Soil Water Potential Measurement

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Two Variables are Needed to Describe the State of Water

Water content	and	**Water potential**
Quantity		Quality
Extent		Intensity

Related Measures

heat content	and	temperature
charge	and	voltage

Extensive vs. Intensive

620 J kg^{-1} K^{-1} X 100 Mg X 270 K = **16700 MJ**	Heat Content	620 J kg^{-1} K^{-1} X 1kg X 1000 K = **0.62 MJ**
270 K	Temperature	**1000 K**

Energy flow?

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Water Potential Predicts

- Direction and rate of water flow in Soil, Plant, Atmosphere Continuum
- Soil “Field Capacity”
- Soil “Permanent Wilting Point”
- Seed dormancy and germination
- Limits of microbial growth in soil and food

Water Potential

Energy required, per quantity of water, to transport, an infinitesimal quantity of water from the sample to a reference pool of pure, free water

Water Potential: important points

- Energy per unit mass, volume, or weight of water
  - We use units of pressure (Mpa, kPa, m H_2O, bars)
- Differential property
  - A reference must be specified (pure, free water is the reference; its water potential is zero)
- The water potential in soil is almost always less than zero

Water potential is influenced by:

- Binding of water to a surface
- Position of water in a gravitational field
- Solutes in the water
- Pressure on the water (hydrostatic or pneumatic)

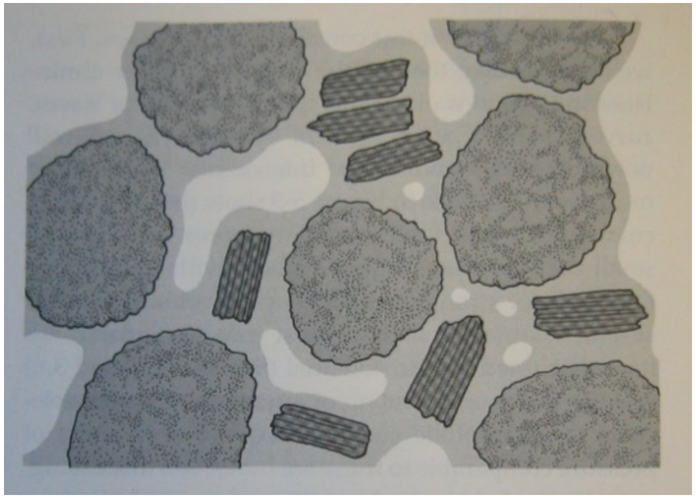
Total water potential = sum of components

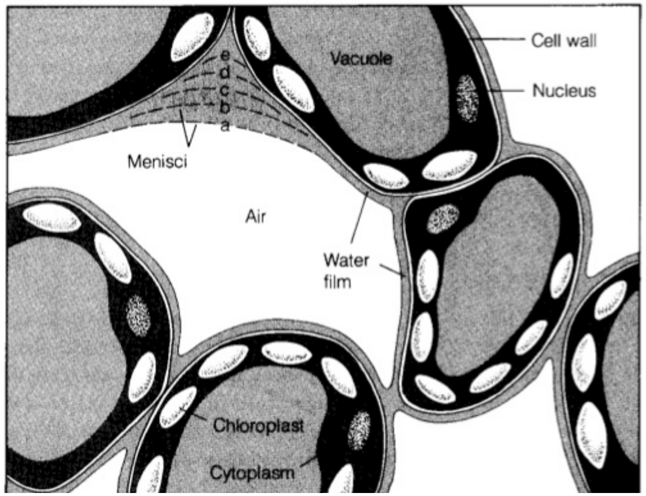
- $\psi_T = \psi_m + \psi_g + \psi_o + \psi_p$

- ψ_T – Total water potential
- ψ_m – matric potential - adsorption to surfaces
- ψ_g – gravitational potential - position
- ψ_o – osmotic potential - solutes
- ψ_p – pressure potential - hydrostatic or pneumatic

