Soil Water

Polarity and H-bonding

Polarity results in hydration of dissolved ions and water adsorption onto polar surfaces.

H-bonding accounts for strong adhesion of to solid surfaces and cohesion among water molecules.

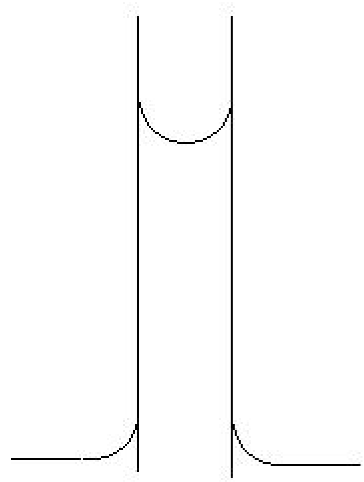
Surface Tension and Capillarity

Surface tension is force per unit length that opposes expansion of the surface area. It can be shown that the pressure difference across a curved air-water interface is directly related to surface tension and inversely related to the radius of curvature of the interface. Thus, when a capillary tube is dipped in water, the reduced pressure at the curved interface is offset by the positive pressure caused by rise of a column of water in the capillary. A relation between the height of rise and radius of the capillary can be derived,

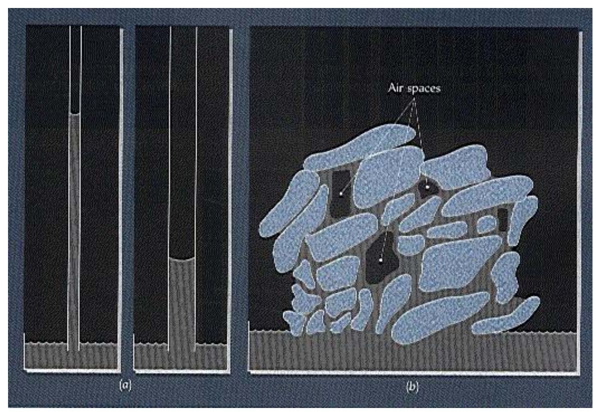
$h = 2T / rgD$

where

T is surface tension
r is radius of curvature (= capillary tube radius for 0 contact angle)
g is acceleration due to gravity
D is density of water



Capillary rise.



Capillarity and capillary bundle model for soil water content and movement.

Soil Water Energy

Energy level of soil water is affected by

Gravity
Attraction by the solid matrix
Pressure (in water saturated soil)
Presence of solutes

Energy level of soil water is defined with respect to a reference -pure water at the same temperature, under atmospheric pressure and at a specified elevation

Working units are various potentials

Energy per unit mass
Energy per unit volume
Energy per unit mass under force of gravity (weight)

Gravitational potential is usually expressed as energy per weight.

$E_g = mgh_g$ $E_g / mg = h_g$ m or cm

Measured with respect to a reference level so that gravitational potential is positive above and negative below reference level.

Matric potential is usually expressed as energy per unit volume.

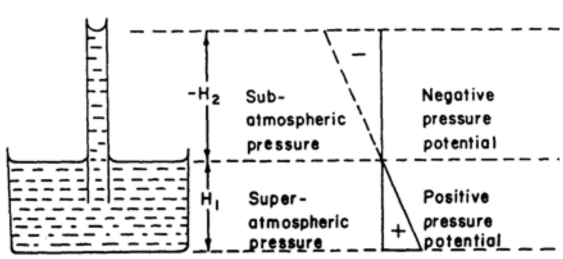
$E_m = PV$ $E_m / V = P$ kPa or bar

Attraction by the solid matrix *reduces* soil water potential relative to pure water so pressure is *negative.*

Pressure potential is also expressed as energy per unit volume.

$E_p = PV$ $E_p / V = P$ kPa or bar

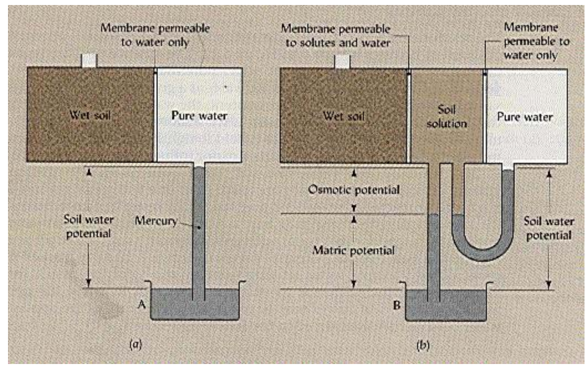
Depth below a free water surface leads only to *positive* values of pressure potential.



