

**Lecture 20\_2:**

**Abiotic stresses**

**Salinity**

**Osmotic stress**

**Osmotic adjustment  
(drought, salinity, osmotic stress)**

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**Salinity stress**

- Under natural conditions, terrestrial higher plants encounter high concentrations of salts close to the seashore and in estuaries where seawater and freshwater mix or replace each other with the tides.
- Far inland, natural salt seepage from geologic marine deposits can wash into adjoining areas, rendering them unusable for agriculture.
- Big problem in agriculture: accumulation of salts from irrigation water.
- Evaporation and transpiration remove pure water (as vapor) from soil  
→ water loss concentrates solutes in soil
  - when irrigation water contains a high concentration of solutes and when there is no opportunity to flush out accumulated salts to a drainage system, salts can quickly reach levels that are injurious to salt-sensitive species
  - estimate: ~ 1/3 of irrigated land on Earth is affected by salt

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**Salt accumulation in soils impairs plant function and soil structure**

**Effects of salts in soil:**

**Sodicity**

High concentrations of Na<sup>+</sup>

Can injure plants directly and degrade soil structure, decreasing porosity and water permeability

Sodic clay soil (caliche) is so hard and impermeable that dynamite is required to dig through it

**Salinity**

High concentrations of total salts

Ca<sup>2+</sup>, Mg<sup>2+</sup>, SO<sub>4</sub><sup>2-</sup>, NaCl can contribute substantially to salinity

Salinity of soil water or irrigation water measured in terms of its electrical conductivity or osmotic potential.

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### Salt accumulation in soils impairs plant function and soil structure

#### Properties of seawater and of good quality irrigation water

Property	Seawater	Irrigation water
Concentration of ions (mM)		
Na <sup>+</sup>	457	<2.0
K <sup>+</sup>	9.7	<1.0
Ca <sup>2+</sup>	10	0.5–2.5
Mg <sup>2+</sup>	56	0.25–1.0
Cl <sup>-</sup>	536	<2.0
SO <sub>4</sub> <sup>2-</sup>	28	0.25–2.5
HCO <sub>3</sub> <sup>-</sup>	2.3	<1.5
Osmotic potential (MPa)	-2.4	-0.039
Total dissolved salts (mg L <sup>-1</sup> or ppm)	32,000	500

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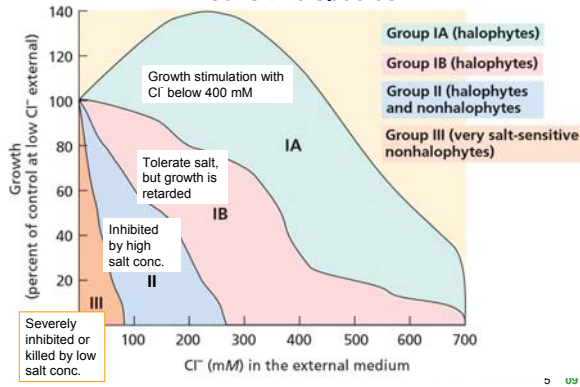
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### Salinity depresses growth and photosynthesis in sensitive species



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### Salinity depresses growth and photosynthesis in sensitive species



Townsend's cordgrass (*Spartina x townsendii*)  
Sugar beet (*Beta vulgaris*)

Sea blite (*Suaeda maritima*)  
Salt bush (*Atriplex nummularia*)

Group IA (halophytes)

Group IB (halophytes)

Group II (halophytes and nonhalophytes)

Group III (very salt-sensitive nonhalophytes) Fruit trees

**Halophytes** (grasses that lack salt glands):  
*Festuca rubra*,  
*Puccinellia peisonis*

**Nonhalophytes:**  
cotton, barley

Red fescue (*Festuca rubra*)



