The Role of Calcium in Plant Nutrition

Philip J. White

The James Hutton Institute

Dundee, United Kingdom

IPI-CAU-ISSAS Symposium

Kunming, 7 November 2019

The Chemistry of Calcium

The firth most abundant elements in earth's crust (4.15% by weight) present in minerals (limestone, gypsum, appetite, fluorite…)

Group 2 alkali metal
Large divalent cation (Ca^{2+}) with high affinity for negatively charged surfaces

Ca^{2+} binds to proteins and regulates their activity

Salts mostly very soluble, although exceptions
($Ca(OH)_2$, $CaCO_3$, $CaSO_4$, Ca-phosphates, Ca-oxalate)

$CaCO_3$ buffers the soil solution to alkaline pH

Low solubility of Ca-phosphates can compromise
P-nutrition and cellular biochemistry

White (2015) *Handbook of Plant Nutrition*, pp.165-198.

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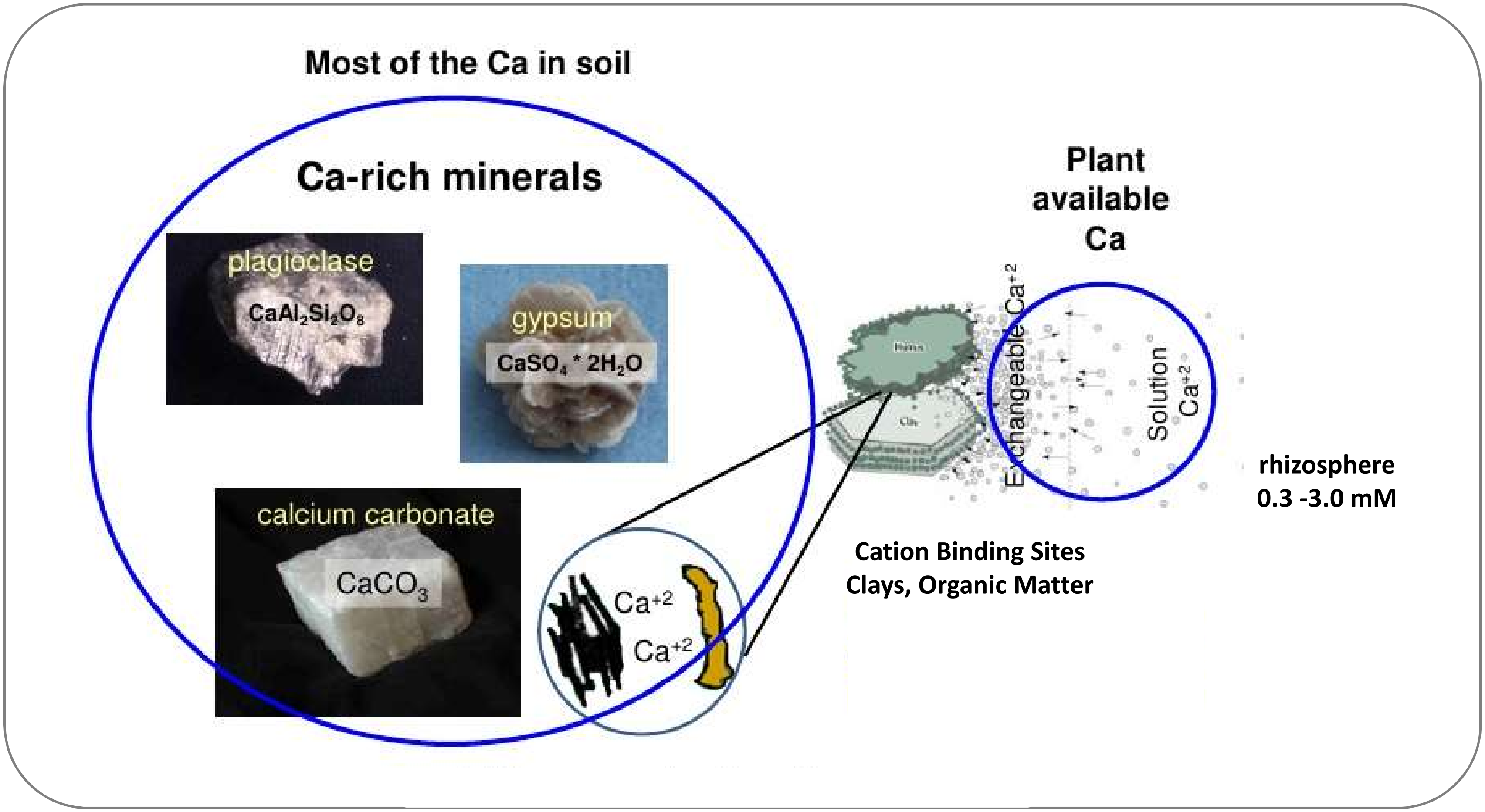
Calcium in Rocks and Soils