Matric potential (Ψ_m) adsorptive forces

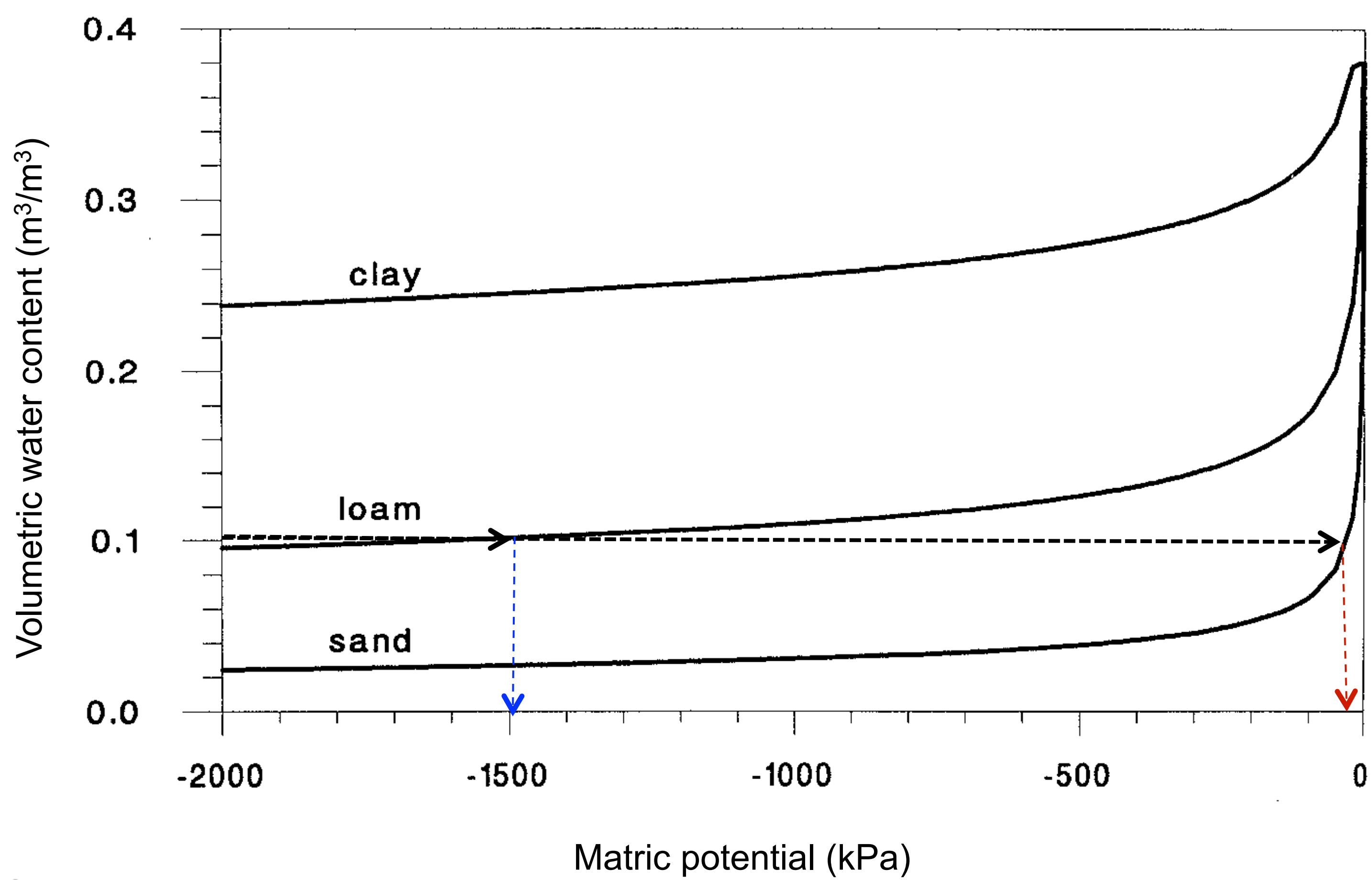
- Hydrogen bonding of water to surfaces
  - Always negative
  - Most important component in soil
  - Highly dependent on surface area of soil





From Jensen and Salisbury, 1984

Soil Water Retention Curves

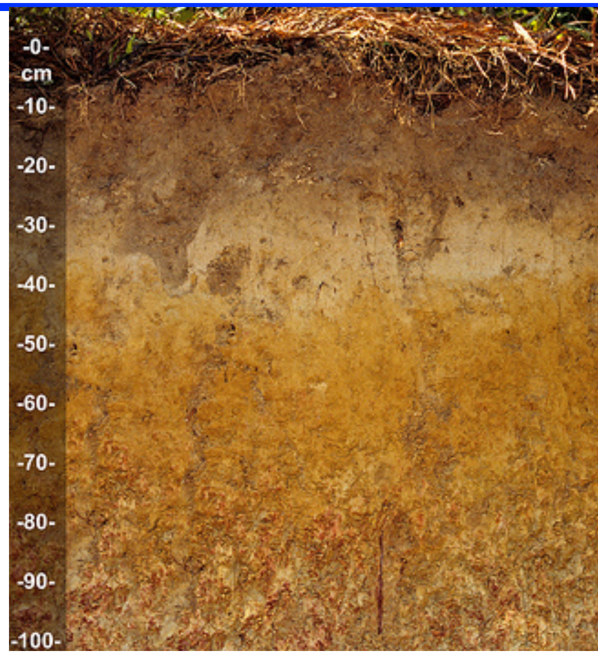


Gravitational potential (Ψ_g)

$$\Psi_g = g * h * \rho_{water}$$
$$= 9.81\ m\ s^{-2} * 10\ m * 1\ Mg\ m^{-3}$$
$$= +\ 98.1\ kPa$$

Gravitational potential (Ψ_g)

1 m



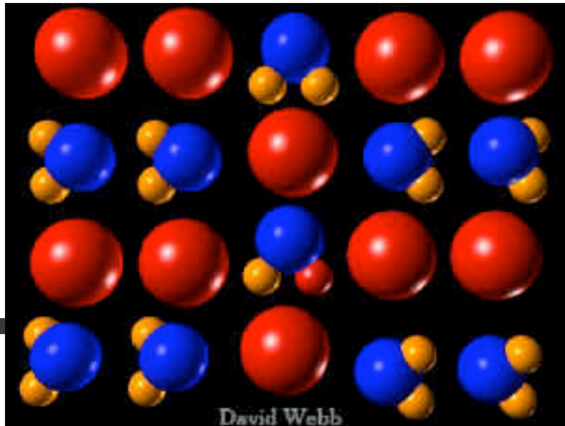
Reference Height
(soil surface)

$.81\ m\ s^{-2} * 1\ m = -\ 9.81\ kPa$

$$\Psi_g = g * h * \rho_{water}$$
$$= 9.81\ m\ s^{-2} * 1\ m * 1\ Mg\ m^{-3}$$
$$= -\ 9.81\ kPa$$

Osmotic potential (Ψ_o) - solutes

- Arises from dilution effects of solutes dissolved in water
  - Always negative
  - Only affects system if semi-permeable barrier present that lets water pass but blocks salts
    - Plant roots
    - Plant and animal cells
    - Air-water interface



Osmotic potential (Ψ_o) - solutes

$$\Psi_0 = C\phi vRT$$

C = concentration of solute (mol/kg)
ϕ = osmotic coefficient - 0.9 to 1 for most solutes
ν = number of ions per mol (NaCl = 2, $CaCl_2$ = 3, sucrose = 1)
R = gas constant
T = Kelvin temperature

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Pressure potential (Ψ_p)

- Hydrostatic or pneumatic pressure (or vacuum)
  - Positive pressure
    - Surface water
    - Groundwater
    - Leaf cells (turgor pressure)
    - Blood pressure in animals
  - Negative
    - Plant xylem

