Overview: Trunk Water Potential Sensors

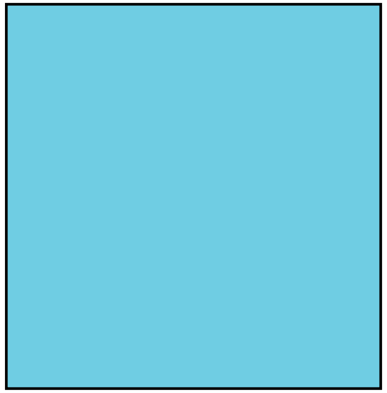
February 5-6, 2024

Outline

- How water potential sensors work
  - Water tension
  - Sensor description
  - Install kit description
  - How sensor measures water tension in-situ
  - Factors that affect readings
- Sensor assembly, calibration, preparation
  - Pressure calibration
  - Gel protection
  - Water filling
  - Response testing
  - Stability and temperature testing
  - Initial storage
- Status of individual crops
  - Validated
  - Works well, needs more validation
  - Initial testing looks good
  - Potential issues
  - Wet crops
  - Untested

Definition of Water potential (Ψ)

$$P - P_{\text{pure, unbound water}} = \Psi = \frac{RT}{v_l}\ln\left(RH_{gas}\right)$$

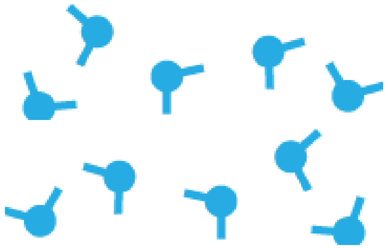


$\mu_1 = \mu_2$

Equilibrium

$\mu_2 = \mu_3$

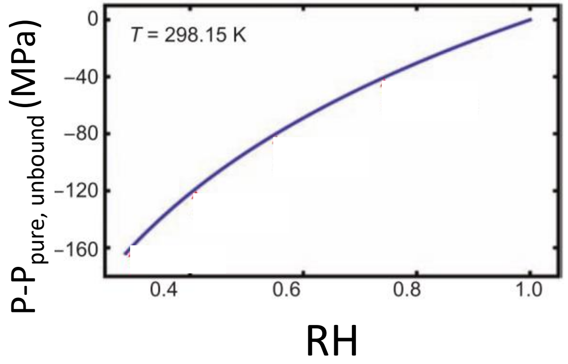
Equilibrium



Pure liquid water

Water
+soil
+salts
+pressure
+height

Water vapor

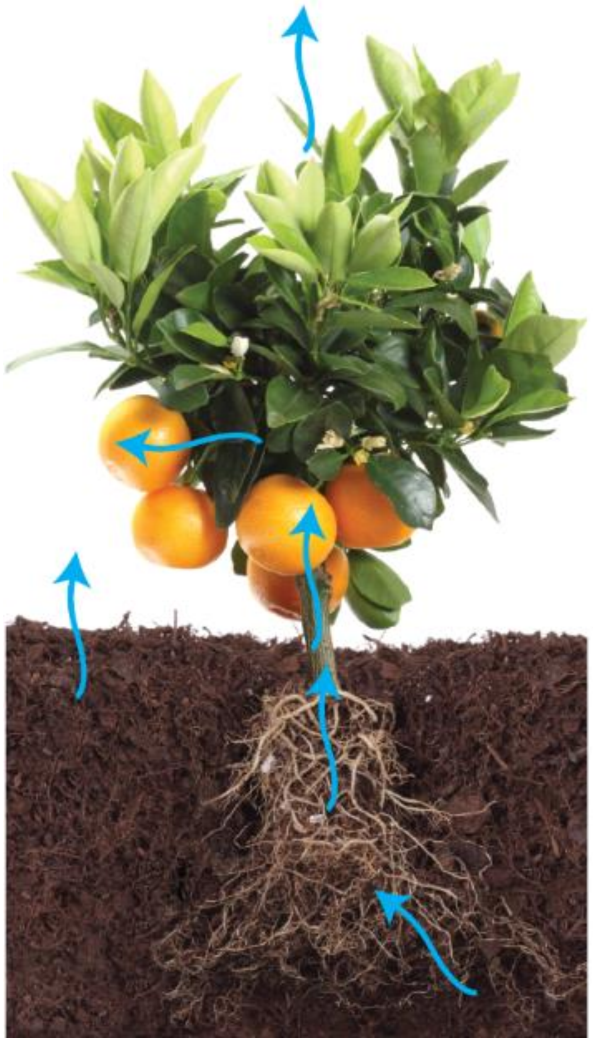


Adapted from: Caupin and Stroock, 2013

Measure of water potential energy in a system

Water potential: the driving force

Drives flow



$$\Psi_{atmosphere} = -100\text{MPa}$$
$$RH = 50\%$$

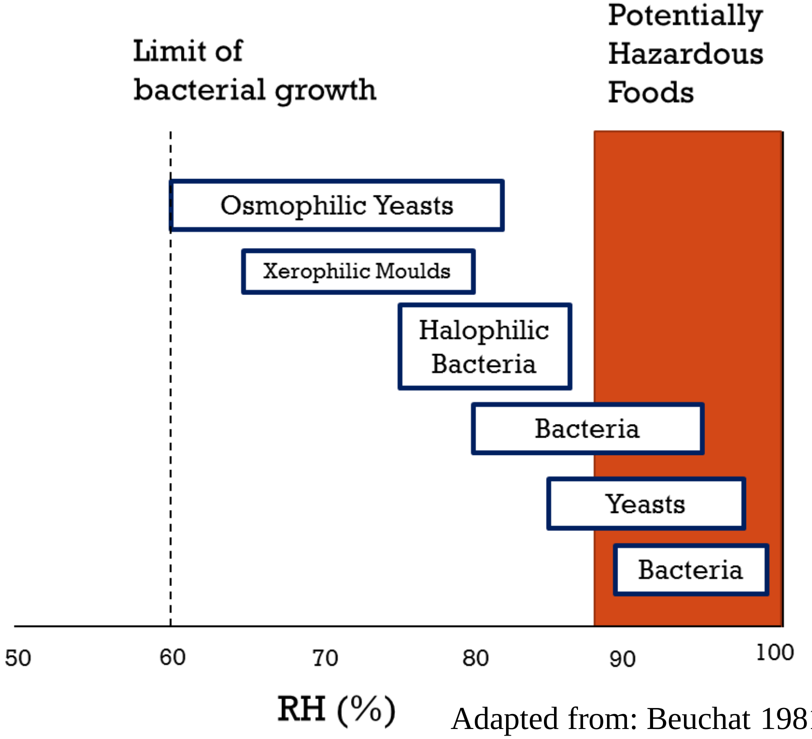
$$\Psi_{leaf} = -2\text{MPa}$$
$$RH = 98.5\%$$