Positive and negative pressures in relation to a free water surface.

Osmotic potential also expressed as pressure and in units of kPa or bar. The presence of solutes reduces soil water potential relative to pure water. Osmotic potential has negligible effect on water movement except where a semi permeable membrane exists and when movement is in the vapor phase.

Total water potential is the sum of the various components.



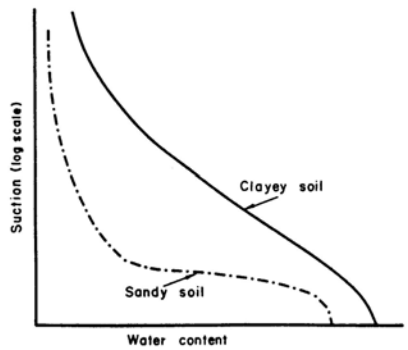
Contributions of matric and osmotic potentials to total soil water potential.

Soil Moisture Content and Matric Potential

Relationship between soil moisture content and matric potential is the *soil moisture characteristic curve*. As matric potential decreases (becomes more negative), volumetric water content decreases. The shape of the soil moisture characteristic curve depends on soil structure and texture.

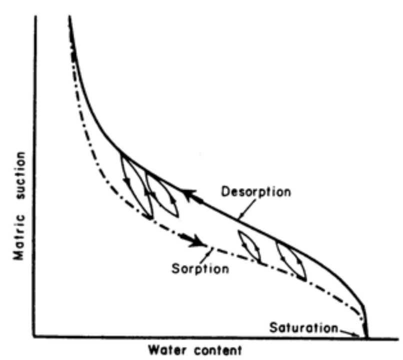
Decrease in volumetric water content with decrease in matric potential is more gradual in a clay than in a sand because sand is dominated by large pores which empty at larger (less negative) values of matric potential but clay has a broader, more uniform range of pore sizes.

Decrease in volumetric water content with decrease in matric potential is more gradual in a soil with little structure than in a soil with well developed structure since there are fewer interaggregate macropores in a soil with little structure.



Soil moisture characteristic curves for a sand and a clay. Suction is the absolute value of matric potential (or negative pressure, tension).

The shape of the curve is different if the water content and potential data are generated by drying (draining a saturated sample) or wetting (saturating a dry sample). This phenomenon is called *hysteresis*. When drying volumetric water content is larger for any value of matric potential than when wetting. There are several possible causes including geometric irregularities in soil pores resulting in the *ink bottle effect*.



Hysteresis of wetting and drying branches of a soil moisture characteristic curve.

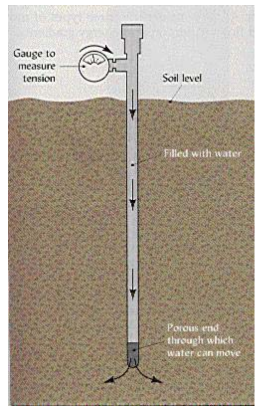
Content

Gravimetric
Neutron scattering
Time domain reflectometry (TDR)

Potential

Tensiometer

Measures matric potential. Consists of an air-tight system open to soil via saturated ceramic cup. The matric potential in the tensiometer equals that in the soil. The negative pressure or tension is measured by vacuum gauge or pressure transducer.



Tensiometer.

Soil Water Movement

Water movement in soil is from a zone of relatively high to low water potential. Movement may occur by saturated or unsaturated liquid flow or in the vapor phase.

Total water potential under saturated conditions may include gravitational and pressure components. Under unsaturated conditions it includes gravitational and matric potentials. In order to solve flow problems, one must express both components in the same units, usually length units. To convert from pressure (positive or negative, matric), since $E_p / V = mgh_p/V = P$, division by mg/V gives an equivalent length, h_p.

