Water Relations of Grapevines & a bit of Soils

Andrew J. McElrone

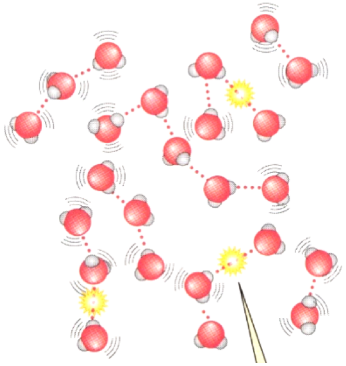
USDA

UC DAVIS
UNIVERSITY OF CALIFORNIA

Water Relations of Grapevines

- Why is this important
- Concept of water potential
- Root pressure, bud push, and drought
- Long distance transport
- Cellular water relations and growth
- Stomatal control gas exchange
- Deficit irrigation

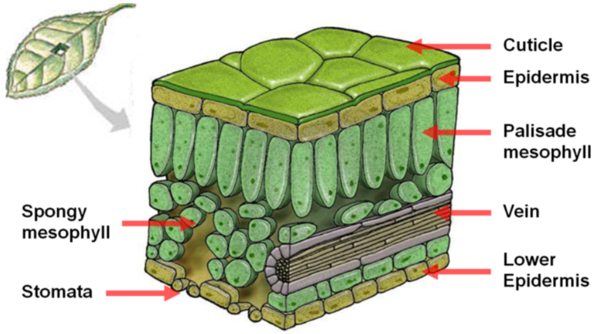
Importance of water for grapevines



- solvent
  - gases, minerals and other substances dissolved
  - site of all metabolic reactions
- constituent – 70 to 95% of plant mass is water
  - essential for maintaining structure (hydrostatic skeleton)

- reactant
  - substrate for photosynthesis

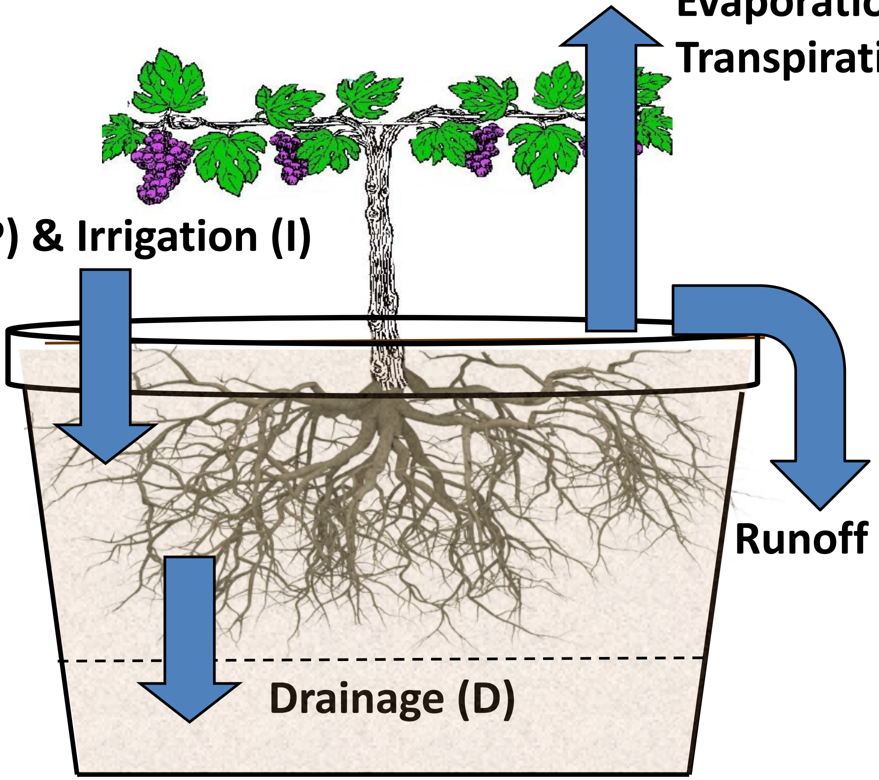
- currency
  - traded to atmosphere for CO_2
    - ~400 H_2O molecules are lost for every molecule of CO_2 absorbed
  - cooling effects



Irrigation management

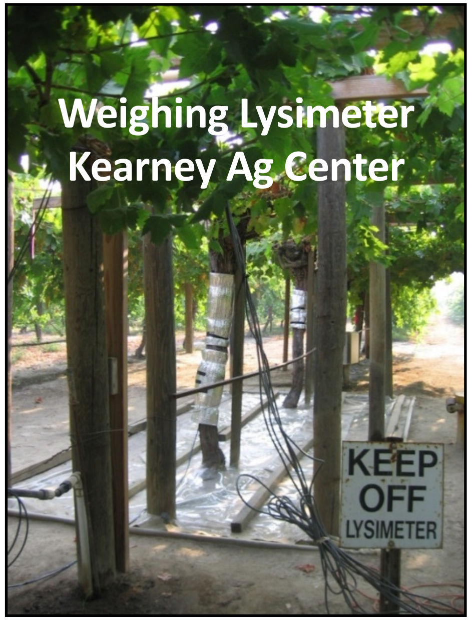
1) How much water?
2) When to apply it?

Vineyard Water Balance



Change in soil water = P + I – ET – D – R

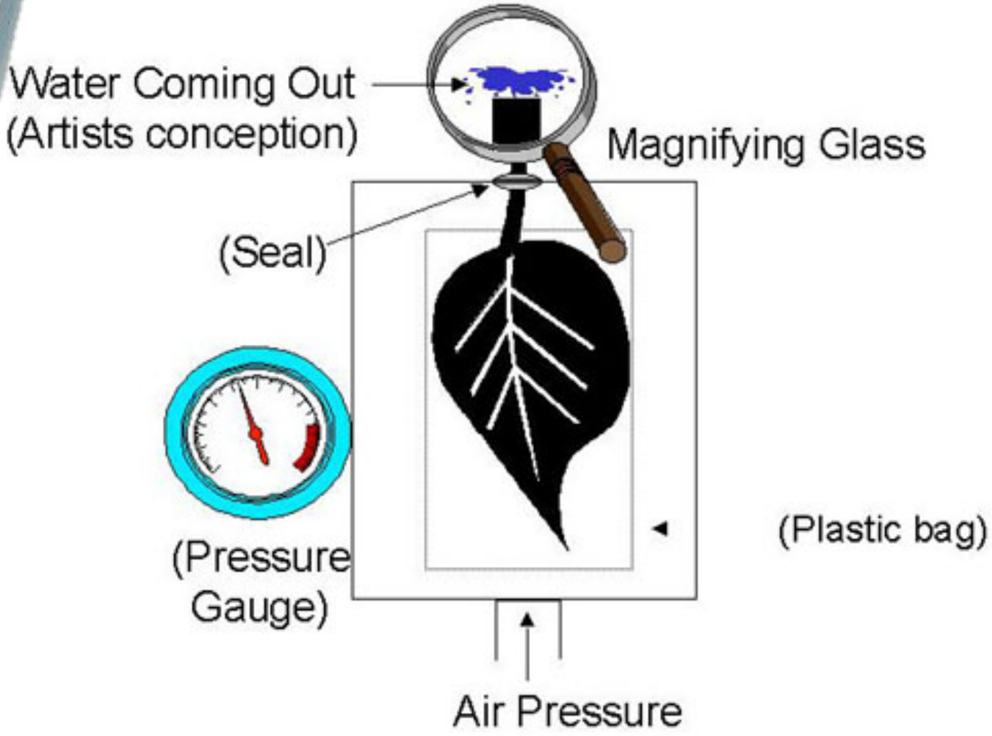
Gains (P + I)   Losses (ET – D – R)



<u>Factors Impacting Water Use</u>

- Evaporative demand
- Growth stage of vines
- Presence of a cover crop
- Canopy Size/Trellis type
- Row/Vine spacing
- Vineyard slope and aspect
- Vine health
- Hard pan
- Rooting depth
- Soil type

Water potential for tracking water stress and scheduling irrigation



Describing the forces driving water movement from one place to another

- Water potential: A measure of the potential energy of water relative to pure water

- Measured in units of pressure
  - 1 bar = 0.1 MegaPascal (MPa)

- Pure water at room temp at sea level

  has Ψ_w = 0 bars = 0 MPa

$$\Psi_w$$



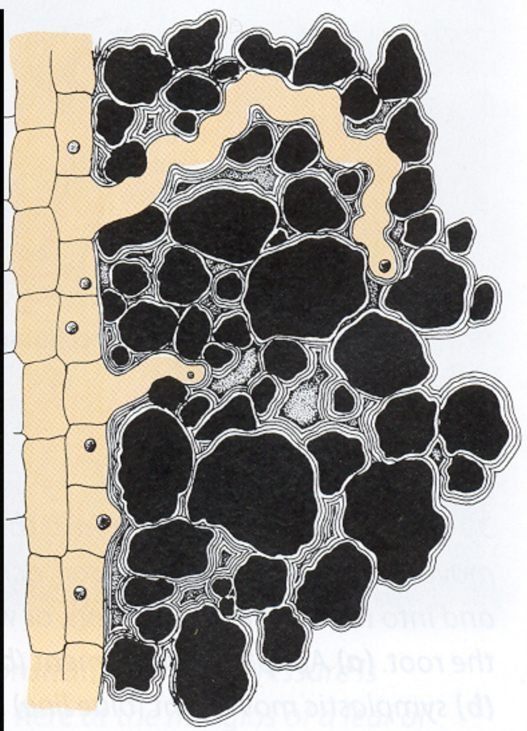
Describing the forces driving water movement from one place to another

