Hochschule Geisenheim University

Chloride in Soil:

From Nutrient to Soil Pollutant and Plant Toxicant

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Cl^- – concentration in shoot of glycophytic crops: 1 to 20 mg/g DW

Deficiency at kiwi: intercostal chlorosis

Toxicity at maize: leaf margin necrosis

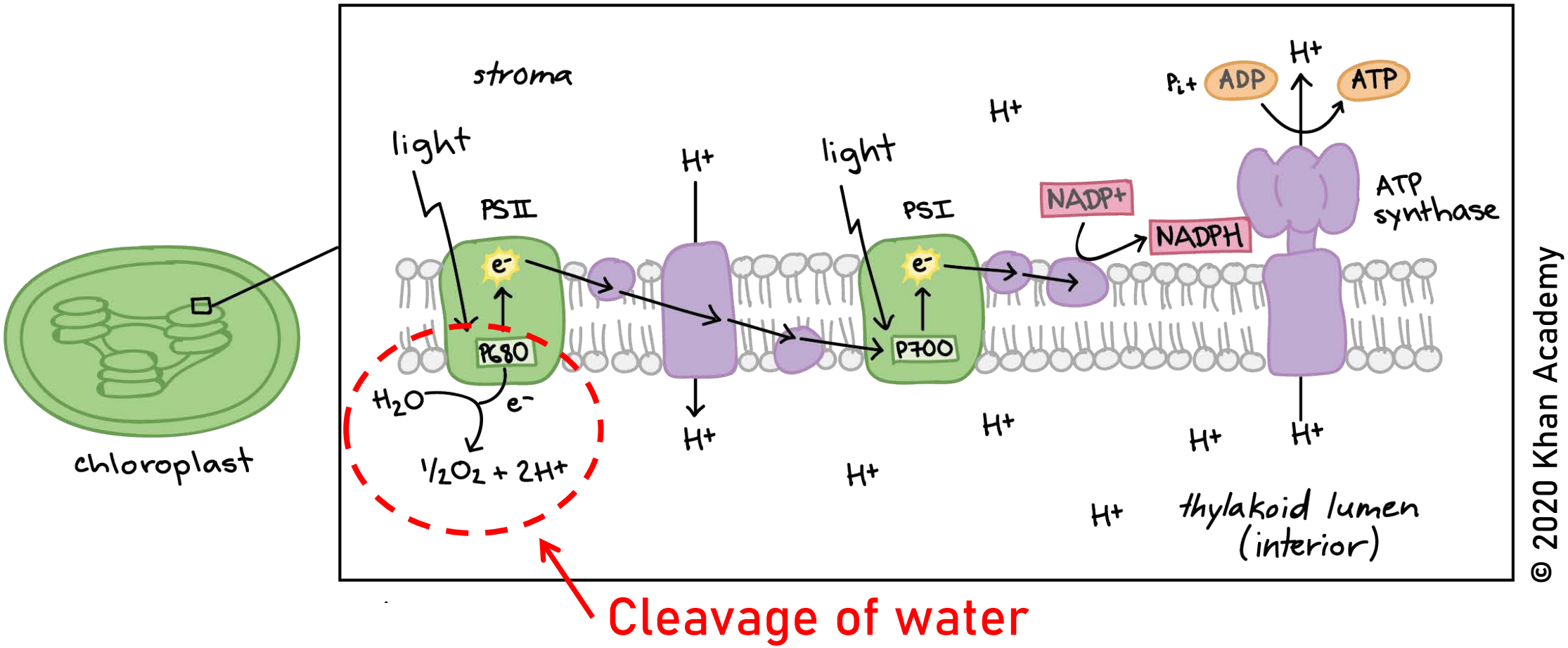
Toxicity tresholds:

Citrus rootstocks, grapevines: > 4-7 mg/g dw,
Potatoes, tomatoes, wheat: > 15-33 mg/g dw.
Sugar beet: > 50 mg/g dw.

Halophytes, like grey mangrove, require higher chloride levels for photosynthesis.

Physiological functions of Cl^- in plants

Photosynthetic electron transport chain



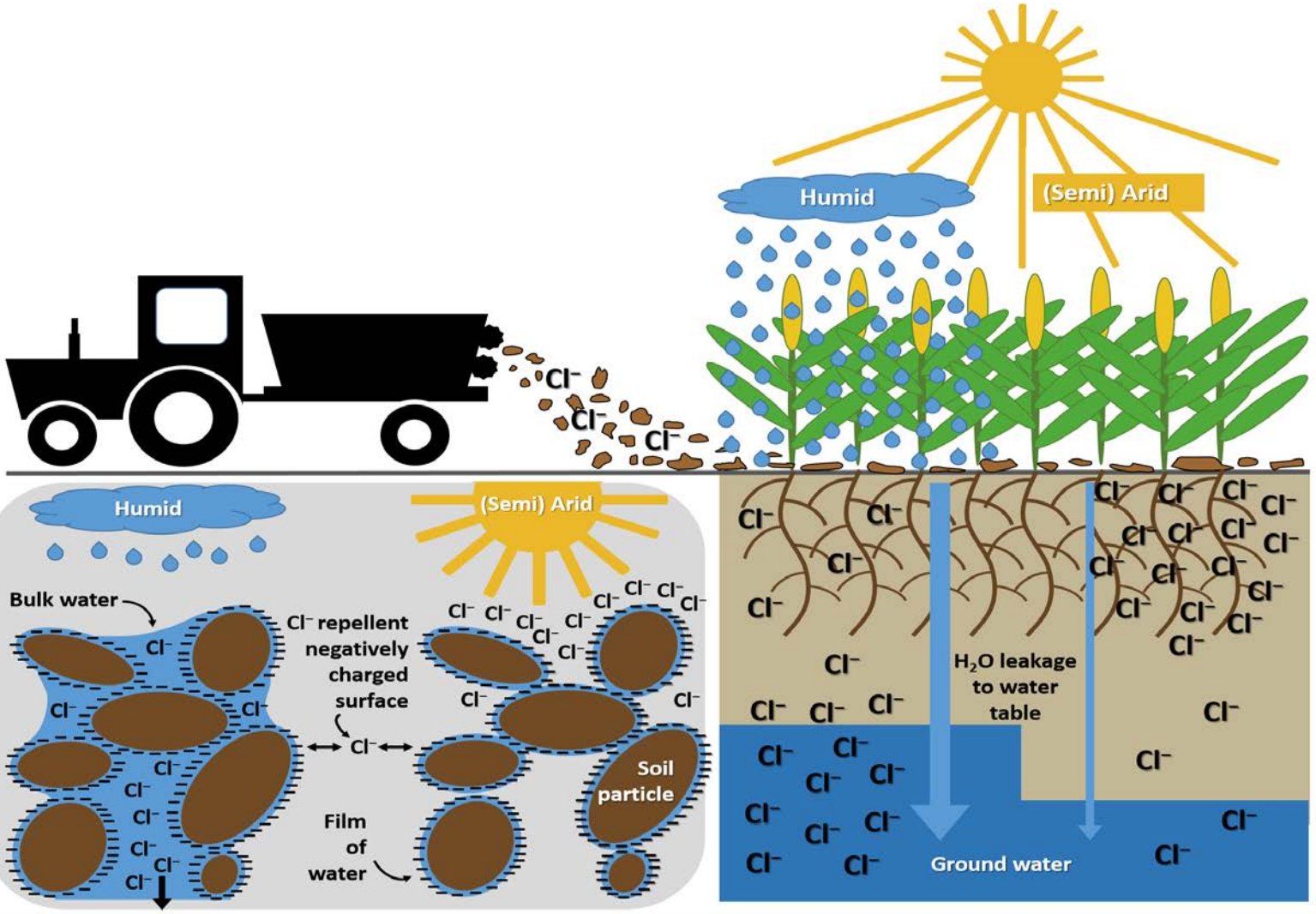
Mizuno & Inazu, 1982, Japanese Journal of Soil Science and Plant Nutrition, 5