Water potential ranges and units

Condition	Water Potential (MPa)	Water Potential (m H_2O)	Relative Humidity (h_r)	Freezing Point (^oC)	Osmolality (mol/kg)
Pure, free water	0	0	1.00	0	0
Field Capacity	-0.033	-3.4	0.9998	-0.025	0.013
	-0.1	-10.2	0.9992	-0.076	0.041
	-1	-102	0.993	-0.764	0.411
Permanent wilting point	-1.5	-153	0.989	-1.146	0.617
	-10	-1020	0.929	-7.635	4.105
Air dry	-100	-10204	0.478	-76.35	41.049

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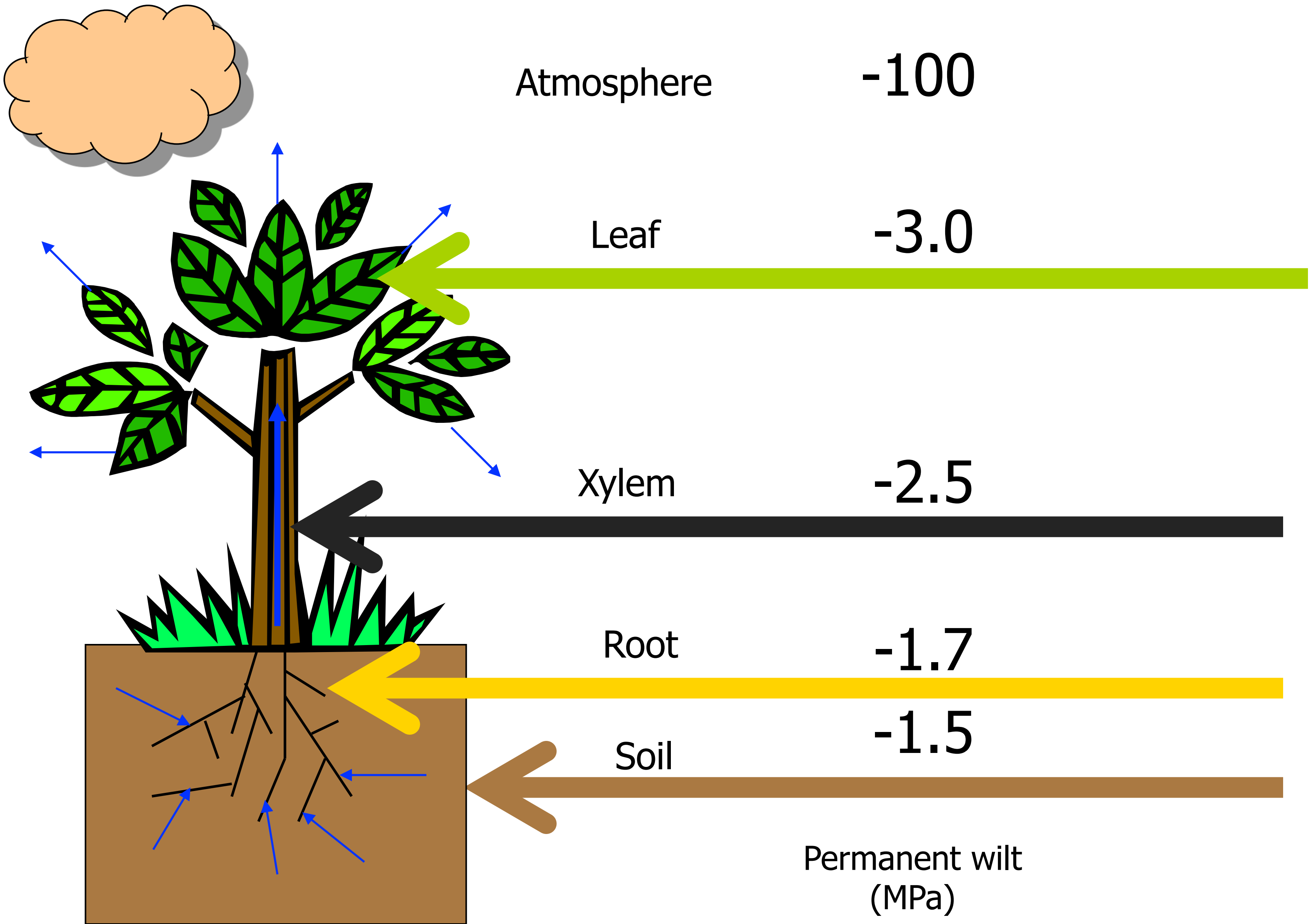
Water potentials in Soil-Plant-Atmosphere Continuum

