AGRY 515 2014

- Radial Transport across the Root
- Ion Fluxes across Membranes
## Table 1. (Table 2.2 in text) 3 Observations…?

Table 2.2
Changes in the Ion Concentration of the External (Nutrient) Solution and in the Root Press Sap of Maize and Bean

<table>
<thead>
<tr>
<th>Ion</th>
<th>External concentration (mm)</th>
<th>Concentration in the root press sap (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>After 4 days&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Maize</td>
</tr>
<tr>
<td>Potassium</td>
<td>Initial</td>
<td>2.00</td>
</tr>
<tr>
<td>Calcium</td>
<td>1.00</td>
<td>0.94</td>
</tr>
<tr>
<td>Sodium</td>
<td>0.32</td>
<td>0.51</td>
</tr>
<tr>
<td>Phosphate</td>
<td>0.25</td>
<td>0.06</td>
</tr>
<tr>
<td>Nitrate</td>
<td>2.00</td>
<td>0.13</td>
</tr>
<tr>
<td>Sulfate</td>
<td>0.67</td>
<td>0.61</td>
</tr>
</tbody>
</table>

<sup>a</sup>No replacement of water lost through transpiration.

Marschner, 1995
Fig. 1. How far can K⁺ travel “passively”? 

Waisel et al., 1995

Figure 1 Aspects of the rhizosphere that may influence the arrival of ions at the absorptive surface of the root. The extent of the unstirred layer that surrounds roots in solution culture is indicated. In this layer ions can be at quite different concentrations to those in the bulk solution.
Fig. 2. (Similar to Fig. 2.32) Apoplastic and Symplastic pathways

Taiz and Zeiger, 2002
Fig. 2A (Fig. 2.1 in text)

FIGURE 2.1 Cross-section of two rhizodermal cells of a maize root. V, vacuole; C, cytoplasm; W, cell wall, E, external solution. Courtesy of C. Hecht-Buchholz.
Fig. 2.13  Relative uptake of boron by barley roots as a function of the external solution pH. Uptake at pH 6 = 100 at each supply concentration. Solid line: percentage of undissociated H$_3$BO$_3$. Key for boron concentrations mg l$^{-1}$: ▼, 1.0; □, 2.5; ○, 5.0; ▼, 7.5; ■, 10.0. (Reproduced from Oertli and Grgurevic, 1975, by permission of the American Society of Agronomy.)

Marschner, 1995
Fig. 4. Symplastic Movement

Fig. 2.35  Model for symplasmic (1) and apoplastic (2) pathways of radial transport of ions across the root into the xylem. Key: $\rightarrow$, active transport; $\leftarrow$, resorption. (Modified from Läuchli, 1976a.)

Marschner, 1995
**Fig. 5.** (Fig. 2.33 in text) Plasmodesmata

**FIGURE 2.33** Schematic representation of plasmodesmata including substructural components. Solute fluxes between adjacent cells occur in the cytoplasmic sleeve, between the plasma membrane and the appressed endoplasmic reticulum (ER) forming the desmotubule. Partial control of solute fluxes by callose deposition in the cell wall. The cytoplasmic sleeve is interrupted by actin and other proteins that create microchannels through which solutes can diffuse. *Modified from Maule (2008).*
Fig. 6. Generalized Plant Cell

Figure P-2 A generalized plant cell. The drawing is based on the appearances of cellular organelles in electron micrographs. (W. A. Jensen and F. B. Salisbury, 1984, Botany, p. 46.)

Salisbury and Ross, 1985
Fig. 7. Lauchli’s principal membrane fluxes

Barber and Bouldin (eds.), 1982. ASA Special Pub. #49

Fig. 2. Model of principal membrane fluxes in a root (net salt flux in xylem, $J_s = \Phi_{cx} - \Phi_{xc}$).
FIGURE 2.12 Nomenclature of unidirectional (φ) and net (J) solute fluxes across the plasma membrane between cytoplasm (c) and the external solution (o) or xylem (x), and across the tonoplast between the cytoplasm (c) and the vacuole (v) of a stereotypical root cell. Figure adapted from White and Broadley (2001).
Fig. 17 (Fig. 2.7 in text) Types of transport mechanisms

