POTASSIUM IN PLANT
GROWTH AND YIELD

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Fertilizing potato with potassium

High K

Low K

Low K

High K

Fertilizing sweet potato with potassium

Low K

High K

High K

Low K
Control

K Deficiency

Cakmak et al., 1994, J. Experimental Bot.
POTASSIUM IN CROP PRODUCTION

- Alleviation of Effects of Stress Factors
- Photosynthesis
- Enzyme Activation
- Phloem Export of Photosynthates
- Cell elongation
- Protein Synthesis
- Water Regime
K and Cell Elongation/Extension

In most cases, cell extension is the consequence of the accumulation of K in the cells that is required for both stabilizing the pH of the cytoplasm and increasing the osmotic potential in vacuoles.

Cell elongation by GA is dependent on K supply
Potassium is essentially needed for cell elongation

Potassium is essential for GA3 (gibberellin)-induced cell elongation/extension, especially under deep-seeding conditions (seedling establishment!!!)

Potassium is needed for turgor potential to avoid drought stress in arid environment

Potassium and GA act synergistically in elongating cells

(Chen et al., 2001; Plant Cell Environ. 24: 469-476)
Auxin-stimulated cell elongation is also dependent on presence of potassium.

There is a strong correlation between expression of K-channel proteins and cell elongation following application of auxin

Rogg et al., 2001, Plant Cell
TRH1 encoding a potassium transporter protein: essential for root tip growth. As cell elongation is driven by turgor pressure, the operation of K translocators is crucial for growth.

In the mutant lines without TRH1 protein root hair formation was totally blocked.
Root Hair Formation

With K protein

Without K protein

Rigas et al., 2001, Plant Cell, 13: 139-151
TRH mediating K transport essential for root hair formation.

Rigas et al., 2001, Plant Cell, 13: 139-151
Potassium is a critical mineral nutrient in tree growth and wood formation.

In cambial region and xylem differentiation zone a strong potassium demand has been shown.

Differentiating xylem cells involved in wood formation represent a strong sink for potassium that provides the driving force for cell expansion

Langer et al., 2002; Plant Journal, 32: 997-1009
K nutritional status strongly affects development of wood producing cells

Potassium concentration in xylem tissue, cambium/xylem differentiation zone and phloem tissue

Langer et al., 2002; Plant Journal, 32: 997-1009
Under K deficiency cambial and cell-expansion zones lack 2-3 cell layers each

Lack of cell divisions in the vessel development region results in reduced wood production

Langer et al., 2002; Plant Journal, 32: 997-1009
The cambium cells divide and make new **wood** on the inside and new **inner bark** on the outside. In this way, a tree gets bigger around as it grows!
Potassium is highly needed for wood production.

Potassium is driving force for expansion of wood producing cells.
Photosynthesis and Potassium

In K-deficient leaves photosynthesis is impaired at different levels:

- Stomatal CO$_2$ flux into chloroplasts
- Conversion of light energy into chemical energy
- Rubisco activity/CO$_2$ reduction
- Phloem export of photosynthates and,
- Detoxification of toxic O$_2$ species
Photosynthesis and Potassium

During a mild K deficiency in cotton, increased stomatal resistance is first to result in a decrease in net photosynthesis and, as the deficiency becomes more acute, biochemical factors contribute.

Effect of Varied K Supply on Photosynthesis in Cotton

Bednarz and Oosterhuis, 1999; J. Plant Nutr.
Decrease in photosynthesis with K deficiency becomes more distinct when plants are exposed to elevated CO$_2$ concentrations.

Enhanced K requirement of plants when exposed to increasing CO$_2$ concentration in atmosphere.
Effect of Elevated CO$_2$ on Photosynthesis at Varied K Supply

Barnes et al., 1995, Plant Cell Environ.
The transport of K\(^+\) across the plasma membrane and tonoplast causes the turgor changes of guard cells. Stomata open when guard cells accumulate potassium (red dots), which lowers the cells’ water potential and causes them to take up water by osmosis. The cells become turgid.