Sources of Cl^- and depositions to soils

Source		[Cl^-]	Reference	Depositions (Cl^- ha^{-1} yr^{-1})	References
Earth crust		**0.50 g kg^{-1}**	Yaalon, 1963		
Soil		**0.10 g kg^{-1}**	Bohn et al., 2001		
Soil solution		**2 mg l^{-1}**	Brucher, 2007		
Oceans		19.0 g l^{-1}	Stumm & Morgan, 1996		
KCl fertilizer (99 % purity)		**470 g kg^{-1}**		**0344.86 kg** *	Stumm & Morgan, 1996
Precipitation (shore)		20-50 mg l^{-1}	Yaalon, 1963	175.00 kg	Yaalon, 1963
Precipitation (continental areas)		2-6 mg l^{-1}	Yaalon, 1963	1. - 1.3 kg	Jackson & Jobbágy, 2005
Irrigation water (med. salt cont)		**200 g/m^3**	**Xu et al., 2000**	**1000.00 kg** #	Xu et al. 2000
Pig slurry	Farrowing sows	3.57 kg/m^3	Moral et al., 2008	282.00 kg ¥	Moral et al., 2008
Pig slurry	**Finishers**	**5.12 kg/m^3**	**Moral et al., 2008**	**0458.00 kg** ¥	Moral et al., 2008
Pig manures (faeces, urine, grain)		1.70 g l^{-1}	Krapac et al. 2002		

Geilfus, Envir. Exp. Bot.. 2019

Animal slurries are rich in Cl^-



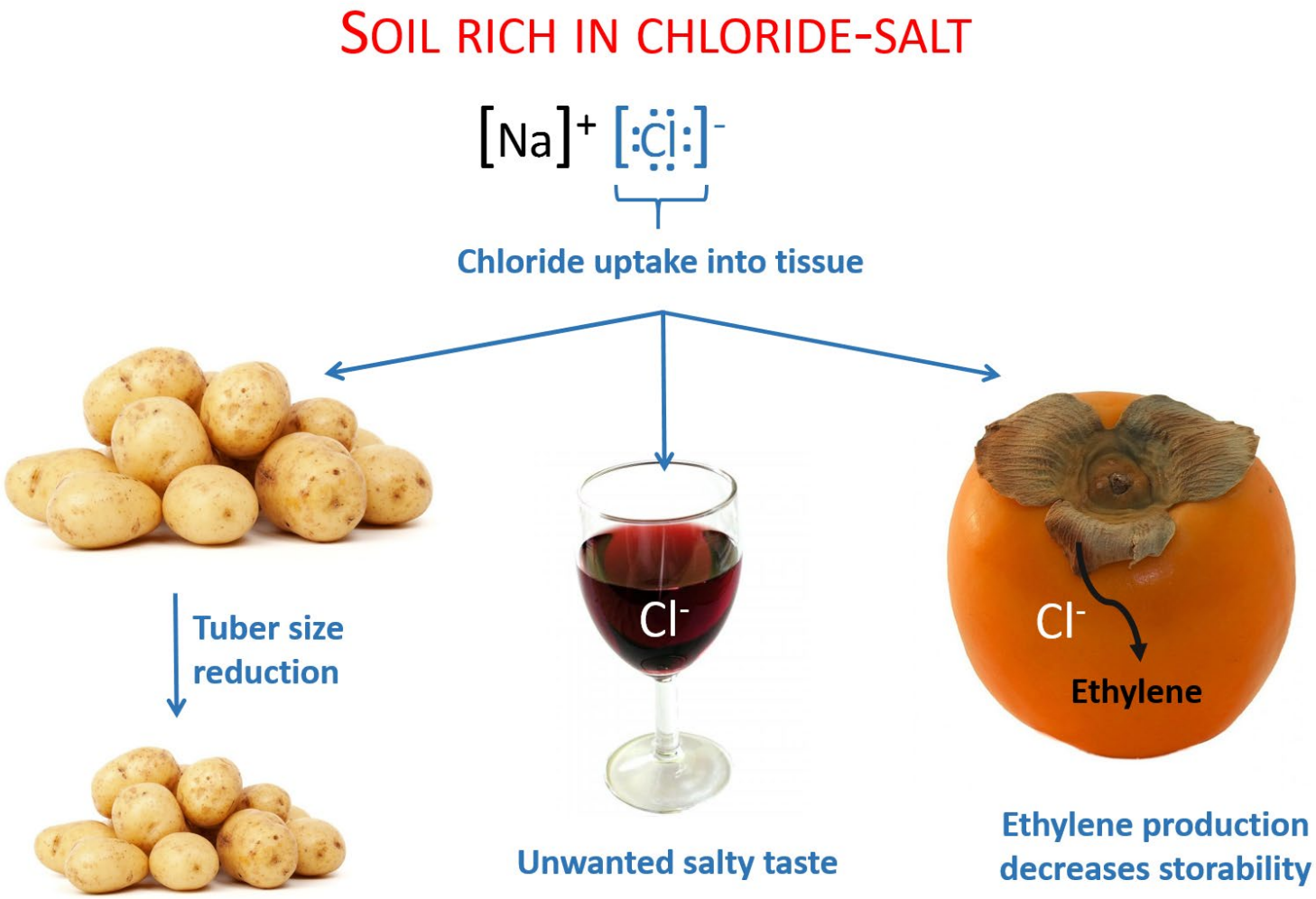
- Animal slurries are rich in Cl−.
- In humid regions, Cl− leaches easily through macrospores.
- Aluminosilicates in soil have negatively charged surfaces that repel Cl− anions.
- In (semi)-arid regions, insufficient precipitation prevents Cl− leaching.
- Accumulation of Cl− in soils can reduce soil fertility.

