Water relations in plants

Water is a main determinant of plant growth and yield

Types of water in plants
- apoplastic (outside the cells)
- symplastic (inside the cells)
  - in cytoplasm
  - in organelles

The roles of vacuoles
- regulation of solute and salt content
- storage of sugars for osmotic regulation

The water content of plant parts depends on
- species or cultivar
  - xerophiton, drought sensitive – drought tolerant
  - woody – herbaceous
- type and age of tissue
  - meristem, young or ageing

Changes of water content at different ages of corn
1. vegetative growth
2. flowering
3. seed set
4. ripening

The ways water is transported in plants
- diffusion
- bulk flow
- osmosis
How can water cross plasmamembranes?
- slow diffusion through lipid bilayers
- water selective channels (aquaporins)

\[ \Psi_w = \Psi_s + \Psi_p + \Psi_m + \Psi_g \]

**Water potential**

Chemical potential (free enthalpy) per unit volume of water (\( \Psi, \text{pszi} \))

\[ \Psi_w = \Psi_s + \Psi_p + \Psi_m + \Psi_g \]

- \( \Psi_s \) - osmotic
- \( \Psi_p \) - pressure
- \( \Psi_m \) - matrix
- \( \Psi_g \) - gravitational potentials

**Water potential:**
- determines the direction of water movement
- describes the water status of the plant
- generally, calculation with \( \Psi_s + \Psi_p \) is sufficient

**\( \Psi \) of air**
- 100 % RH 0 bar
- 90 % > -141 bar
- 50 % > -933 bar
- open air in summer < 50 % < -1000 bar

**\( \Psi \) and water movement in plants**
- from higher \( \Psi \) to lower \( \Psi \)

Potential exemption: bulk flow

**Water potential gradient through a plant**

**Flow of water through the plant**
- to lower \( \Psi \)
- from higher \( \Psi \)
Water in the soil

Water uptake by the roots

Root pressure
- lacrimation (on cut surfaces)
- guttation (from hydatodes)

Root has minor contribution to sap flow

Transpiration, the cohesion-tension theory

The major driving force for water movement in plants is tension derived from transpiration and transmitted by cohesion of water molecules.

3 phases of transpiration
- vaporization
- diffusion
- getting through the stomata
Effect of the wind

Transpiration depends on
- area of transpiring surface, stomatal density
- dRH
- diffusional resistances

Diffusional resistances
- resistance of stomata
- resistance of boundary layer

The thickness of boundary layer depends on
- wind
- appendices on leaves
- morphology of stomata
- position of leaves
- canopy structure

Stomata

Special epidermal cells:
- unique cell wall morphology
- contain chloroplast
- strong osmo- and turgor regulation
- role of K⁺ and Cl⁻/malate ions

open stomata
- photosynthesis
- water loss

closed stomata
- no photosynthesis
- water retained

Stomatal movements

Stomata open
- good water supply
- light (blue light receptors)
- low CO₂ concentration within the leaf
- high RH outside
- diurnal rhythm

Stomata close
- drought
- dark
- high CO₂ concentration within the leaf
- low RH outside
- diurnal rhythm
- abscisic acid (ABA)

Mechanisms and regulation of fast stomatal movements
Slow metabolic changes may also affect stomatal function

In the dark: starch accumulates (osmotically inactive)
- high water potential, stomata close

In the light: sugars are composed from starch and by photosynthesis, or taken up from surrounding cells (osmotically active)
- low water potential, stomata open

Saccharose may contribute significantly to stomatal opening

Peristomal transpiration
- through the wax layer of the cuticle
- not quickly adjustable
- depends on e.g. water supply, age, available N, light conditions

Wild type and wax overproducer alfalfa plants after 3 cycles of drought/rewatering

Cavitation
Temperature change forecast to the 2071-2100 period, relative to the 1961-1990 period.

Water stress and its consequences in plants

Osmotic stress induces ABA biosynthesis

Compartmentisation of ABA plays a role in the stress response

Tha notabilis ABA mutant tomato shows wilt phenotype
Physiological consequences of water loss

<table>
<thead>
<tr>
<th>Physiological change</th>
<th>Tissue water potential</th>
<th>( \Psi_t )</th>
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<tbody>
<tr>
<td>Growth ( - )</td>
<td>-</td>
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<td>Cell wall thick ( - )</td>
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<tr>
<td>Protein synth. ( - )</td>
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<tr>
<td>Nitrate reductase ( + )</td>
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<td>ABA level ( + )</td>
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<td>Stomatal aperture ( - )</td>
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<tr>
<td>Photosynthesis ( - )</td>
<td>-</td>
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</tbody>
</table>

Physiological change

Water stress reduces transpirational cooling

Water stress tolerance of plants

Responses to osmotic stress (drought, salt, cold)

- escape
- avoidance
  - water saving
  - dynamic morphological changes (leaf tilting, curling, dropping)
- tolerance (allows water spending)
  - osmotic adjustment
  - chaperon activity
  - other molecular defences

Morphological traits influence drought hardiness

Acclimation – at the plant level
Adaptation – at the species level

Young cotton plants shedding leaves after different levels of water stress
Osmotic adjustment occurs in maize but not soybean during the day.

**Protective compounds in response to water stress**
- prolin
- trehalose, sucrose, sorbitol, inositols, mannitol
- glycin-betaine

**Proteins with protective function against water stress**
- LEA proteins (e.g. dehydrins)
- chaperons (e.g. HSPs)
- enzymes for detoxification

**Consequences of drought can be measured with instruments**
- infrared thermography
- chlorophyll fluorescence
- photosynthetic activity
- porometry

**Strategies for engineering osmotic stress tolerance**
- Overexpression of antioxidant enzymes
- detoxifying enzymes of osmolyte production
- appropriate regulators (transcription factors)
- specific signal transduction components
- enzymes affecting membrane lipid composition

Changing expression of a protein (ERA1) involved in ABA signalling improves drought tolerance of canola.
Overproduction of trehalose in tobacco

wild + trehalose phosphate synthase (TPS)