www.slideshare.net/jbgruver/science-and-management-of-ca-and-mg

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Calcium in Rocks and Soils

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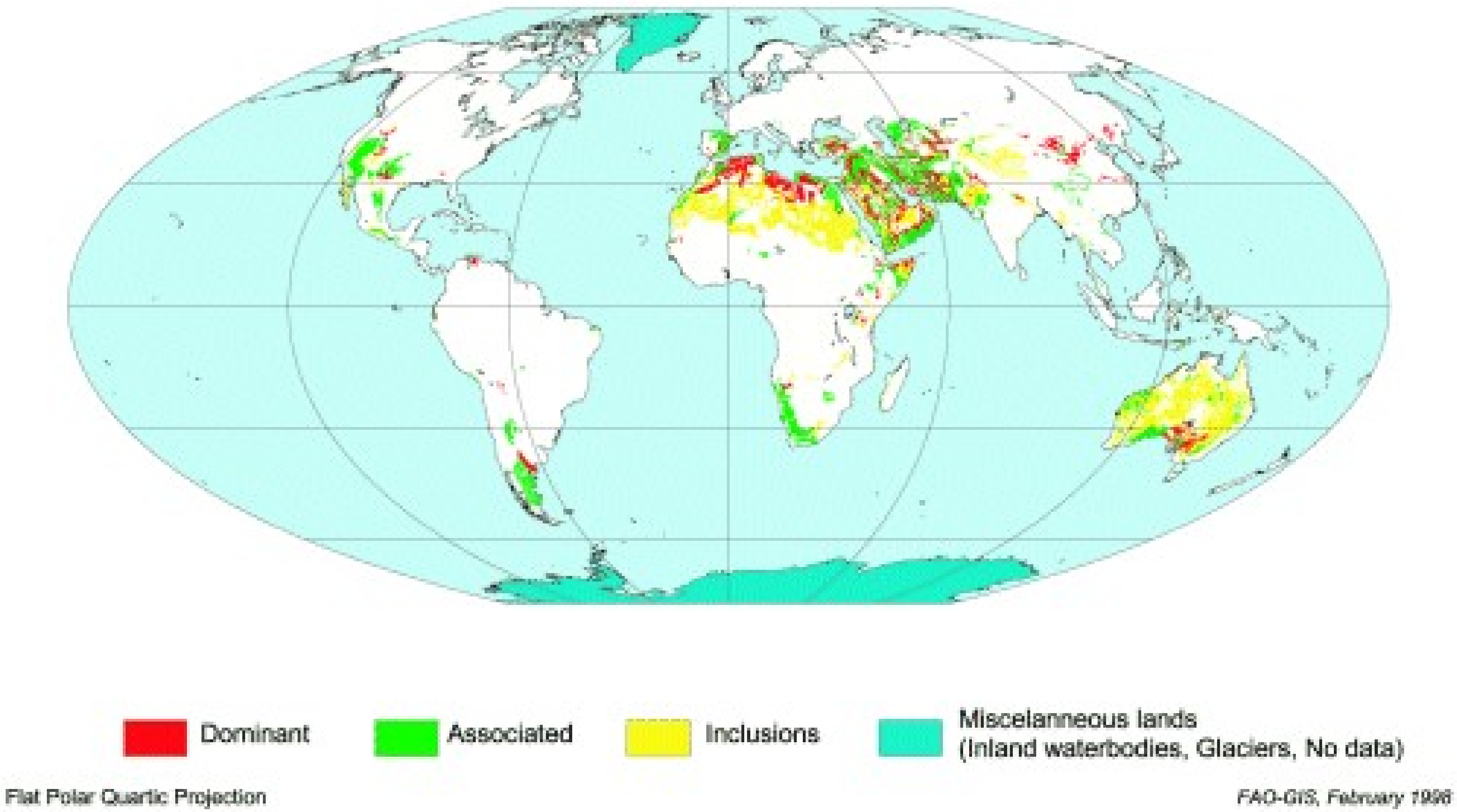
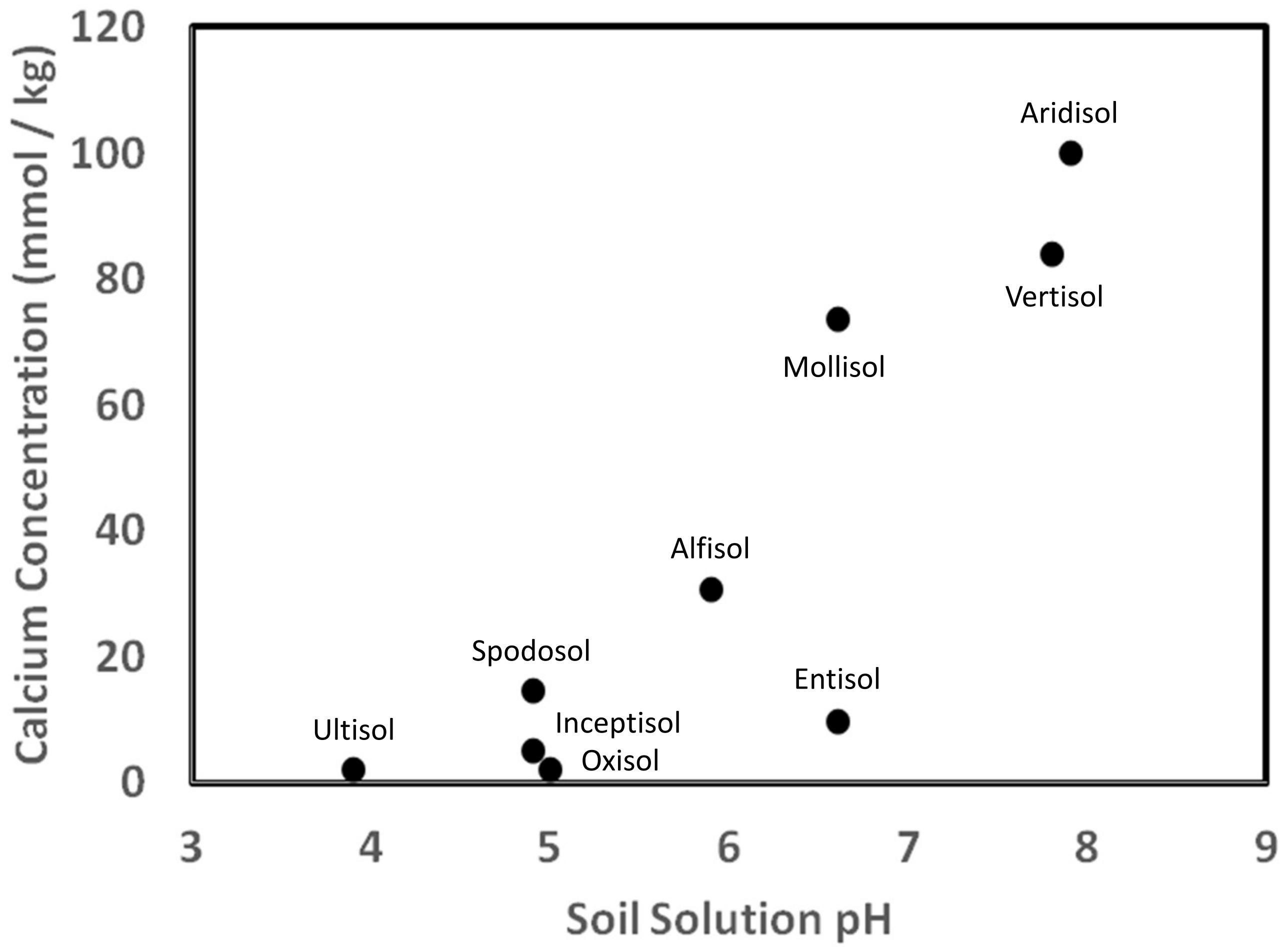
Calcareous Soils – Calcisols



Calcisol area = 1 000 million ha, mostly in arid /semi-arid tropics and subtropics

Soil Calcium is often Correlated with pH



Pilbeam & Morley (2007) *Handbook of Plant Nutrition*, 121-144

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Soil pH affects Nutrient Phytoavailability

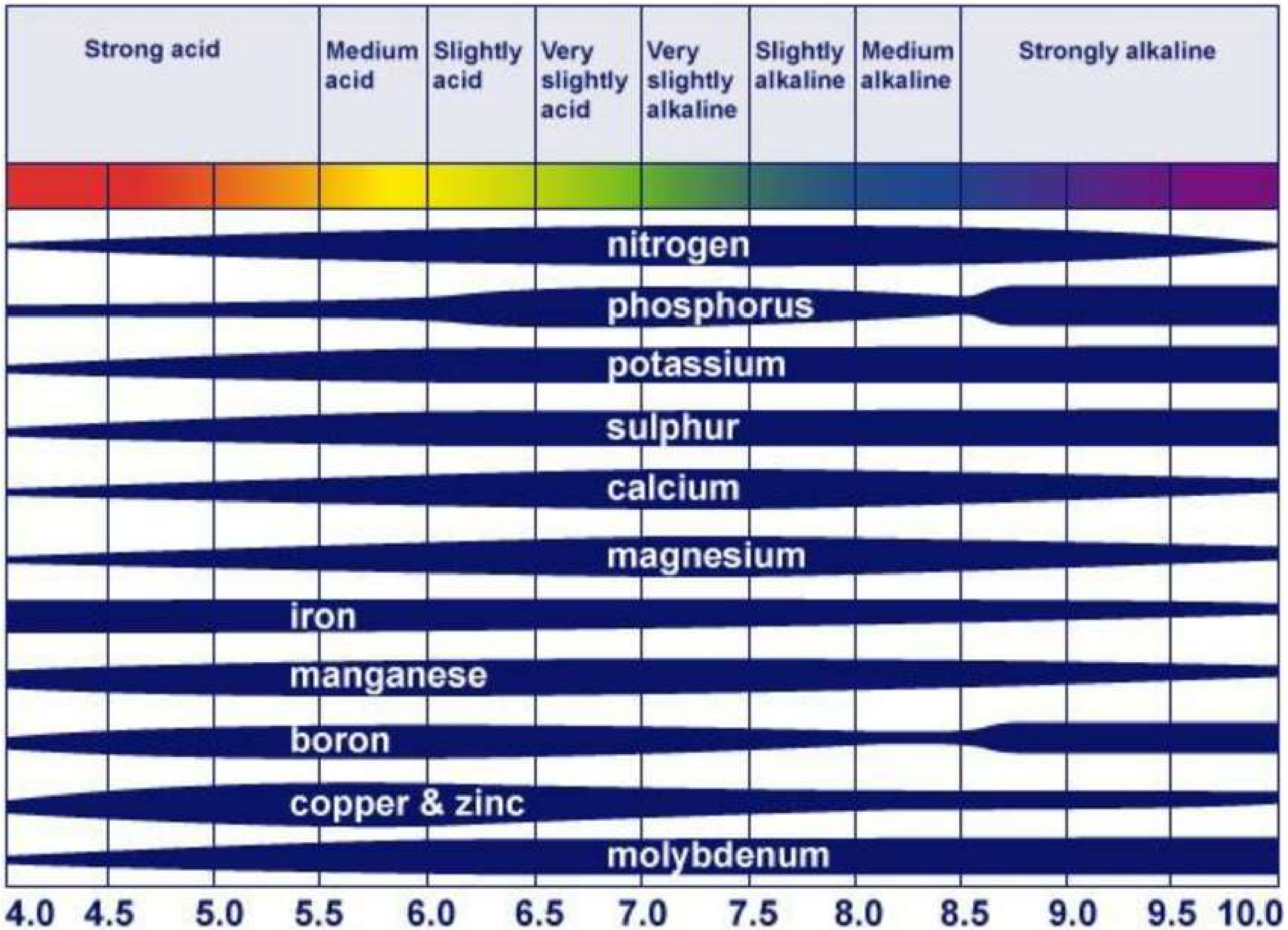
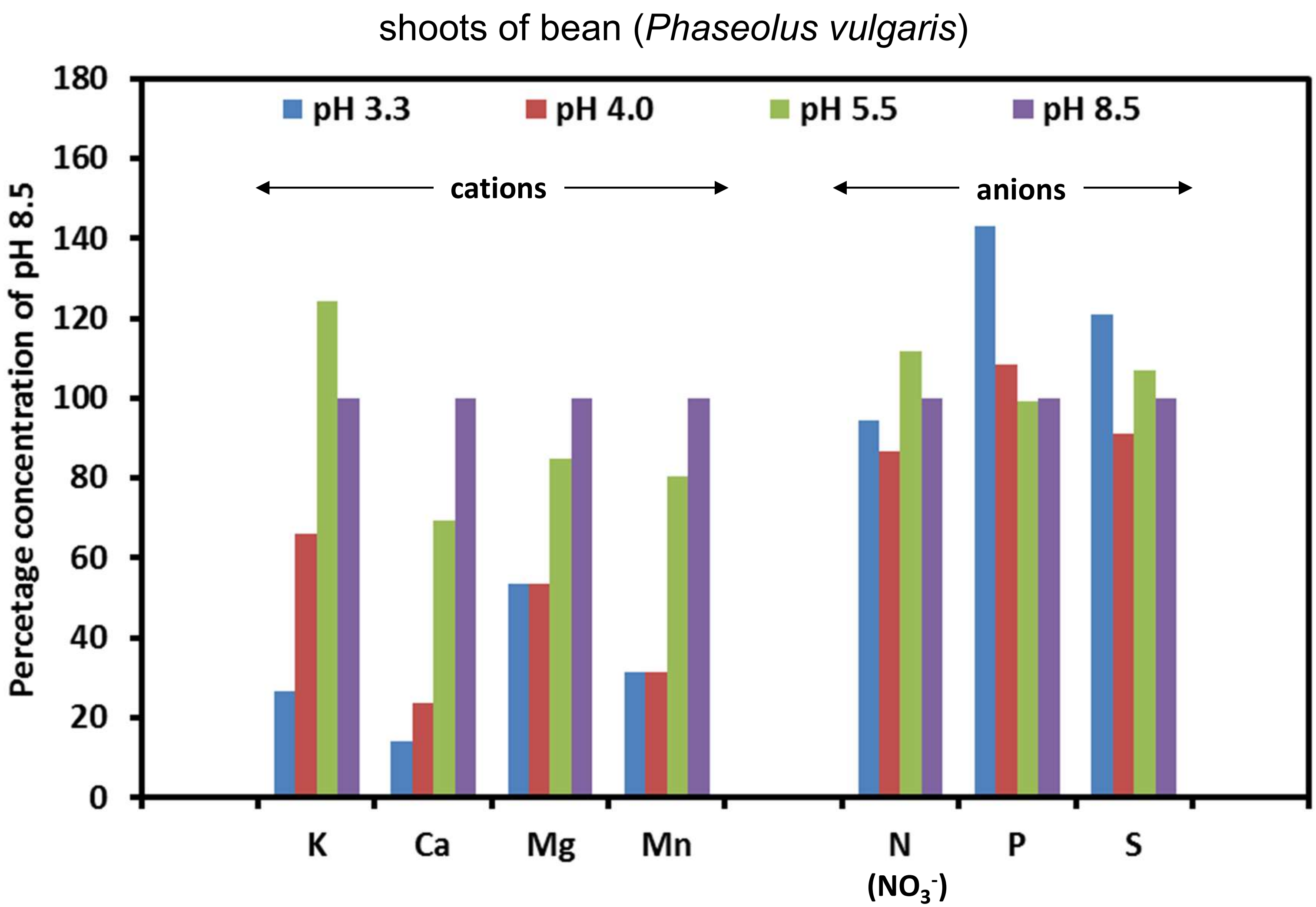