Geilfus, Envir. Exp. Bot.. 2019

Plant physiological dysfunctions under Cl^- toxicity

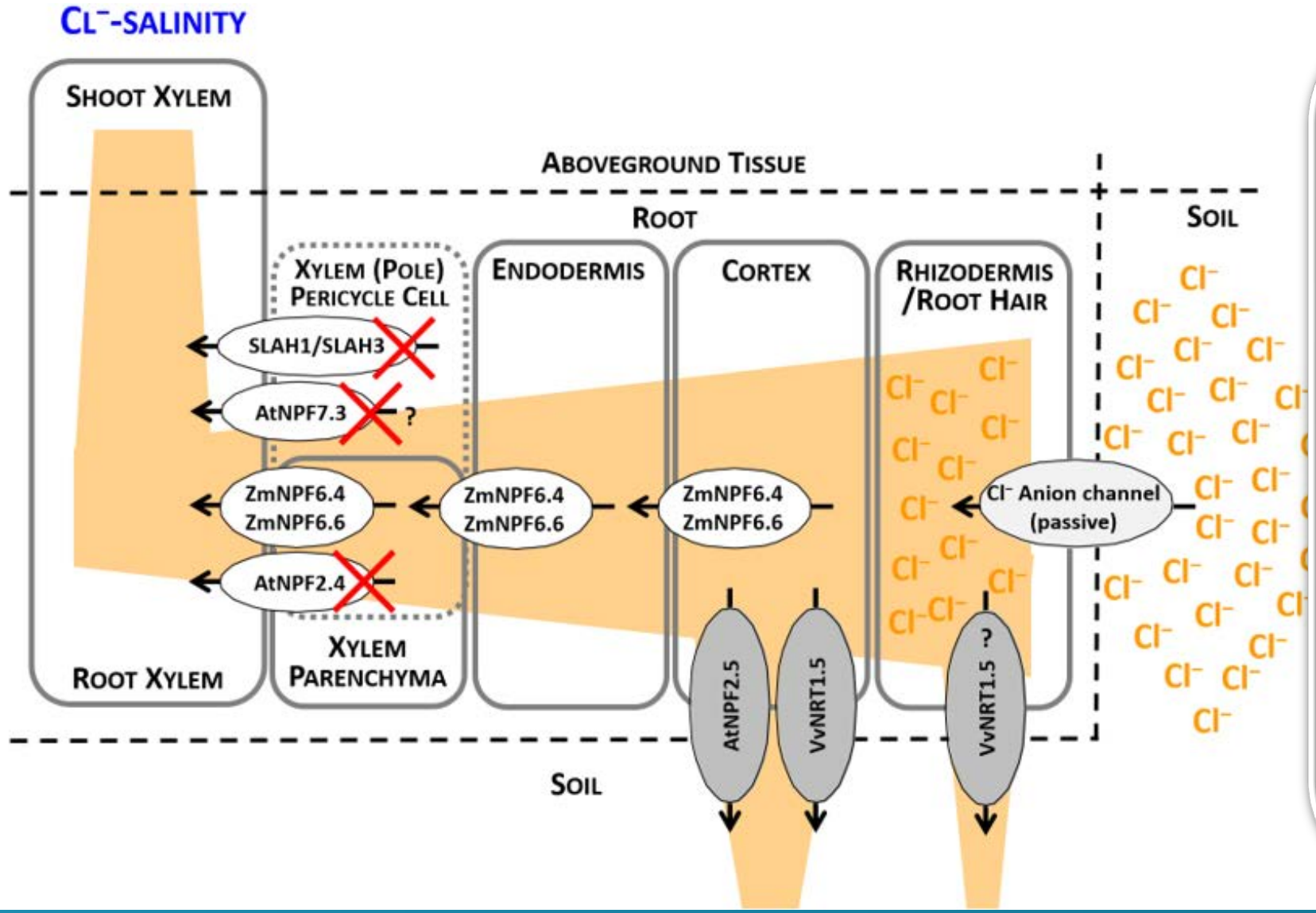
Crop		Symptom and implication for food quality	Reference
Avocado tree	*Persea americana*	**Dampened root growth impairs water supply**, reduced fruit production possibly due to dehydration, leaf necrosis and premature leaf abscission	[88,149,150]
Citrus	*Citrus spp.*	Yield loss, reduced leaf and branch growth, leaf yellowing, leaf bronzing, burned tips, leaf abscission, accumulation of Cl^- in fruit juices	[46,135,137,151]
Field bean	*Vicia faba*	Shoot growth depression, chlorophyll degradation, **reduction in photosynthetic capacity** and quantum yield	[83,84]
Grapevine	*Vitis vinifera*	Growth reduction, lack of nitrogen in the shoot, accumulation of Cl^- in berries which confers salty taste	[74,100,131]
Kiwifruit	*Actinida deliciosa*	Leaf scorch, leaf drop, **reduction of phosphor and nitrogen leaf content**	[22,152]
Potato	*Solanum tuberosum*	Decreased tuber yield, retarded shoot growth and emergence, decline in photosynthesis, impaired nitrogen uptake	[90,92,93]
Soybean	*Glycine max*	Leaf scorch and yield reduction	[103,156]
Tomato	*Lycopersicon esculentum*	Restricted growth and impaired fruit setting, lack of shoot nitrogen, increased defoliation, blossom-end rot, reduced fruit water content, putative positive aspect on aromatic compounds in fruits.	[1,3,46,101,157]
Wheat	*Triticum aestivum*	**Yield loss, lack of nitrogen in the shoot**, potentially inhibitory for translation of RNA	[81,90,106]

Cl^--toxicity: quality problems in crop products



Geilfus, Plant Sci., 2018

Radial movement of Cl^- through root and xylem loading



Non-saline Conditions:

•Active uptake: Cl– is actively taken up by a proton symporter.

Cl–-Salinity Conditions:

• Passive uptake: Cl– is taken up passively via anion channels.

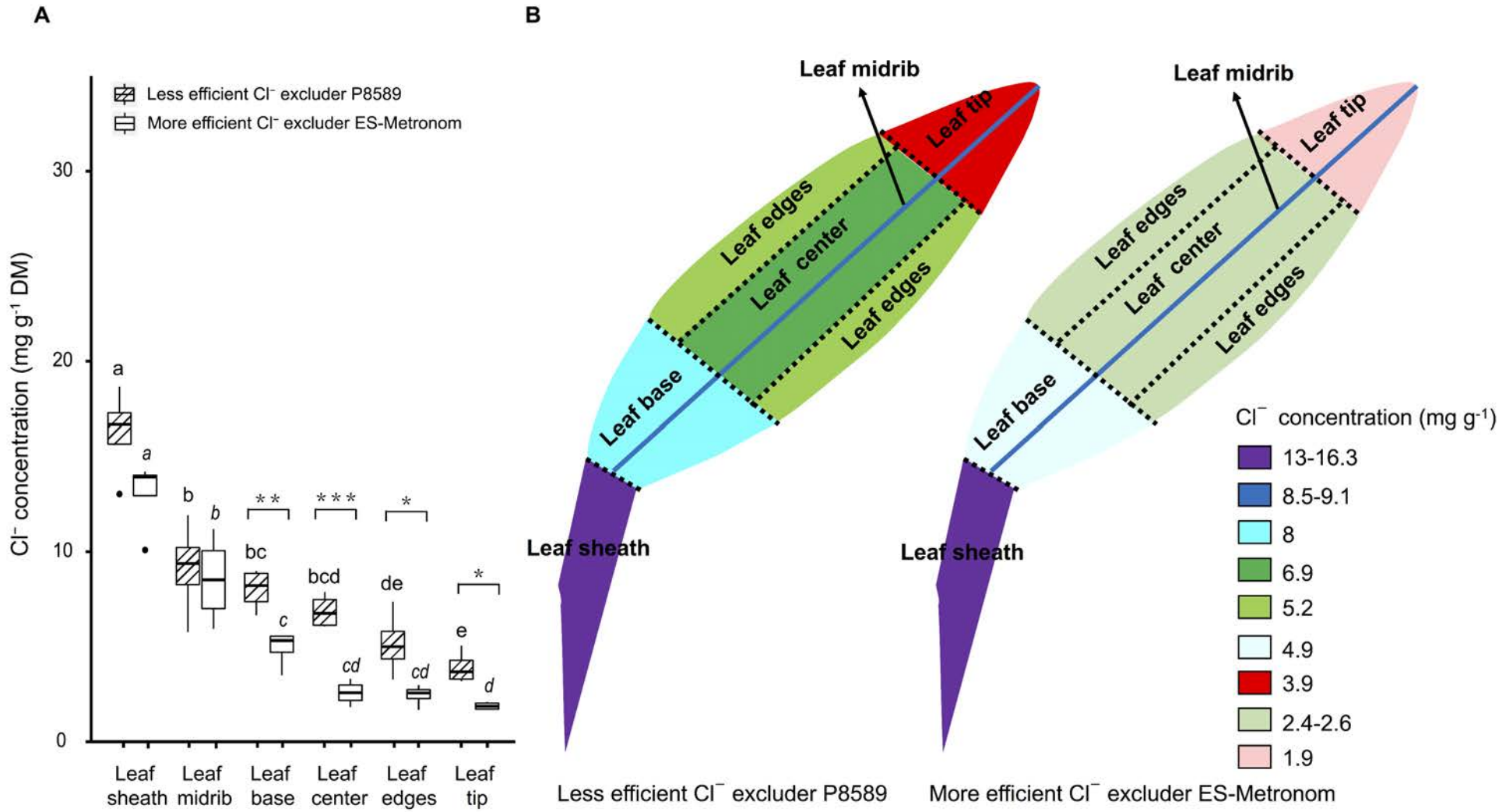
• ZmNPF6.4 functions as a high-affinity chloride selective transporter.