FIGURE 2.7 Nomenclature of transport proteins. Schematic representation of primary active transport mechanisms, such as ABC transporters (e.g., glutathione conjugate pump), metal transporters (e.g., Ca^{2+}-ATPase) and H^{+}-ATPases, secondary active transport mechanisms, such as the K^{+}/H^{+} symporter or the Na^{+}/H^{+} antiporter, and passive transport mechanisms, such as the NH_{4}^{+} carrier and the K^{+} channel. *Figure adapted from White (2003).*
### Fig. 8. Active and Passive Transport

<table>
<thead>
<tr>
<th>Chemical potential in compartment A</th>
<th>Chemical potential in compartment B</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tilde{\mu}_j^A$</td>
<td>$\tilde{\mu}_j^B$</td>
<td>Passive transport occurs spontaneously down a chemical-potential gradient. $\tilde{\mu}_j^A &gt; \tilde{\mu}_j^B$</td>
</tr>
<tr>
<td>$\tilde{\mu}_j^A$</td>
<td>$\tilde{\mu}_j^B$</td>
<td>At equilibrium, $\tilde{\mu}_j^A = \tilde{\mu}_j^B$. If there is no active transport, steady state occurs.</td>
</tr>
<tr>
<td>$\tilde{\mu}_j^A$</td>
<td>$\tilde{\mu}_j^B$</td>
<td>Active transport occurs against a chemical potential gradient. $\tilde{\mu}_j^A &lt; \tilde{\mu}_j^B$</td>
</tr>
<tr>
<td>$\tilde{\mu}_j^A$</td>
<td>$\tilde{\mu}_j^B$</td>
<td>$\Delta G$ per mole for movement of $j$ from A to B is equal to $\tilde{\mu}_j^B - \tilde{\mu}_j^A$. For an overall negative $\Delta G$, the reaction must be coupled to a process that has a $\Delta G$ more negative than $-(\tilde{\mu}_j^B - \tilde{\mu}_j^A)$.</td>
</tr>
</tbody>
</table>
Fig. 9. Active and Passive Transport (cont.)

Initial conditions:
\[ [\text{KCl}]_A > [\text{KCl}]_B \]

Diffusion potential exists until chemical equilibrium is reached.

Equilibrium conditions:
\[ [\text{KCl}]_A = [\text{KCl}]_B \]

At chemical equilibrium, diffusion potential equals zero.
Fig. 10. Measure Membrane potential (also see Fig. 2.8b in text)
Table 2. Nerst Equation Applied

<table>
<thead>
<tr>
<th>Ion</th>
<th>Concentration in external medium (mmol L⁻¹)</th>
<th>Internal concentration (mmol L⁻¹)</th>
<th>Predicted</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>K⁺</td>
<td>1</td>
<td>74</td>
<td>74</td>
<td>75</td>
</tr>
<tr>
<td>Na⁺</td>
<td>1</td>
<td>74</td>
<td>74</td>
<td>8</td>
</tr>
<tr>
<td>Mg²⁺</td>
<td>0.25</td>
<td>1340</td>
<td>1340</td>
<td>3</td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>1</td>
<td>5360</td>
<td>5360</td>
<td>2</td>
</tr>
<tr>
<td>NO₃⁻</td>
<td>2</td>
<td>0.0272</td>
<td>0.0272</td>
<td>28</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>1</td>
<td>0.0136</td>
<td>0.0136</td>
<td>7</td>
</tr>
<tr>
<td>H₂PO₄⁻</td>
<td>1</td>
<td>0.0136</td>
<td>0.0136</td>
<td>21</td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>0.25</td>
<td>0.00005</td>
<td>0.00005</td>
<td>19</td>
</tr>
</tbody>
</table>

Source: Data from Higinbotham et al. 1967.
Note: The membrane potential was measured as −110 mV.
Fig. 11 Active Vs. Passive Ion Fluxes
Fig. 12. Evidence: Consumption of ATP

Barber and Bouldin (eds.), 1982. ASA Special Pub. #49

Correlation between influx of K⁺ and K⁺-stimulated ATPase activity of membranes in four different cereal roots (r = 0.94) (Fisher et al., 1970).
Fig. 13. Evidence: ATP / H+ Pump

![Graph showing the correlation between net H+ efflux and K+ influx in roots of 24 barley varieties. Roots of intact seedlings exposed to 1 mM K₂SO₄ plus 0.5 mM CaSO₄ for 24 h (r = 0.88) (Glass et al., 1981).]