Image from growing-life.com

Solution pH affects Shoot Composition



Islam et al. (1980) *Plant & Soil* 54: 339-357

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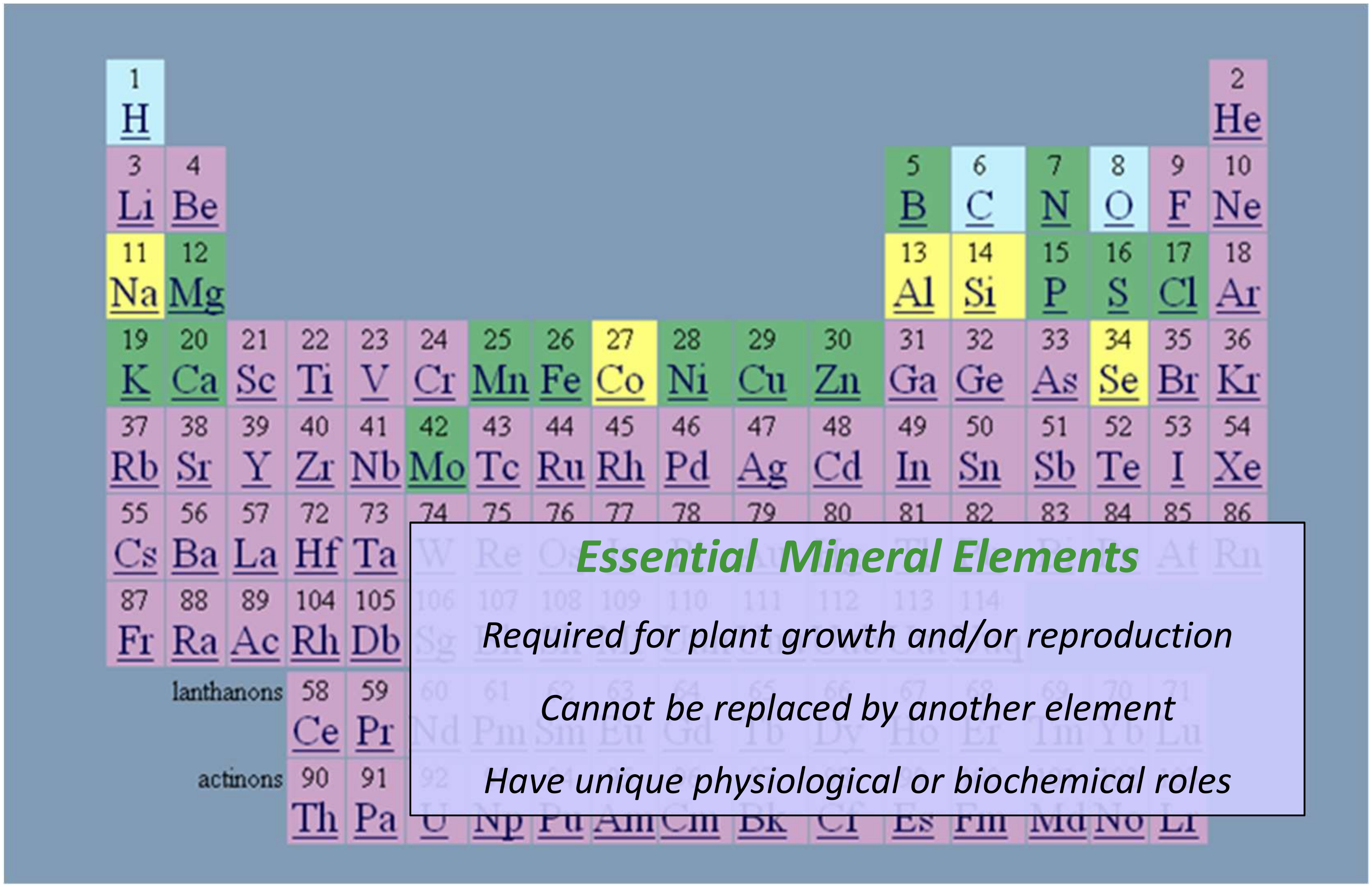
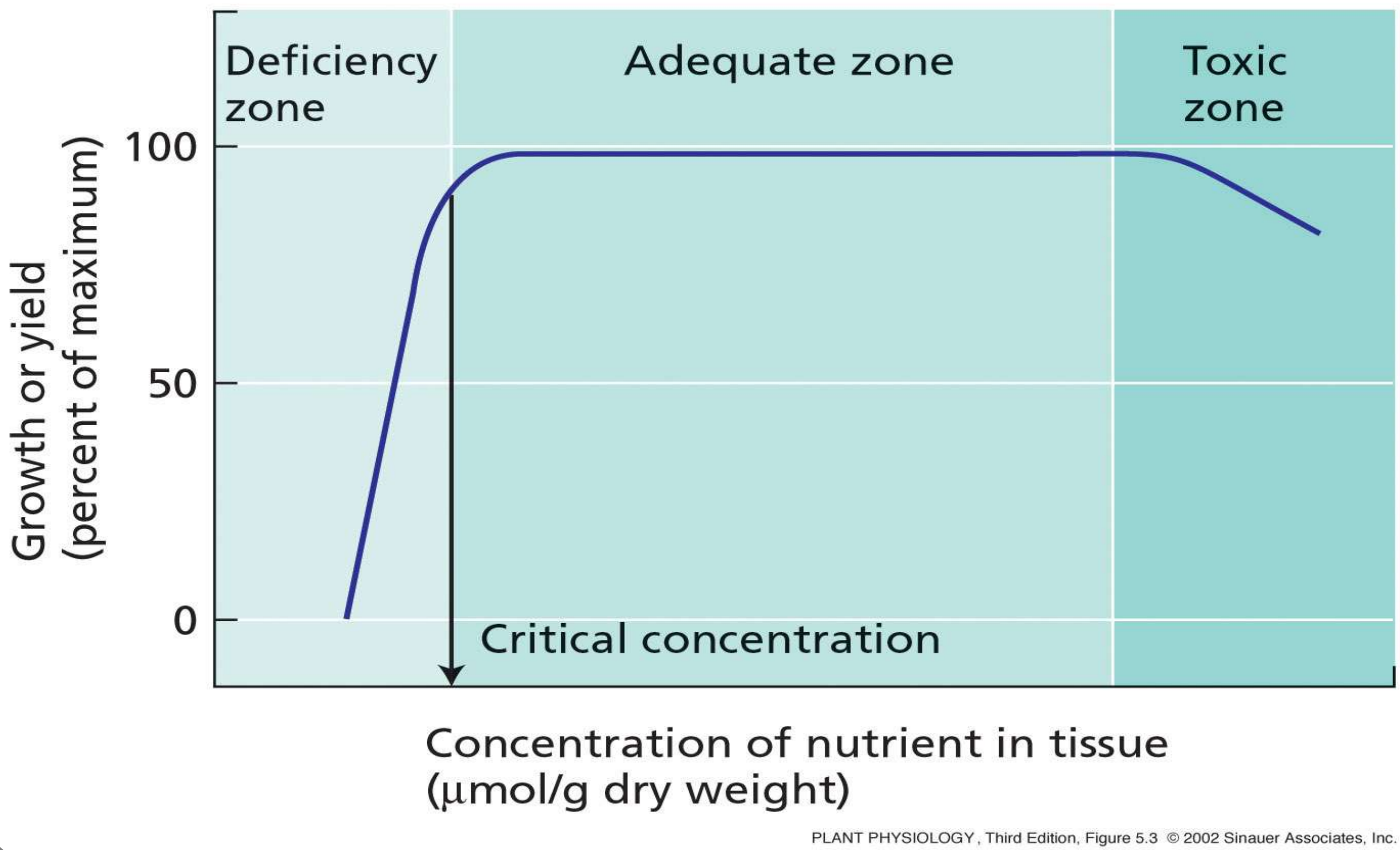
Calcium is Essential for Plant Nutrition



