to the attractive forces between water and soil solids as represented through adsorption and capillarity. It will always be negative.

Osmotic potential: That portion of the total water potential due to the presence of solutes in soil water. It will always be negative.

Gravitational potential: That portion of the total water potential due to the difference in elevation of the reference pool of pure water and that of the soil water. Since the soil water elevation is usually chosen to be higher that that of the reference pool, the gravitational potential is usually positive.

Concepts

Soil water can be divided into three major categories: gravitational, capillary and hygroscopic. Soil water interacts with soil particles and peds, is present in capillary pores and drains through large pores. It is therefore necessary to classify water to identify its major functions.

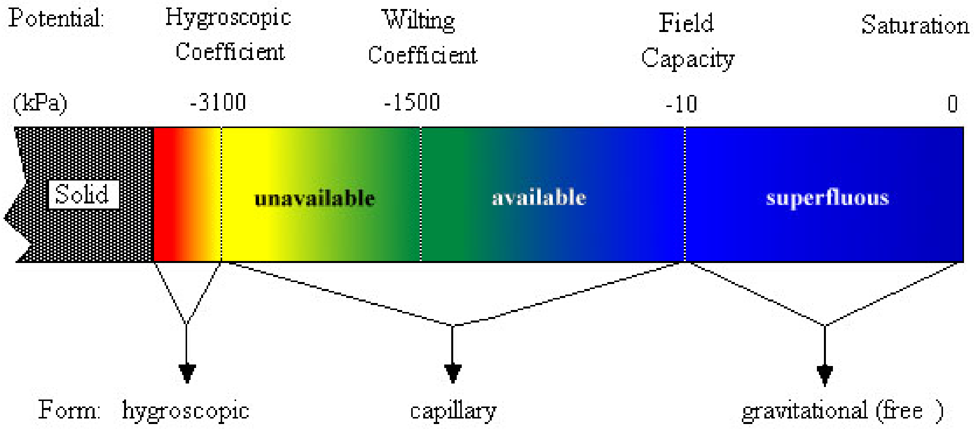

Fig. 8.5. Classification of soil water (after Heaney; Crown and Palylyk, 1995). Reproduced with permissions from authors.

The classification of soil water is also determined by the way water molecules interact with mineral and organic surfaces, cations and anions in soil (Fig. 8.6). The interaction with charged surfaces, cations and anions reduces the energy of water molecules because the water molecules are more organized.

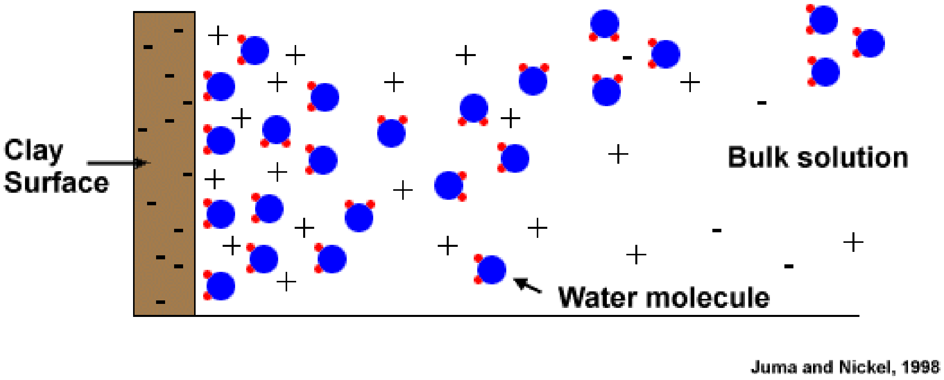

Fig. 8.6. Interaction of water molecules with clay surfaces, and cations and anions in soil.

Soil Water Potential:

The movement and retention of water, uptake and translocation in plants, and loss of water to the atmosphere are all controlled by energy gradients. The forms of energy involved are potential (related to position), kinetic (related to movement) and electrical (related to cations and anions). The differences in energy levels determine the direction and rate of water movement in soils and plants. The difference in energy levels between pure water and soil water is termed soil water potential. It is made up of matric, osmotic and gravitational potentials.