• Reduced xylem loading:

• Down-regulation of AtNPF7.3, AtNPF2.4, AtSLAH1.

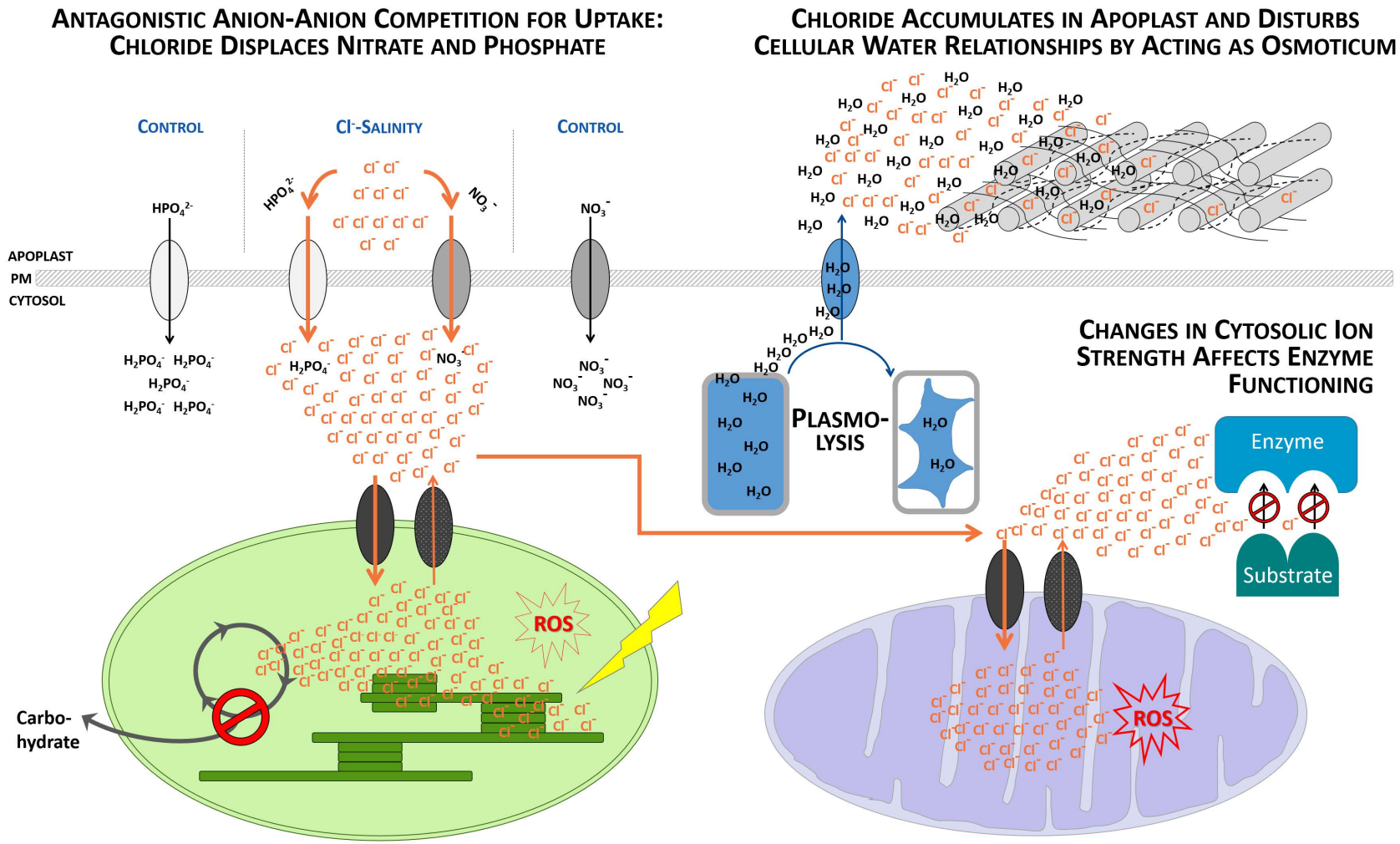
Geilfus, Envir. Exp. Bot.. 2019

Cl^-- distribution in maize leaves that contrast in tolerance



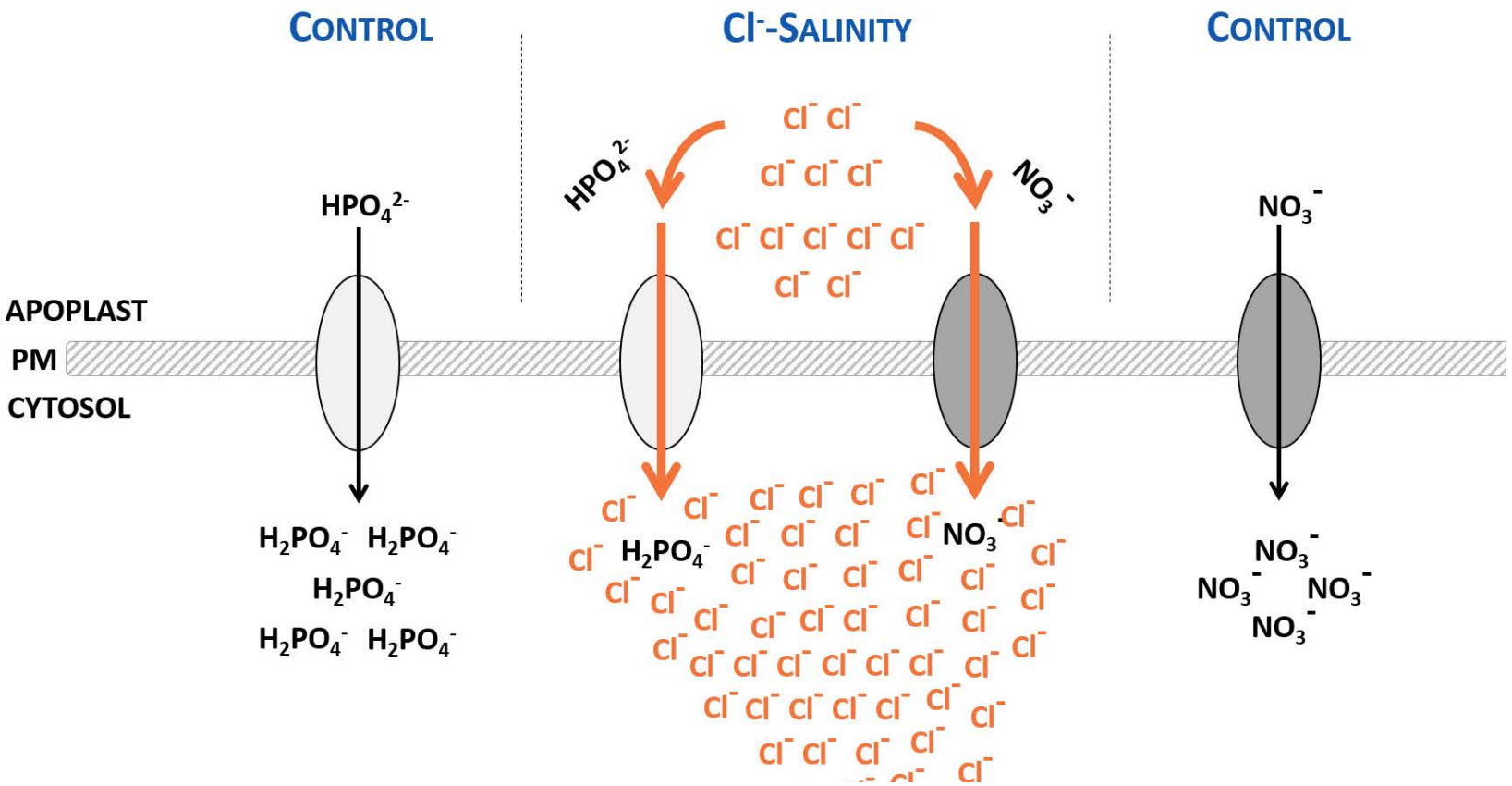
