BIOL 695

PLANT WATER RELATIONSHIPS

CHAPTER 4
Mengel et al., 5th Ed

WATER POTENTIAL - 1

$$\Psi = \frac{\mu_w - \mu^o_w}{v_w}$$

Ψ = water potential
μ_w = chem potential of water in system
μ°_w = chem potential of pure free water
V_w = partial molar vol of water in system

Units for water potential - kPa or Mpa
Pa = Pascal
1 bar = 10^5 Pa

WATER POTENTIAL - 2

$\Psi = \psi_p + \psi_s + \psi_m$

ψ_p - pressure potential = hydrostatic pressure - positive

ψ_s - osmotic potential - effect of solutes - negative

ψ_m - matric potential - capillarity and adsorption effects - negative

Gradient in Water Potential

- Potential of Pure Free Water = 0
- Potential in plants < 0 (-0.1 - -1.5 MPa)
- Gradient during day (stomata open)
  - atmosphere >> leaf cells > xylem sap > root cells > external solution

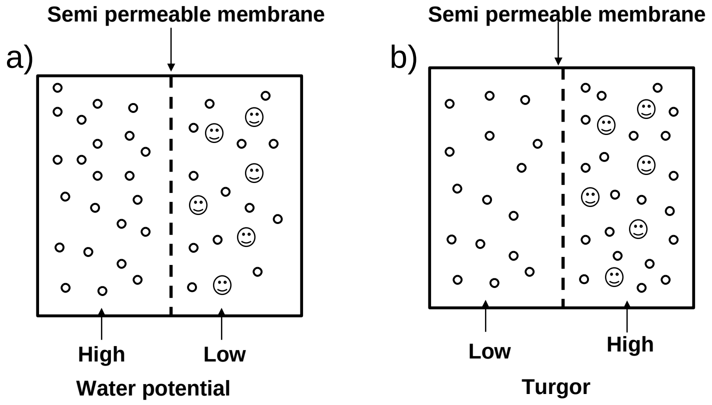
Gradient in Water Potential

- Water potential, Ψ, represents driving force for water transfer in cells, tissues, whole plants
- Water movement is function of potential difference and resistance to flow
- Resistance from cell walls, membranes, cuticles, etc.

$$F = \frac{\Psi_1 - \Psi_2}{R}$$

Ψ_1, Ψ_2 = water potential at two points
F = flow rate
R = resistance

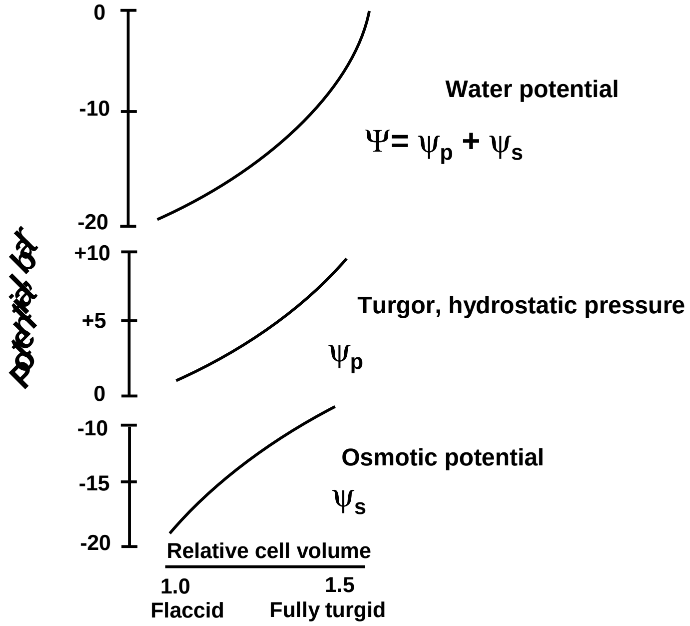
OSMOSIS



Water molecule- ∘
Sucrose molecule - ☺

a) net H_2O movement-high to low Ψ
b) equilib. Between both H_2O Ψ / high turgor in sucrose sol'n / no net water movement