- Water movement is driven by differences in Ψ_w and continues until equilibrium

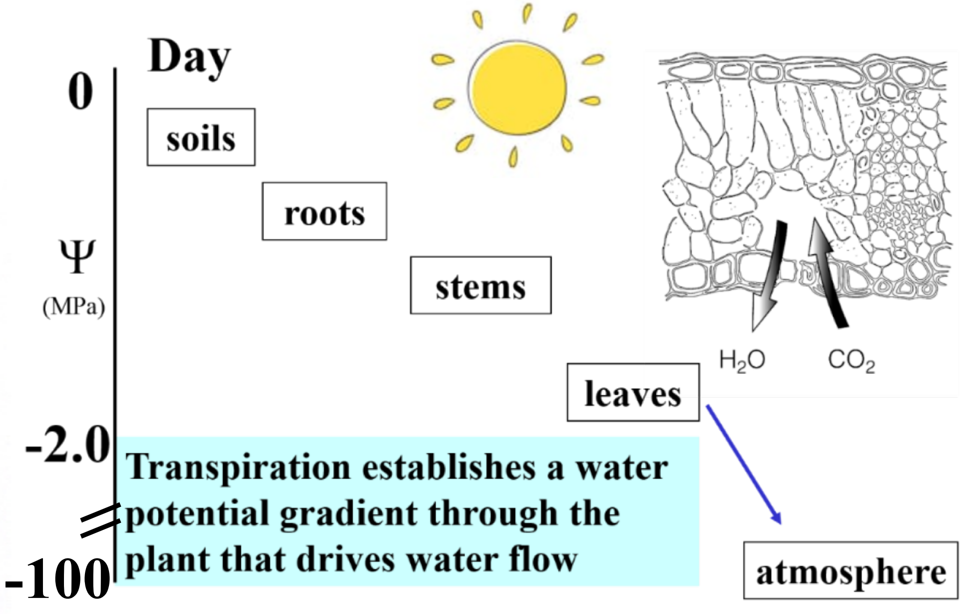
High Ψ_w ➔ Low Ψ_w

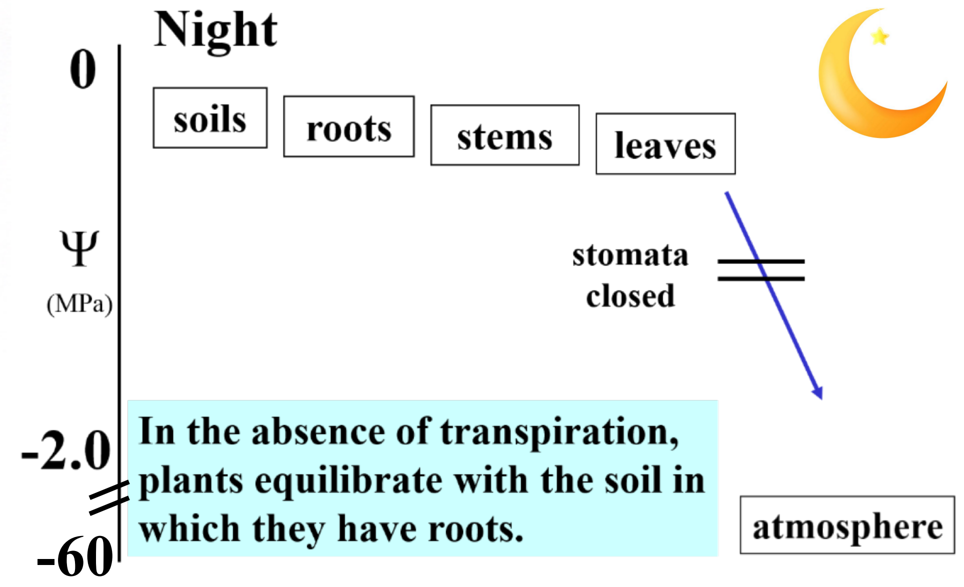
0 ➔ negative

The high end of the Ψ_w gradient: soil

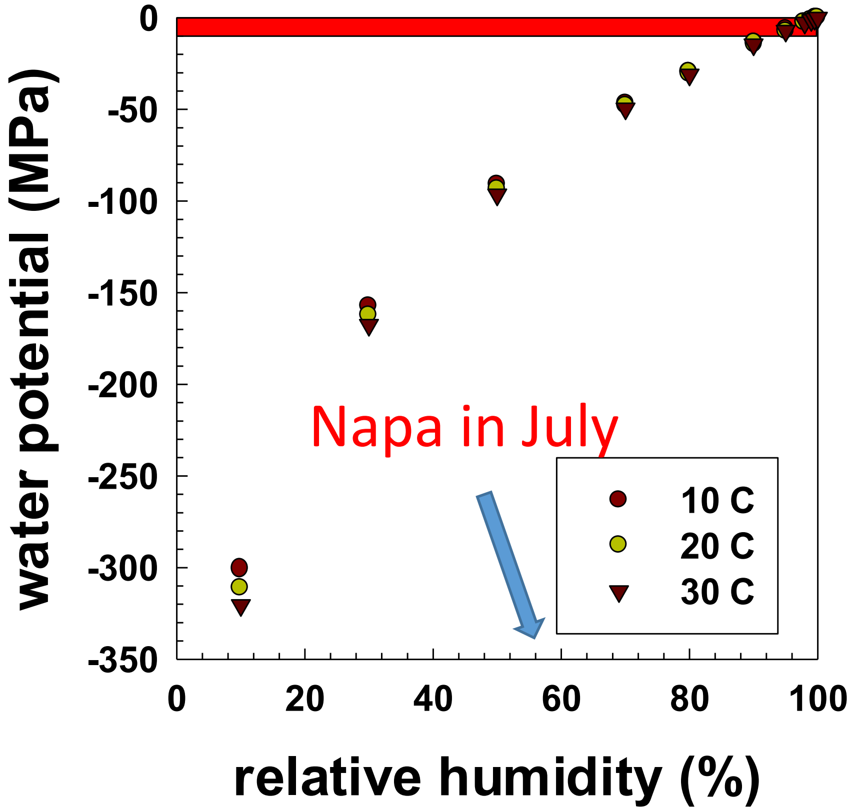


Soil Ψ_w defines the highest plant Ψ_w

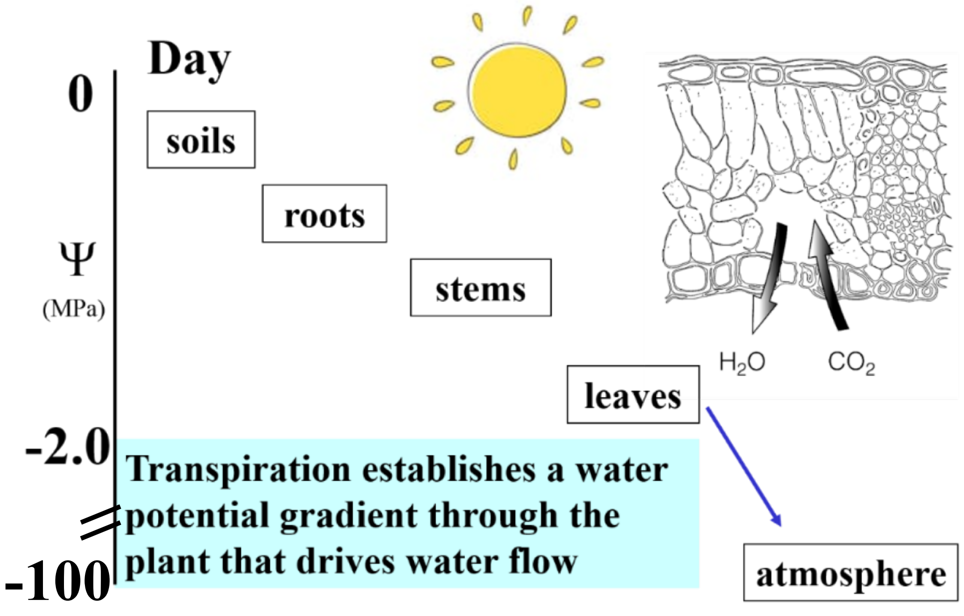


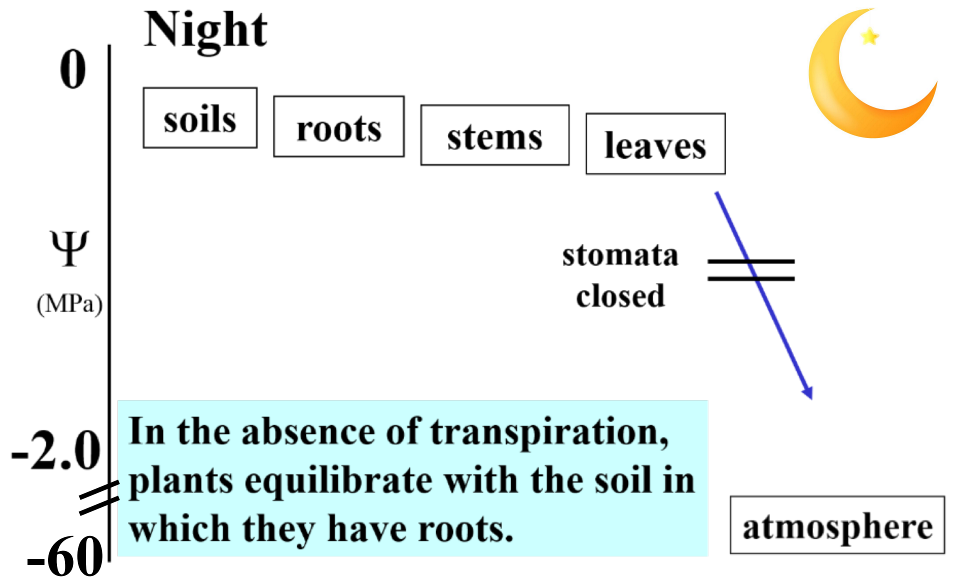


The low end of the Ψ_w gradient: air

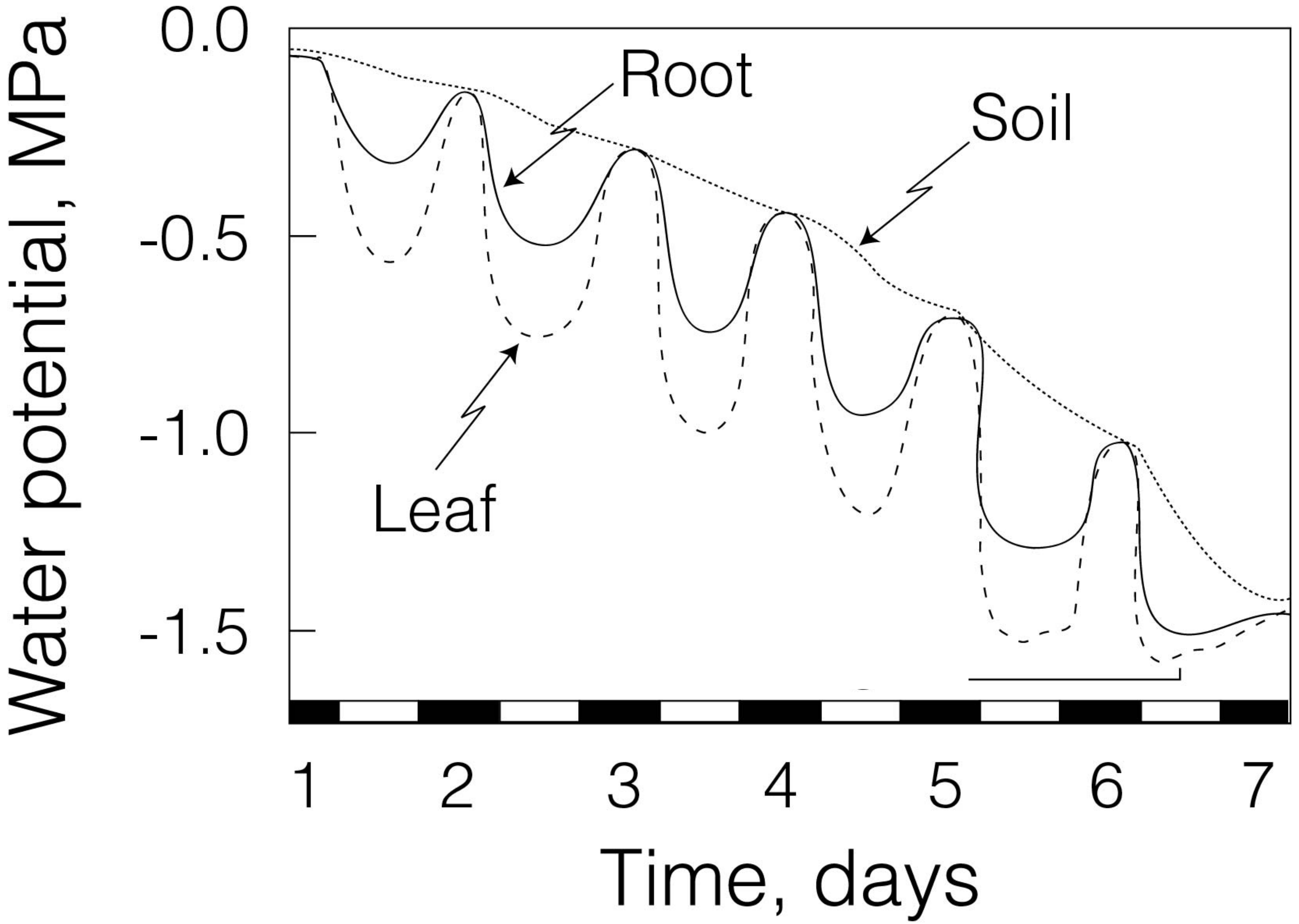


$$\Psi_{\text{water vapor}} = 135 \text{ MPa} \ln(RH/100)$$





Changes in Ψ as soil dries



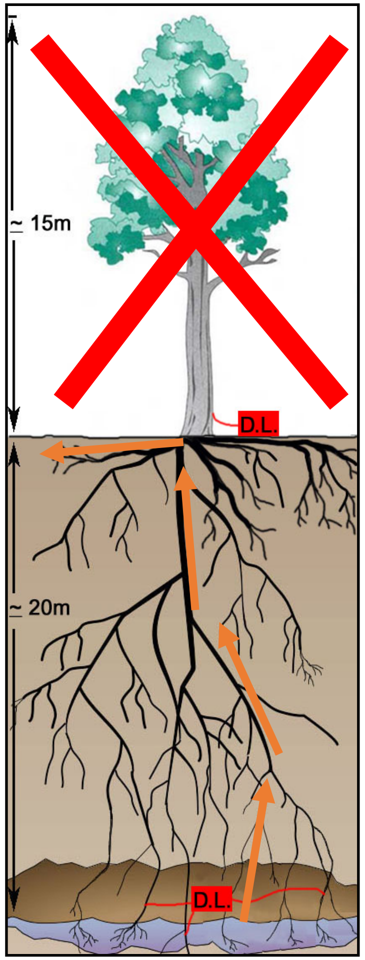
Hydraulic redistribution of deep water

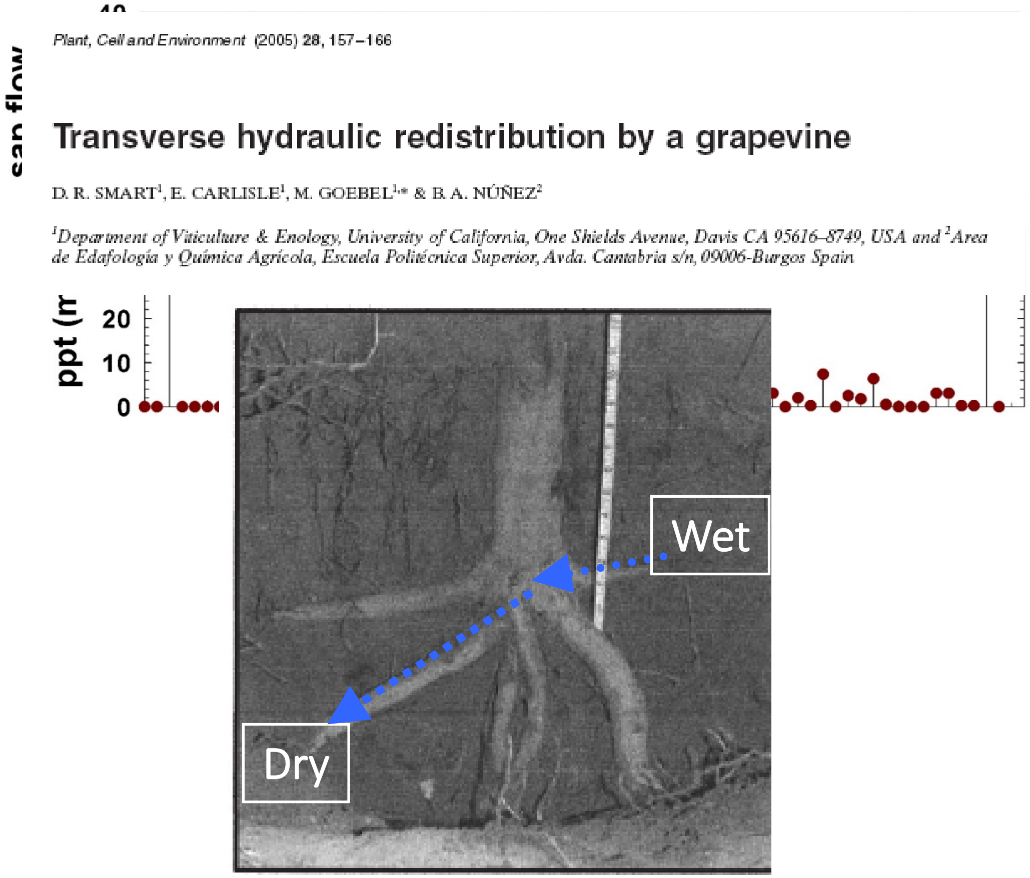
Not only from roots to leaves, but also from wet soil to dry soil via roots

e.g. deep water (Ψ_{high}) → shallow soil (Ψ_{low})

Occurs at night when primary gradient to leaves is absent

Night





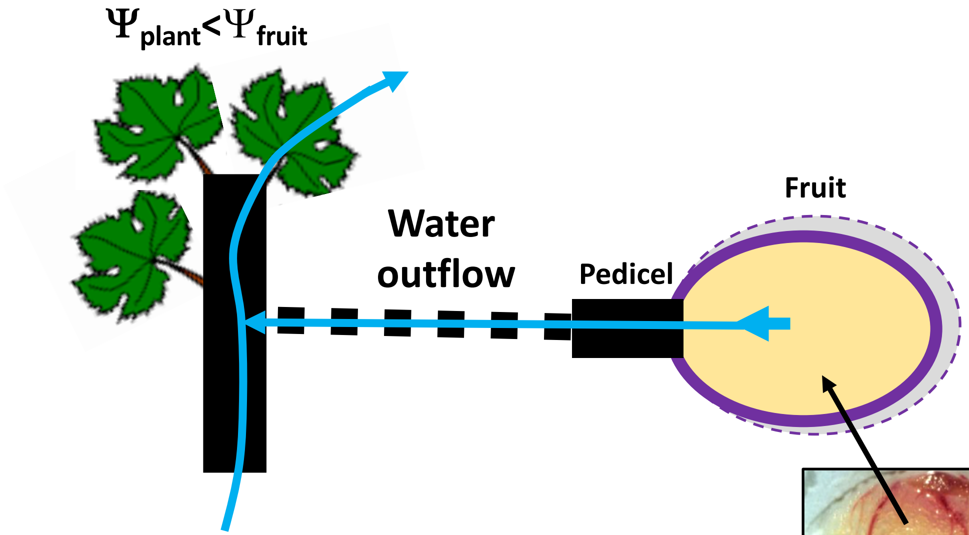
Plant, Cell and Environment (2005) 28, 157–166