Zhang et al., 2020

Why excessive Cl^- is toxic for cells



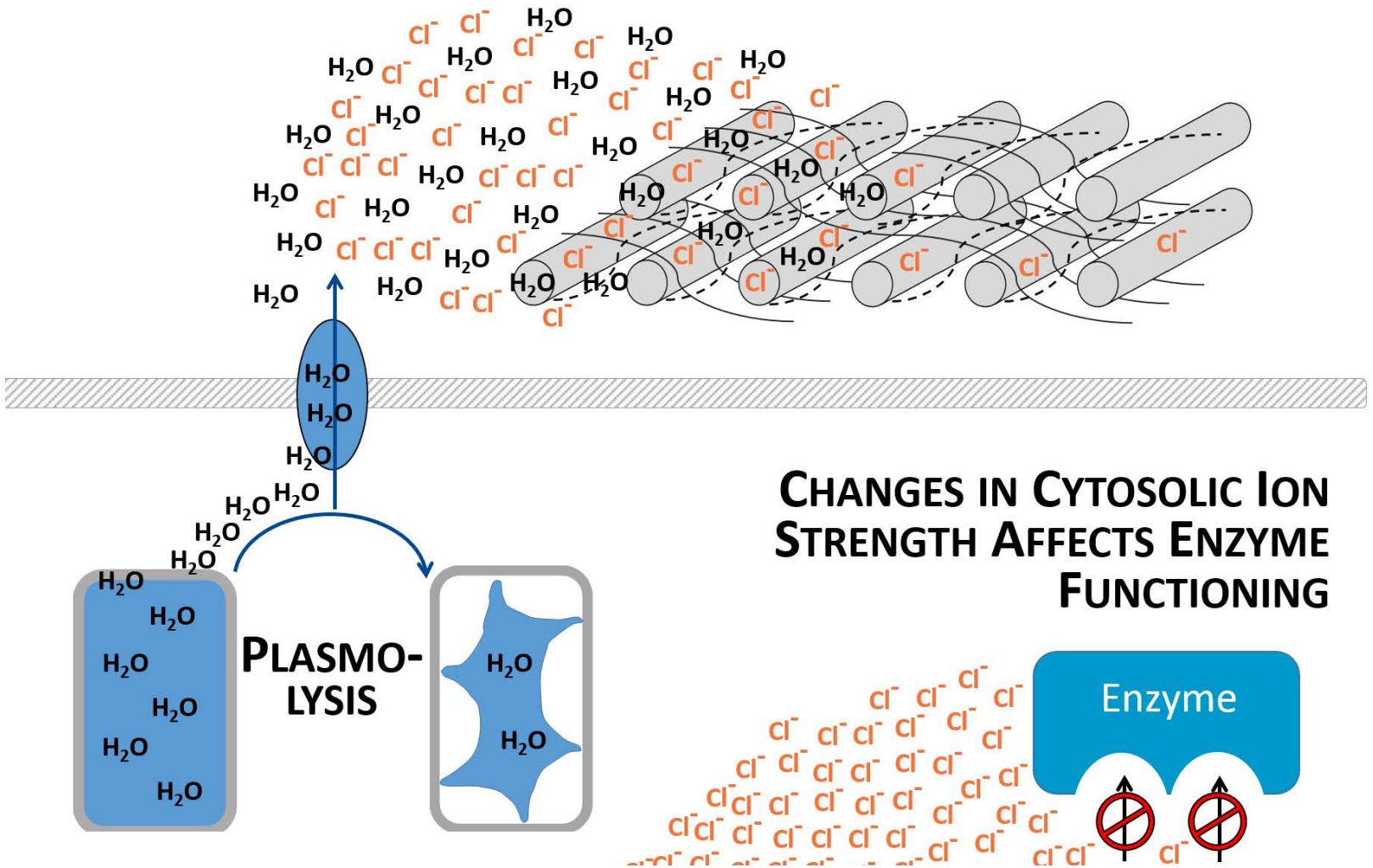
Geilfus, Plant & Cell Physio., 2018

Antagonistic Anion-Anion Competition for Uptake: Chloride Displaces Nitrate and Phosphate