*Suaeda maritima*



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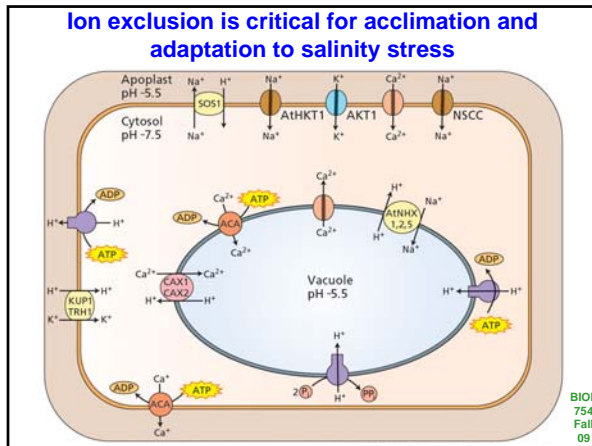
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### Ion exclusion is critical for acclimation and adaptation to salinity stress

**Membrane transport proteins mediating Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup> transport during salinity stress**

SOS1 = plasma membrane Na<sup>+</sup>/H<sup>+</sup> antiporter  
 ACA = plasma/tonoplast membrane Ca<sup>2+</sup>-ATPase  
 KUP1/TRH1 = high-affinity K<sup>+</sup>-H<sup>+</sup> co-transporter  
 atHKT1 = sodium influx transporter  
 AKT1 = K<sub>in</sub> channel  
 NSCC = non selective cation channel  
 CAX1/2 = Ca<sup>2+</sup>/H<sup>+</sup> antiporter  
 atNHX1/2/5 = endomembrane Na<sup>+</sup>/H<sup>+</sup> antiporter

Plasma membrane and tonoplast Ca<sup>2+</sup> channel proteins and vacuolar proton-pumping ATPases and pyrophosphatases may also play a role.

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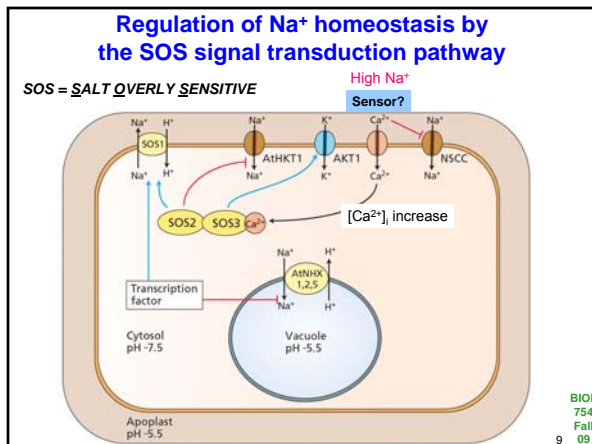
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### Osmotic stress changes gene expression

- Accumulation of solutes due to water deficit or salinity stress causes osmotic stress
- Several genes coding for enzymes associated with osmotic adjustment are **up-regulated** by osmotic stress and/or salinity
  - pyrroline-5-carboxylate synthase, a key enzyme in the proline biosynthetic pathway
  - betaine aldehyde dehydrogenase, an enzyme involved in glycine betain accumulation
  - myo-Inositol 6-O-methyltransferase, a rate-limiting enzyme in the accumulation of the cyclic sugar alcohol pinitol
  - glyceraldehyde-3-phosphate dehydrogenase to allow an increase in carbon flow into organic solutes for osmotic adjustment

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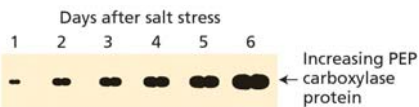
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### Osmotic stress changes gene expression

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  - increase in phosphoenolpyruvate (PEP) carboxylase in ice plant (*Mesembryanthemum crystallinum*) during the salt-induced shift from C<sub>3</sub> metabolism to CAM



Salt stress was induced by the addition of 500 mM NaCl to the irrigation water. Detection of PEP protein by Western Blot analysis.