Grusak et al. (2016) *eLS*, doi: 10.1002/9780470015902.a0001306.pub2

Deficiency and Toxicity



Taiz & Zeigler (2006) *Plant Physiology*, Fourth Edition

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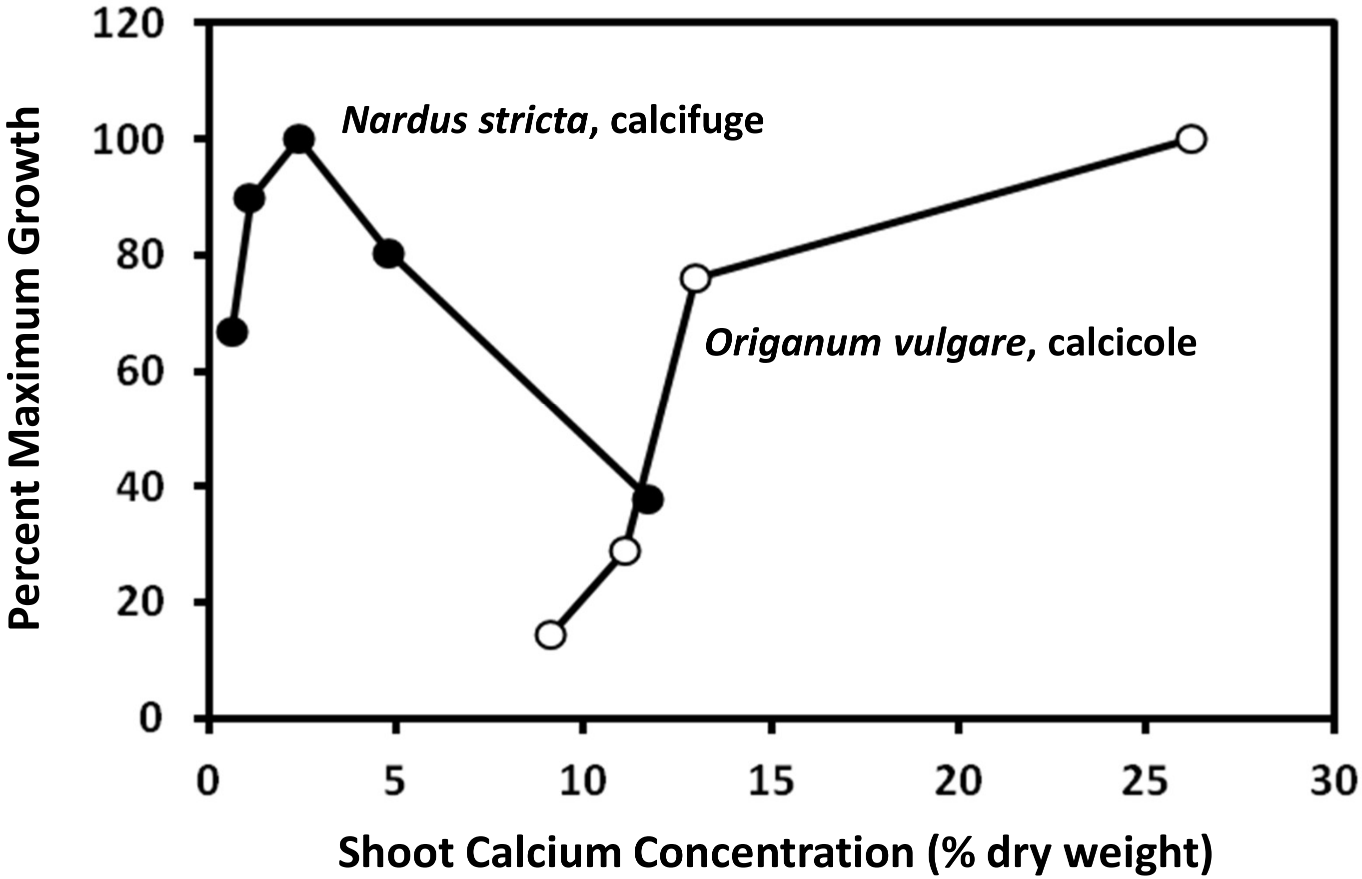
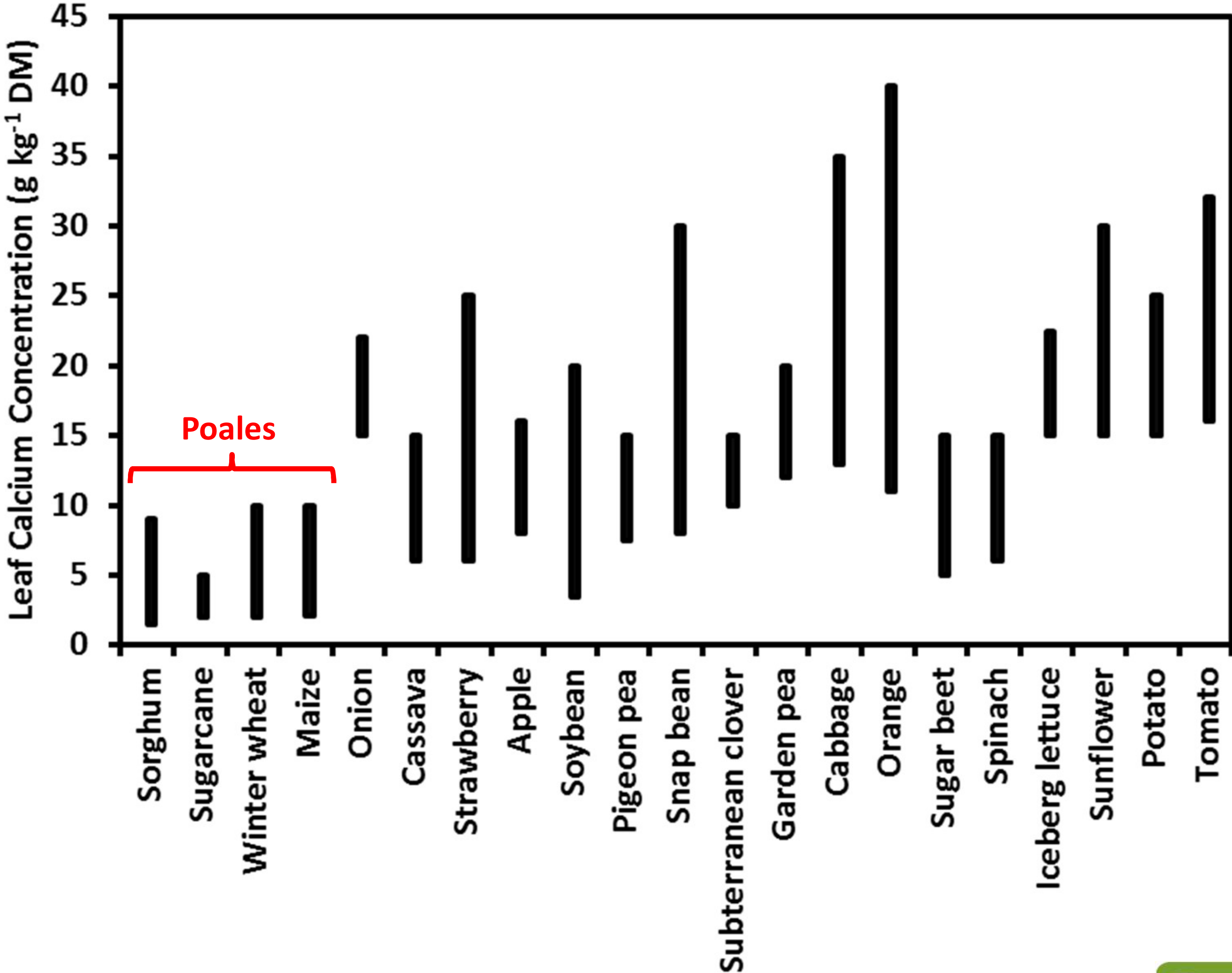
Calcicoles and Calcifuges