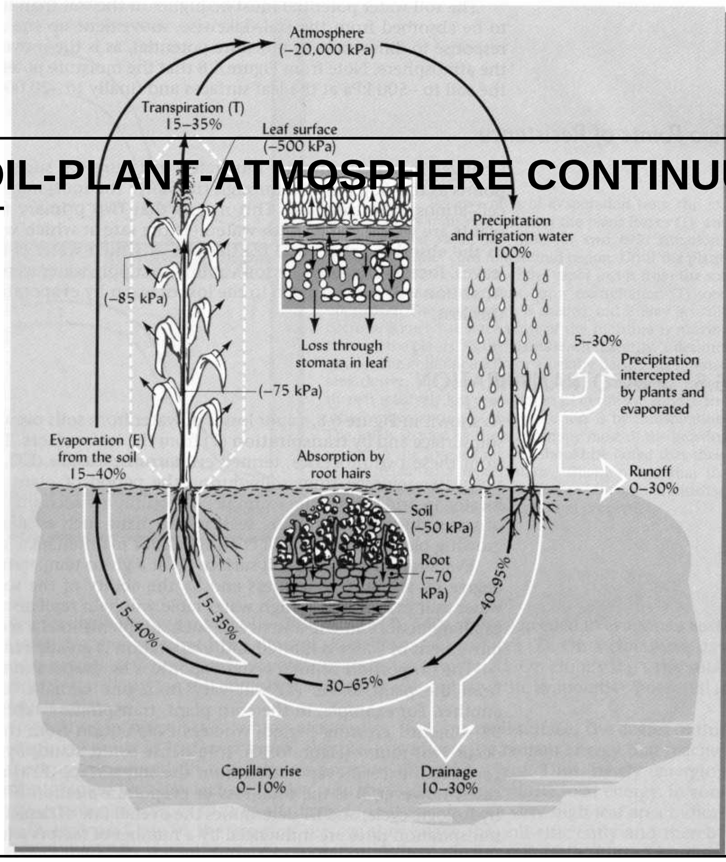
OSMOTIC POTENTIAL



OSMOSIS

- Plant cell takes in water due to Ψ_1 - Ψ_2
  - ψ_s in cell increases as solutes are diluted
  - ψ_p in cell increases
  - ψ_s affected by organic & inorganic solutes
- Production of osmotica during the day may lessen water loss, by affecting ψ_s
- Plasmolysis may occur when cells lose water
- Imbibition - uptake of H_2O by dry plant material by adsorption (esp important for seeds)

SOIL-PLANT-ATMOSPHERE CONTINUUM



WATER BALANCE

SPAC = Soil - Plant - Atmosphere Continuum

-major component of hydrologic cycle

Water movement - two major points of resistance
- **root-soil water interface**
- **leaf cell-atmosphere interface**

Component	Moisture potential
Atmosphere	-20,000 kPa
Leaf surface	-500 kPa
Upper plant (internal)	-85 kPa
Lower plant (internal)	-75 kPa
Soil water	-50 kPa

WATER BALANCE

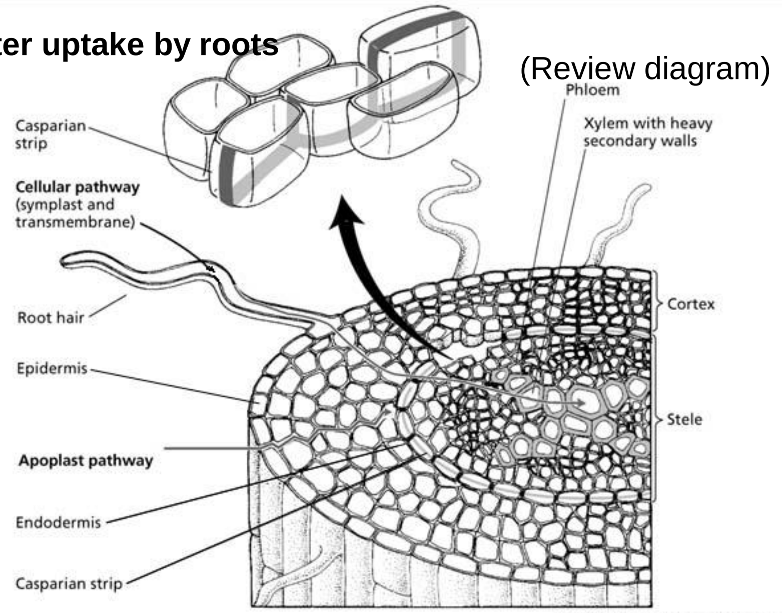
Water translocation - primary steps:

- **transport from soil solution to xylem**
- **vertical transport from roots upward**
- **release of water at plant-atmos. Interface**
- **text, Figure 4.3**

WATER BALANCE

Water uptake by roots

(Review diagram)



WATER BALANCE

• Metabolic processes influence water uptake
  $\Rightarrow$ synthesis reactions
    $\Rightarrow \Psi_s$
      $\Rightarrow$ water uptake

• Metabolic processes influenced by:
  - extreme temperature
  - low O_2
  - toxic substances

• Trace some sequence of events caused by above stressors ???