$$\Psi_{stem} = -1\text{MPa}$$
$$RH = 99.3\%$$

$$\Psi_{root} = -0.1\text{MPa}$$
$$RH = 99.9\%$$

$$\Psi_{soil} = -0.01\text{MPa}$$
$$RH = 99.99\%$$

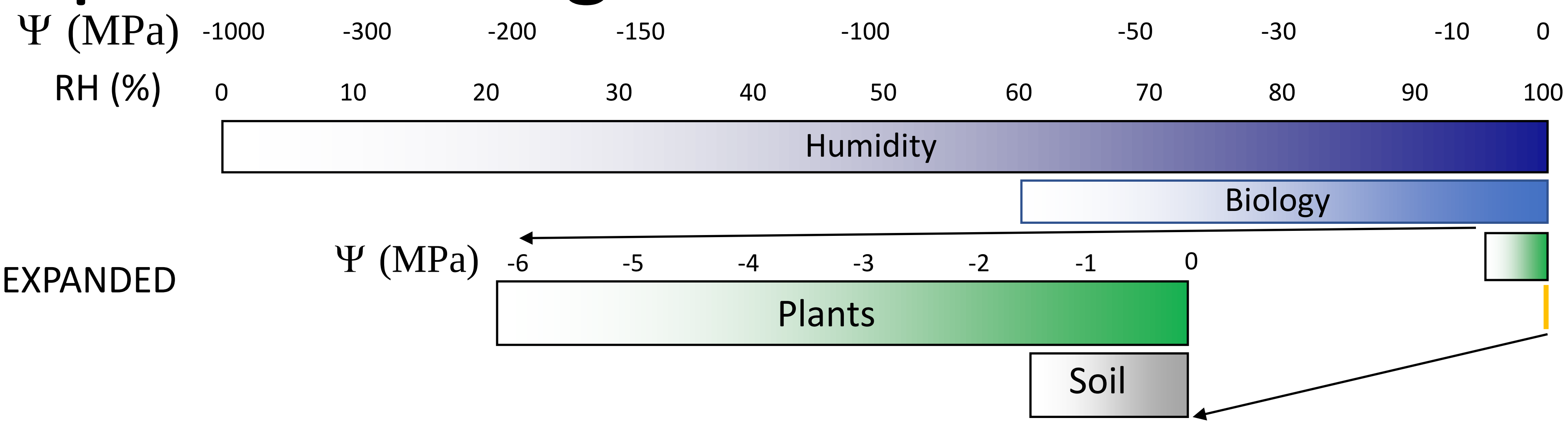
Sets water availability



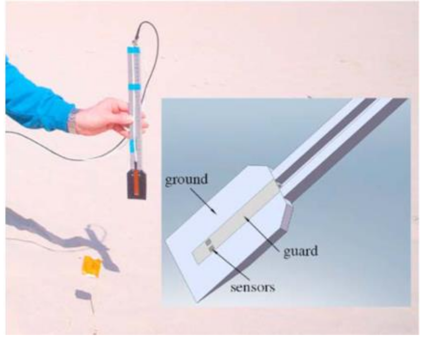
Adapted from: Beuchat 1981

$$\Psi_{concrete} > -22\text{MPa}$$
$$RH > 85\%$$

Water potential ranges + in-situ sensors



Accuracy (expanded)	2 MPa	0.2 MPa	0.1 MPa	0.005 MPa
Range	-1000 MPa	-10 MPa	-10 MPa	-0.1 MPa