Barber and Bouldin (eds.), 1982. ASA Special Pub. #49
Fig. 14. Evidence: ATP & Membrane Potential

-150
-130
-110
-90
-70
-50
-30
0
20
40
60
80

Cell membrane potential (mV)

Time (minutes)

0.1 mM CN⁻ added

CN⁻ removed

PLANT PHYSIOLOGY, Third Edition, Figure 6.5 © 2002 Sinauer Associates, Inc.
Fig. 15. Carrier Concept & Michaelis-Menten Kinetics

$I_{\text{max}}$ or capacity factor

$V_{\text{max}}$

$C_{\text{min}}$ = the min. conc. needed for uptake

$K_m$ = [substrate] at $\frac{1}{2} I_{\text{max}}$

$I(V_0) = \frac{I_{\text{max}} (C_s - C_{\text{min}})}{K_m + (C_s - C_{\text{min}})}$

$I(V_0)$
Fig. 16. More than one carrier or transport mechanism?
**Fig. 2.7** Nomenclature of transport proteins. Schematic representation of primary active transport mechanisms, such as ABC transporters (e.g., glutathione conjugate pump), metal transporters (e.g., Ca\(^{2+}\)-ATPase) and H\(^+\)-ATPases, secondary active transport mechanisms, such as the K\(^+\)/H\(^+\) symporter or the Na\(^+\)/H\(^+\) antiporter, and passive transport mechanisms, such as the NH\(_4^+\) carrier and the K\(^+\) channel. *Figure adapted from White (2003).*
Transport proteins of the tonoplast and plasma membrane of plant cells. See text (Section 2.4.1) for details.
Fig. 19. Schematic of principal mechanisms of ion transport

Marschner, 1995

Fig. 2.8 Principal mechanisms of ion transport in plasma membranes. (A) H⁺ pumping ATPase; (B) ion channel; (C) carrier; (D) coupling proteins for signal perception and transduction. (Modified from Hedrich et al., 1986; with permission from Trends in Biochemical Sciences.)
FIGURE 2.21 Model for internal pH stabilization and for charge compensation at different ratios of cation:anion uptake from the external solution. A. Excessive uptake of cations (Cat⁺), for example, with K₂SO₄ supply. B. Excessive uptake of anions (An⁻), for example, with Ca(NO₃)₂ supply.
Fig. 21. Distribution of channels, symporters, and antiporters in a typical plant cell
Uniport channels (pores, no binding) and carriers (bind) for passive ion uptake, and pumps that use ATP to transport ions against a concentration gradient.
Fig. 23. Schematic of symport and antiport

(A) Symport

OUTSIDE OF CELL

H⁺ A

H⁺ B

CYTOPLASM

H⁺ A

H⁺ B

(B) Antiport

Low

High

Electrochemical potential gradient of substrate A

High

Low

Electrochemical potential gradient of substrate B
Active uptake of an ion (S) through a symport using the energy stored in the proton gradient across the membrane.
Fig. 25. Schematic of a PP\textsubscript{i}ase pump

Cation (M\textsuperscript{+}) transport against a concentration using an ATP-driven carrier
Fig. 26. Aquaporin water channel in a membrane are involved in water transport and osmoregulation. Flux is influenced by phosphorylation.

ASPB,
Biochemistry and Molecular Biology of Plants, 2000
Fig. 27. Features of Transporters

Two dimensional view of a carrier protein spanning a membrane.

Three dimensional model of a potassium channel showing the pore through which K ions travel. Positively charged regions are blue, while negatively charged regions are red.

ASPB, Biochemistry and Molecular Biology of Plants, 2000