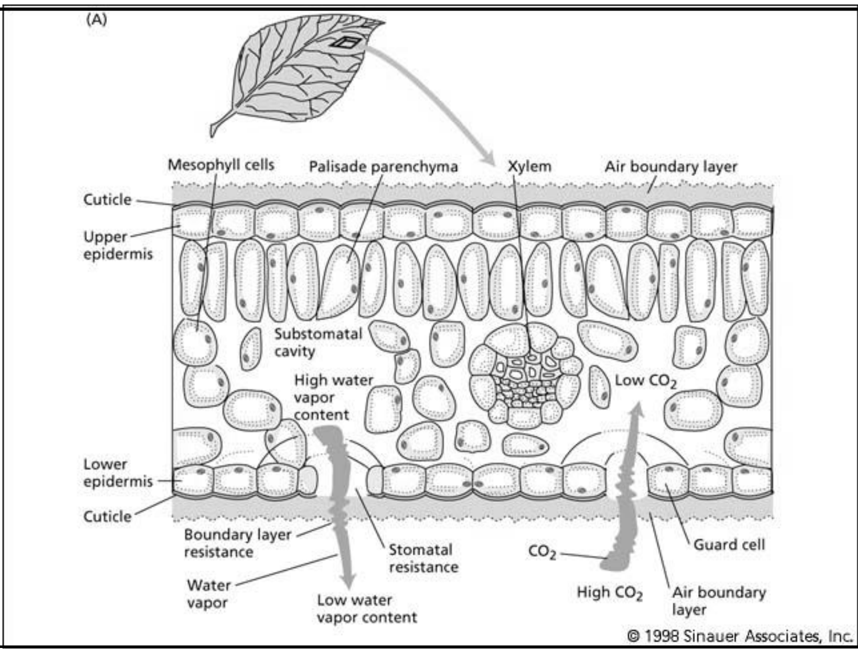
WATER BALANCE

• Resistance to inflow of H_2O through roots by:
  - epidermis
  - cortex
  - endodermis
  - central cylinder