Louge *et al.*, 2013

Capacitive/resistive

Source: soilmoisture.com

Leaf Pressure Chamber

Source: ICT International

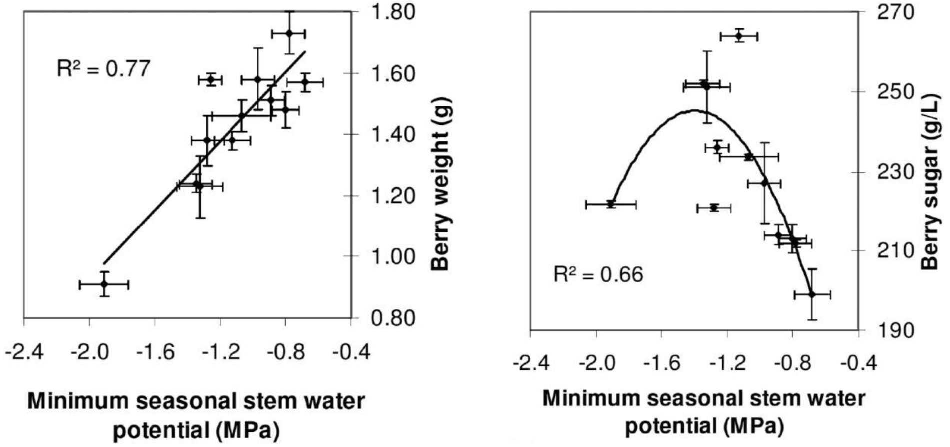
Stem Psychrometer

Source: Irrometer

Soil Tensiometer

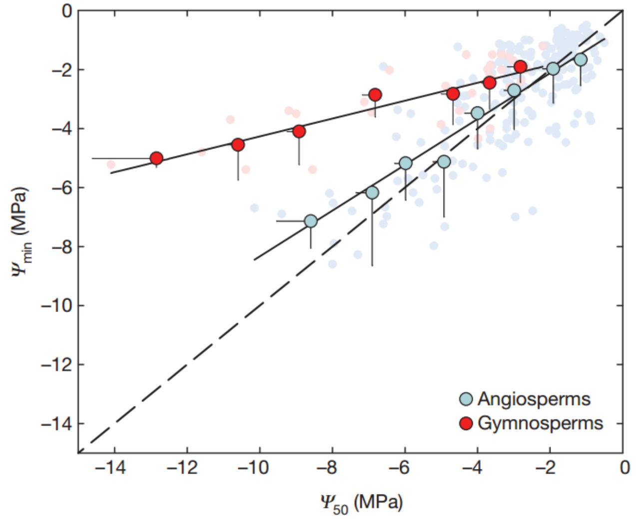
Water potential in agriculture

Produce quality + characteristics



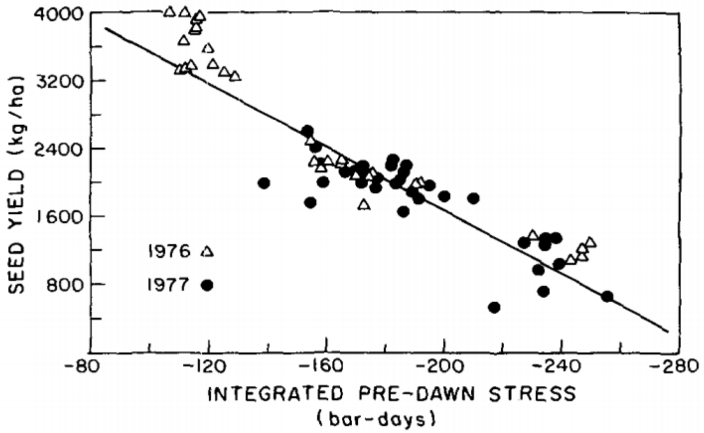
Adapted from: Leeuwen *et al.*, 2009

Plant survival



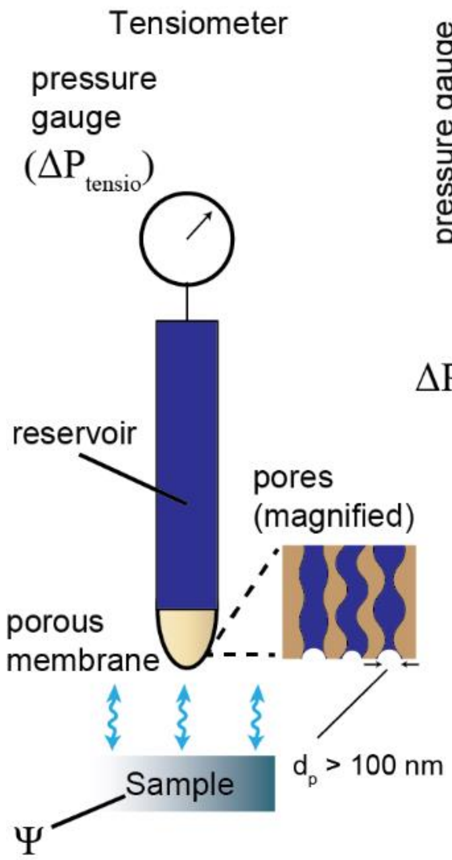
Choat *et al.*, 2012

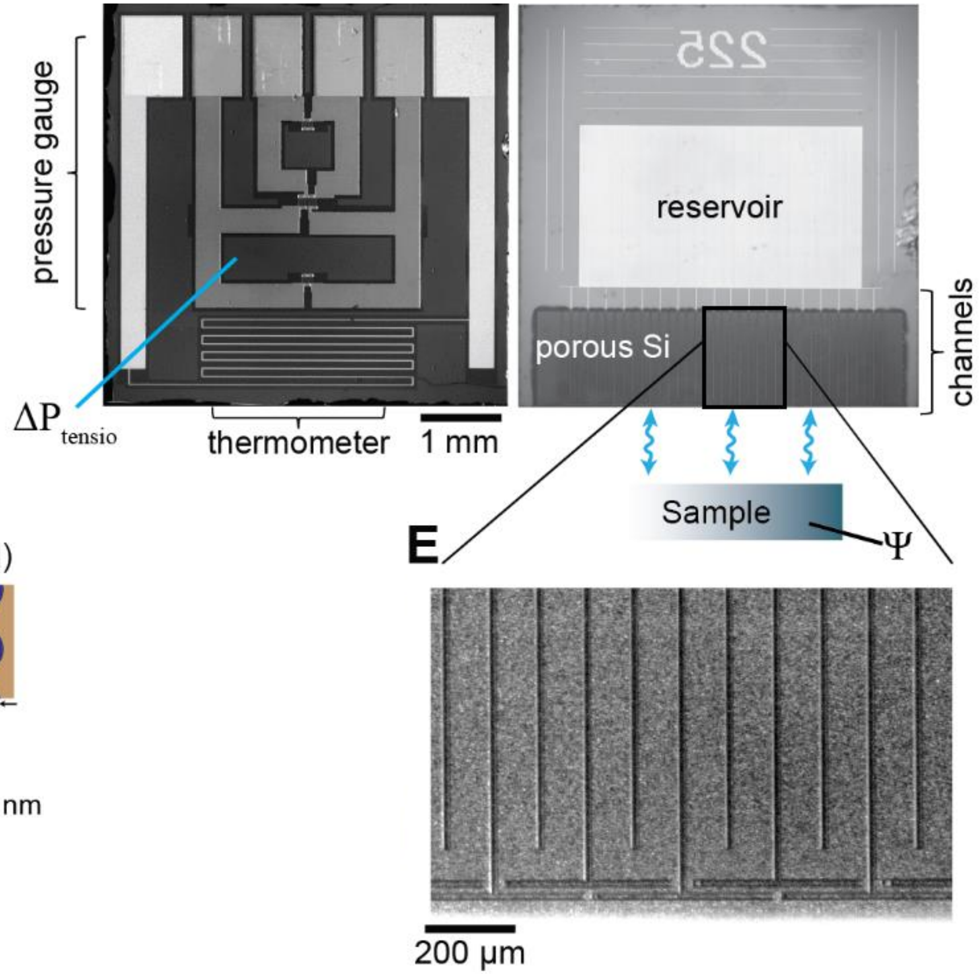
Agricultural yield

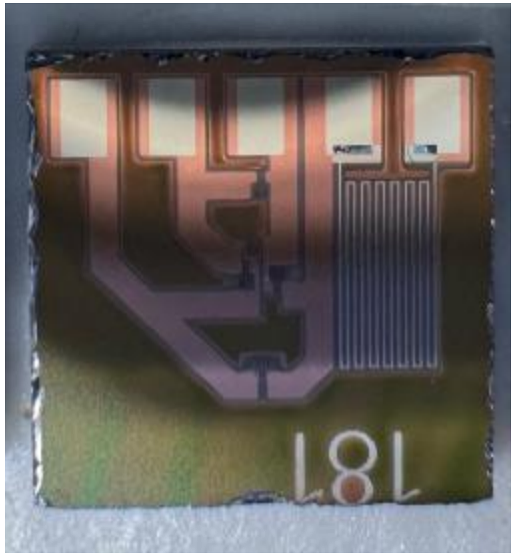


Shouse *et al.*, 1981

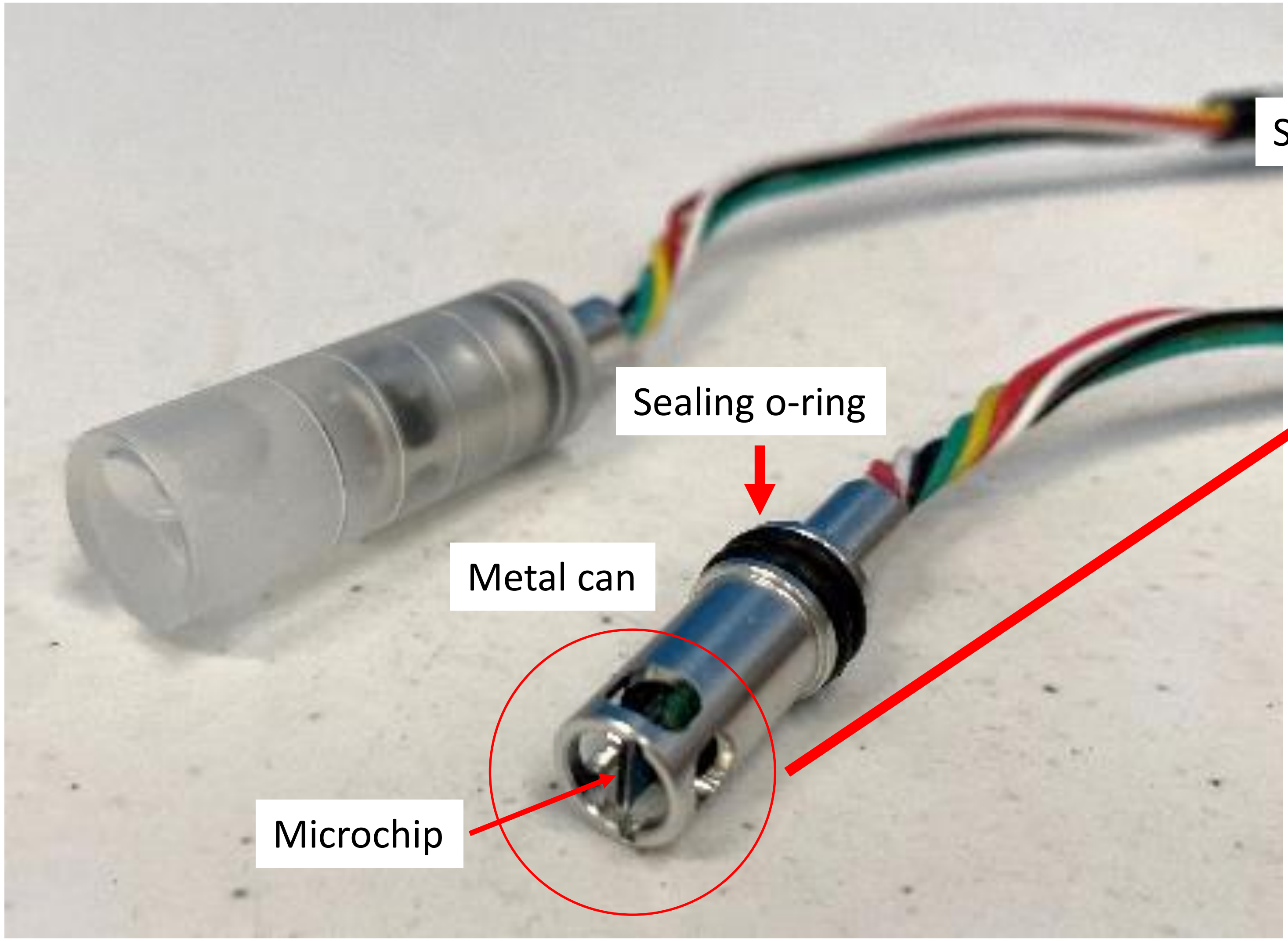
Microchip tensiometer for in-situ water potential measurement