Although unsaturated flow is more common than saturated flow, water saturation may occur in the lower part of poorly drained soils, above an impeding layer or near the surface during a heavy rain.

Saturated Flow

Described by (Henri) Darcy's law

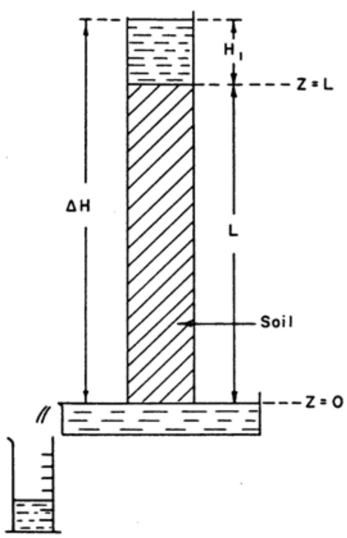
$Q = K_S A ([H_{T\ inflow} - H_{T\ outflow}] / L)$

where

Q is volumetric flow (cm^3/s)
A is total cross sectional area (cm^2)
K_S is the saturated hydraulic conductivity (cm/s)
L is flow length (cm)
$[H_{T\ inflow} - H_{T\ outflow}] / L$ is potential gradient

$H_T = H_G + H_P$

Water flux (volume per unit area and time) is $q = K_s ([H_{T\ inflow} - H_{T\ outflow}] / L)$



Saturated water flow through a column of soil due to a decreases in gravitational and pressure potentials.

Magnitude of K depends on pore size distribution:

If large proportion of macropores, K_s is large
Sandy soils generally have larger K_s than clayey soils
Highly porous, fractured or aggregated soils have larger K_s than dense, compact soils

Unsaturated Flow

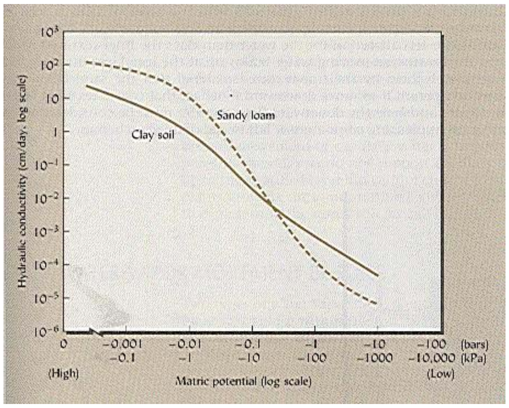
More complex phenomenon because K decreases with decreasing volumetric water content (or matric potential). Unsaturated water flow is down a potential gradient and is described by

$q = K(W) ([H_{T\ inflow} - H_{T\ outflow}] / L)$

where K(W) is hydraulic conductivity as a function of volumetric water content. Note that since the soil is unsaturated, $H_T = H_G + H_M$.

$K(W) < K_S$ because the cross sectional area for water movement is less in unsaturated soil than saturated soil, the path length of flow is longer due to increased tortuosity and most importantly, since flow is restricted to smaller size pores as the soil becomes drier and the resistance to flow increases.

K(W) decreases rapidly as volumetric water content decreases and, since the soil moisture characteristic exhibits hysteresis, K(W) is also affected by hysteresis. Interestingly, K(W) of clay > K(W) of sand at low water content.



Rapid decrease in unsaturated hydraulic conductivity with decreasing matric potential.

Since texture and structure vary within the profile, K_S and K(W) vary and complex water flow patterns often occur. For example, clay under sand may produce a perched water table. Also, coarse soil material under fine also impedes drainage. The latter occurs because at the wetting front, K(W) of the coarse material < K(W) of the finer overlying layer. In similar fashion, layering also restricts upward movement of water from a deeper water table.

Vapor Phase Water Movement

Occurs by diffusion in response to a vapor pressure gradient.