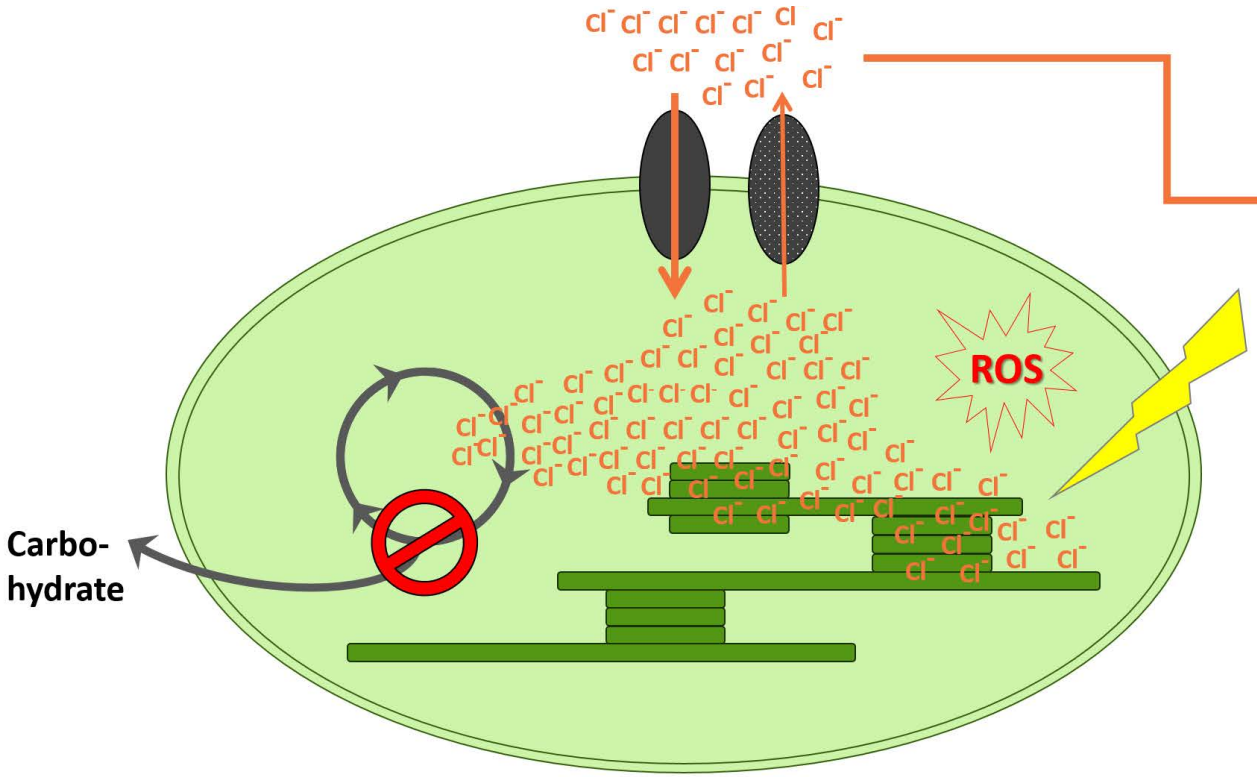
Geilfus, Plant & Cell Physio., 2018

Chloride Accumulates in Apoplast and Disturbs Cellular Water Relationships by Acting as Osmoticum

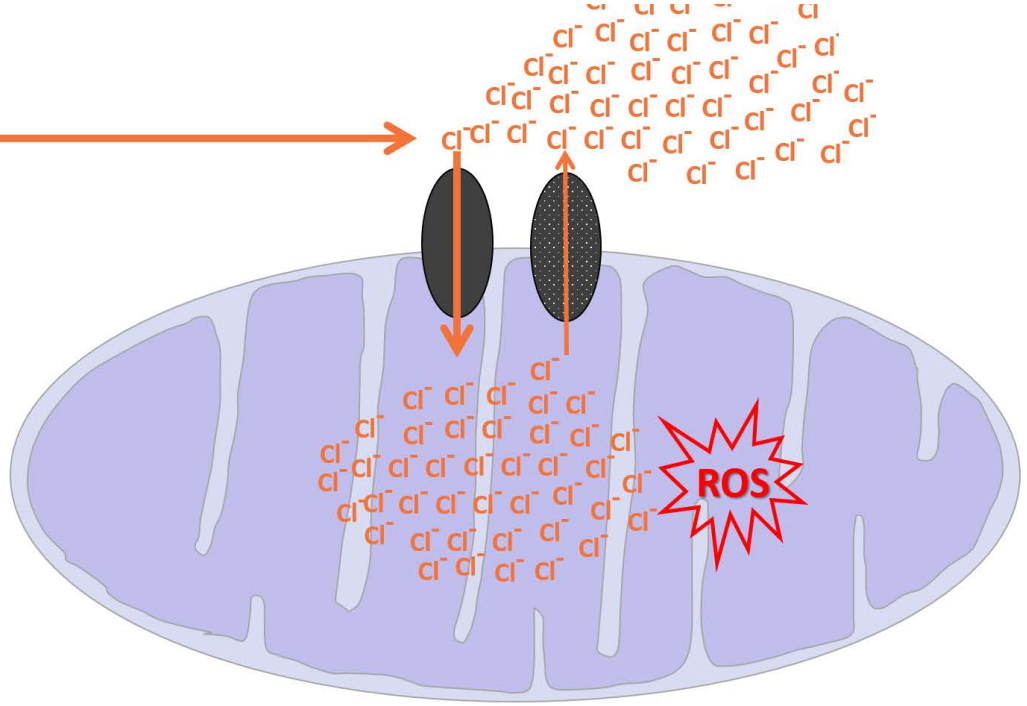


Changes in Cytosolic Ion Strength Affects Enzyme Functioning

Geilfus, Plant & Cell Physio., 2018



BREAKDOWN OF CHLORIDE HOMEOSTASIS:
ROS BURST DUE TO DISTURBED LIGHT- & DARK-REACTION



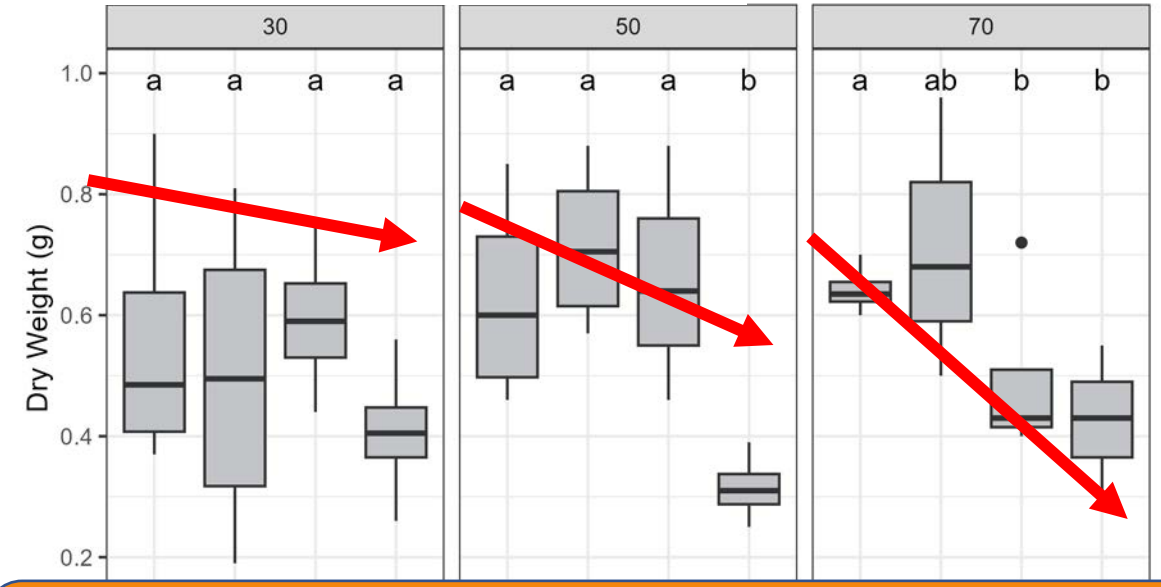
BREAKDOWN OF CHLORIDE HOMEOSTASIS:
ROS BURST DUE TO DISTURBED RESPIRATION

Geilfus, Plant & Cell Physio., 2018

Is Cl^- in moderate amounts actually not so bad after all?