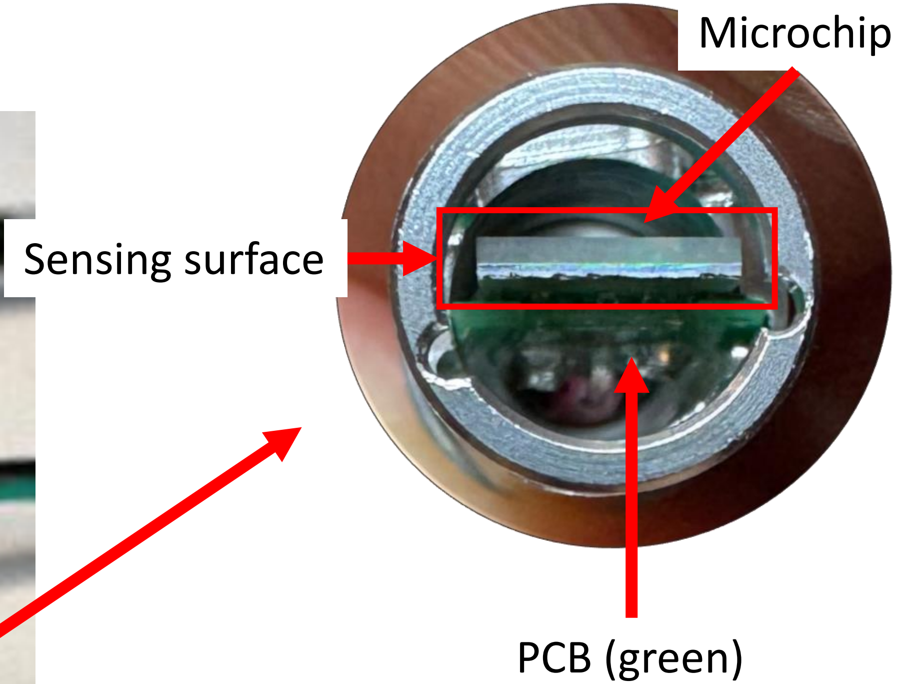






Microtensiometer probe

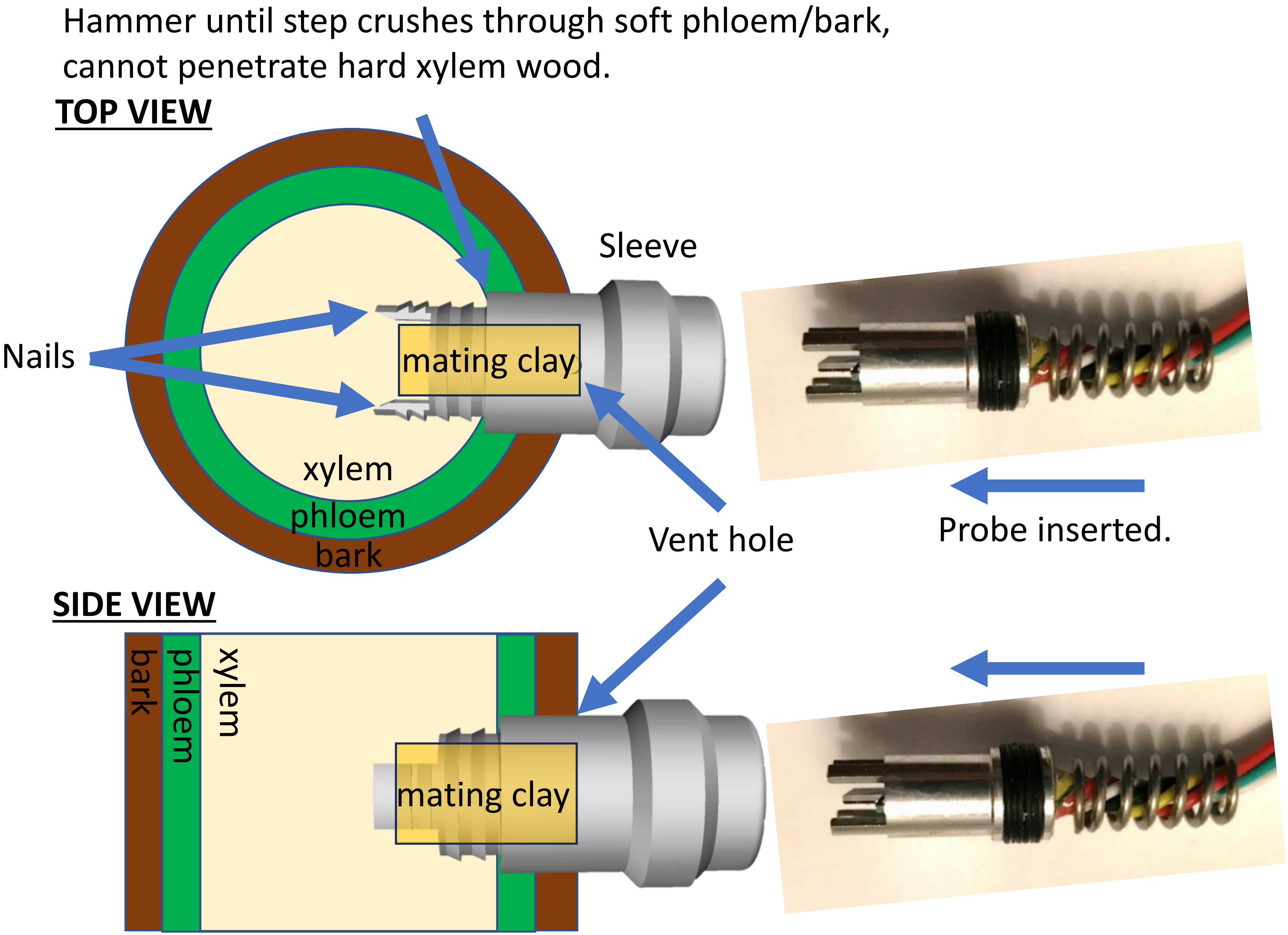




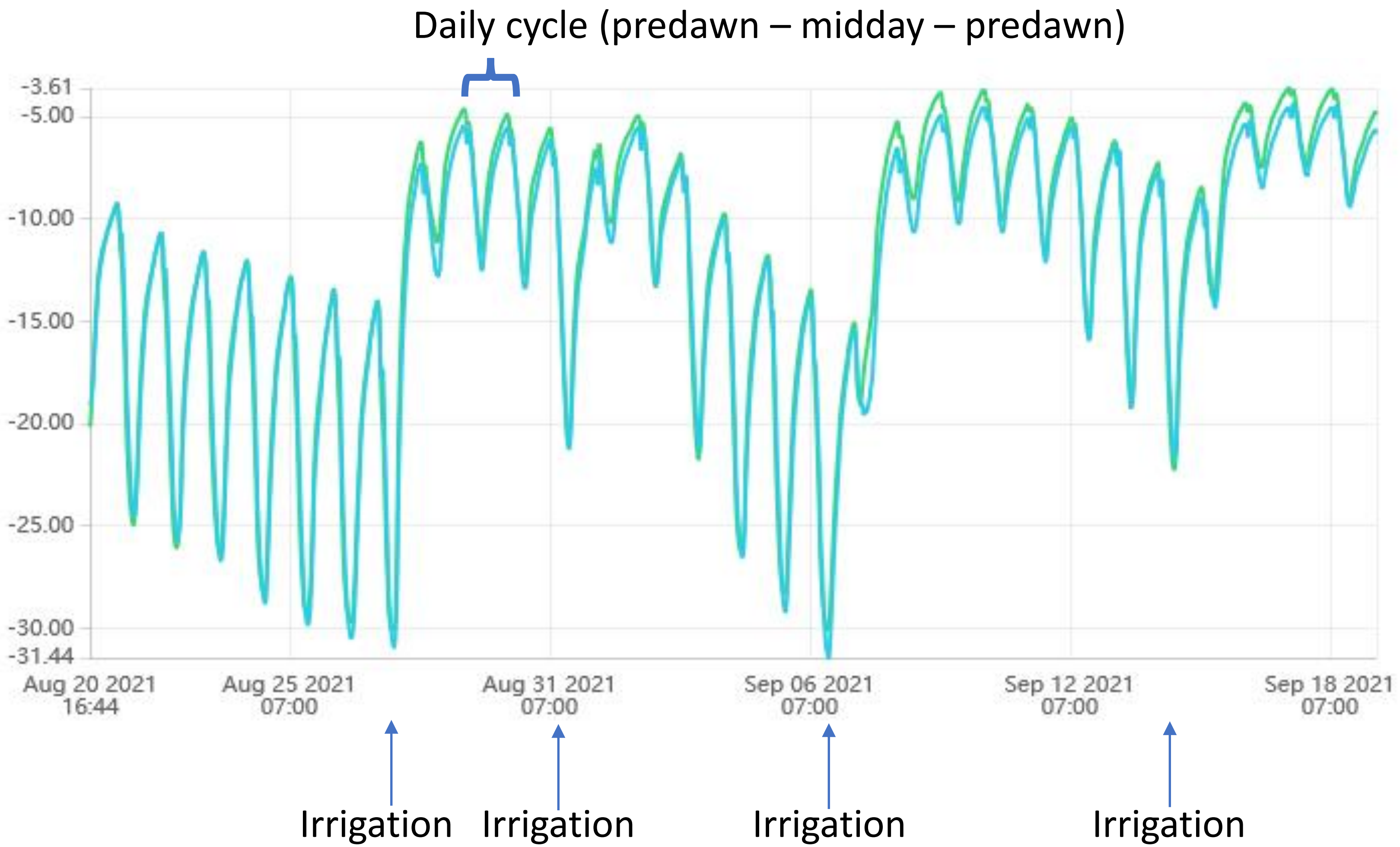
Chip is soldered onto a PCB, housed in metal can.
The front edge of the microchip is the sensing surface, where water is exchanged between the sensor and xylem.

Installed probe – how water potential is sensed