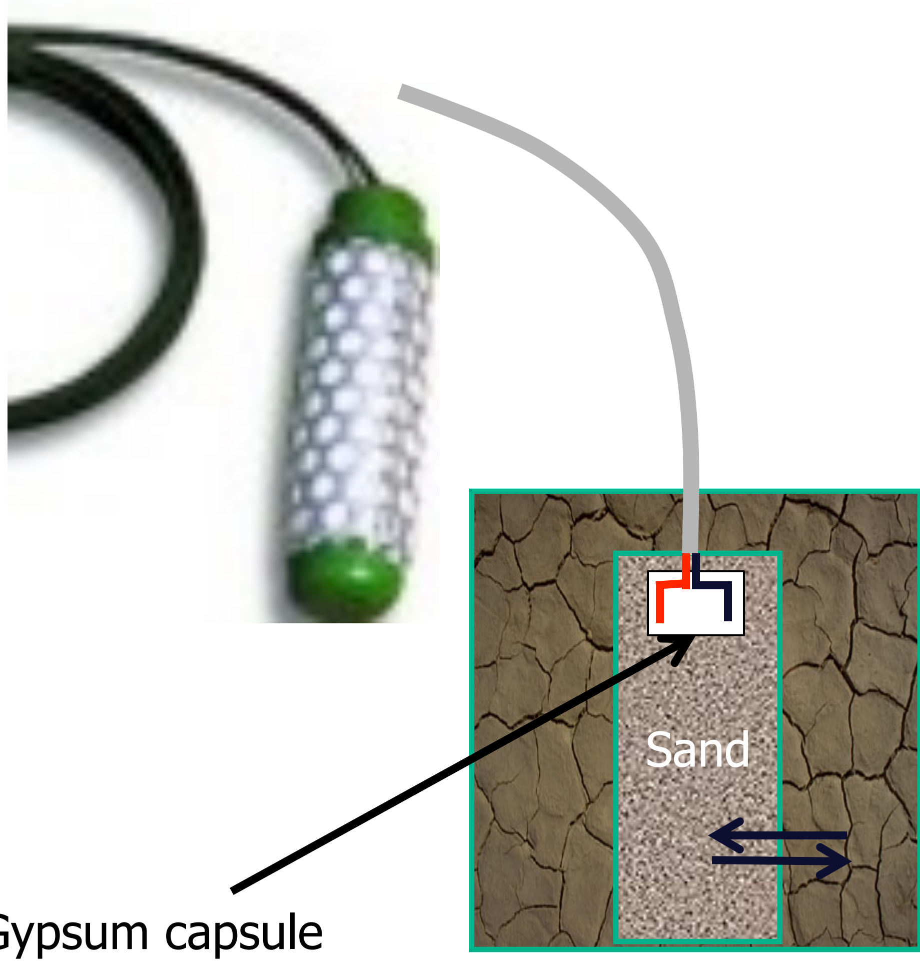


Measuring Soil Water Potential

- Solid equilibration methods
  - Electrical resistance
  - Capacitance
  - Thermal conductivity
- Liquid equilibration methods
  - Tensiometer
  - Pressure chamber
- Vapor equilibration methods
  - Thermocouple psychrometer
  - Dew point potentiameter

Electrical Resistance Methods for Measuring Water Potential

- Standard matrix equilibrates with soil
- Electrical resistance proportional to water content of matrix
- Inexpensive, but poor stability, accuracy and response
- Sensitive to salts in soil



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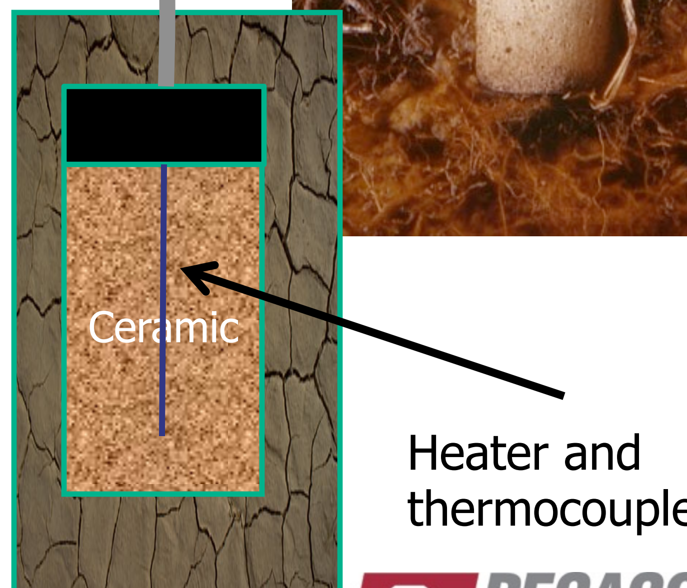
Heat Dissipation Sensor

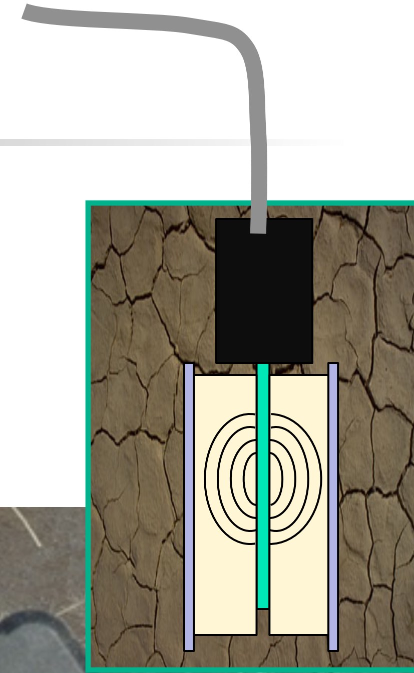
- Robust (ceramic with embedded heater and temperature sensor)
- Large measurement range (-0.01 to -100 MPa)
- Stable (not subject to salts and dissolution
- Requires complex temperature correction
- Requires individual calibration



Capacitance Methods for Measuring Water Potential

- Standard matrix equilibrates with soil
- Water content of matrix is measured by capacitance
- Stable (not subject to salts and dissolution
- No calibration required

- Range -0.01 MPa to air dry (-100 MPa)
- Good accuracy from -0.01 to -1.5 MPa, errors larger in dry end



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Liquid Equilibration: Tensiometer

- Equilibrates water under tension with soil water through a porous cup
- Measures tension of water
- Highest accuracy of any sensor in wet range
- Limited to potentials from 0 to -0.09 MPa
- Significant maintenance requirements

Liquid Equilibration: Pressure chamber

- Moist soil placed on saturated porous plate
- Plate and soil sealed in chamber and pressure applied, outflow at atmospheric pressure
- Ψ_{soil} ≈ negative of pressure applied
- Common method for moisture characteristic curves

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Liquid Equilibration: Pressure chamber

- Equilibrium time
  - Hours at wet end
  - Months or more at dry end (maybe never)
- Recent work shows that samples at -1.5 Mpa only reached -0.55 Mpa
  - Hydraulic contact between plate and soil sample
  - Low K_{unsat} at low water potential

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Gee et. al, 2002. The influence of hydraulic disequilibrium on pressure plate data. Vadose Zone Journal. 1: 172-178.