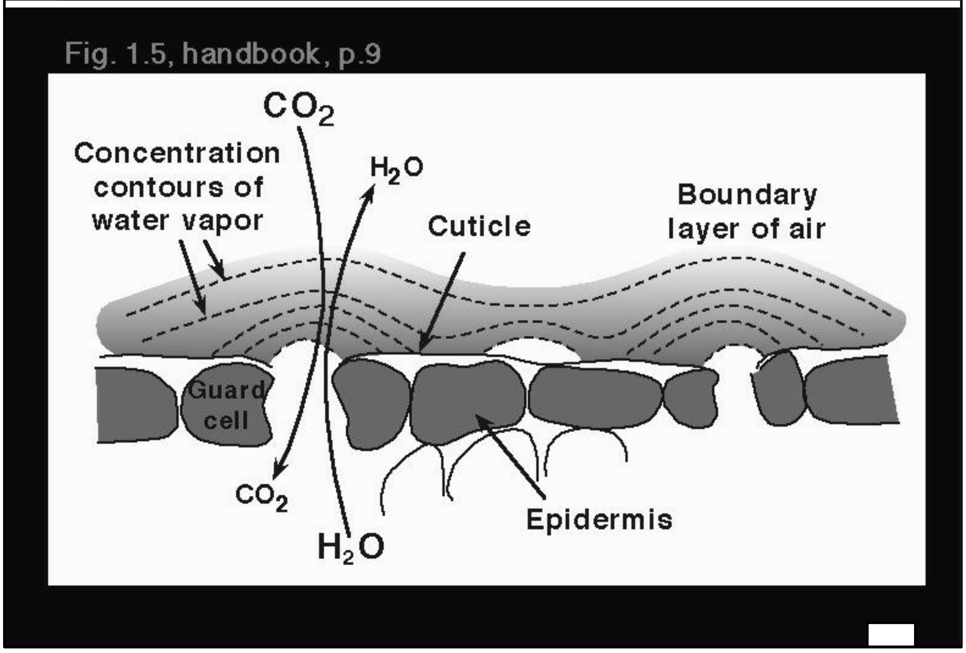
• Flow in roots often is very slow

• Diurnal H_2O stress from high transpiration rates and insufficient root flow

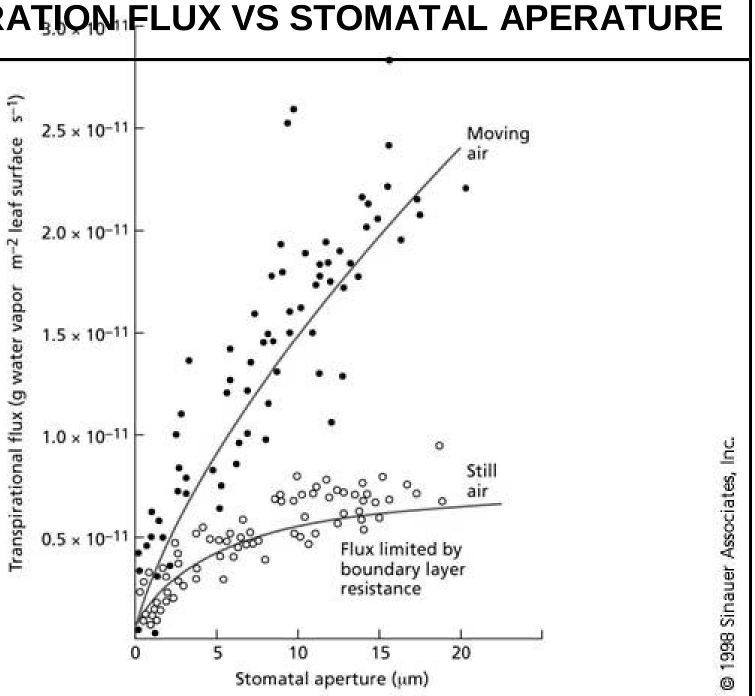
TRANSPIRATION / XYLEM WATER MOVEMENT



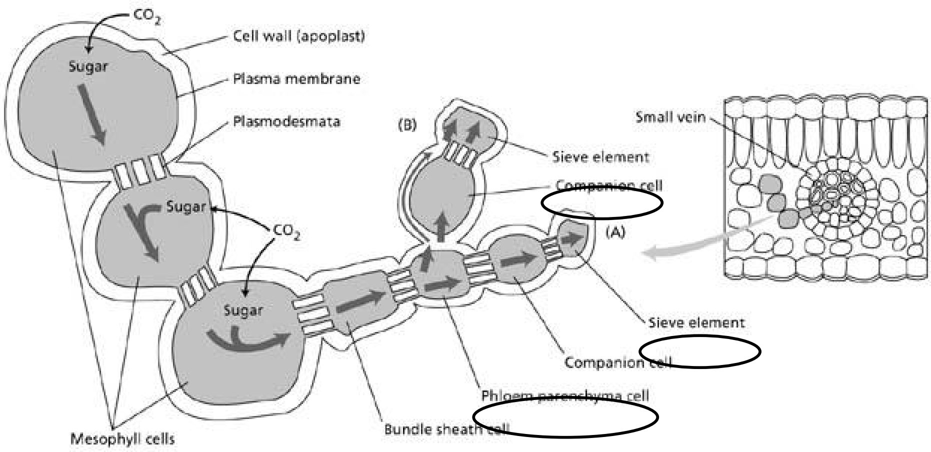
LEAF BOUNDARY LAYER DYNAMICS



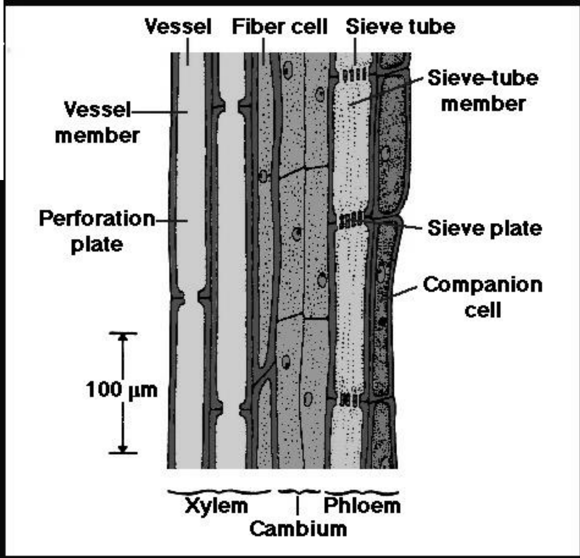
TRANSPIRATION FLUX VS STOMATAL APERATURE