Gravitational Potential (Ψ_g):

The formula for gravitational potential is $\Psi_g = gh$ where g is the acceleration due to gravity and h is the height of soil water above a reference elevation. Gravity plays an important role in removing excess water from the upper rooting zones following heavy precipitation or irrigation. It is generally positive.

Matric Potential (Ψ_m):

Matric potential is universally important. It determines the movement of soil water, the availability of water to plants, and is considered as a variable in civil engineering problems.

Osmotic Potential (Ψ_o):

Osmotic potential is attributable to the presence of solutes in the soil solution. These may be inorganic salts or organic compounds. The attraction of water to solute ions or molecules reduces the energy of water. Plant roots create an osmotic potential because they have a higher solute concentration in their cells.

Soil Water Potential Curves:

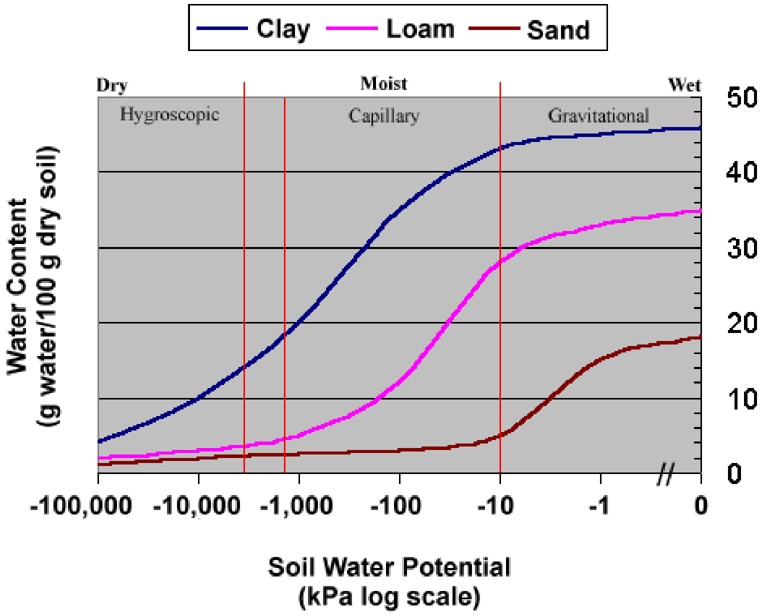

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Fig. 8.7. Soil water potential curves for three mineral soils with different textures.

Water Calculations

Gravimetric Moisture Content:

The amount of water contained in a soil sample at a given time is referred to as the soil water content. Soil water content can be expressed in many ways. To avoid confusion, soil scientists have adopted a universal convention. Unless stated otherwise, the expression of water content (θ_m) is the mass of water expressed as a percentage of the mass of the solid phase, after drying in an oven at 105°C for 12 hours. Water content is thus expressed on an "oven dry" (OD) basis. The simplest determination of soil water content is based on this concept. A portion of soil is weighed moist, placed in an oven at 105°C for 12 hours and weighed dry, the mass of water is divided by the mass of OD soil and multiplied by 100 to give θ_m.

Problem: Determine the gravimetric moisture content using the following data:
Soil moist mass = 150 g; Soil oven-dry mass = 102 g; mass of water = 48 g;

Solution: soil water content, θ_m = (mass of water/mass of OD soil) x 100
= (48 g /102 g) x 100 = 47 %.

Volumetric Moisture Content:

In order to calculate the volumetric content of soil, θ, it is necessary to know the bulk density (Db) of soil. The relationship between mass and volume water contents for a soil is:

$$\theta = \theta_m \text{ x } \frac{\text{bulk density of soil}}{\text{density of water}}$$

Problem: A soil sample with loam texture has 20 % gravimetric moisture content (θ_m) and a bulk density (Db) of 1.25 Mg/m^3. Calculate the volumetric moisture content (θ).

Solution:

$$\theta = \theta_m \text{ x } \frac{\text{bulk density of soil}}{\text{density of water}}$$

$$\theta = 20 \text{ x } \frac{1.25 \text{ Mg / m}^3}{1.0 \text{ Mg / m}^3} = 25\%$$

Percent Pore Space:

Pore space in soil can be filled with water and air. In order to calculate percent (total) pore space in soil information about bulk density (Db) and particle density (Dp) is needed. The relationship between these variables is described by the following equation:

$$\% \text{ pore space} = (1 - \frac{Db}{Dp}) \text{ x } 100$$

Problem: Calculate the pore space in a cultivated clay subsoil with a bulk density (Db) of 1.28 Mg/m^3.