Water Potential and Relative Humidity

Relative humidity (h_r) and water potential (Ψ) related by the Kelvin equation:

$$\Psi = \frac{RT}{M_w} \ln h_r$$

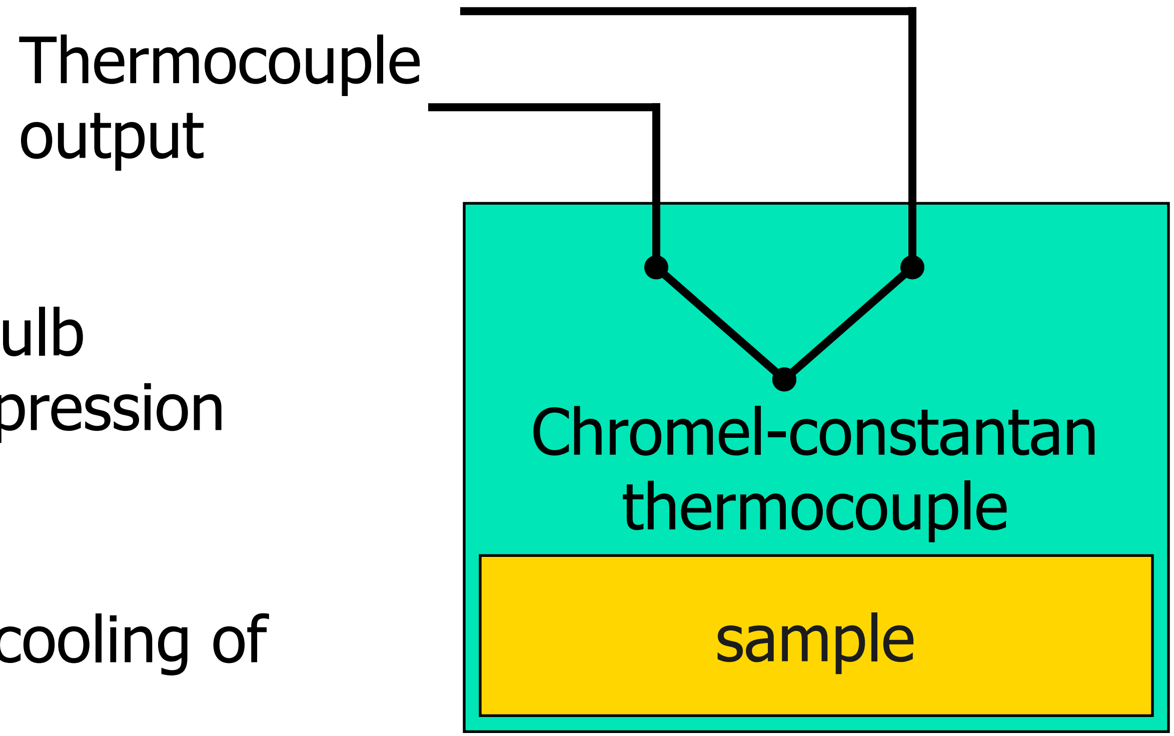
R is universal gas constant
M_w is molecular mass of water
T is temperature

Condition	Water Potential (MPa)	Relative Humidity (h_r)
Pure, free water	0	1.000
Field Capacity	-0.033	0.9998
Permanent wilting point	-1.5	0.989

Vapor Equilibrium Methods

- Thermocouple psychrometer
  - Measure wet bulb temperature depression of head space in equilibrium with sample
- Dew point hygrometer
  - Measure dew point depression of head space in equilibrium with sample

Thermocouple Psychrometer



Measures wet bulb temperature depression

Water potential proportional to cooling of wet junction

Sample Chamber Psychrometer

- Measures water potential of soils and plants
- Requires 0.001C temperature resolution
- 0 to – 6 MPa (1.0 to 0.96 RH) range
- 0.1 MPa accuracy (problems in wet soil)

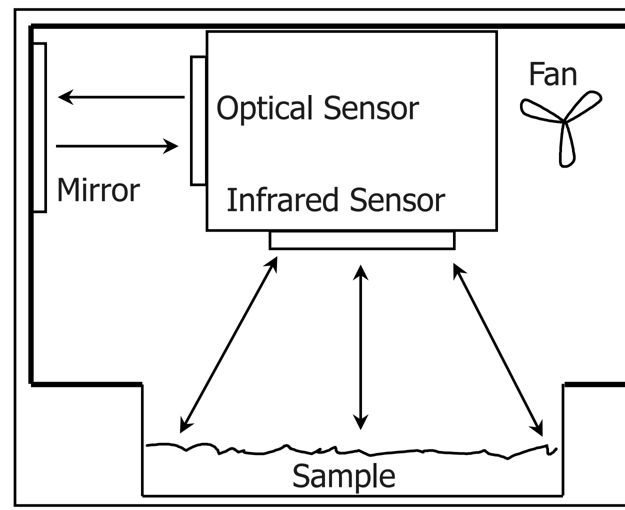
In Situ Soil Water Potential

Soil Psychrometer

Readout

Chilled Mirror Dew Point

- Cool mirror until dew forms
- Detect dew optically
- Measure mirror temperature
- Measure sample temperature with IR thermometer
- Water potential is approximately linearly related to Ts - Td