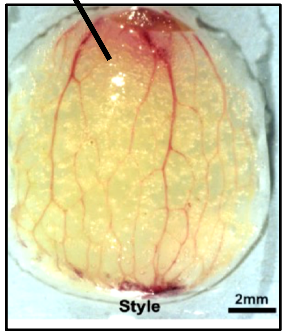
Transverse hydraulic redistribution by a grapevine

D. R. SMART[1], E. CARLISLE[1], M. GOEBEL[1,*] & B. A. NÚÑEZ[2]

[1]Department of Viticulture & Enology, University of California, One Shields Avenue, Davis CA 95616–8749, USA and [2]Area de Edafología y Química Agrícola, Escuela Politécnica Superior, Avda. Cantabria s/n, 09006-Burgos Spain

Berry dehydration post-verasion – Back flow





Berries remain hydraulically connected
(Chatelet et al. 2008)

Components of Water Potential

Gravitational

$$\Psi_w = \Psi_g +$$

effect of elevation of water in one place relative to another

Components of Water Potential

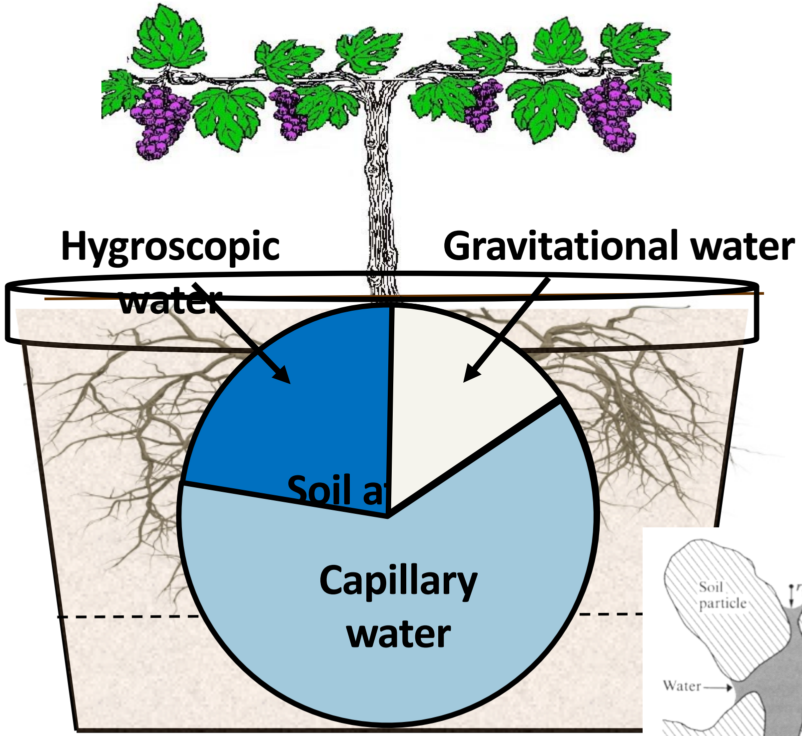
Gravitational

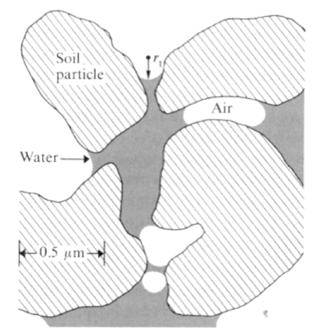
$$\Psi_w = \Psi_g + \Psi_m$$

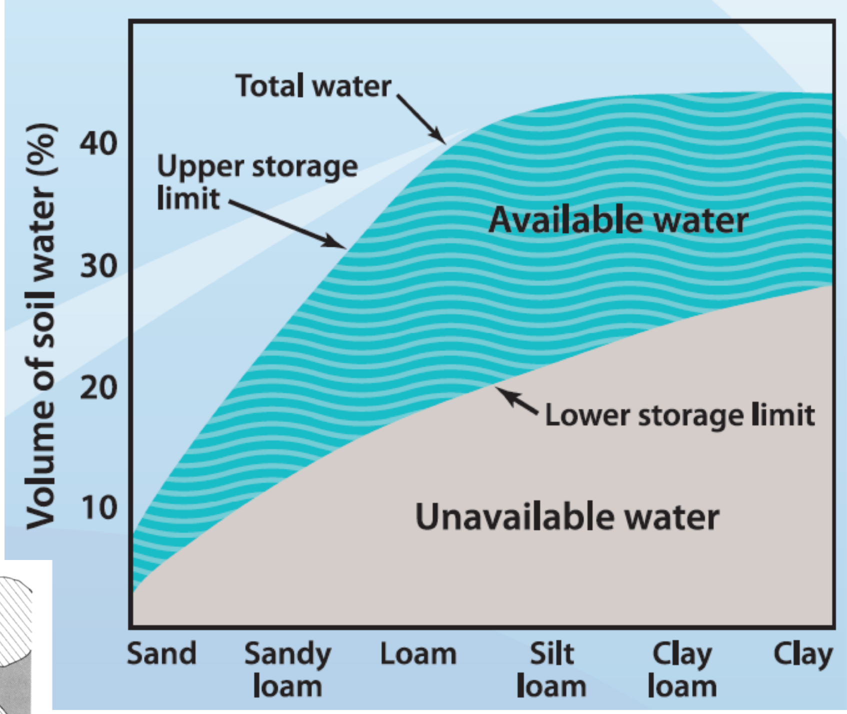
Matric

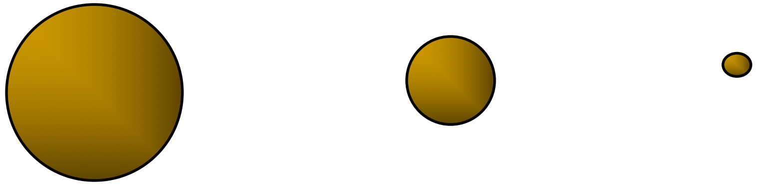
effect of interactions with small pores where water molecules are attracted surfaces