Solution: In problems such as these, the particle density may not be given. For most mineral soils, the particle density (Dp) approximates that of common soil minerals and is approximately equal to that of common silicate materials (i.e. 2.65 Mg/m^3). Therefore:

$$\% \text{ pore space} = (1 - \frac{1.28}{2.65}) \times 100 = 51.7\%$$

Depth of Wetting:

When water is added to a dry soil, it will wet each layer from its present water content to field capacity and then the excess (gravitational water) will leach and wet lower layers. In order to calculate the depth of wetting, it is necessary to calculate the storage capacity on a mass as well as on a volume basis.

Problem: How deep will a 1.8 cm rain wet a uniform soil layer that presently contains 28% gravimetric moisture content (θ_m)? The gravimetric moisture content (θ_m) at field capacity for this soil layer is 42% and the bulk density (Db) is 1.3 g/cm^3.

Solution:

(a) Storage capacity on a gravimetric basis (θ_m) = field capacity - present water content
= 42% - 28% = 14%

(b) Storage capacity on a volumetric basis (θ) $= 14\% \times \frac{\text{bulk density of soil}}{\text{density of water}}$

$$= 14\% \times \frac{1.3 \text{ Mg}/\text{m}^3}{1.0 \text{ Mg}/\text{m}^3} = 18\%$$

This means that 1 cm^3 of soil will hold 0.18 cm^3 of water, i.e., a soil that is 1 cm deep will store 0.18 cm of water.

(c) Depth of wetting = Volume of rain/volume of water stored per cm of soil
= 1.8 cm/0.18 cm water per cm of soil
= 10 cm

Morainal materials are sediments generally consisting of well-compacted material that is non-stratified and contains a heterogeneous mixture of particle sizes, often in a mixture of sand, silt and clay that has been transported beneath, beside, on, within or in front of a glacier and has not been modified by other intermediate agents. Some examples of morainal land forms are: basal till (ground moraine), lateral and terminal moraines, and hummocky ice-disintegration. In hummocky areas, the surface texture and bulk density of soil is extremely variable. Therefore, the amount of water stored is these soils is also variable.

Applications

In this exercise, a uniform amount of waste water from lagoons is being applied to four different kinds of soil. The land owner would like to know the depth of wetting for each soil. Using the information presented in this section, calculate the porosity and wetting depth for each soil if 5 cm of waste water is applied to each soil.

Table 8.1. Sample problem and solution to calculate the depth of wetting in different textured soils with different amounts of initial water content using the method described in this subsection.

Texture	Bulk Density (Mg/m^3)	Initial Water Content (%)	Field Capacity (%)	Porosity (%)	Wetting Depth (cm)
Clay	1.05	20	45	60.4	19.0
Clay Loam	1.10	12	35	58.5	19.8
Loam	1.20	10	30	54.7	20.8
Sandy Loam	1.40	3	15	47.2	29.8

8.4 Water Movement

Definitions

Sub microscopic pores: These pores are so small that they do not allow clusters of water molecules to form fluid particles or continuous water flow paths. The laws of fluid mechanics are not applicable to these pores so they are often disregarded in problems dealing with water flow in soils.

Capillary pores: In these pores the shape of the interface between air and water is determined by the configuration of pores and by forces on the interface. The resulting interface is called the capillary meniscus. The flow of water in these pores is considered to be laminar (movement of fluid particles in a direction parallel to each other) and dominant in soils.

Macropores (non-capillary pores): These pores are of a sufficient size that capillary menisci are not formed. The shape of the interface between air and water is considered planer (flat), and hence, capillary forces are nil. The flow of water in such pores can be either in the form of a film moving over all irregularities of the walls, induced by their roughness or shape, or in some cases, turbulent flow when the pores contain considerably more water.

Saturated flow: The movement of water through a soil that is temporarily saturated. Most of the water moves downwards, and some moves more slowly laterally.