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WP4 Dew Point Potentiameter

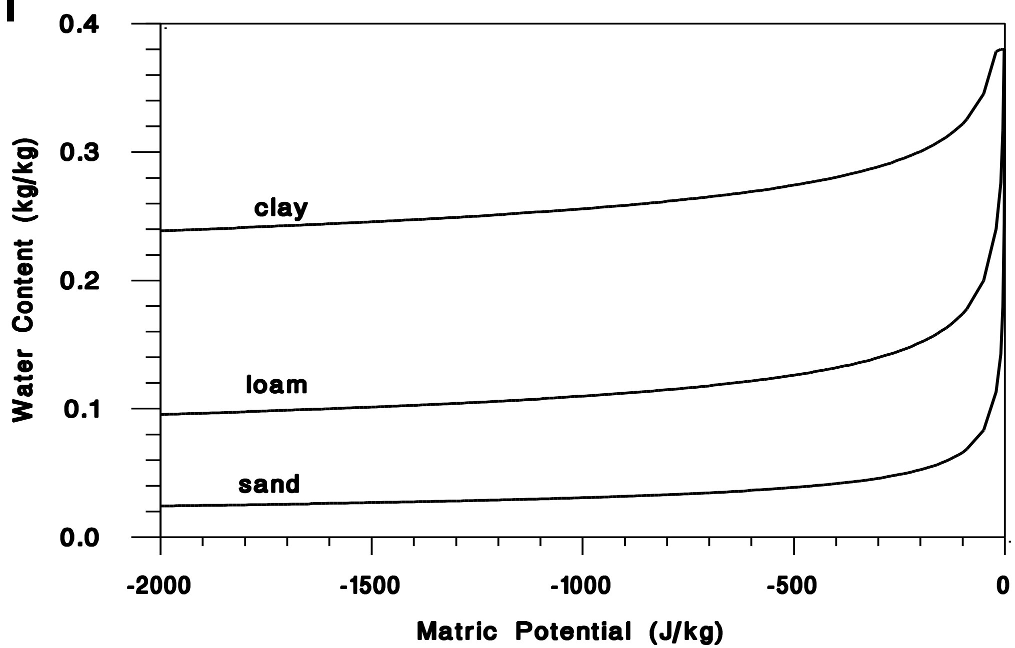
- Range is 0 to -300 MPa
- Accuracy is +/-0.05 MPa
  - Excellent in dry soil
  - Problems in wet soil
- Read time is 5 minutes or less

Some applications of soil water potential

- Soil Moisture Characteristic
  - Plant Available Water
  - Surface Area
  - Soil Swelling
- Hydropedology
- Water flow and contaminant transport
- Irrigation management

Soil Moisture Characteristic

- Relates water content to water potential in a soil
- Different for each soil
- Used to determine
  - plant available water
  - surface area
  - soil swelling



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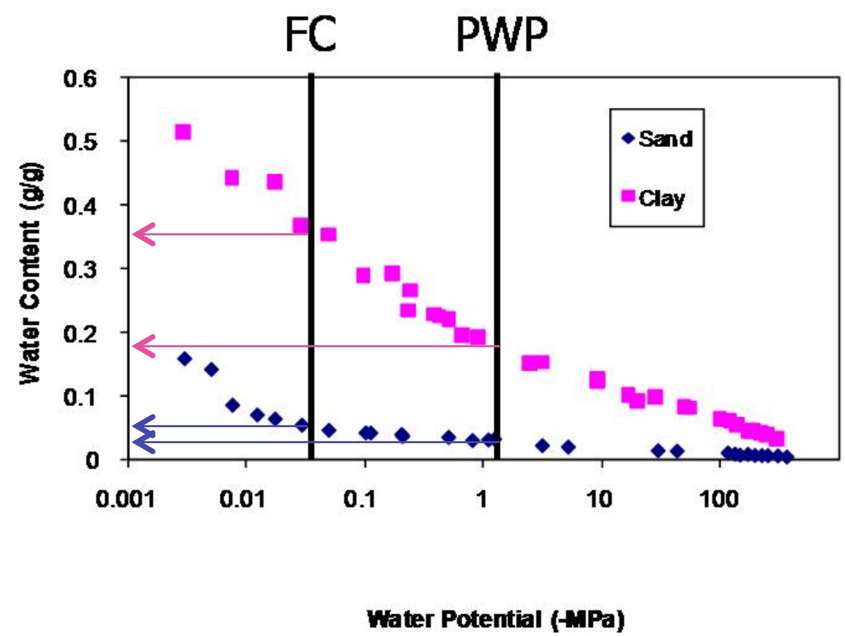
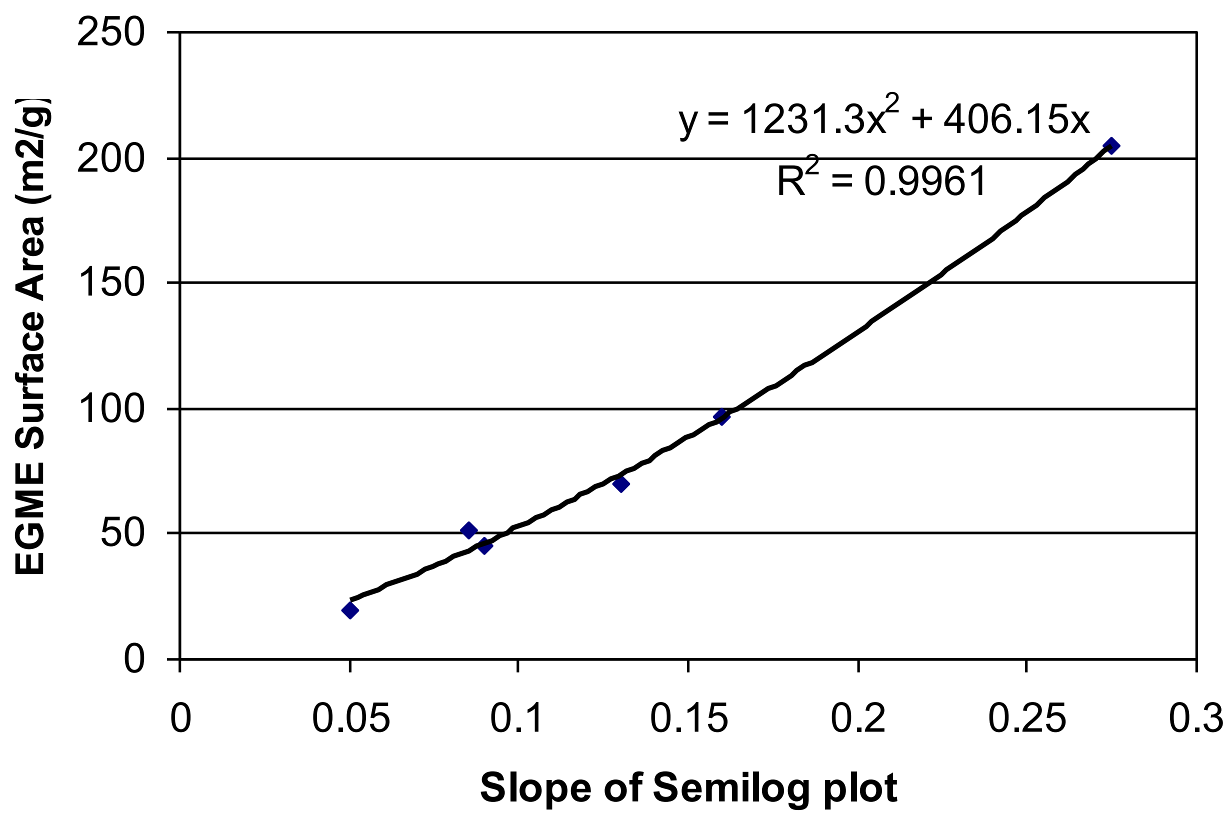
Plant Available Water