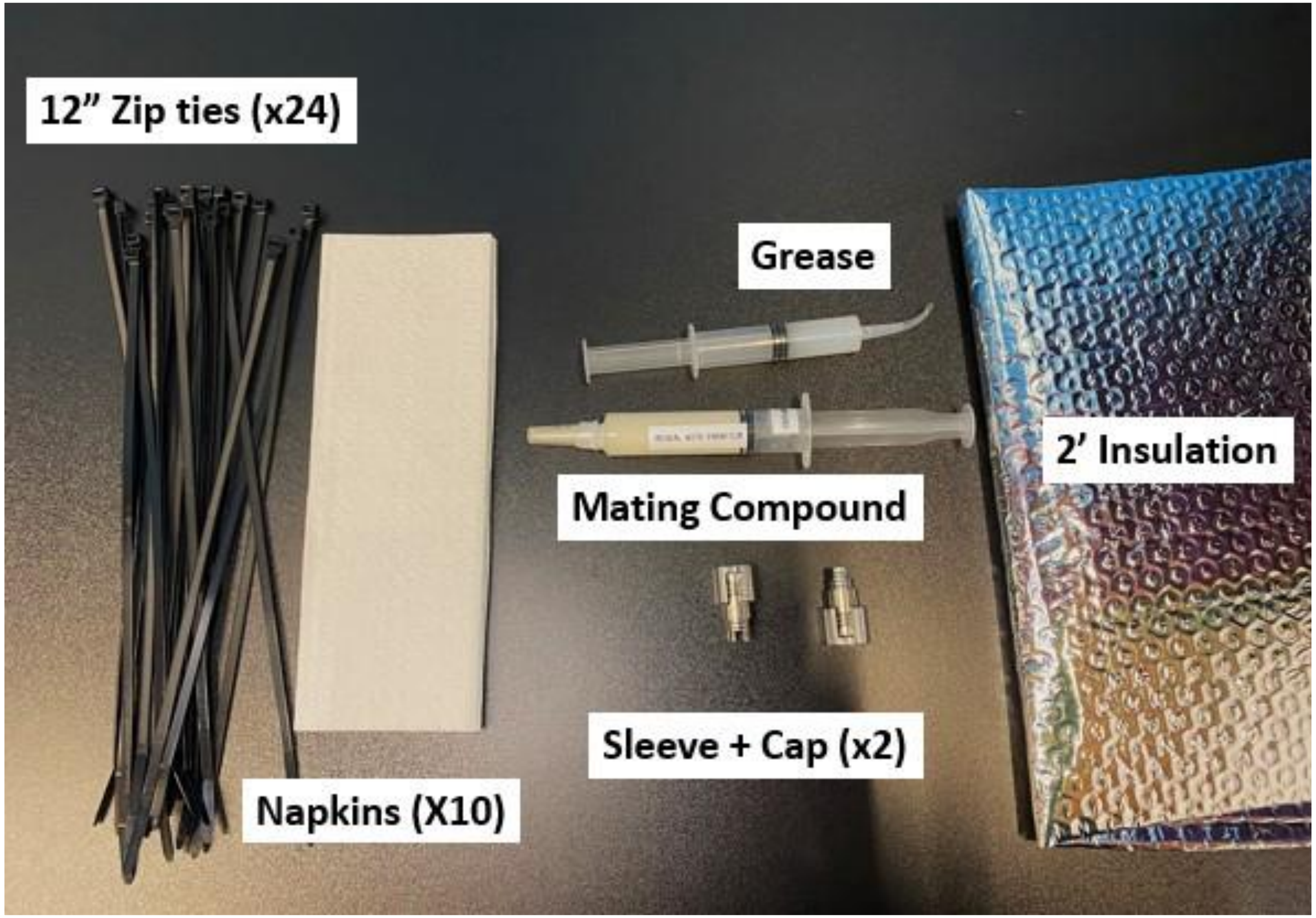
- Sleeve is hammered such that front opening sits inside the xylem.
- Excess xylem is drilled out.
- Mating clay is inserted in drilled hole.
- Probe inserted into sleeve, pushes extra clay out.
- Mating clay is a slurry of kaolin+water, creates a liquid connection between the xylem and chip sensing surface. Many small pore-channels that move water.