CELLULAR TRANSPORT - CELL CONNECTION



XYLEM / PHLOEM CONFIGURATIONS

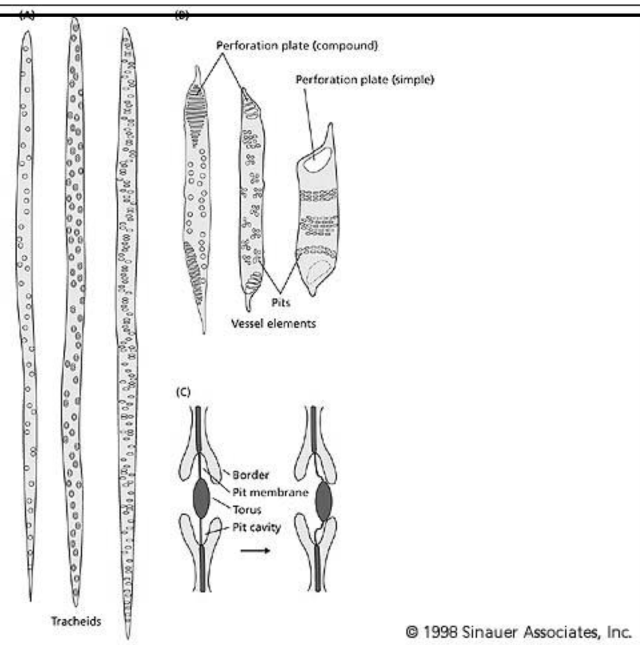


XYLEM

- Long-distance transp predominately
  - Non-living xylem
    - Continuous xylem vessels
    - or Tracheids (2 - 6 mm long)
      - Conifers
      - Tracheids also in Annuals at:
        - Root-shoot junctions
        - Nodes of stems

XYLEM

TRACHEIDS



Xylem Transport

- Tracheids
  - cause internal resistance, but
  - facilitate xylem-phloem transfer
- Xylem transport driven
  - by transpiration intensity
  - to smaller extent by Root Pressure
- Xylem sap is dilute solution

Solute Flow

- Unidirectional (Acropetal - base to apex)
- But counter flow possible
  - Fruit to leaves
- Transport in phloem
  - Bi-directional
    - Influenced by source- sink relat'n
- Ions entering root other than root tip
  - Must move thru phloem to root tip

Accumulation of Ions

- ^{45}Ca rapidly transported to shoot
- ^{22}Na transport is restricted
- ^{42}K is very mobile and moves in both phloem and xylem

Transfer Cells

- Loading and unloading mediated
  - Elements & organic solutes between xylem and phloem
- BUT not adequate to transfer fertilizer from one side of tree to other (Text, Fig 4.11)
- Preference to direct vascular connections

COMPOSITION & CONCENTRATION OF XYLEM SAP

- Influenced by
  - Species
  - Nutrient supply to plant
  - Assimilation infl by water dilution
    - Transpiration & time of day
    - Ontogenesis (individual plant devel)
    - Divert decline by removing pods

CONC. OF ORGANIC ACIDS and MINERAL ELEMENTS

- **Depends of root cation-anion uptake**
- **Changes during season**
- **Polyvalent heavy metal cations**
  - **In organic acids**
  - **Amino acids**
  - **Peptides**

FORM & DISTRIBUTION OF N IN XYLEM SAP

- **Nitrate reduction in roots & shoots**
- **Conc of NH_4^+ in the xylem very low even if high NH_4^+ in soil.**
- **Depends of N supply**
  - **NO_3^-**
  - **NH_4^+**
  - **N_2 fixation**

ABA SIGNAL TO SHOOT OF ROOT WATER STATUS

- Soil dries ⇒
  - Stomatal conductance decreases
  - Leaf turgor decreases
  - ABA increases & pH increases
  - Concentration in xylem, not leaf impt
  - Cell division & elongation inhibited
  - Growth slows down - Yield down

XYLEM UNLOADING - ADSORPTION AND RESORPTION

- Interaction between cations & negatively charged vessel walls
- Cations also adsorbed by surrounding tissue