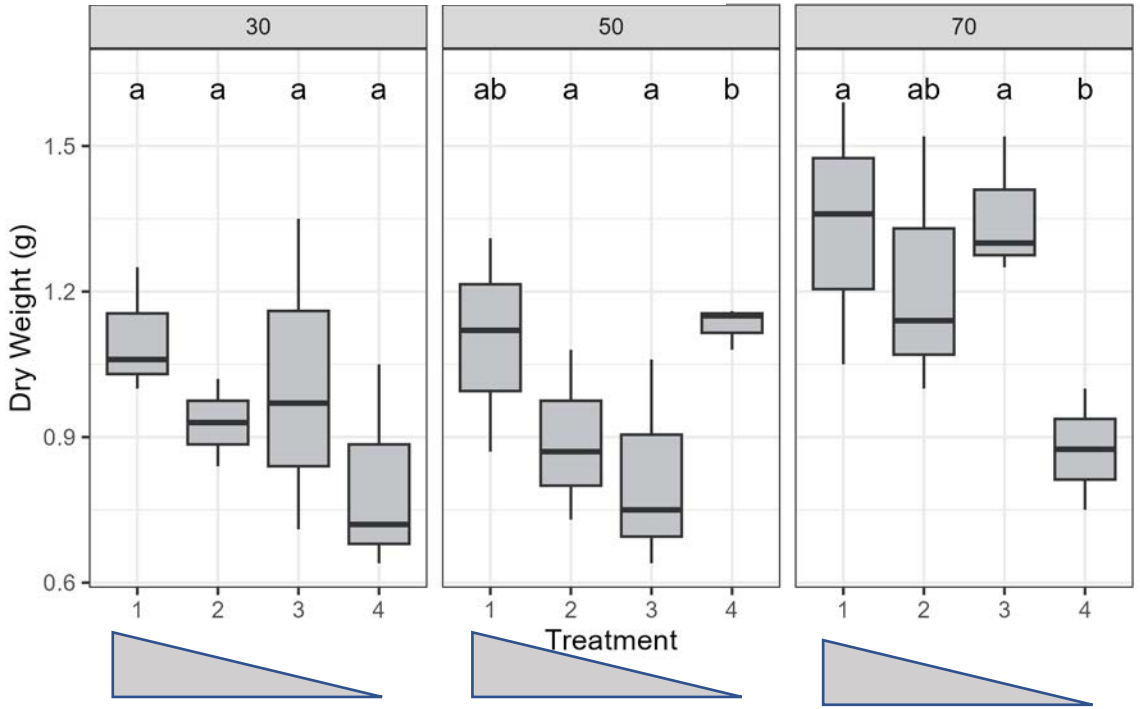
Dry weight Hordeum vulgare L.

Water content in soil (%)



Dry weight Vicia faba L.

Water content in soil (%)



Nitrate/Chloride-Ratio

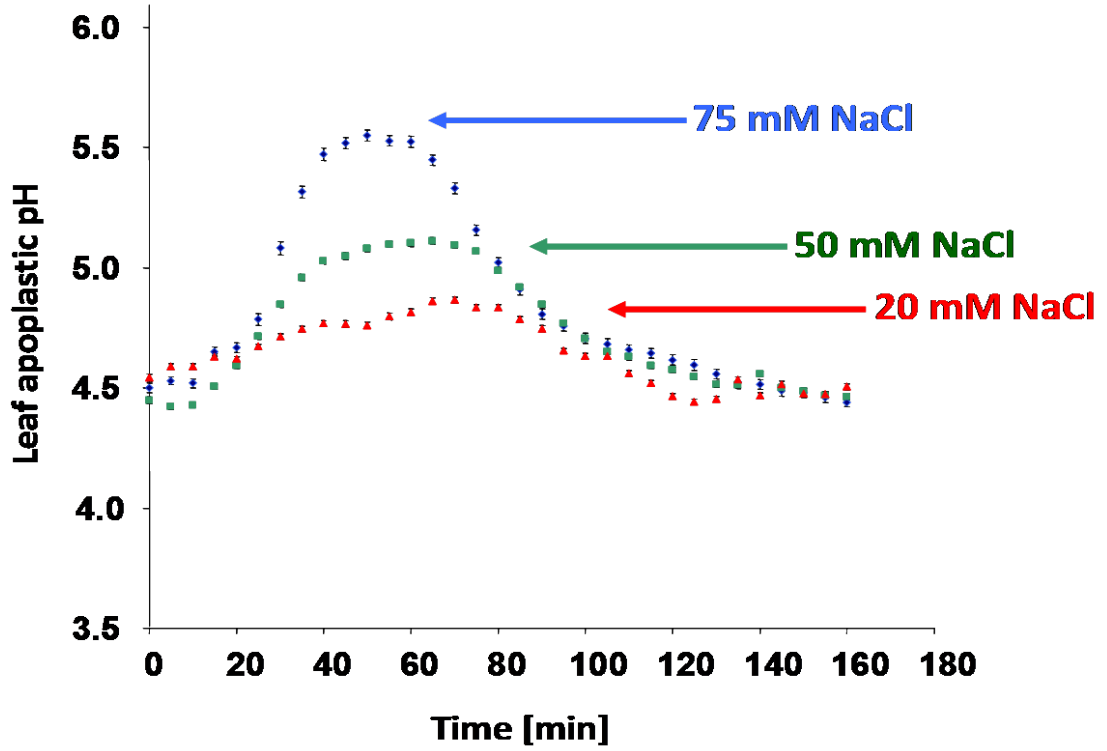
Nitrate/Chloride-Ratio

Nitrate/Chloride-Ratio

Cl^- is a micronutrient, but during its function in osmo- and turgor-regulation, it can accumulate in the vacuole to a final concentration of 150 mM