- Two measurement methods needed for full range
  - Hyprop, tensiometer, pressure plate in wet end
  - Dew point hygrometer or thermocouple psychrometer in dry end
- Field capacity (-0.033 Mpa)
  - Upper end of plant available water
- Permanent wilting point (-1.5 Mpa)
  - Lower end of plant available water
  - Plants begin water stress much lower



Surface Area from a Moisture Characteristic



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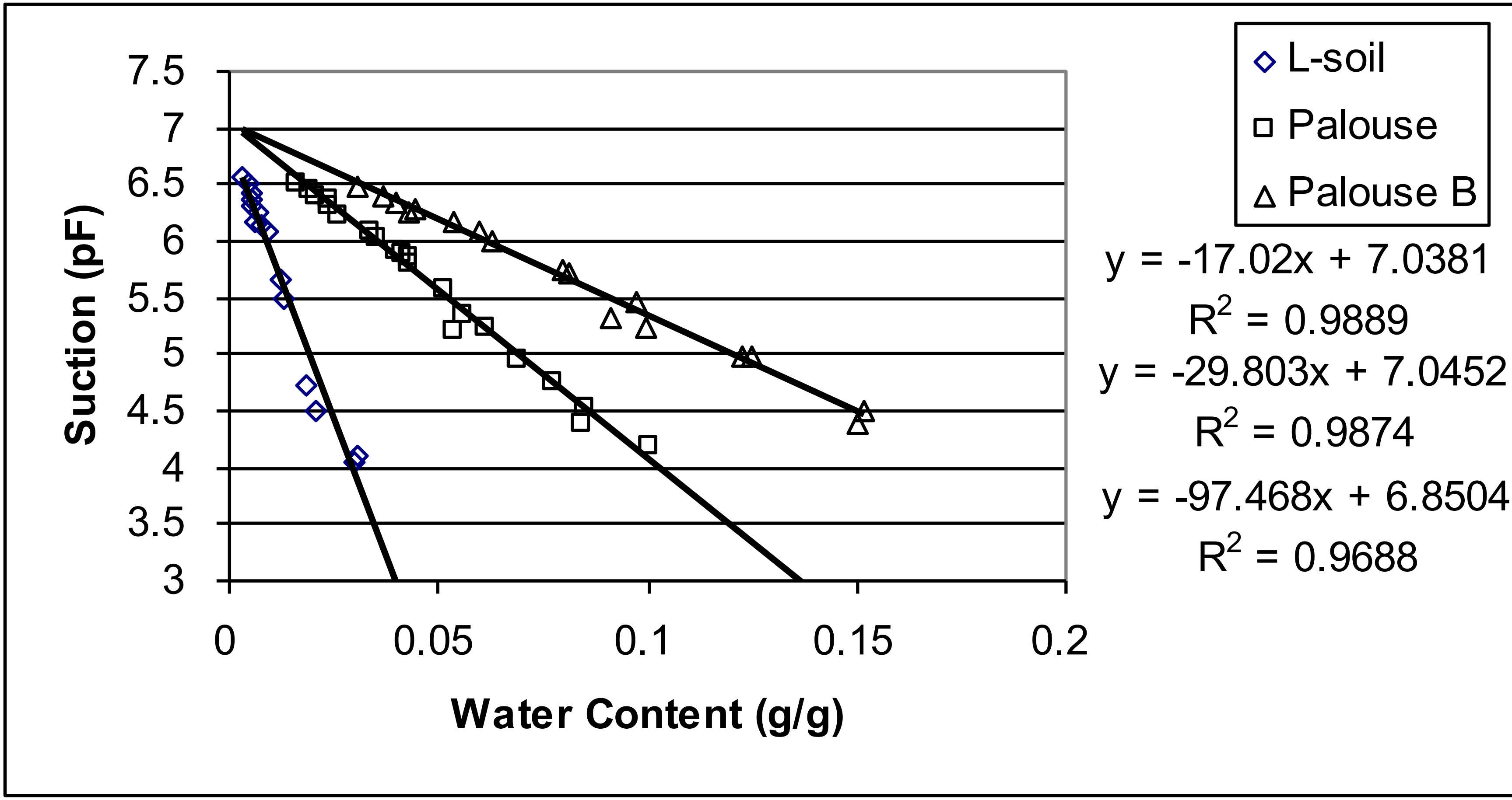
pF Plot to get Soil Swelling



Expansive Soil Classification from McKeen(1992)

Class	Slope	Expansion
I	> -6	special case
II	-6 to -10	high
III	-10 to -13	medium
IV	-13 to -20	low
V	< -20	non-expansive

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Hydropedology

- Requirements:
  - Year around monitoring; wet and dry
  - Potentials from saturation to air dry

- Possible solutions:
  - Soil psychrometers (problems with temperature sensitivity)
  - Capacitance matric potential sensor (limited to -0.5 MPa on dry end)
  - Heat dissipation sensors (wide range, need individual calibration)

Water Flow and Contaminant Transport

- Requirements:
  - Accurate potentials and gradients during recharge (wet conditions)
  - Continuous monitoring
- Possible solutions:
  - Capacitance matric potential sensor
  - Pressure transducer tensiometer (limited to -0.09 MPa on dry end)