1) **Gravitational**- excess water in soil pores that drains out; **not available to plants**
2) **Capillary-** water left in soil pores after excess drains; held in place by surface tension; **amount available to plants**
3) **Hygroscopic-** water held at very high tensions; extracted with oven drying; **not available to plants**









Surface Area per Volume 6 600 6000

Components of Water Potential

Gravitational

Osmotic

$$\Psi_w = \Psi_g + \Psi_m + \Psi_\pi$$

Matric

effect of dissolved solutes

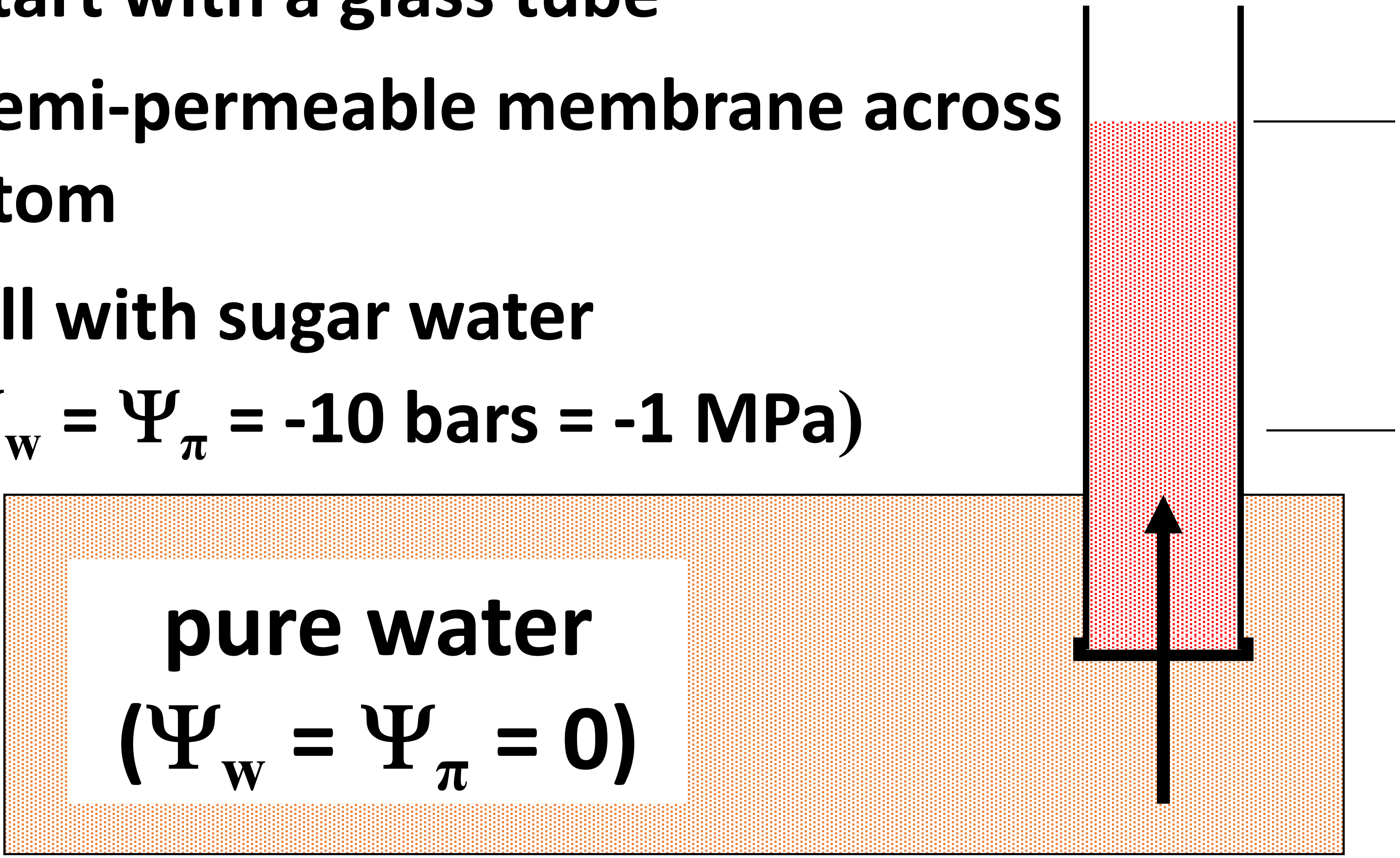
Example of Osmotic Potential

1. start with a glass tube

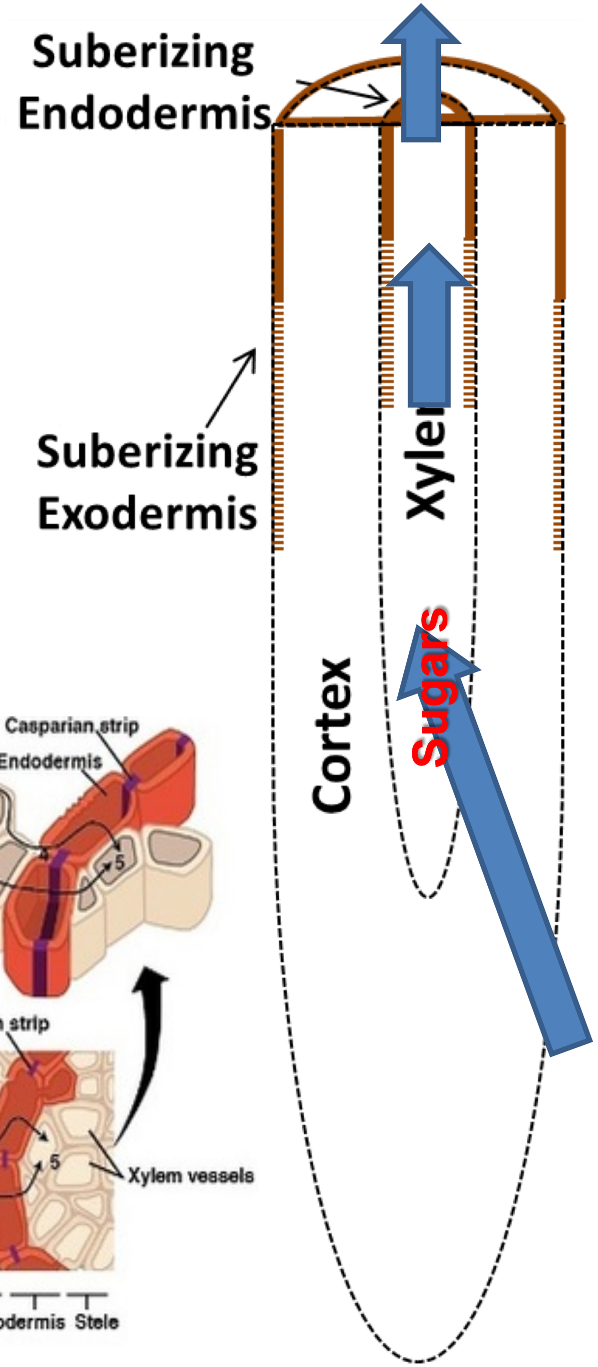
2. semi-permeable membrane across bottom

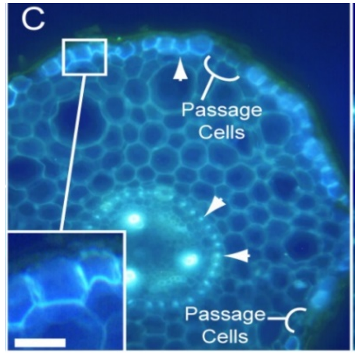
3. fill with sugar water

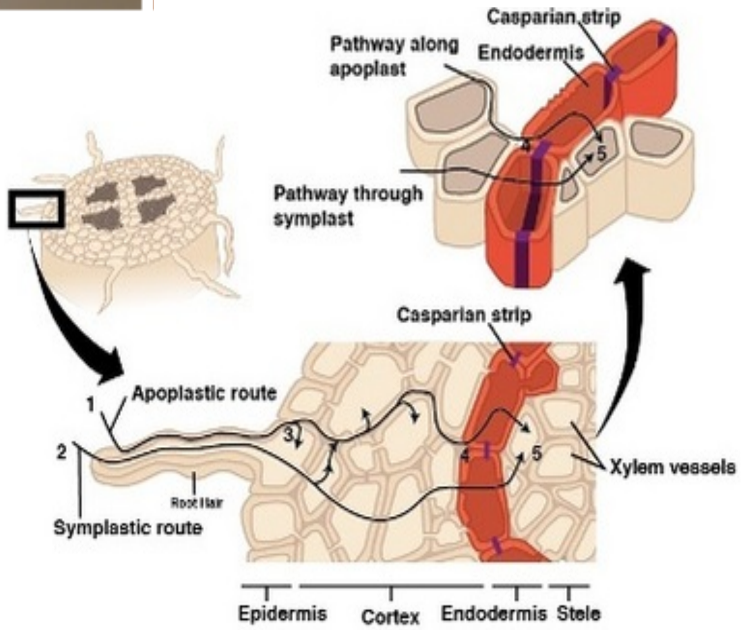
($\Psi_w = \Psi_\pi$ = -10 bars = -1 MPa)



Root pressure in grapevines

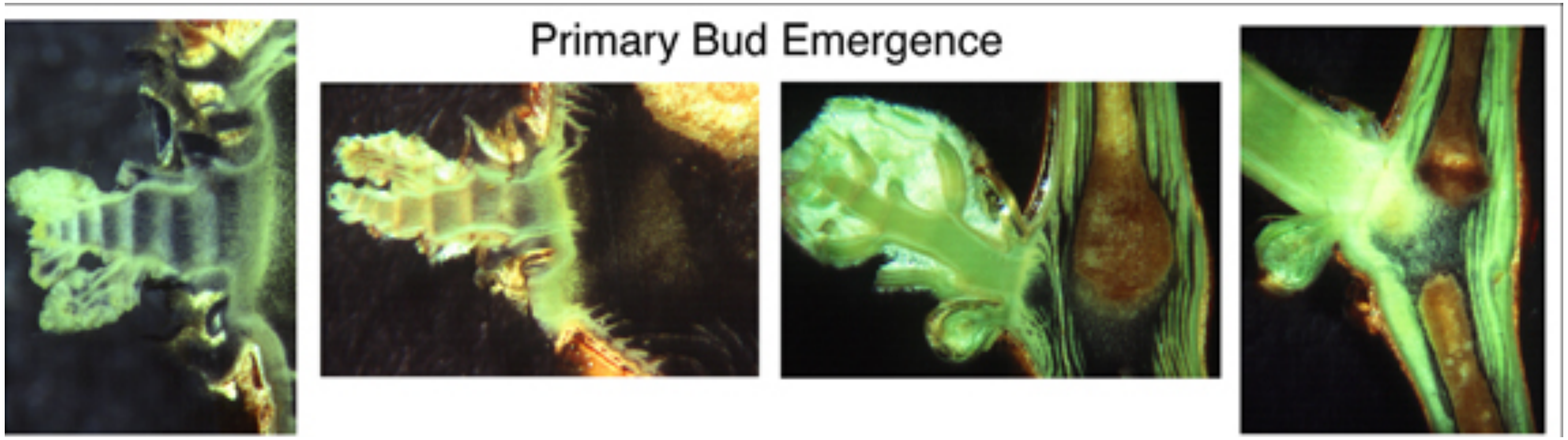






Root pressure in grapevines

- Signals activation of roots
- Rehydrate buds
- Deliver cytokinens from roots
- Refill cavitated vessels
- Provide sugar without phloem transport