DEGREE OF RETARDATION OF CATION TRANSLOCATION

- Depends on:
  - valency of cation: Ca^{2+} > K+
  - Its own activity (Zn^{2+} readily adsorbed)
  - Activity of competing cations
  - Charge density neg grps (dic - mono)
  - pH varies 5 to 7
  - Diameter of xylem vessels

TRACE METAL IONS

- Transport enhanced when complexed (cofactors)
  - Zn^{2+}
  - Cu^{2+}
  - Cd^{2+}

Na^+ MOVEMENT SPECIES SPECIFIC

- Na^+ remains in roots of natrophobic plants e.g. *Phaseolus vulgaris*
  - Selectively accumulated in xylem parenchyma
  - Retranslocation into roots
- Na^+ translocated to leaves of natrophilic species e.g. sugar beets

Mo ACCUMULATION IN XYLEM PARENCHYMA

- Preferential accumulation in roots and stems of beans but not tomatoes
- Which would suffer first from toxic Mo levels in growth medium.
  - The tomato - more trans to top.

RELEASE & SECRETION ALONG TRANSPORT PATHWAY

- **Composition if xylem sap changed with release of solutes from adj cells**
  - **Non-legumes fertilized with NO_3^-**
    - **NO_3^- decreases & glutamine inc with increasing length of path**
  - **Legumes - ratio shifts to amino acids with increasing length of path**

MAINTENANCE OF CONTINUOUS SUPPLY OF NUTRIENTS

- **Resorption or Release of nutrients**
  - **Ample root supply: ions resorbed by stem from xylem sap**
  - **Insufficient root supply: ions released from stem into xylem sap**
- **Measured by rapid NO_3^- test of stem base**

XYLEM UNLOADING IN LEAVES

- Solutes transported in xylem vessels into leaves.
  - Preferential into areas of rapid evaporation
    - Leaf margins
    - Stomata
  - Necrosis at margins unless eliminated
    - Loading into phloem or guttation

PREVENTION OF EXCESSIVE SALT ACCUMULATION IN LEAVES

- Accumulation of low soluble salts in apoplasm
  - In gymnosperms where ionic conc in symplasm must be kept low
- Xylem sap can be low in solutes when reaches leaves

BUNDLE SHEATH CELLS

- Exhibit intensive proton excretion
  - Acidifies the apoplasm
  - Proton gradient - driving force for cotransportation of:
    - Amino acids
    - Ureices (cyclic derivities of urea)
    - NO_3^- enters leaf symplasm just like in root cells (Ch 3 - ion pumps)

TRANSPIRATION RATE EFFECT ON DISTRIBUTION WITHIN SHOOT

- Higher in shoot organs with
  - High transpiration rates & duration
  - Maple sun leaves higher Mn^{2+}
  - than shade leaves
- B conc related to loss of H_2O:
  - Leaves > pods >> seeds
  - Petioles < middle leaf < leaf tip
    - Necrosis on leaf margins = B tox

PHLOEM TRANSPORT

- Sucrose conc in phloem of leaves (phloem loading)
  - WHY?
- H_2O sucked into phloem (+) int pres
- Mass flow to sites of lower positive pressure (unloading sinks)

PHLOEM TRANSPORT DIFFERS FROM FLOW IN XYLEM

- Organic compounds are dominant
- Transport in living cells
- Unloading in sink
- Direction of ion transport in phloem controlled by
  - Anatomy
  - Physiology of the species

COMPOSITION OF PHLOEM SAP

(*Nicotiana glauca*)

	Phloem	Xylem	P/X
Dry matter	185	1.2	155
Amino comp	10808	283	38
K	3673	204	18
Ca	83	189	0.44
P	435	68	6.4
Fe	9.4	0.6	16

See also Text, Table 4.5

MOBILITY IN PHLOEM & TRANSFER BETWEEN XYLEM & PHLOEM

- Mg > Zn > Ca
- Ion transfer is “downhill” from phloem to xylem (Ca is exception)
- Xylem to Phloem transp important
  - Xylem transp connected to pt of highest transpiration
    - Not region of highest nutrient need

RELATIVE IMPORTANCE OF XYLEM & PHLOEM TRANSPORT

- Rate
  - Phloem 22 cm h^{-1}
  - Xylem 147 cm h^{-1}
- K, P, Amino N
  - Have high phloem mobility

MINERALS WITH LOW PHLOEM MOBILITY

- Ca transport in xylem
  - Seldom in phloem
- Ca demand for fruit sinks
  - Must be supplied by xylem
    - Potatoes have advantage (direct uptake from soil)

INCREASING Ca CONTENT

- Shoot apices (enclosed by mature leaves) & fruit
  - Low transpiration rates
    - Tip burn
    - BER
    - Bitter Pit
- How do you increase Ca? More fert?