Jefferies & Willis (1964) *J. Ecol.* 52, 691-707

Adequate Leaf Calcium Concentrations



Mills & Jones (1996) *Plant Analysis Handbook II*

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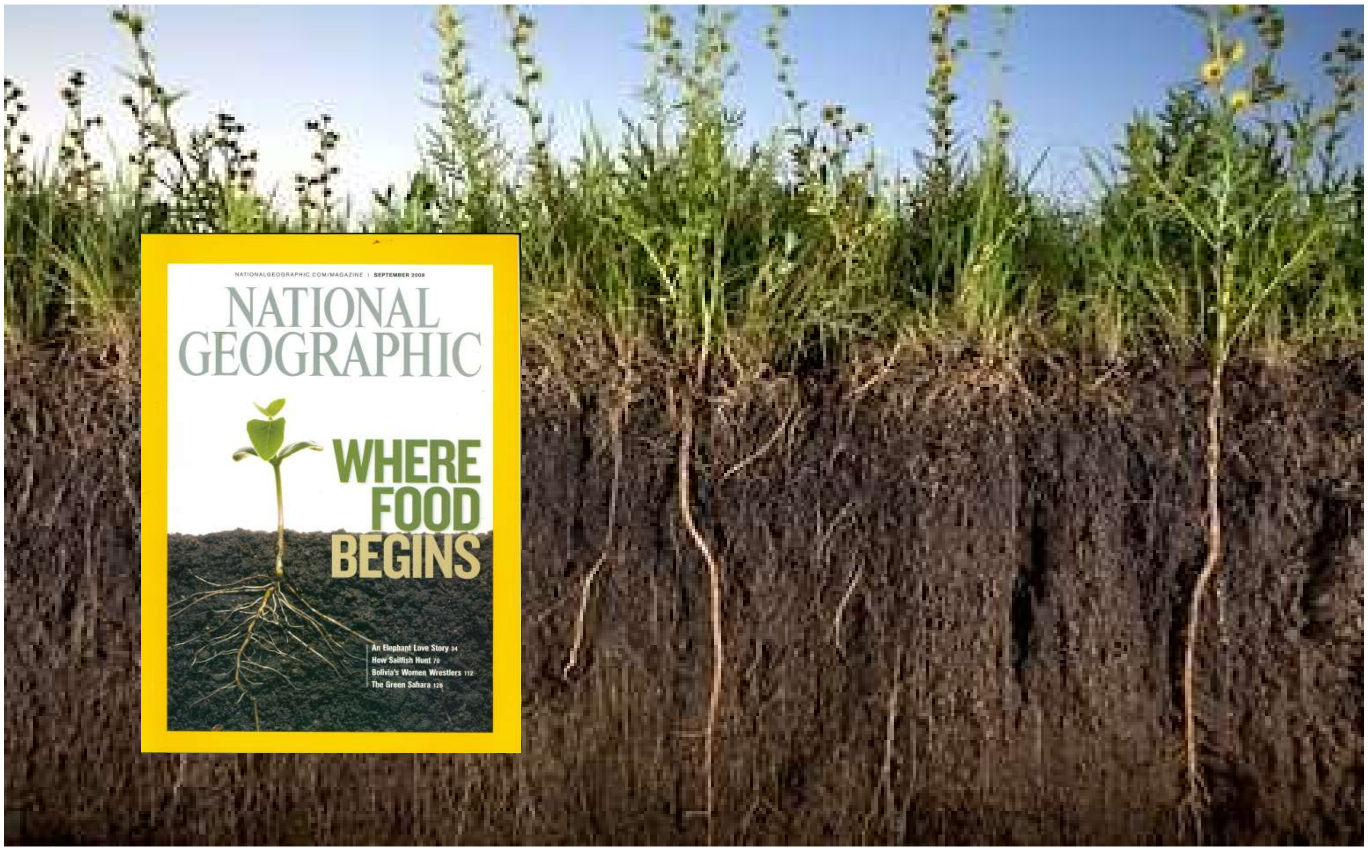
Plants Acquire Mineral Elements From the Soil Solution



National Geographic, September 2008 “Where Food Begins”

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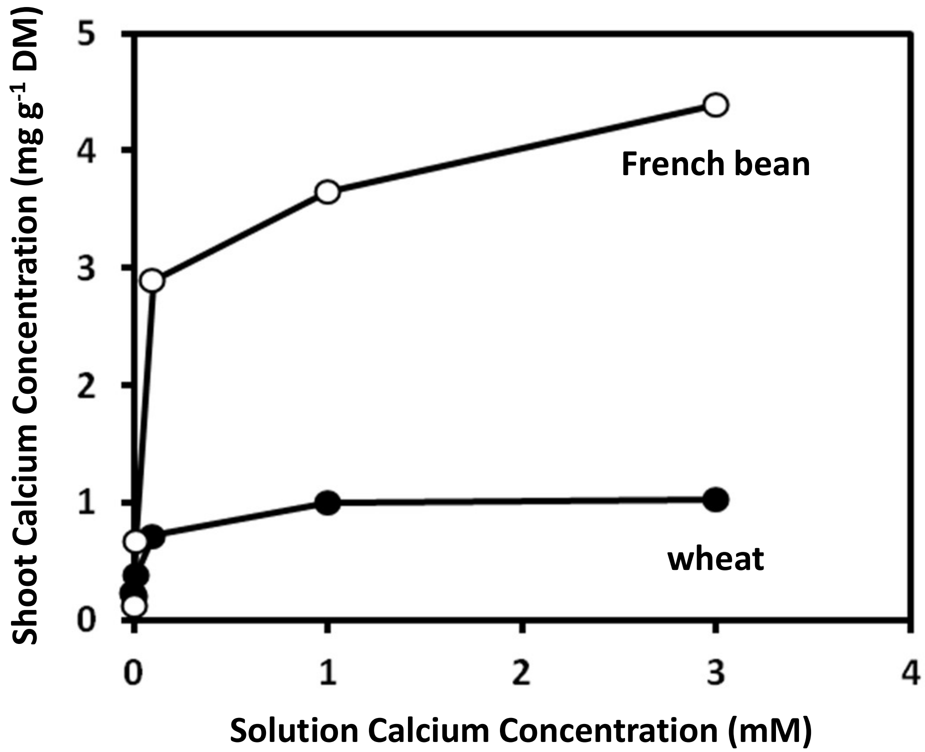
Relationship Between Rhizosphere Solution and Shoot Calcium Concentrations