- also induction of pyruvate-orthophosphate dikinase and NADP malic enzyme

**Osmotic stress induces CAM in some plants – CAM is a remarkable adaptation to water deficit.**

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- Several genes coding for enzymes associated with osmotic adjustment are **up-regulated** by osmotic stress and/or salinity.
  - **LEA proteins** (LATE EMBRYOGENESIS ABUNDANT) discovered by examination of naturally desiccating embryos during seed maturation
    - play role in cellular membrane protection, although function is not well understood
    - accumulate in vegetative tissue during osmotic stress
    - hydrophilic proteins, strongly binding water (protective role may be associated with ability to retain water and to prevent crystallization of cellular proteins and other molecules during desiccation)

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### Osmotic adjustment – Tolerance to drought, salinity and osmotic stress

- **Osmotic adjustment**
  - a biochemical mechanism that helps plants acclimate to dry and saline conditions
- Many drought-tolerant plants can regulate their solute potentials to compensate for transient or extended periods of water stress by making osmotic adjustments, which results in a net increase in the number of solute particles present in the plant cell.

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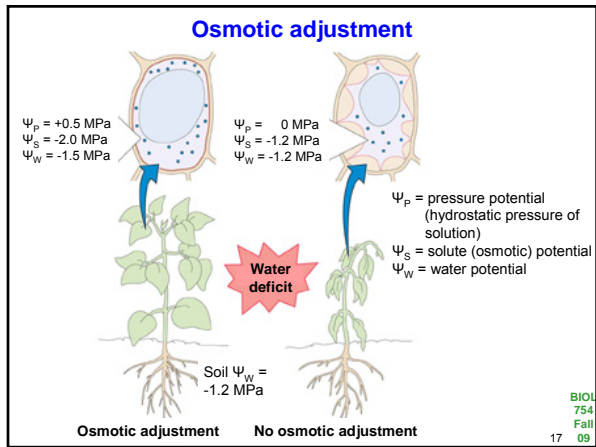
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### Osmotic adjustment

- Osmotic adjustment occurs when the concentrations of solutes within a plant cell increases to maintain a positive turgor pressure within the cell.
- The cell actively accumulates solutes and as a result the solute potential ( $\Psi_s$ ) drops, promoting the flow of water into the cell.
- Osmotic adjustments are believed to play a critical role in helping plants acclimate to drought or saline conditions.

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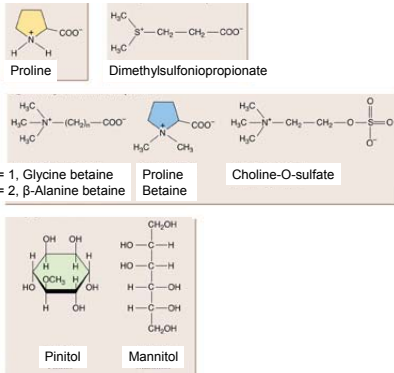
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## Solutes that contribute to osmotic adjustments



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## Proline & glycine betaine

- Glycine betaine accumulation in osmotically stressed plants results from increased rates of synthesis, whereas, with proline, synthesis and catabolism appears to be co-ordinately regulated in response to water stress.
- Glycine betaine is synthesised and accumulated by many algae and higher plants and is not broken down by plants.
- Genetic evidence indicates that accumulation of glycine betaine promotes salt tolerance.

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## Mannitol

- Mannitol = the reduced form of the sugar mannose; broadly distributed among plants.
- Salt stress inhibits sucrose synthesis and promotes accumulation of mannitol.
- Mannitol concentrations increase in response to osmotic stress.
- Mannitol accumulation appears to be regulated by competing pathways and decreasing rates of mannitol consumption and catabolism.

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### D-Pinitol

- Cyclic sugar alcohol, is a major solute in members of the Pine Family and Bean Family.
- Its concentrations are higher among halophytic species and those adapted to drought.
- In leaves, pinitol is localized to the chloroplast and cytosol but not in the vacuoles.

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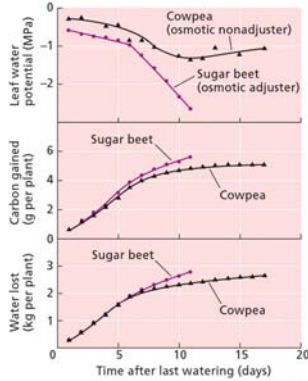
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### Osmotic adjustment promotes dehydration tolerance but does not have a major effect on productivity



Water loss and carbon gain by sugar beet, an osmotically adjusting species, and cowpea, a non-adjusting species that conserves water during stress by stomatal closure.

Plants were grown in pots and subjected to water stress.

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