Recent problems with bud break under drought in North Coast

- Root pressure only generates AFTER water becomes available again
- Fine root dehydration will disconnect the roots from the soil
- Plants are balancing canopy and root activity
- Fill soil profile in late winter to assure adequate push

Components of Water Potential

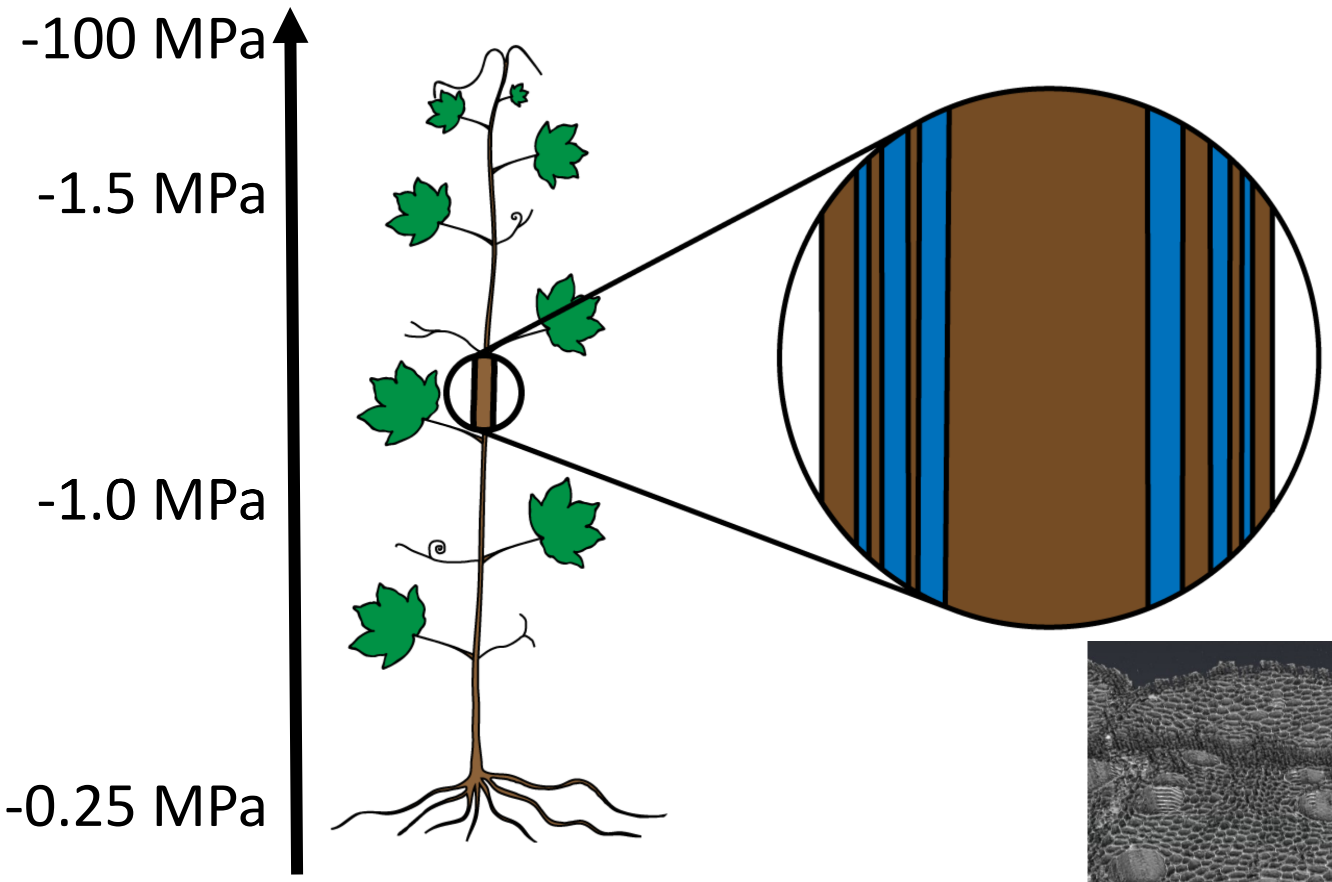
Gravitational Osmotic

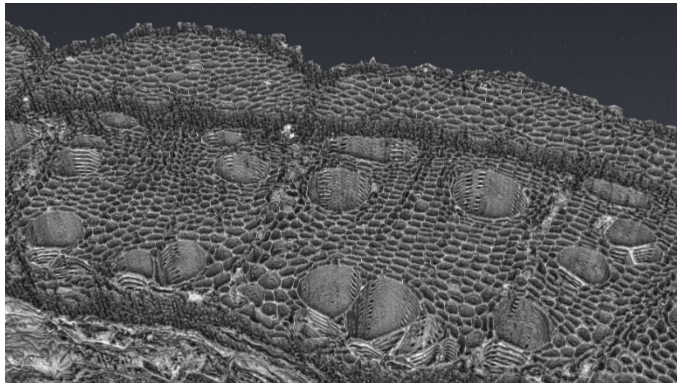
$$\Psi_w = \Psi_g + \Psi_m + \Psi_\pi + \Psi_p$$

Matric Pressure

- **The pressure of liquid water**
- **Zero at atmospheric pressure**
- **Can be positive (root pressure) or negative (tension)**

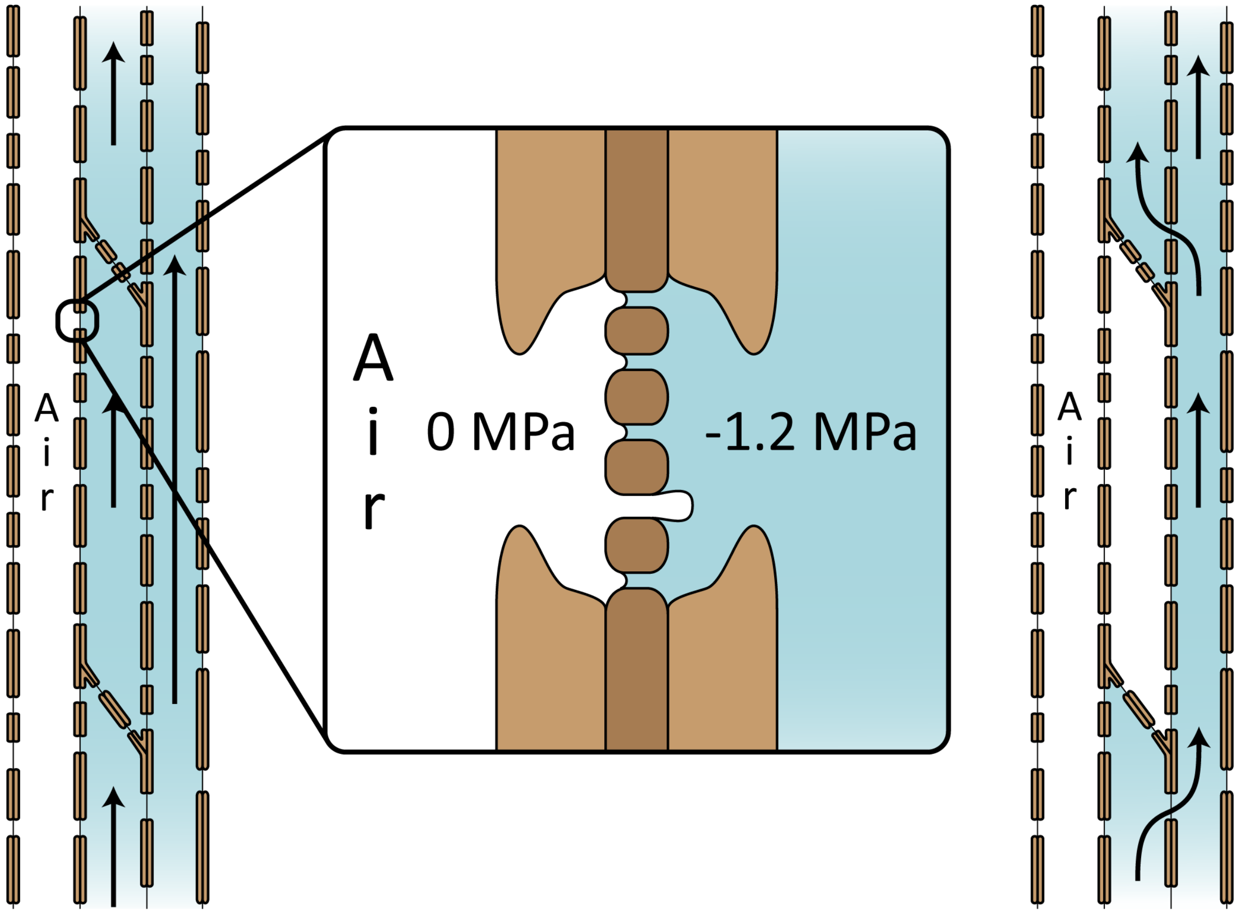
Cohesion-Tension Mechanism of Water Transport