unpublished

Cl^- toxicity is sensed via pH signalling

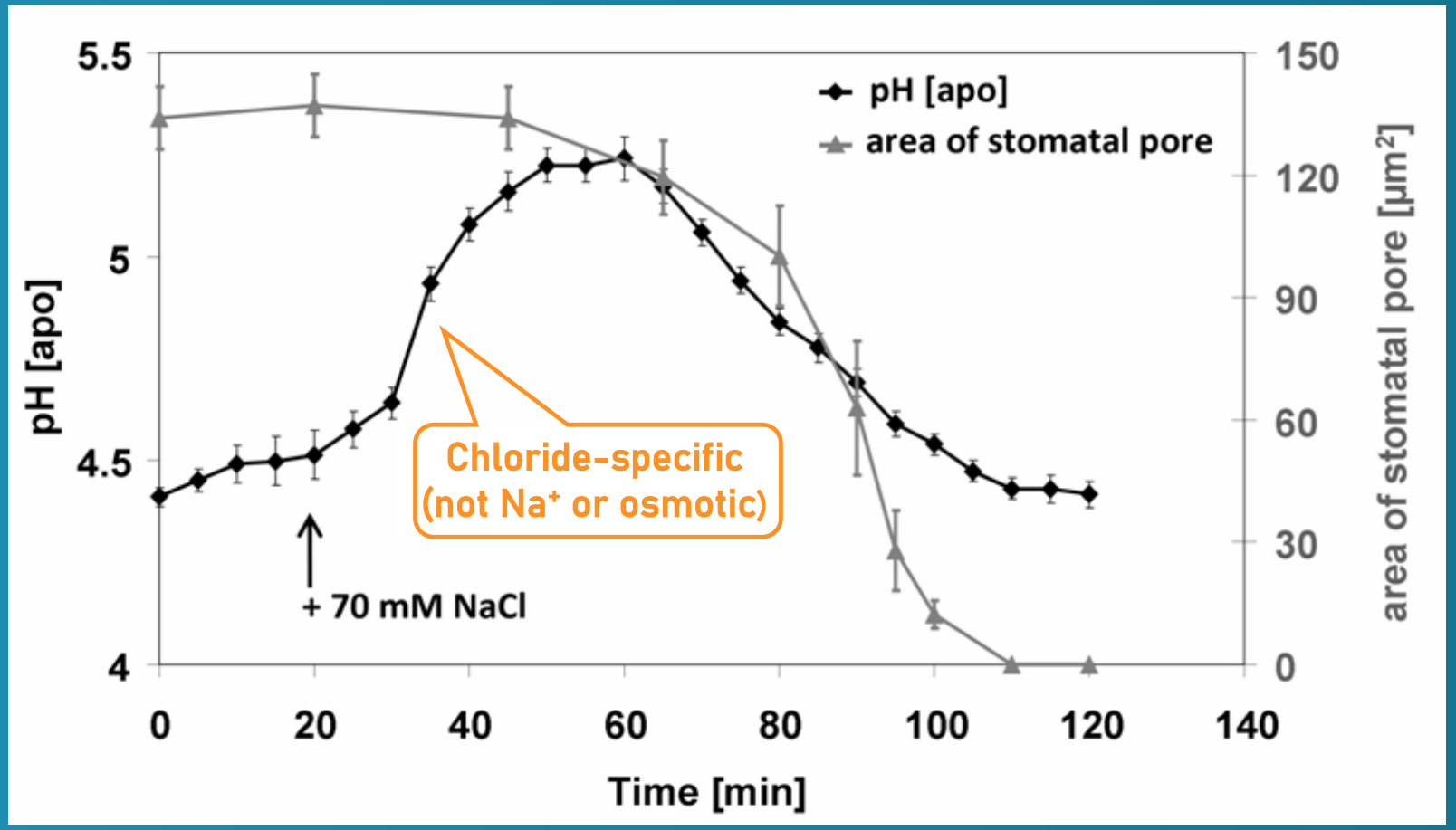


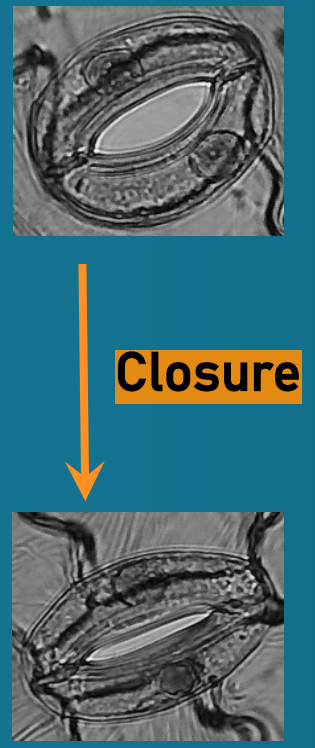
Dose dependency

Apoplastic pH changes in a clear relationship with respect to the incoming stress.

Geilfus et al, PLANT CELL & ENVIRON 2012

pH_{apo} transient correlates with stomatal aperture



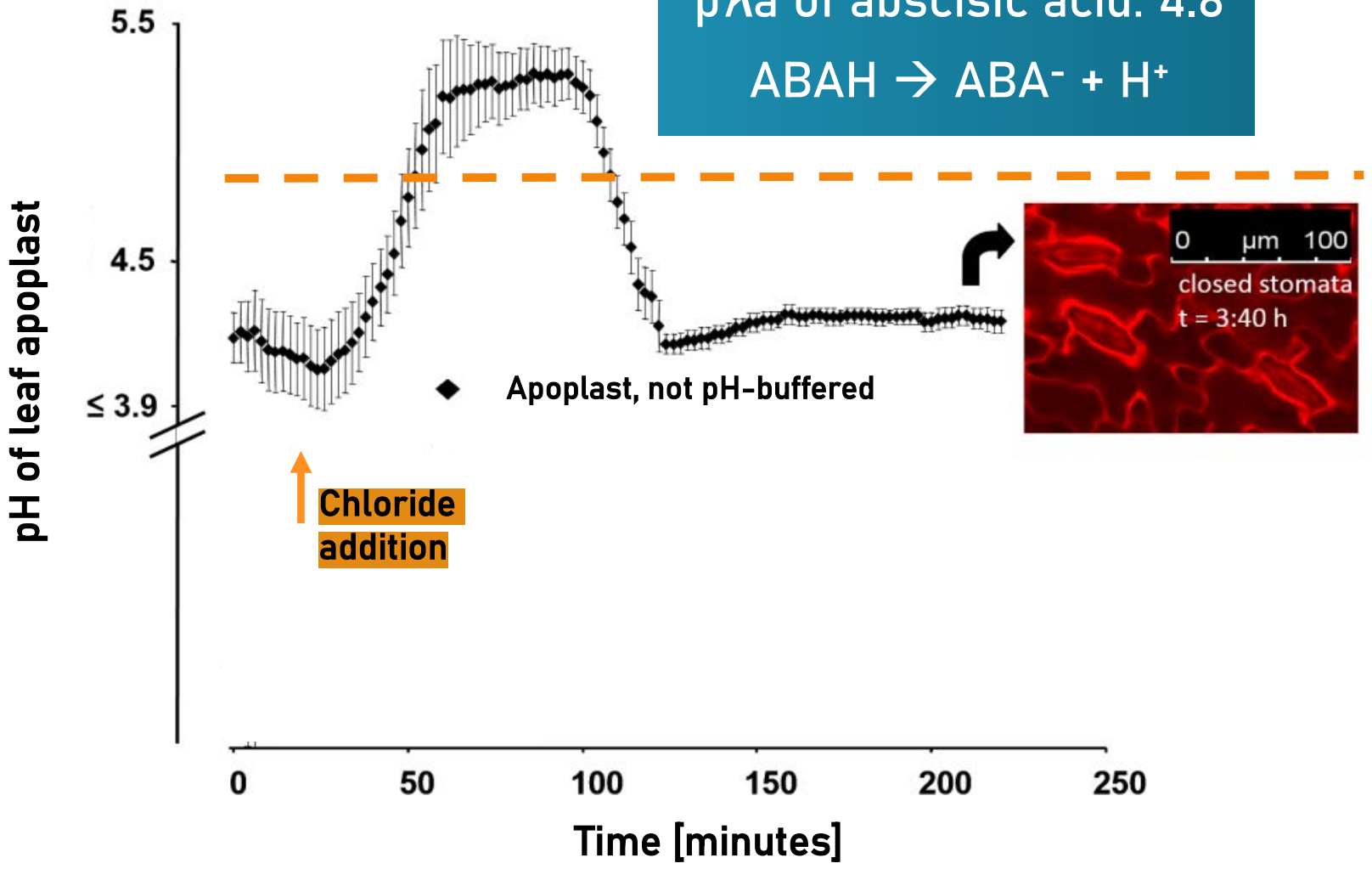


Geilfus et al, PLANT CELL & ENVIRON 2012

pH-transient controls stomatal aperture

p*K*a of abscisic acid: 4.8

ABAH → ABA^- + H^+



Geilfus et al, NEW PHYTOL 2015

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Summary

- High chloride content in manure/fertilizer can cause problem in (semi) arid regions
- For its role as nutrient, traces are sufficient. Moderate levels can have beneficial functions.
- Excessive chloride loads cause leaf damage
  - Breeding for resistance -> chloride exclusion