Islam et al. (1987) *Plant & Soil* 98: 337-395

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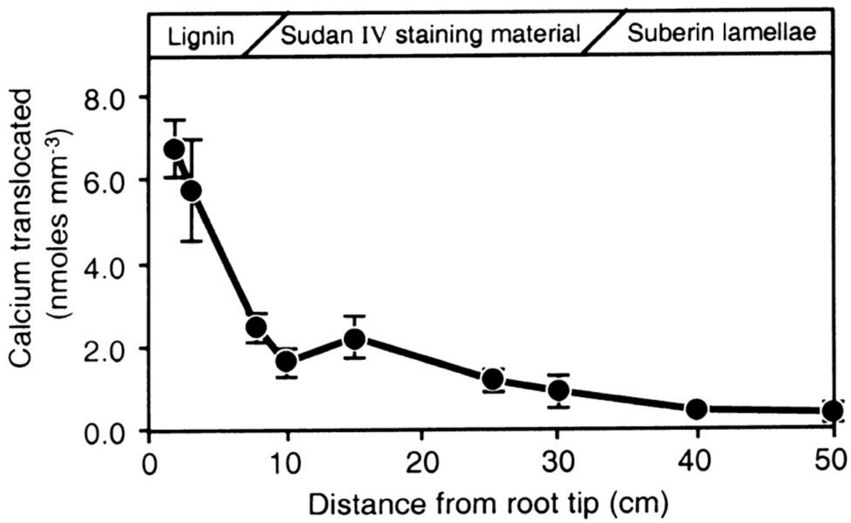
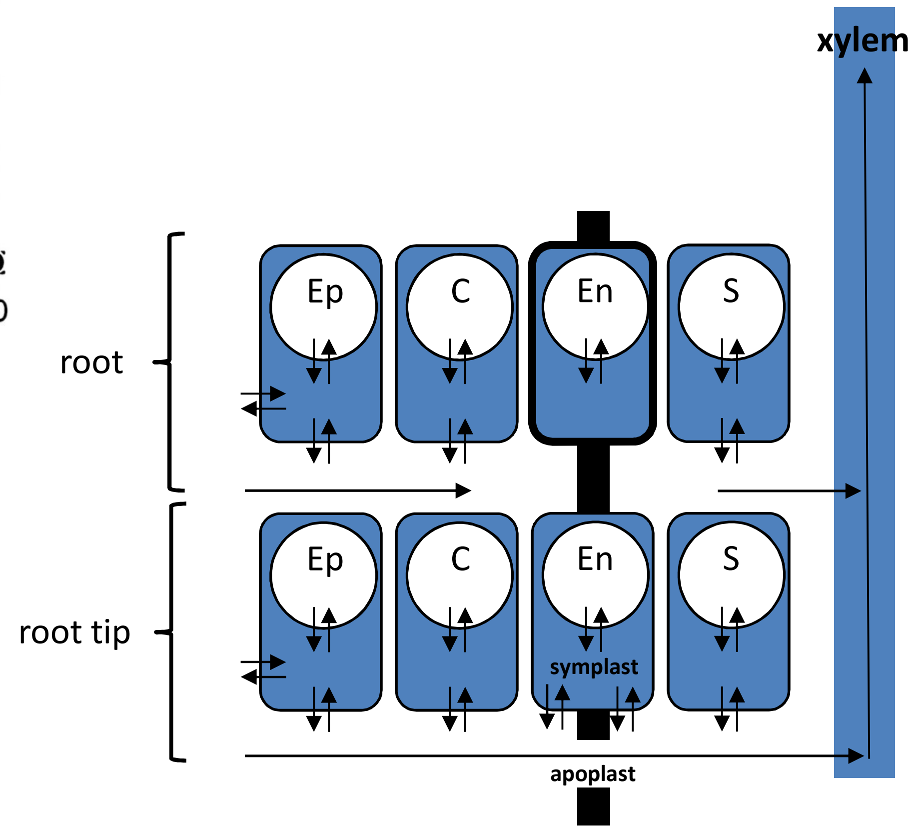
Uptake & Movement of Calcium to Shoots



seminal root of marrow *(Cucurbita pepo L.)*



Harrison-Murray & Clarkson (1973) *Planta* 114: 1-16
White (2001) *J. Exp. Bot.* 52: 891-899

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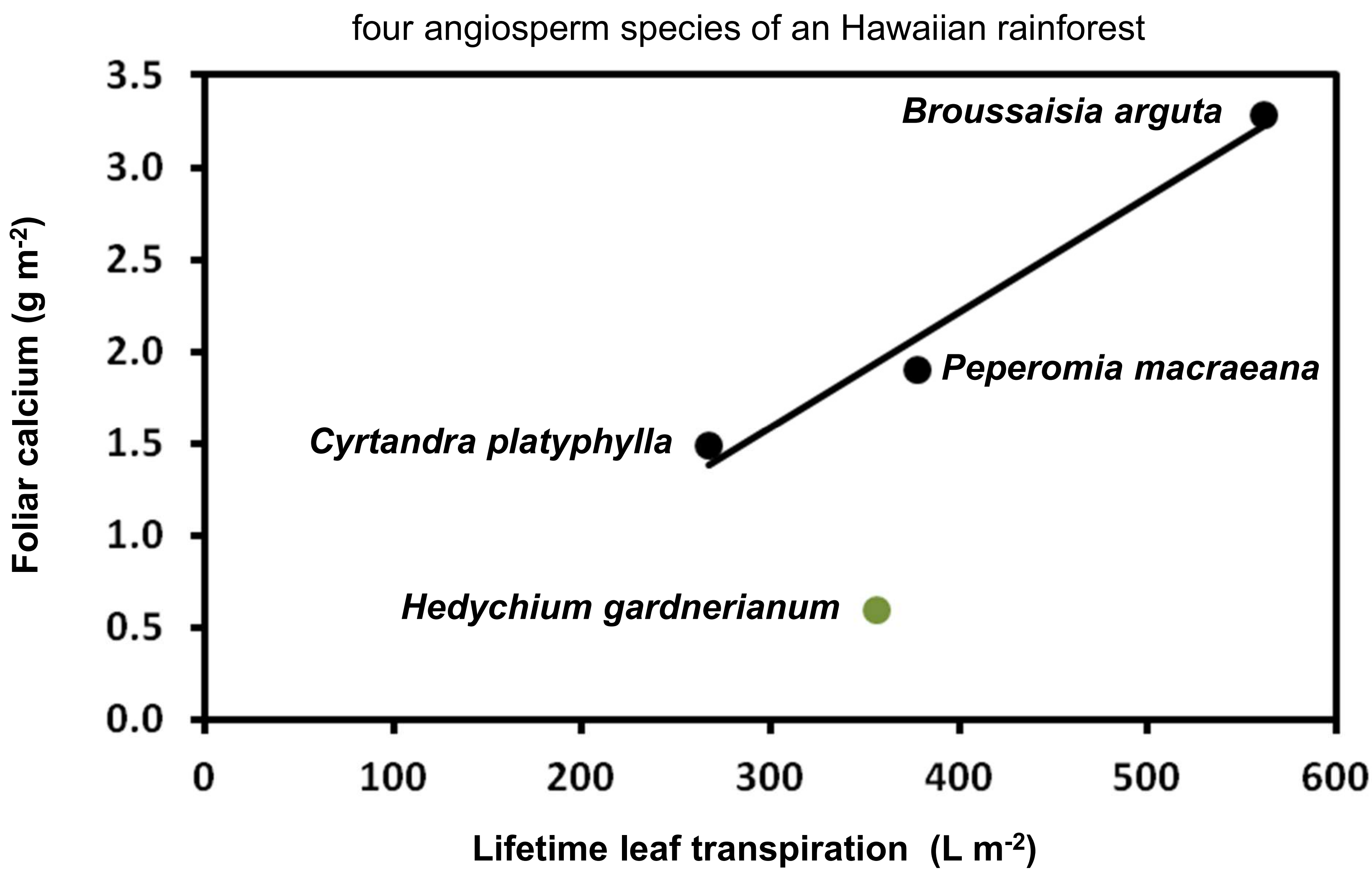
Transpiration and Leaf Calcium