"Stomata regulating transpiration and CO\(_2\) uptake"
Role potassium in stomatal action

When stomata opened, the K content of guard cells increased by factor 2, indicating a very rapid stomatal opening by K uptake

Langer et al., 2004; Plant Journal, 37: 828-838
PHLOEM TRANSPORT

K plays a critical role in phloem transport
<table>
<thead>
<tr>
<th>Component</th>
<th>Concentration (mg mL⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugars</td>
<td>80.0–106.0</td>
</tr>
<tr>
<td>Amino acids</td>
<td>5.2</td>
</tr>
<tr>
<td>Organic acids</td>
<td>2.0–3.2</td>
</tr>
<tr>
<td>Protein</td>
<td>1.45–2.20</td>
</tr>
<tr>
<td>Potassium</td>
<td>2.3–4.4</td>
</tr>
<tr>
<td>Chloride</td>
<td>0.355–0.675</td>
</tr>
<tr>
<td>Phosphate</td>
<td>0.350–0.550</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.109–0.122</td>
</tr>
</tbody>
</table>

*Source: Hall and Baker 1972.*
Potassium is essential for transport of photosynthates into growing organs

AKT2/3: a potassium channel protein and identified as photosynthesize-induced phloem K channel.

Flower induction and rosette development of the *Arabidopsis* with loss of AKT2/3 function (*akt2/3-1* mutant) is delayed

Deeken et al., 2002, Planta, 216: 334-344
Accumulation of Phosphates in K-Deficient Source Leaves

Sucrose concentration (mg Glucose equiv. g\(^{-1}\) DW)

Control: 12
K Deficiency: 76

Cakmak et al., 1994b, J. Experimental Bot.
Decrease in Phloem Export of Sucrose by K-Deficiency

Cakmak et al., 1994b, J. Experimental Bot.
Relative distribution of total carbohydrates between shoot and roots (%)

Control: 84, 16
K Deficiency: 97, 3

Cakmak et al., 1994a, J. Experimental Bot.
Plants suffering from environmental stress factors such as drought, high light intensity and salinity have larger requirement for potassium
Potassium Improved Photosynthesis Under Drought Stress

Sen Gupta et al., 1988, Plant Physiol.
Alleviation of Salt Stress by K Supply

Increased salt sensitivity in the absence of K transporter protein.

AtHKT1 controls root/shoot Na\(^+\) distribution and counteracts salt stress in leaves by reducing leaf Na\(^+\) accumulation.

Maser et al., 2002; FEBS Letters;531: 157-161
Growth of bean plants with low K supply under low and high light intensity
Plants grown under high light intensity require more K than plants grown under low light.
Enhancement of leaf symptoms of K-deficiency by high light

Partially shaded K-deficient bean leaves
REMEMBER:

Photosynthetic Electron Transport and Superoxide Radical Generation

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LIGHT

THYLAKOID

PSII  PSI

2H₂O O₂ ATP

STROMA

O₂ → O₂⁻, H₂O₂, OH⁻ Toxic O₂ Species

CO₂ → Sucrose

Stomatal CO₂ Flux

Phloem Export
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Photosynthetic Electron Transport and Superoxide Radical Generation

LIGHT

THYLAKOID

PSII

PSI

STROMA

O₂ → O₂⁻, H₂O₂, OH⁻
Toxic O₂ Species

CELL DAMAGE

NUTRIENT DEFICIENCY

2H₂O → O₂, ATP

CO₂ → Sucrose
Phloem Export
- Potassium deficiency makes plants sensitive to environmental stress factors.
- Plants under environmental stress factors need additional potassium.
FREE RADICAL DAMAGE TO CRITICAL CELL CONSTITUENTS

$O_2$

$h.v.$

e$^-$

$'O_2$, $O_2^-$, $H_2O_2$, $OH^-$

MEMBRANE

DNA

CHLOROPHYLL

PROTEIN

LIPID PEROXIDATION

MUTATION

CHLOROSIS

PROTEIN DAMAGE

CELL DEATH
Conclusions

- Potassium has several critical roles in plant growth and yield formation including cell elongation, maintenance of turgor pressure and photosynthesis, stomatal closure, protein synthesis and photoassimilate transport.

- Potassium transporter proteins play critical role in K uptake and translocation (contributing to cell elongation) and tolerance to Na toxicity.
Plants exposed to high light intensity or grown under long-term sunlight conditions like in southern countries in Northern Hemisphere have much larger K requirement.

Improving K nutritional status of plants is a major contributing factor to the protection of plants from environmental stress factors under marginal conditions.
Remark: During the late growth stage (generative phase) plants can need higher amount of potassium because at this stage

- high amount of K is required for translocation of carbohydrates
- plants can be exposed to more light and
- topsoil with high root density and high K concentration can be dry (limited K uptake !)

High need for late K application to foliar !!
Obrigado...