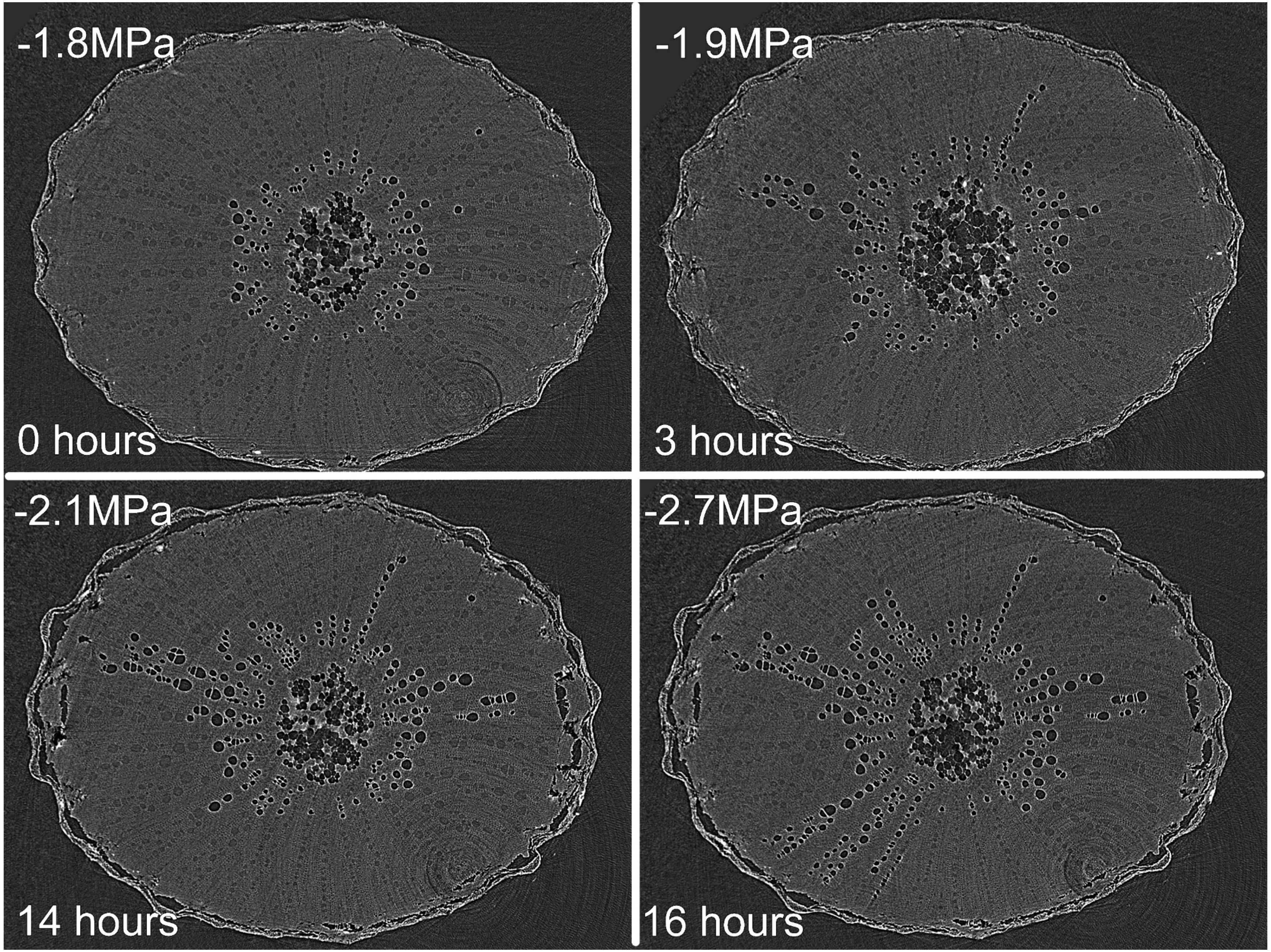
Driven by transpiration
Water is cohesive
Tension in continuous columns
Disrupted by cavitation

Embolism Propagation through Pit Membranes

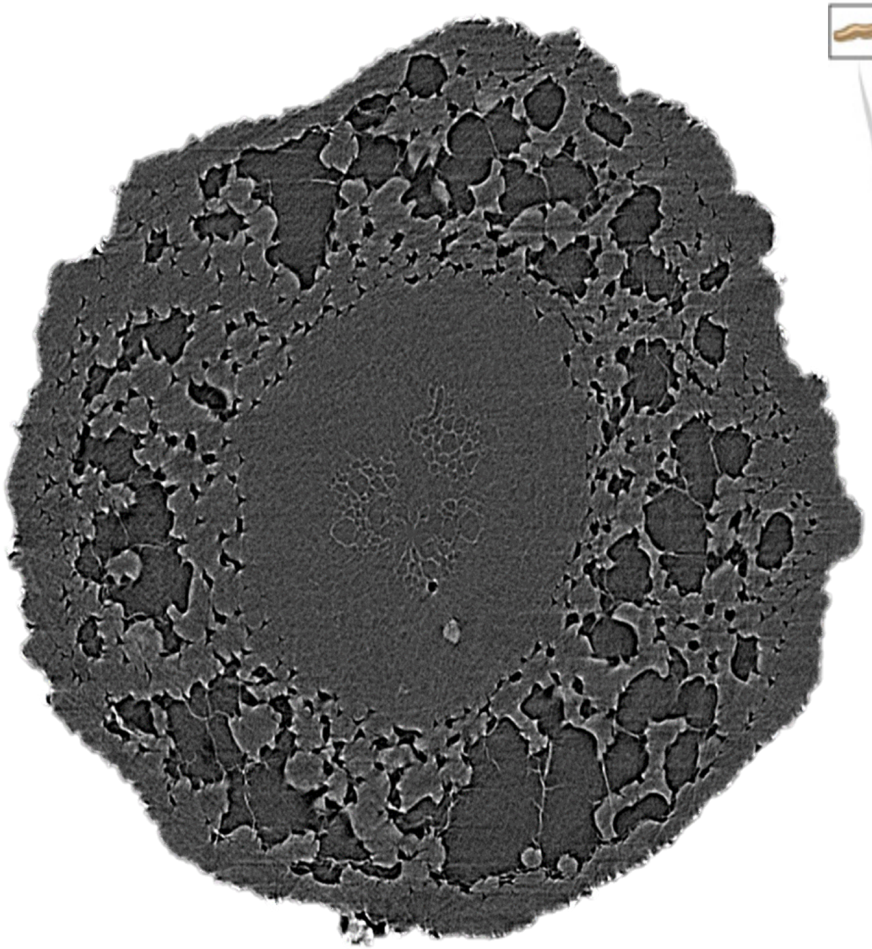


Grapevines were thought to be very susceptible to drought-induced embolism formation

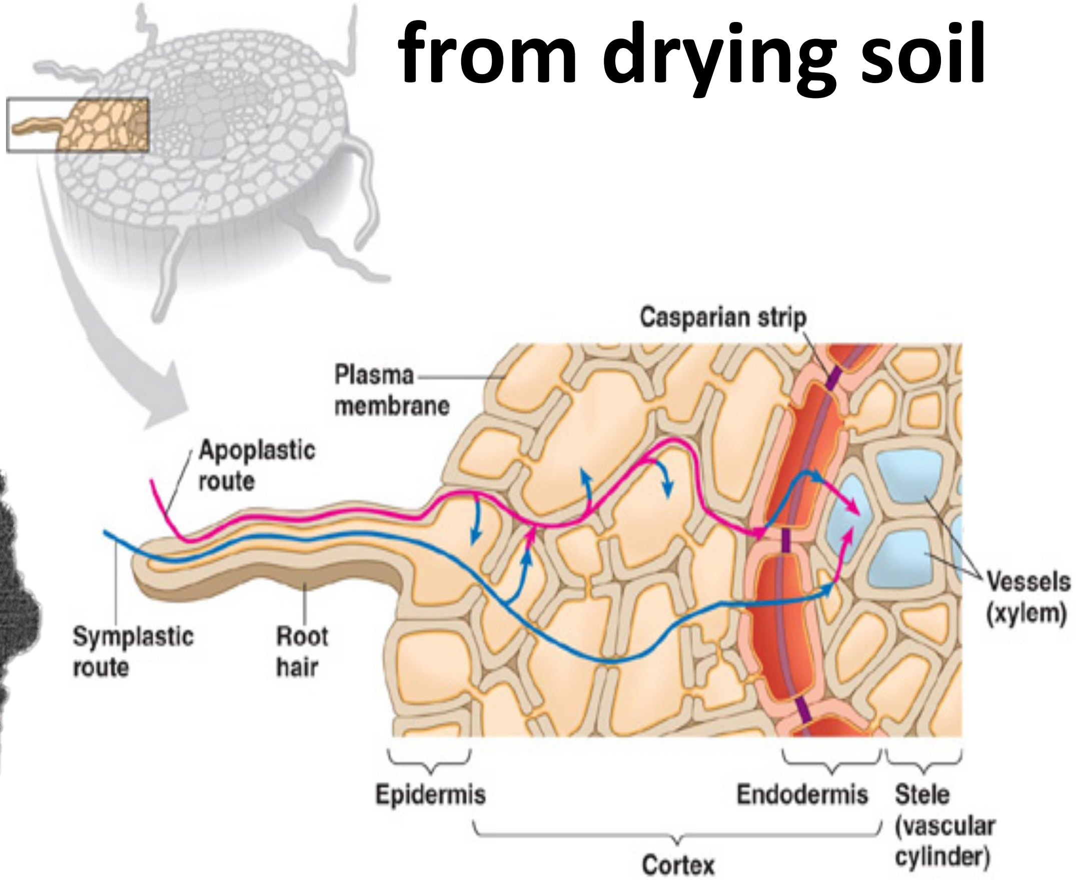
Drought-induced embolism blocks xylem vessels



Cortex disintegrates to disconnect fine roots from drying soil

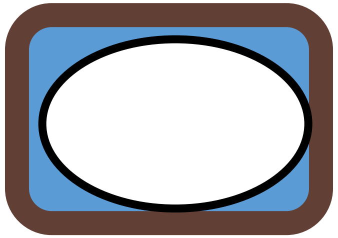


Cuneo *et al*. (2016)



Example of Osmotic & Pressure Potential

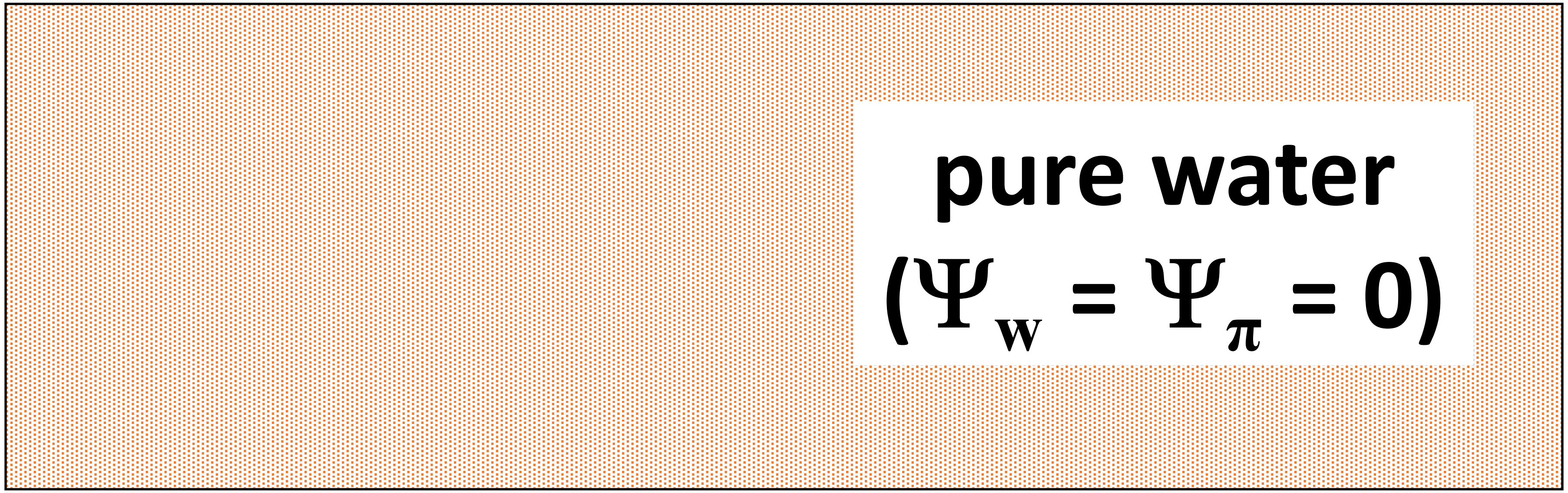
Plant cell with semi-permeable membrane and a cell wall