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Irrigation Management

- Requirements:
  - Continuous during growing season
  - Range 0 to -0.1 Mpa
- Possible solutions:
  - Tensiometer (soil may get too dry)
  - Electrical resistance (poor accuracy)
  - Heat dissipation or capacitance

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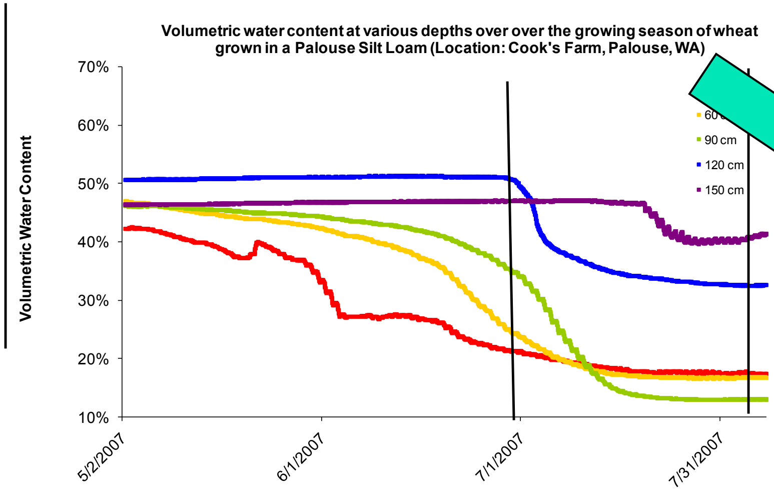
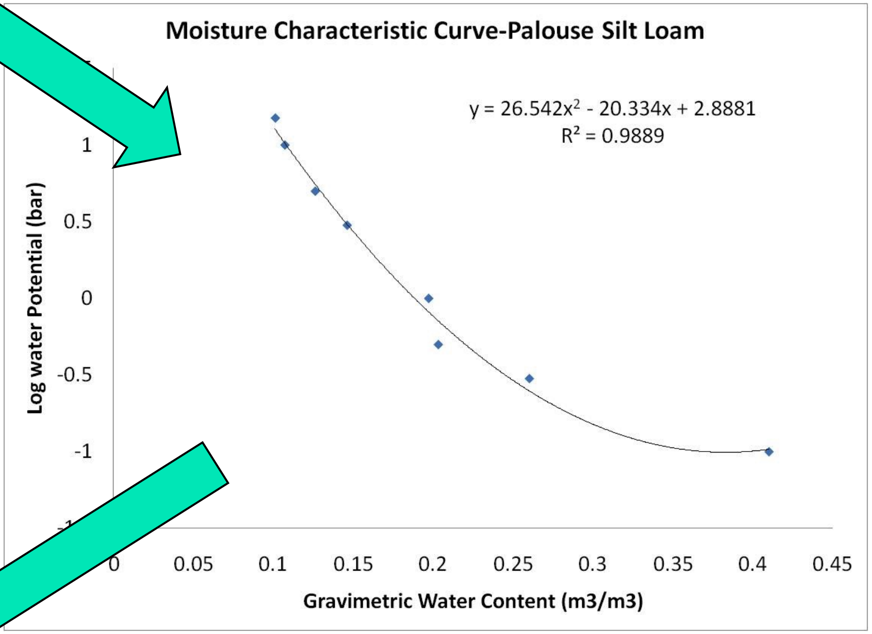
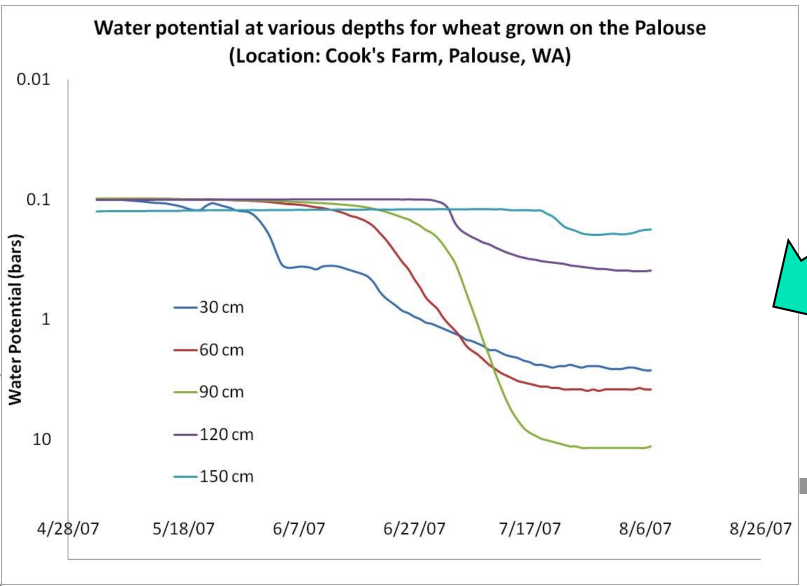
Measuring water content to get water potential

- Requires moisture characteristic curve for converting field measurements from θ to ψ
- Conventional wisdom: time consuming
  - Most moisture release curve have been done on pressure plates
  - Long equilibrium times, labor intensive
- New techniques
  - Fast (<24 hours)
  - Automated

Bridging the gap







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Summary

- Knowledge of water potential is important for
  - Predicting direction of water flow
  - Estimating plant available water
  - Assessing water status of living organisms (plants and microbes)

Summary

- Water potential is measured by equilibrating a solid, liquid, or gas phase with soil water

- Solid phase sensors
  - Heat dissipation
  - Capacitance
  - Granular matrix
- Liquid equilibrium
  - Tensiometers
  - Pressure plates

Summary

- Vapor equilibration
  - Thermocouple psychrometers
  - Dew point potentiameters
- No ideal water potential measurement solution exists
  - Maintenance and stability
  - Accuracy and calibration
  - Ease of use
  - Range of operation