QUESTION

- High transpiration results in tip burn.
  - WHY?

INTERNAL NUTRIENT MOVEMENT

- Once in the root, minerals move up the stem in the transpiration stream
- After minerals are once used in cell metabolism or plant growth, they may be either 1) moved around later in the plant, or 2) become fixed in their first (and only) location

INTERNAL NUTRIENT MOVEMENT

- Those minerals that can be "moved around" - mobile i.e..:
  - Nitrogen
  - Phosphorus
  - Potassium
  - Magnesium
- Those minerals that, once used, are "fixed" - immobile i.e..:
  - Iron
  - Copper
  - Manganese
  - Zinc

NUTRIENT DEFICIENCY

- **Mobile Minerals:**
- When mineral supply gets low, symptoms show up in older leaves (plant moves what it has to new growth, so old growth shows effect of deficiency)

- **Immobile Minerals:**
- When mineral supply gets low, symptoms show up in newer leaves (plant cannot move nutrients to new growth, so new growth shows effect)

RETRANSLOCATION & CYCLING OF NUTRIENTS

- Normal function of leaf
  - Nutrient imported in xylem
  - Nutrient export in phloem
  - Rapid xylem to phloem transfer in leaf blades
- Considerable portion retrans to roots
  - Control uptake by roots, OTHERS?

CYCLING

- Retranslocation of nutrients again loaded into xylem
- K important in maintaining charge balance in shoots & roots of NO_3^- fed plants
- Helps compensate for uneven fertilizer in root zone

REMOBILIZATION OF NUTRIENTS

- Based on utilization of K, P, Mg, amino-N stored in vacuoles
- Breakdown of
  - stored protein
  - cell structures & enzyme proteins
    - TRANSFER INTO MOBILE FORM

EXAMPLES OF REMOBILIZATION

- Seed germination
  - Mineral elements to shoots / roots
  - K, Mg, Ca bound in phytic acid
- Vegetative Stage
  - Remobilization from mature leaves to new leaves
    - Mobile ion like Mg

EXAMPLES OF REMOBILIZATION

- Reproductive Stage
  - Root activity, ion uptake
    - Decreases as result of decreased CHO supply to roots
    - CHO going to fruit, etc.
  - Mineral content of vegetative part drops during seed development

EXTENT OF REMOBILIZATION

- Depends of specific reqmt of seeds & fruits for given mineral
- Mineral status of vegetative parts
- Ratio between source and sink size
- Nutrient uptake by roots (repro phase)
  - Grain takes N & P (90% P remobil from vegetative parts)

REMOBILIZATION OF K, Mg, Ca IN FLESHY FRUIT

- Mg readily supplied by roots
  - Not remobilized unless Mg soil def
- Ca not readily remobilized from apoplast
  - Ca easier to get from soil
- Remobil may lead to self destruction

ALL TOGETHER NOW

- Rigorous remobilization of K
  - By tomatoes bred for mechanical harvesting
  - Heavy fruit load + early, uniform harvest
  - Soils high in K, def in plant. WHY?
- Pecans that overbear - can kill tree.

SELECTIVE REMOBILIZATION

- K ratio in grain is higher
  - than for Na and Cl
- Micronutrients subject to remob if they are high or excessive.
  - If bound in enzymes they are not.
- Compare mobility of micros appl via foliar sprays vs micro from roots

MICRONUTRIENT REMOBILIZATION

- N def enhances Cu and Zn remob
  - Leads to leaf abscission
- Several steps
  - 1. Mobilization within each cell
  - 2. Short transp in symplasm to phl
  - 3. Phloem loading
  - 4. Phloem transport

Why do growing shoot leaves show micro deficiency?

- During reproductive growth enzymes are mobilized (Step 1)
- These veg growth sinks lack capacity to produce ‘signal’ strong enough to induce senescence
- What is signal?
- Nutr removed from metab but steps 2, 3, and 4 do not occur. (Def sym)