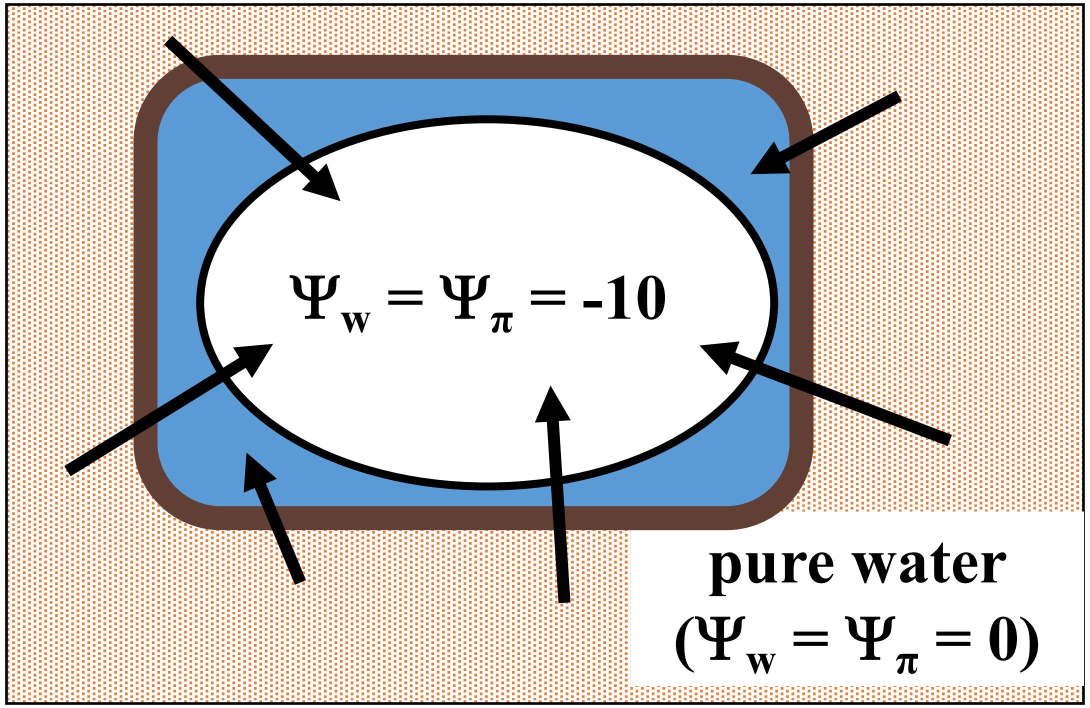
$\Psi_w = \Psi_\pi = -10$ bars

Drop the cell in pure water.

What happens?



Turgor: positive hydrostatic pressure in a cell



balance of outward pressure of cell membrane (osmotically driven water uptake) and of rigid cell wall pushing back

	Ψ_w	=	Ψ_p	+	Ψ_π
Pure Water	0	=	0		0
Cell	0	=	10		-10

at equilibration

(bars)

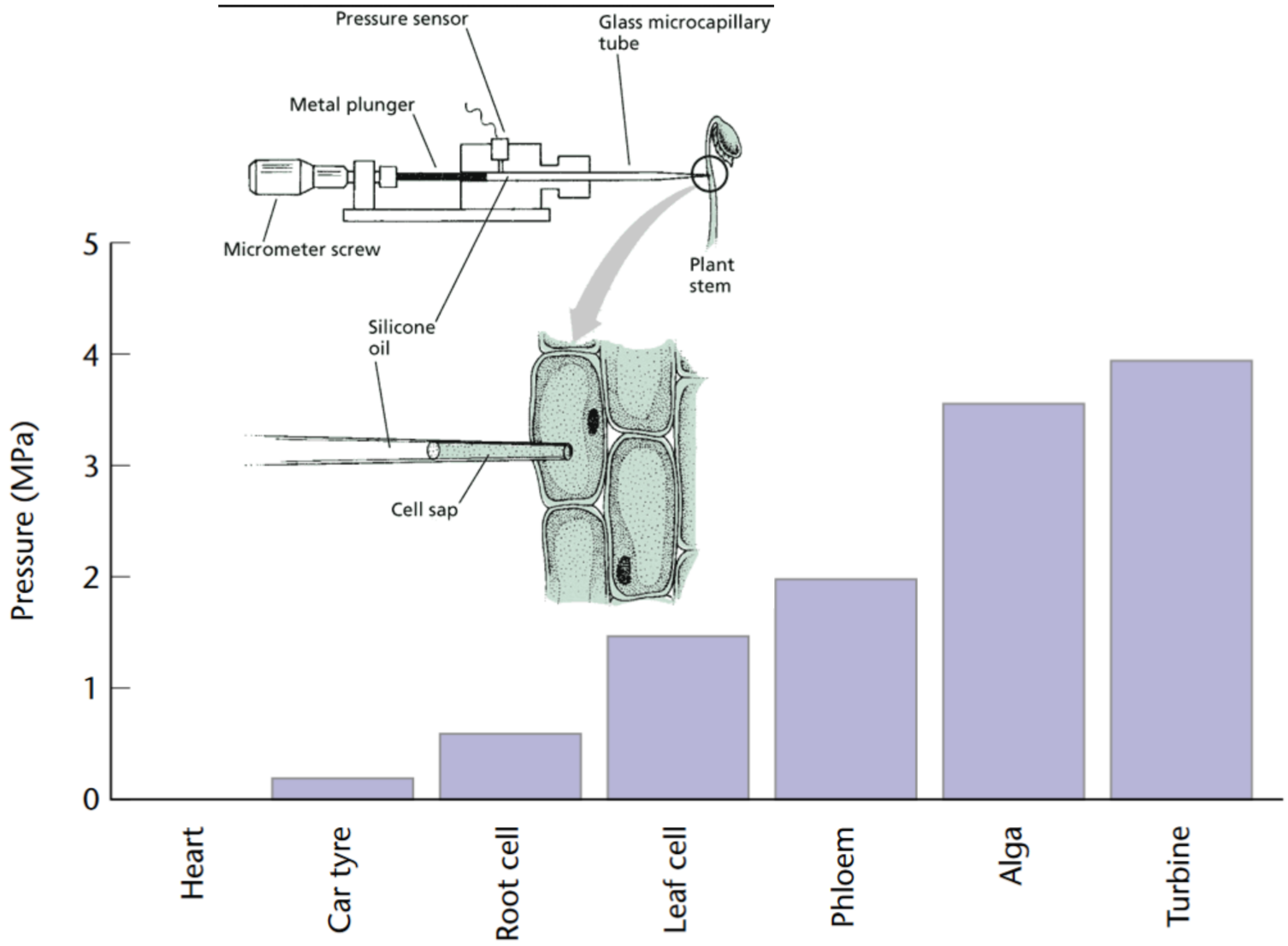
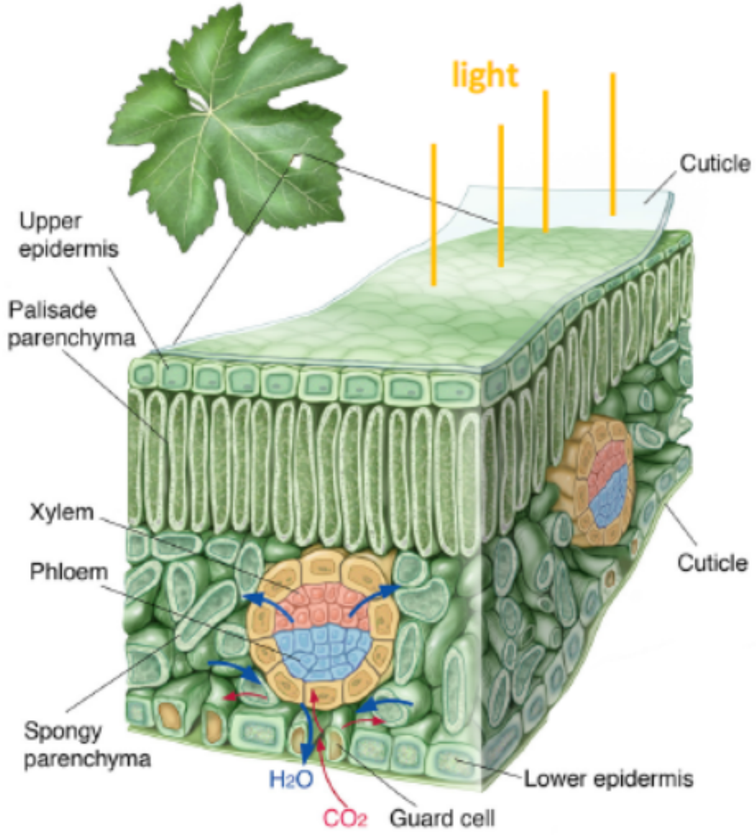
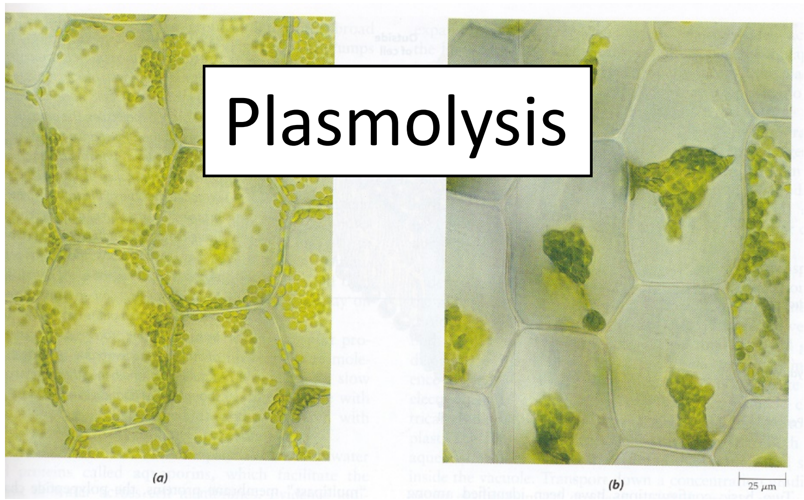


Figure 2 Approximate hydrostatic pressures (turgor) found in a range of situations for comparison with those in cells of vascular plants. Heart: pressure generated in animal circulation. Alga: pressures found in intertidal algae bathed in fresh water. Turbine: approximate pressures generated in the steam turbines of power stations.