P_v decreases as the temperature of liquid water decreases
P_v decreases as soil water content decreases
P_v decreases as solute concentration increases

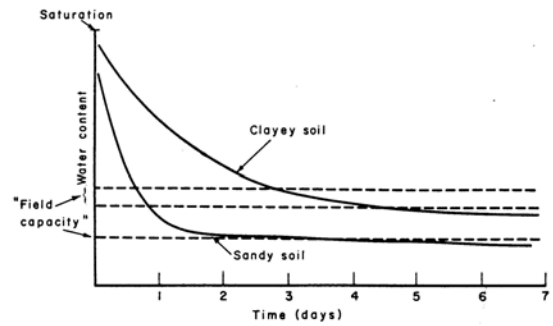
Movement

Warm	to	Cool
Wet	to	Dry
Nonsaline	to	Saline

Soil Water Drainage and Drying Terms

Soil water is constantly moving because potential gradients always exist. As initially wet soil drains and water content decreases, downward water movement rapidly decreases.

The water content when rate of drainage is small is called the *field capacity*. Matric potential = -10 to - 30 kPa at field capacity.

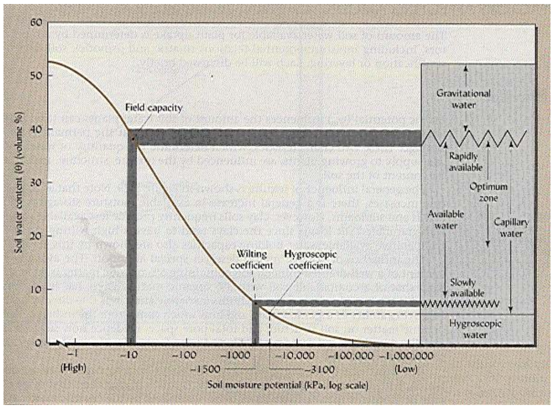


Concept of field capacity.

Drainage continues and redistribution occurs due to evaporation and transpiration (evapotranspiration). Soil water is depleted without further rainfall. At low matric potential water uptake is not sufficiently fast to compensate for transpiration and plants permanently wilt at a matric potential of about -1500 kPa. This is called the *permanent wilting point*.

Soil will continue to dry until only surface adsorbed (hygroscopic) water exists. At the *hygroscopic coefficient*, the matric potential is about -3100 kPa.

All soil water between field capacity and permanent wilting point is called plant *available water*.



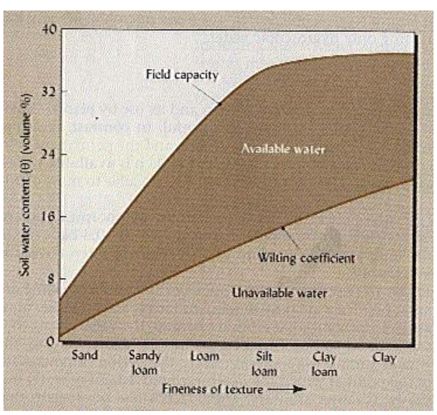
Example soil moisture characteristic showing field capacity, permanent wilting point, hygroscopic coefficient and ranges of plant-available, gravitational, hygroscopic and capillary water contents.

Soil water at matric potentials

field capacity is *gravitational water*
< hygroscopic coefficient is *hygroscopic water*
between is *capillary water*

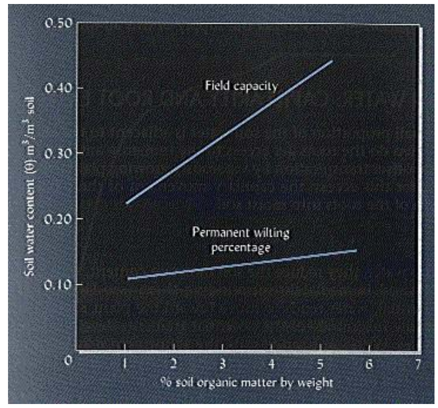
Factors Affecting Plant Available Soil Water

Texture



Effect of texture on the difference between field capacity and permanent wilting point.

Organic matter



Organic matter increases plant-available water.

Osmotic potential
In presence of high level of salt, plants wilt at higher volumetric water content.

Depth of soil and layering
Shallow soil contains less water than deeper soil. Layering affects water movement from water table. Compacted layer restricts root penetration.

Soil Water Supply to Roots

Water moves down potential gradient to root. Root growth and extension expand the volume of soil from which water may be withdrawn and shorten the distance over which soil water must move.