Funk & Amatangelo (2013) *Oecologia* 173: 23-32

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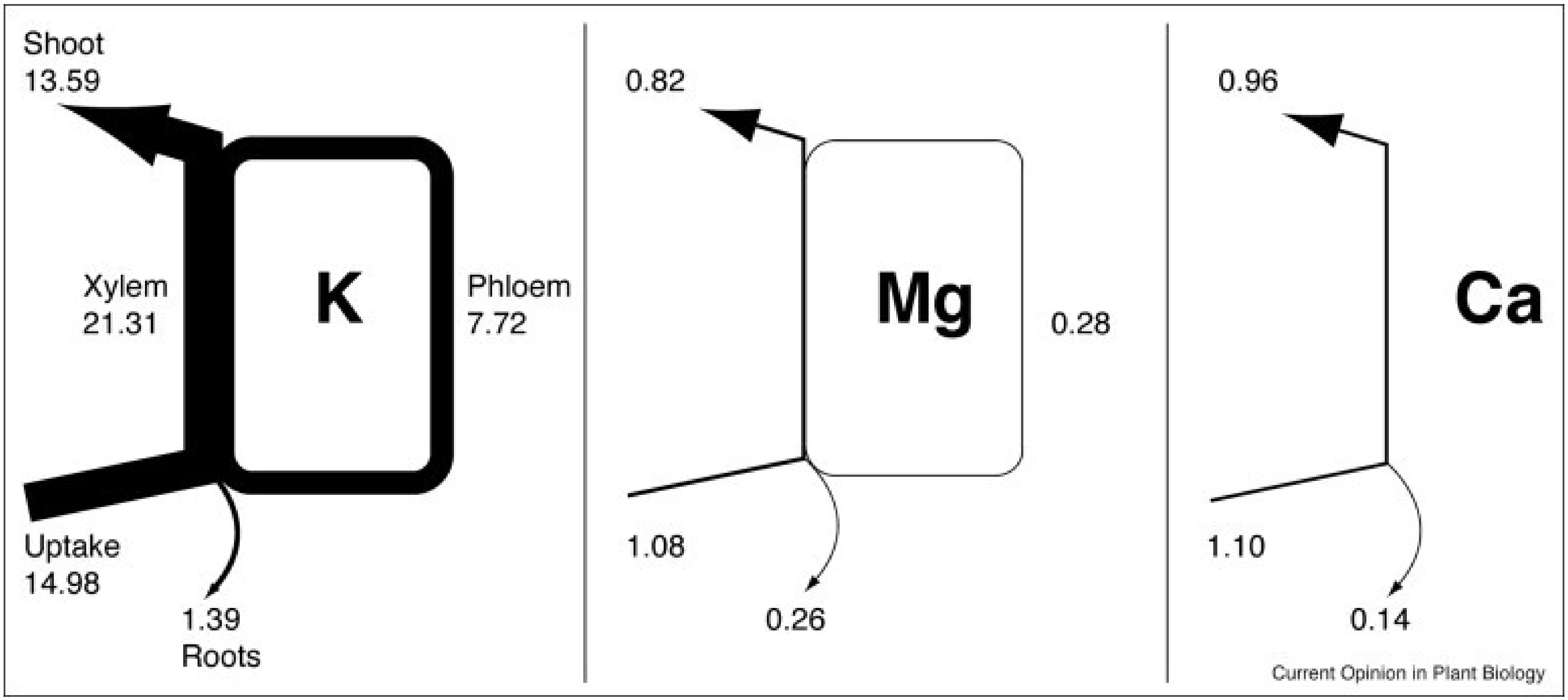
Recirculation within the Plant

uptake and redistribution of cationic elements in rye seedlings (μmol d^{-1})



Karley & White (2009) *Curr. Opin. Plant Biol.* 12: 291-298

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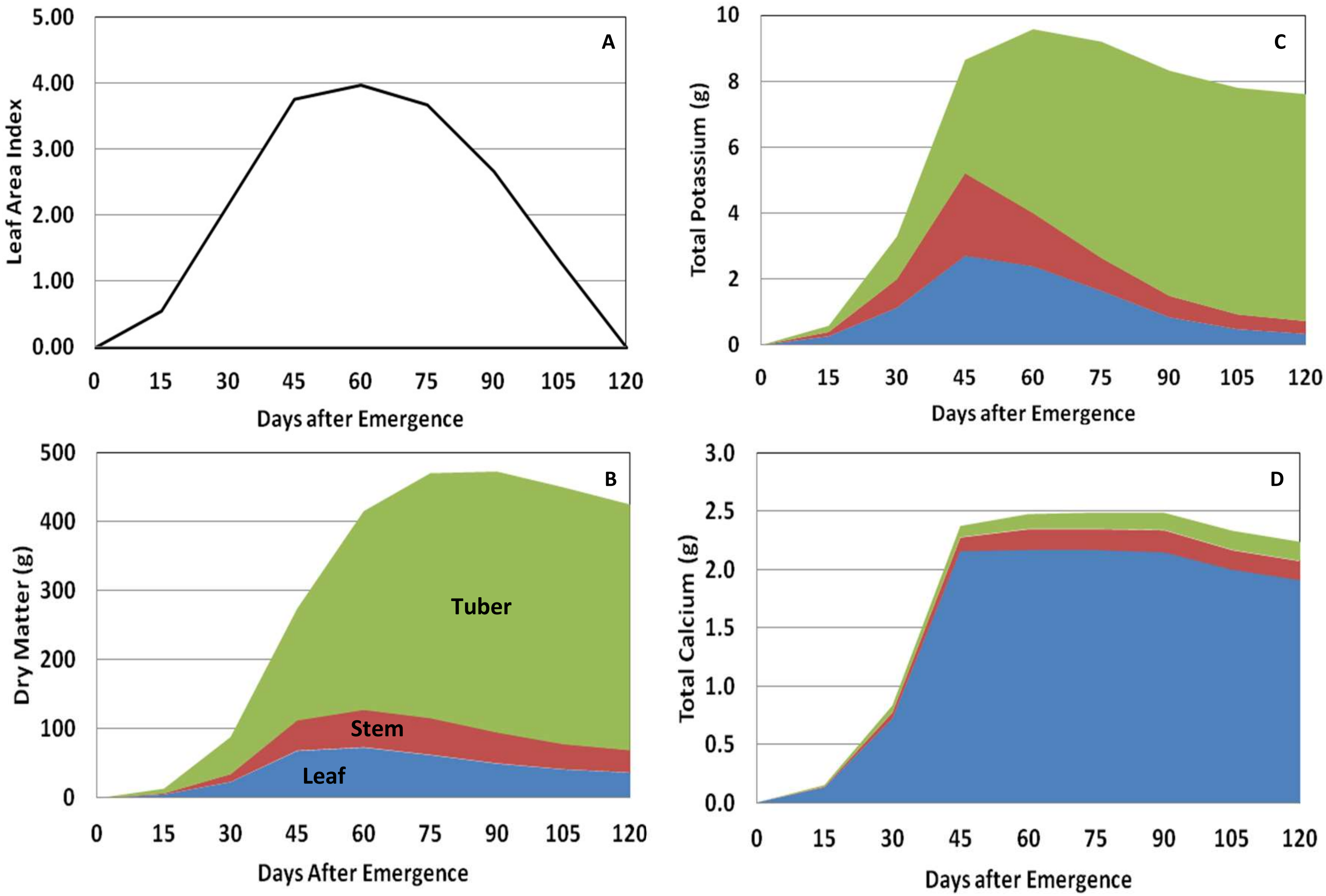
Dynamics of Partitioning in Potato



Kolbe & Stephan-Beckmann (1997a,b)
Potato Research 40: 111-129 and 135-153

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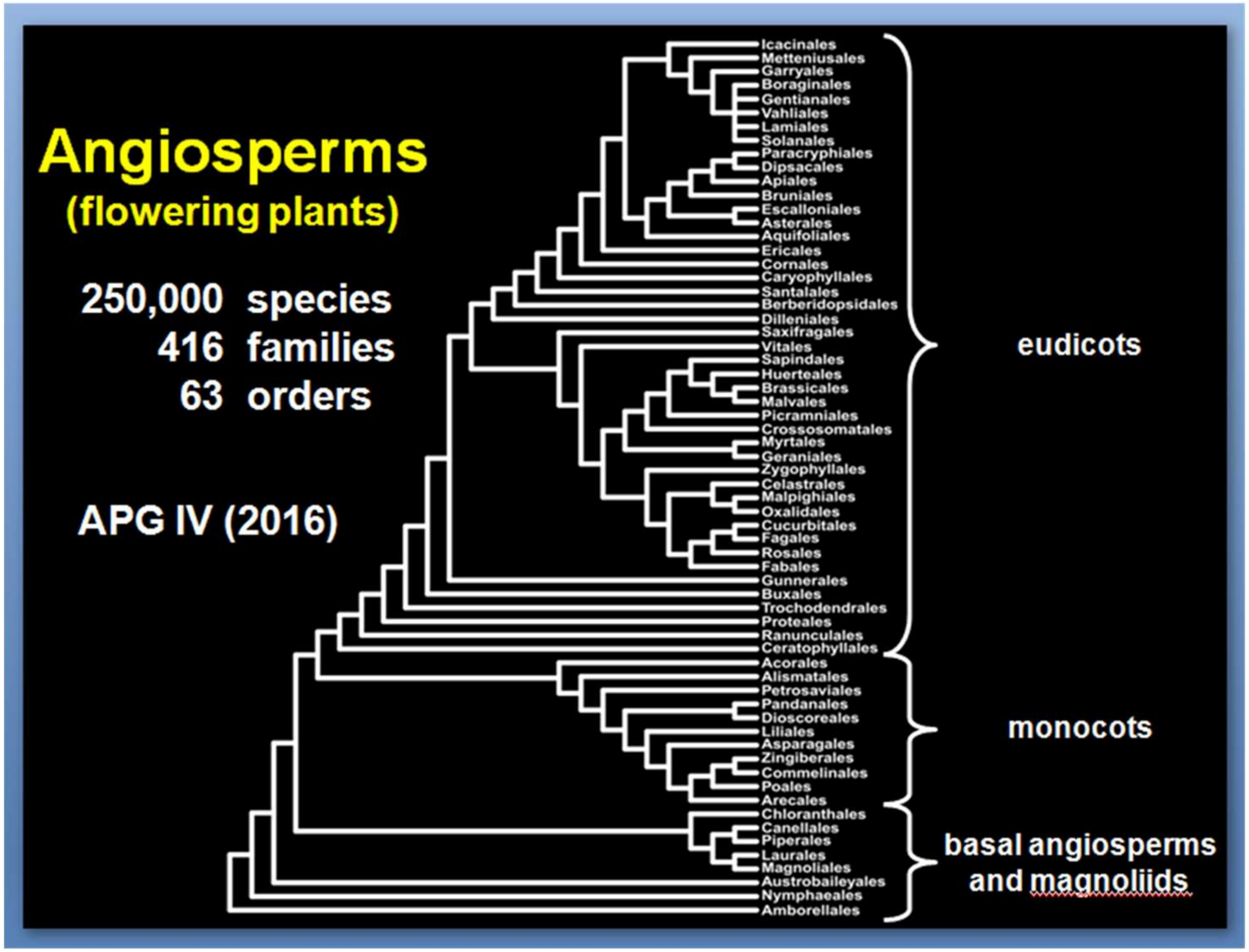
Angiosperm Phylogeny