Pritchard (2001)





Turgor loss in living cells

If Ψ_w *outside* lower than Ψ_π *inside*, water flows out of cell & turgor falls to zero

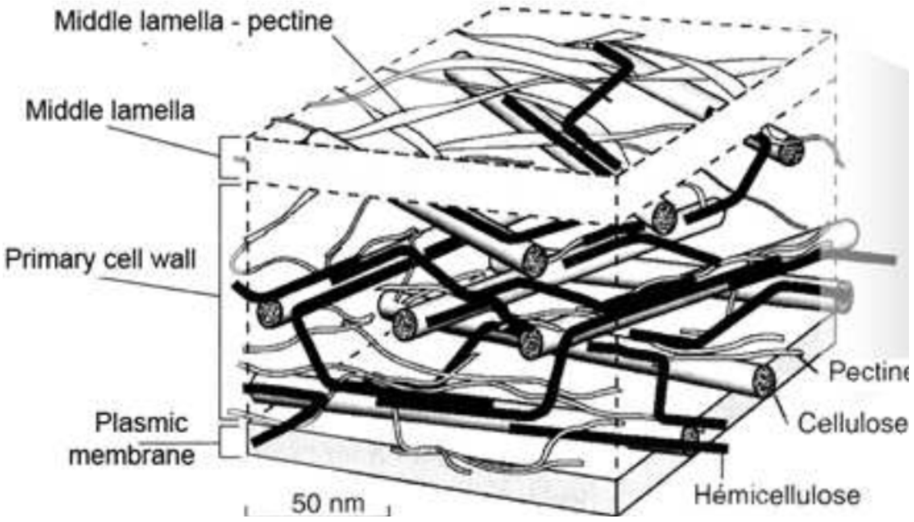
Osmoregulate to avoid turgor loss during drought

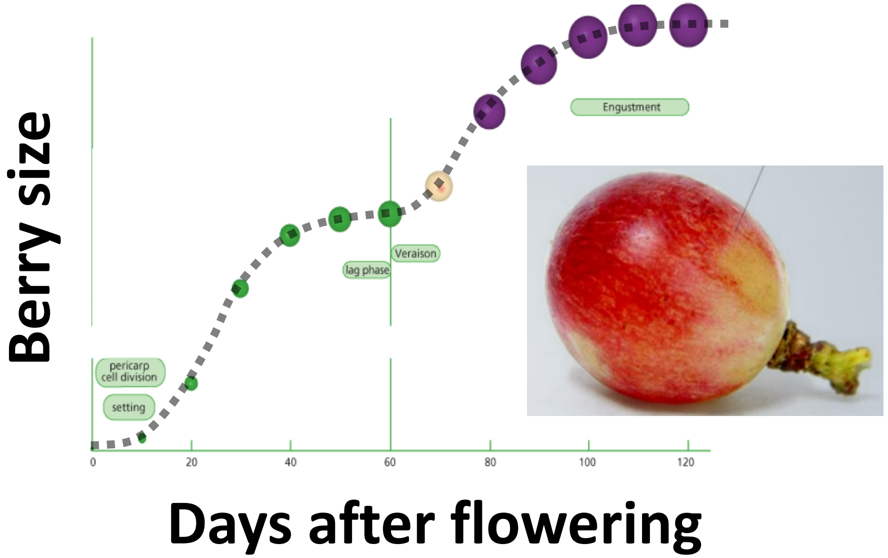
Time	Soil Ψ_w	Plant Ψ_w	Ψ_p	Ψ_π
1	-1 bar	-1 bar	11 bars	-12 bars
2	-7 bars	-7 bars	5 bars	-12 bars
3	-7 bars	-7 bars	13 bars	-20 bars
4	-14 bars	-14 bars	6 bars	-20 bars

- Active regulation of Ψ_π allows the cell to maintain turgor
- Grapevines can osmoregulate (Düring 1984)

Role of turgor pressure

1. Cell expansion

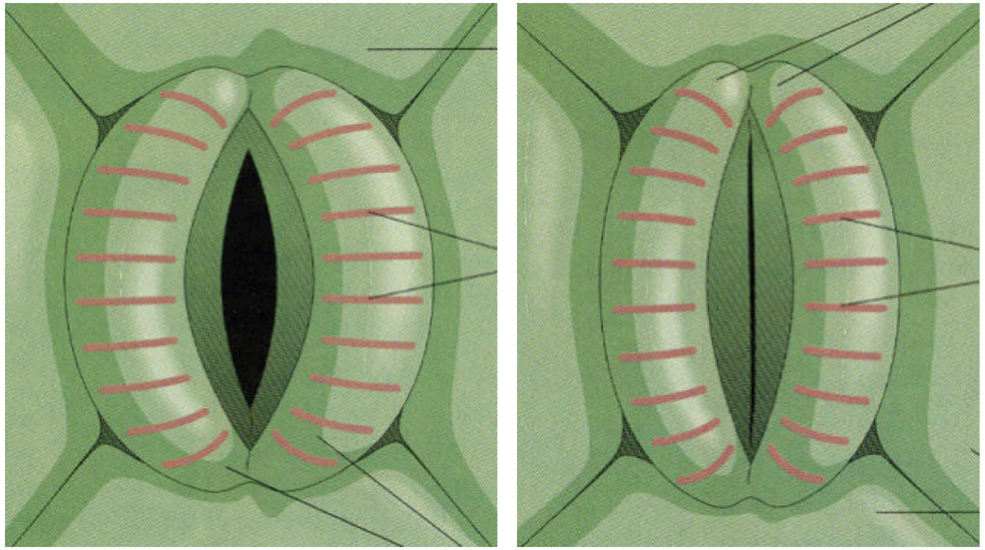




Role of turgor pressure

1. Cell expansion
2. Plant movements
   - Tropisms (gravity & sun), Nutation (tendrils)
3. Structure of herbaceous parts (Hydrostatic skeleton)
4. Stomatal opening and closing

Influx/efflux of K^+ into/out of guard cells induces rapid change in turgor



Pressure Flow Mechanism of Phloem

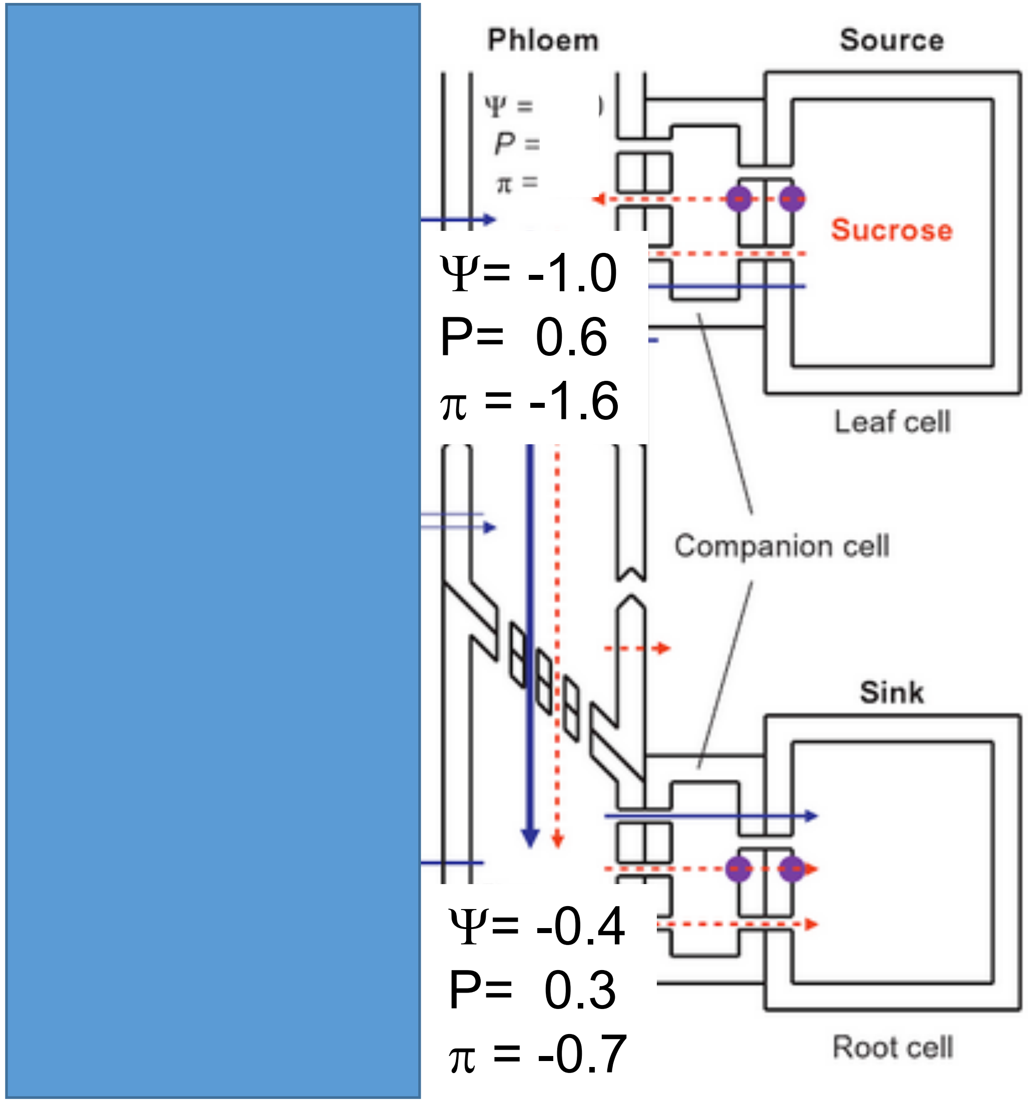


FIGURE 5.1

Schematic representation of the movement of phloem sap from regions of high pressure in a source to regions of low pressure in a sink. The purple circles represent solute transporters. All values are in MPa.

Modified after Evert (2006), Nobel (2009), and Taiz and Zeiger (2006).

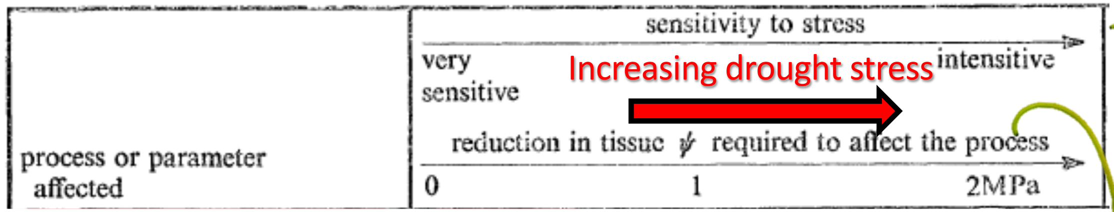
Deficit irrigation: what is it?

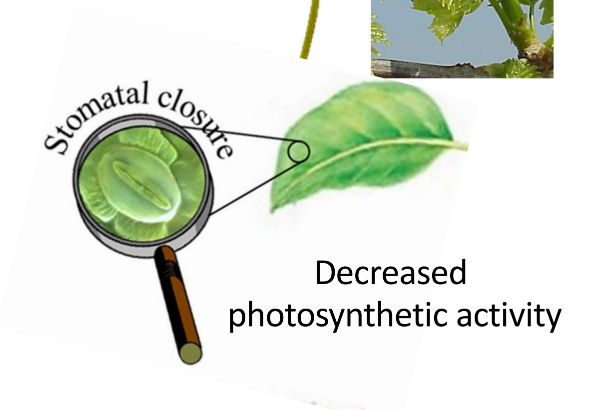
- an irrigation practice where a crop is purposefully supplied less water than its full requirement for optimal plant growth
- **Regulated deficit irrigation**- deficit irrigation strategy triggered by specific stress thresholds during certain phenological stages

Deficit irrigation: what are the benefits?

- Used to:
  - Reduce water use and associated costs
  - Improve fruit quality
  - Control excess vegetative growth
  - Reduce cost of hedging and multiple leaf removal
  - Reduce disease pressure
  - Shrink harvest window (Table grapes)
  - Reduce soil loss (runoff) and fertilizer loss (drainage)

Generalized Response of Plant Processes to Water Stress





Source: Hsiao (1973) *Ann Rev of Pl Phys*

- **Increased secondary metabolites**

Seasonal/Longer term responses:

- Decreased yield
- Leaf shedding
- Decreased bud fruitfulness

Summary

- Water relations are an integral part to vine health and productivity
- Irrigation allows you to manage most aspects
- Factors like rootstock, variety, soil, type, trellising, irrigation system, etc. must be considered

Ken Shackel's Pressure Bomb Videos

https://www.youtube.com/watch?v=8G9DjQxFkkY

https://www.youtube.com/watch?v=Xe9aWiD6vOw

Arturo Calderon's Video in Spanish

https://www.youtube.com/watch?v=83FXDi8Vkxg