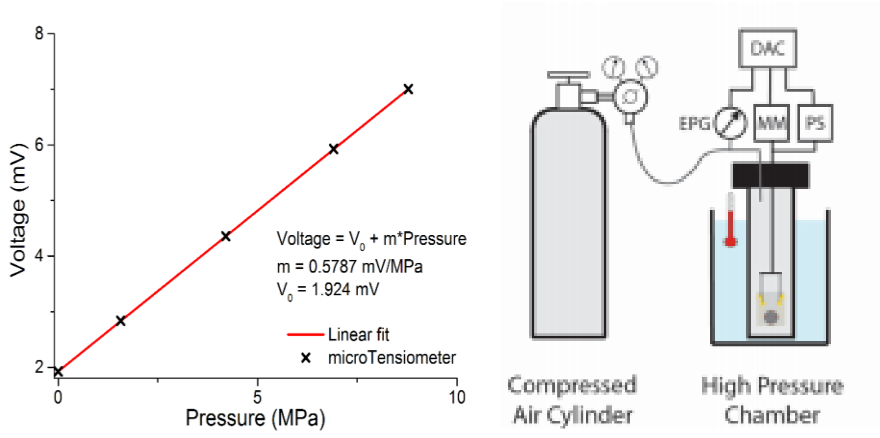
Sample SWP data (almond)



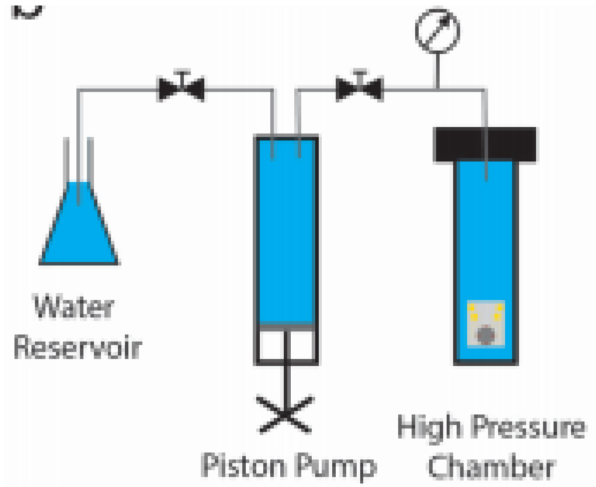
Install kit parts



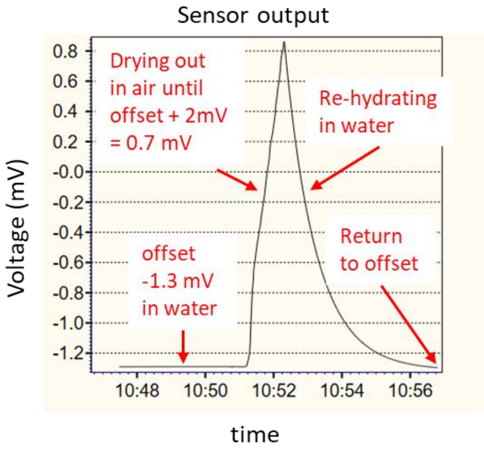
Factory test/calibration steps



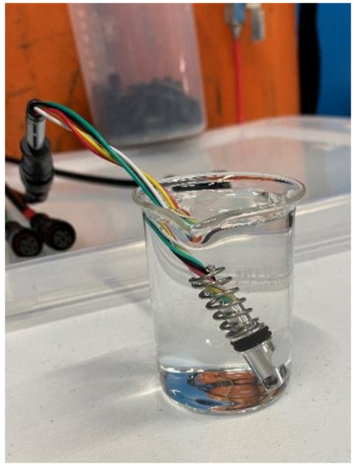
Pressure calibration



Water pressure filling (40 bars)



Response testing



4-day stability/temperature testing

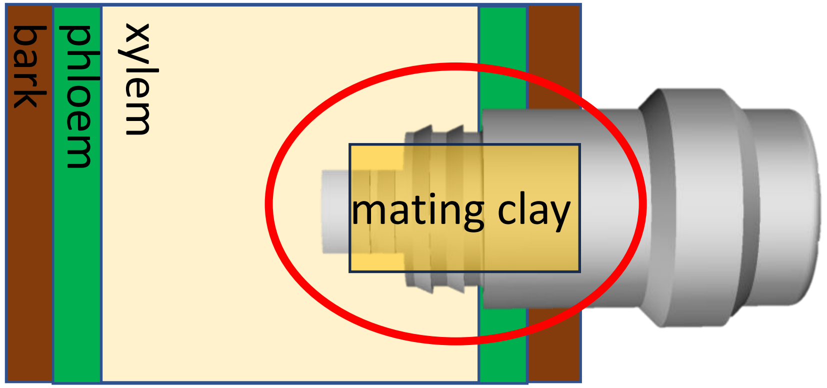
Storage in preservative solution

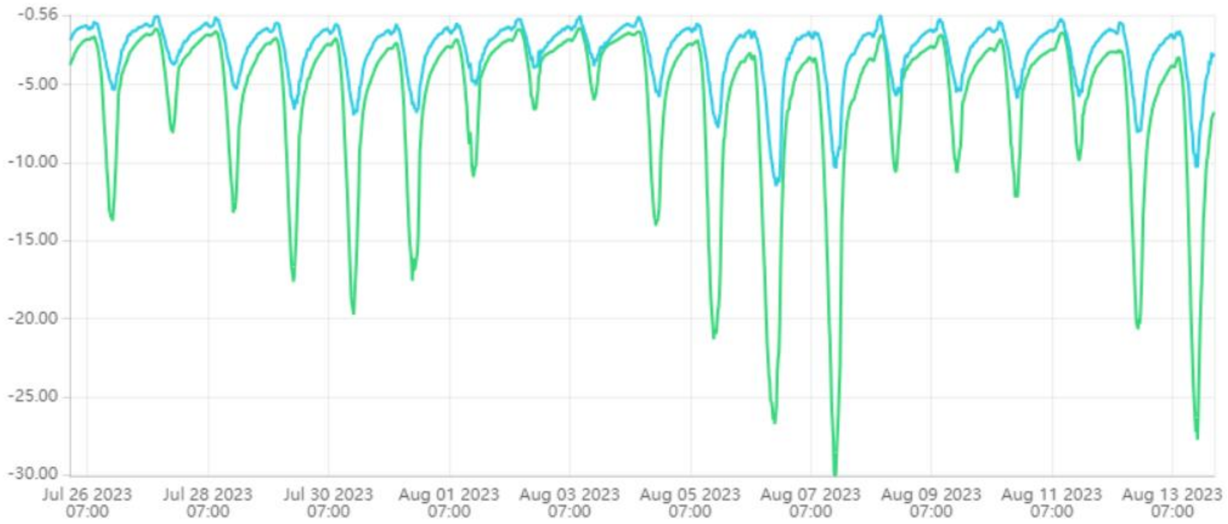
Factors that affect readings

- Hydraulic connection
- Wound closure
- Response speed of sensor
- Freezing temperatures
- Water leaks in and out of sleeve/install.
- Too low WP causes cavitation

Breaks in the hydraulic connection

- Voids in the hydraulic connection will cause big drop in measured SWP during hot times of the day.
- This means voids in the mating clay.
- Caused by:
  - Bubbles introduced to the mating clay during install (unlikely)
  - Movement of the probe due to poor installation
  - Excessive shaking/swaying of the branch.
  - Very large tensions cause pores inside mating clay to cavitate and stop water-transfer.

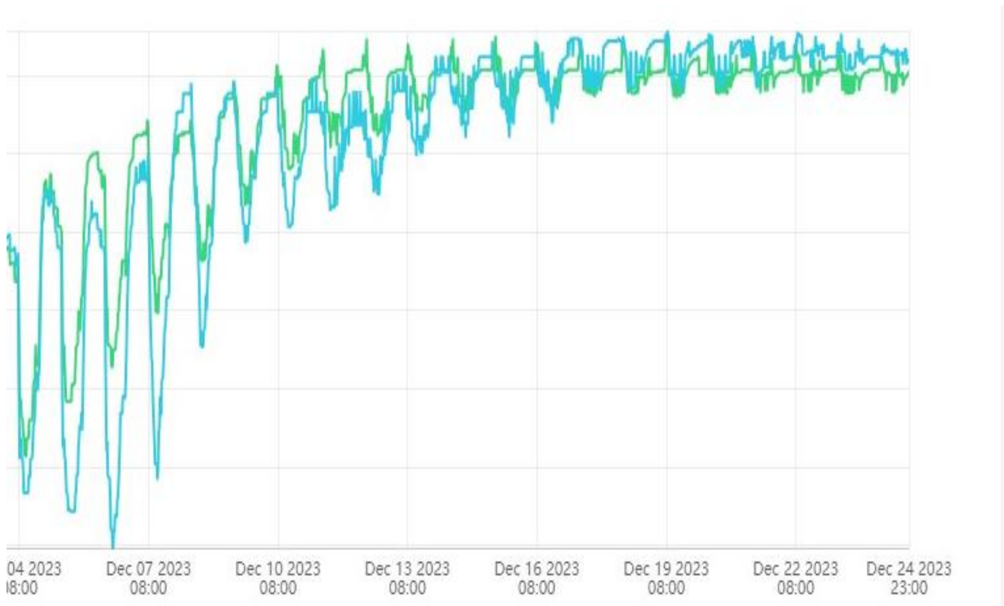




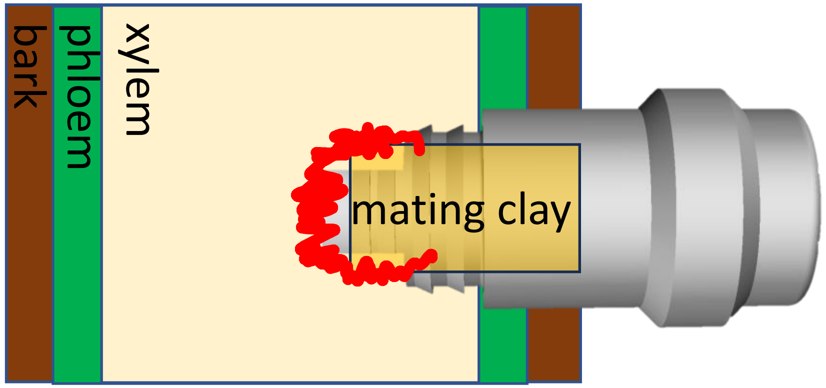
Green sensor has broken hydraulic connection

Sealing of the install wound (by the plant)

- In some trees, such as almond, the install wound partially seals during the winter, causing the data to shrink.



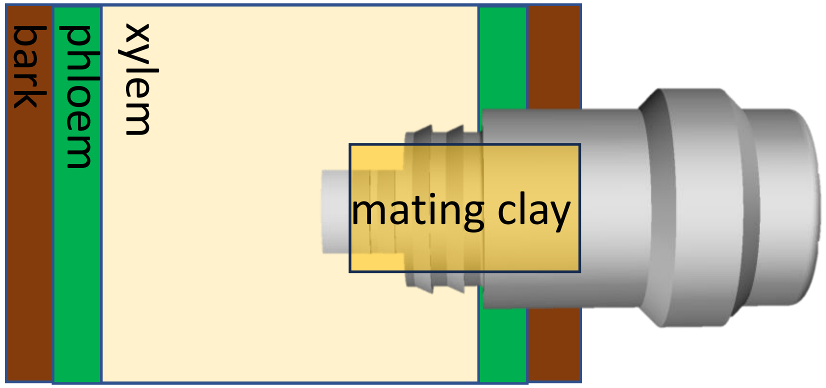
Shrinking of measured SWP

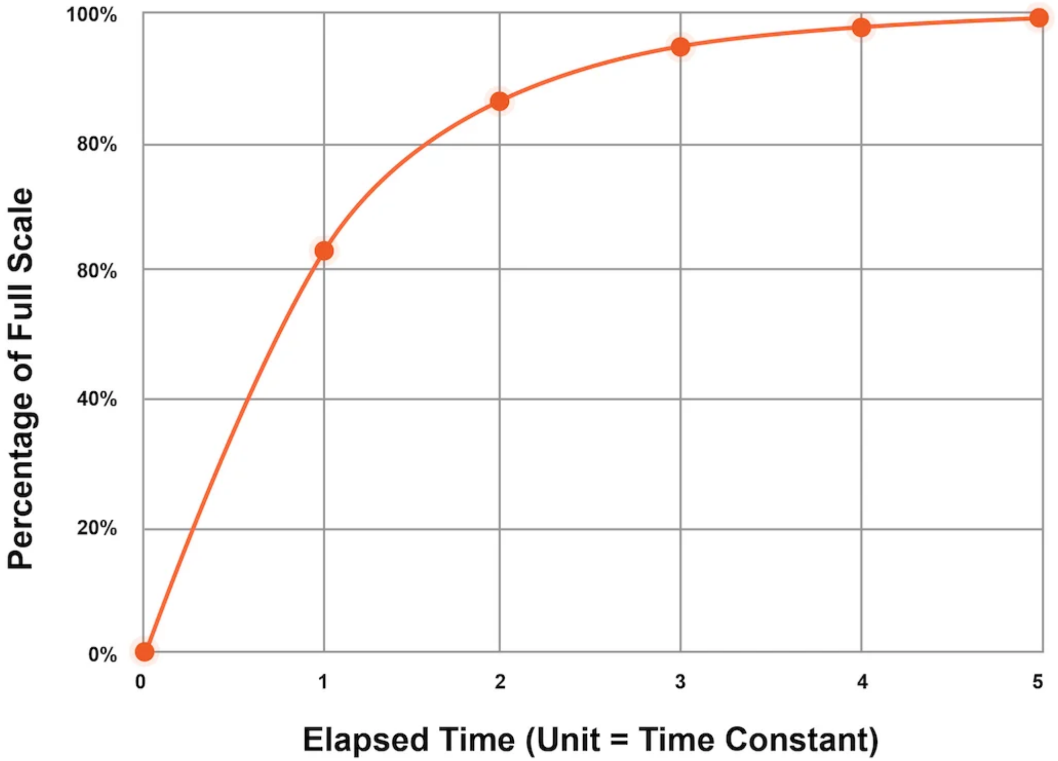


Install wound closure by biological processes

Sensor speed

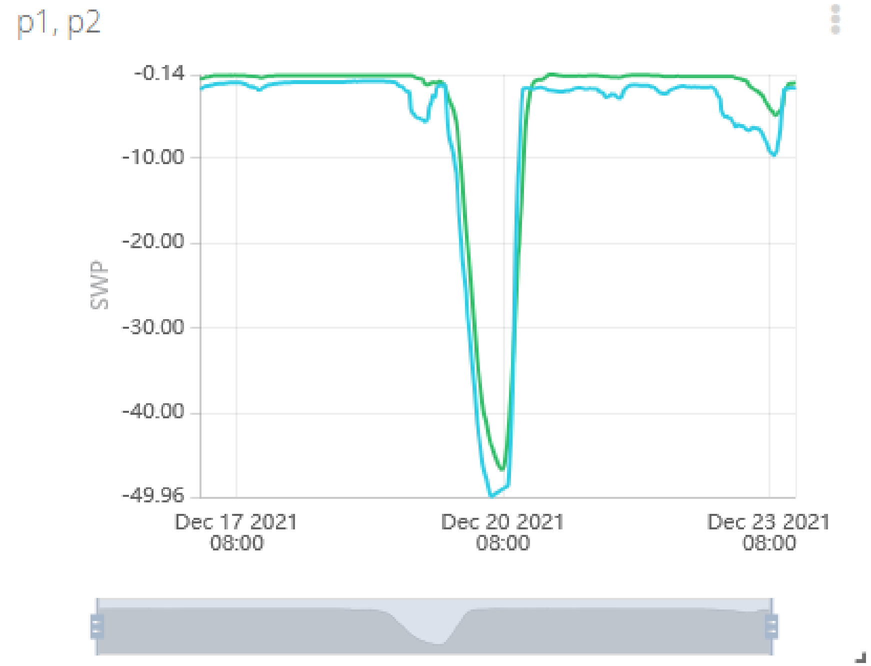
- The sensor will always lag the tree SWP by some amount. This lag is caused by combination of: sensor response speed + ‘speed’ of mating clay equilibrium.
- Probe response speed is factory measured to be less than time constant of ~22 minutes.
- Measured lab response speed of installed sensors is usually ~30 minutes or less.
- This means it can take up to 1 hour for a sensor to equilibrate to 85% of tree SWP.
- Conclusion: sensor may lag tree by 1-2 hours, or more depending on the installation.

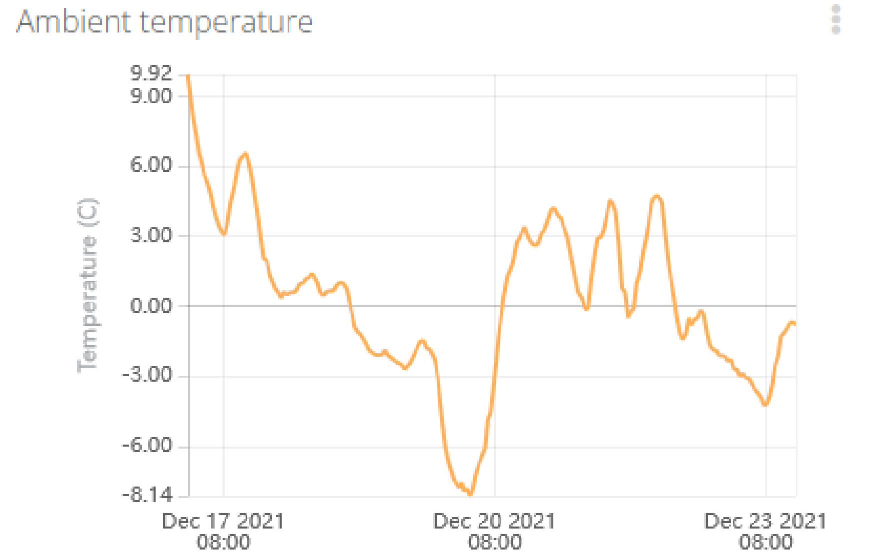




Freezing temperatures

- Will cause sensor to read very low SWP, eventually break due to freezing of water.



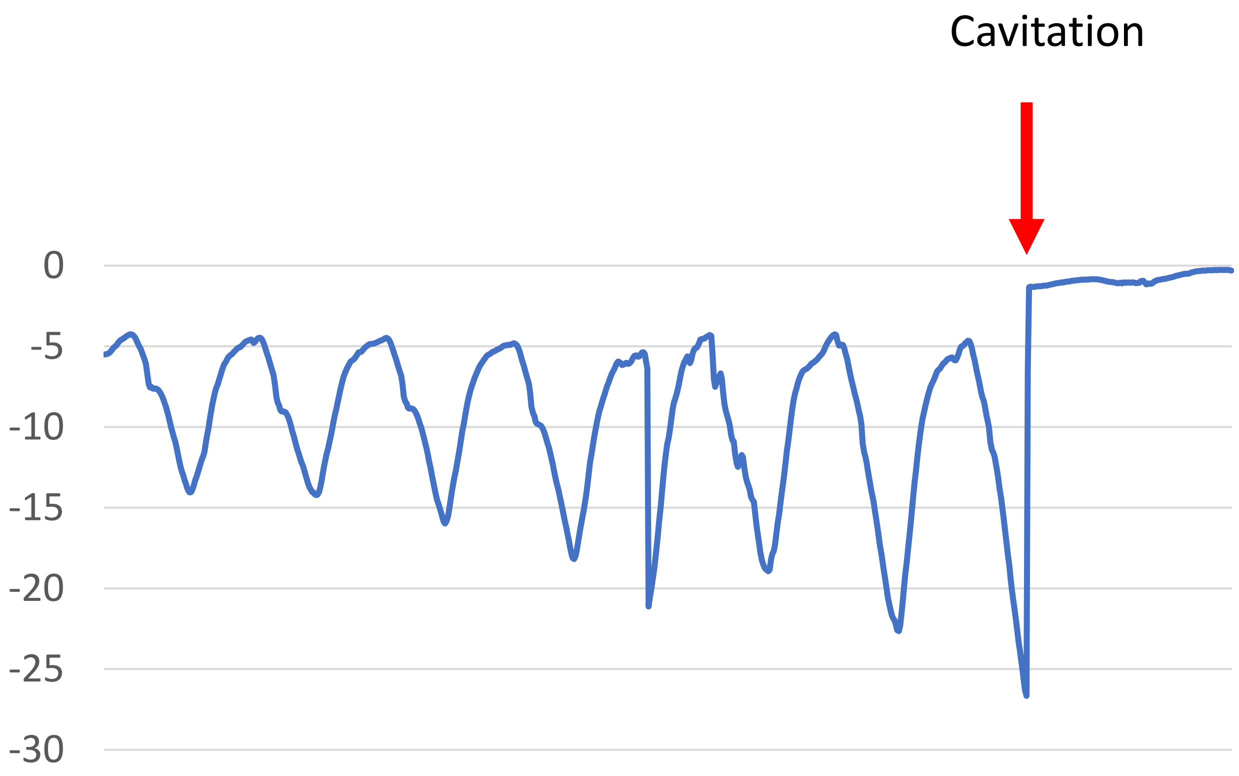


Water vapor leaks in/out of installation

- Water getting in/out will lead to dry-down. Or wetting during rain.
- Sensor goes to zero (very wet) when it rains.
- Sensor measures lower and lower SWP over days when drying out.
- Current designs will often have a very small water leak that doesn't affect the data, but can become a problem when it rains.
    - Important to keep insulation loose to allow excess water to evaporate.

Very low SWP measurements cause cavitation

- Sensors are tested to withstand tensions of -35 bar. Lower tensions may cavitate the sensor and render it useless.



Crop status

Perfect	Works well Needs more testing	Initial testing looks good	Potential issues (sometimes)	'Wet' crops (don't use!)
Almond	Grape	Hazelnut	Citrus	Avocado
Prune	Cherry	Pine	Pistachio	Walnut
Apple		Blueberry	Apricot	Pecan
Olive		Cotton	Kiwi	
		Mango	Cacao	
		Fig		
		Olive		