The Angiosperm Phylogeny Group (2016)
Bot. J. Linn. Soc. 181: 1-20

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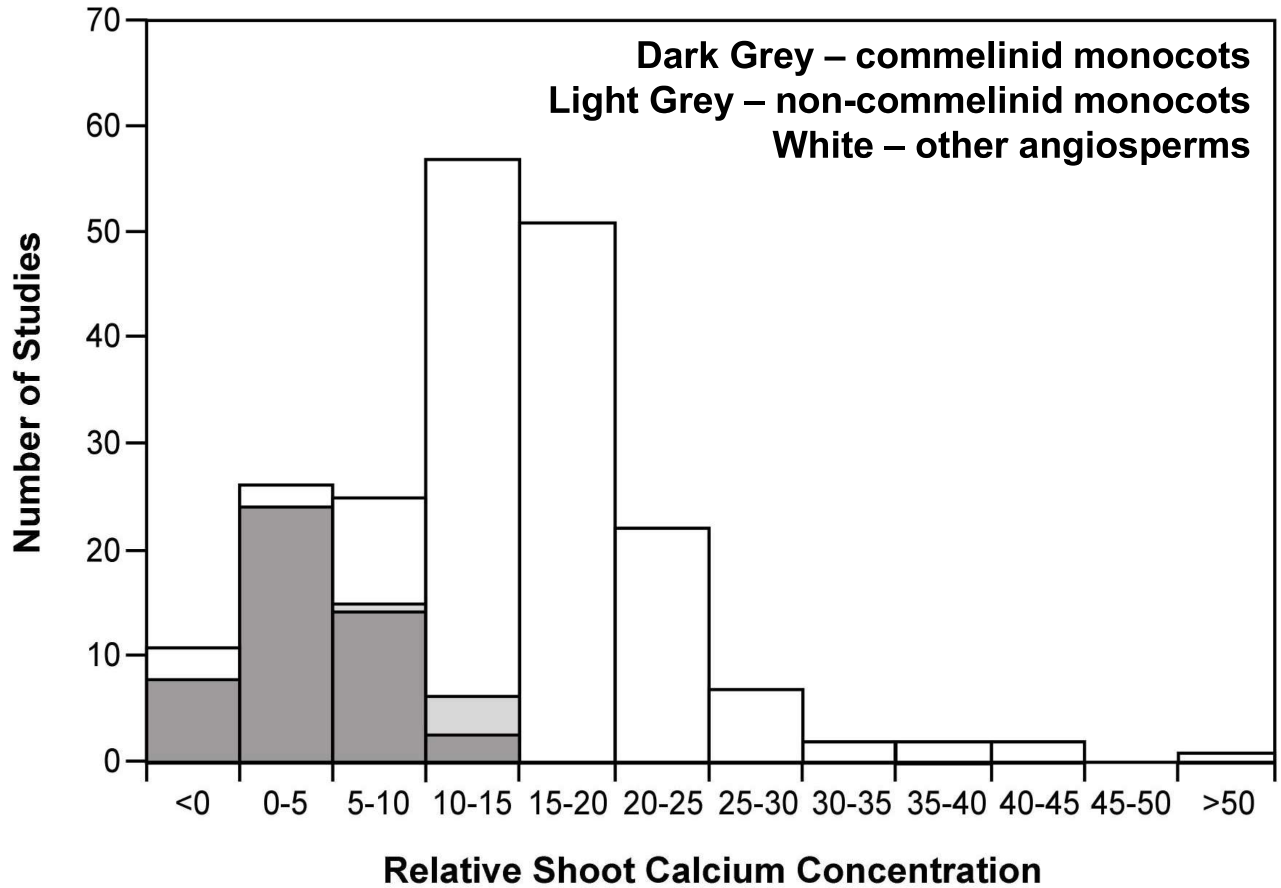
Shoots of Commelinid Monocots Low Calcium Concentrations



White (2015) Calcium. In: *A Handbook of Plant Nutrition*, pp. 165-198. ISBN 987-1-4398-8197-2.

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Cell Wall Cation Exchange Capacity

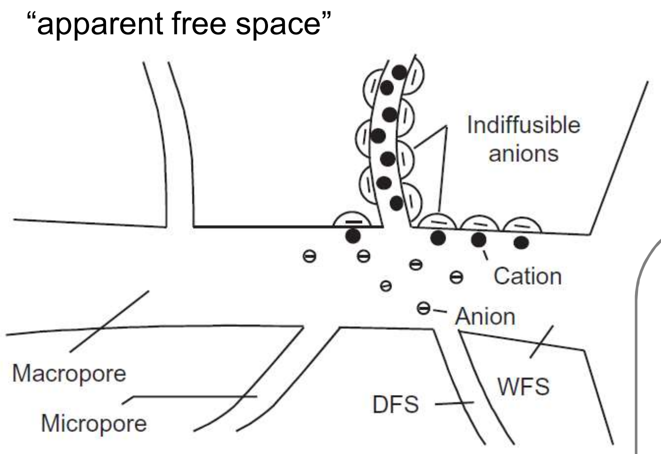
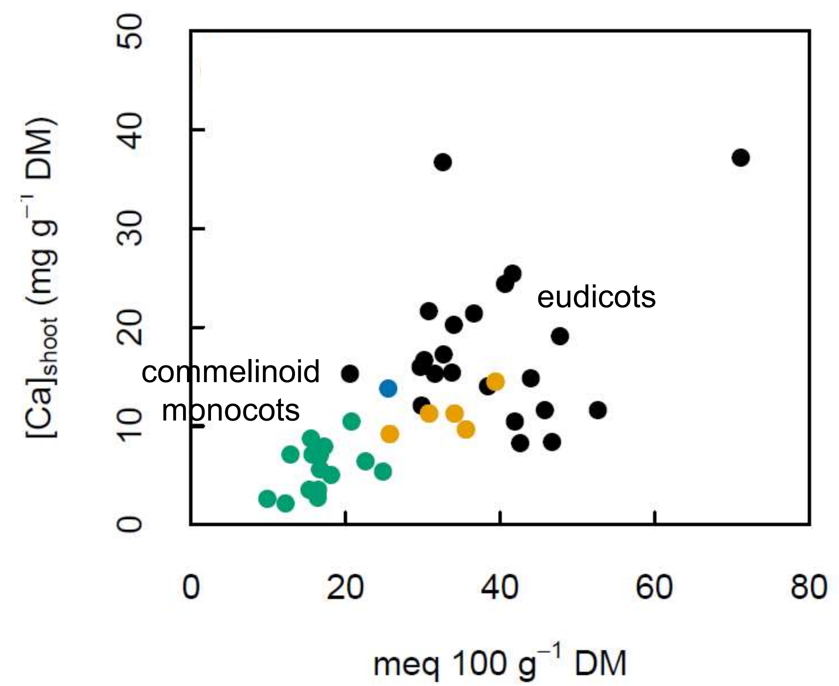


TABLE 2.4 Cation exchange capacity of root dry matter of different plant species

Plant species	Cation exchange capacity (mmol (100 g)$^{-1}$ dw)
Wheat	23
Maize	29
Bean	54
Tomato	62

Based on Keller and Deuel (1957).



White (2012) *Marschner's Mineral Nutrition of Higher Plants*, pp. 7-47
White et al. (2018) *Annals of Botany* 122: 221-226

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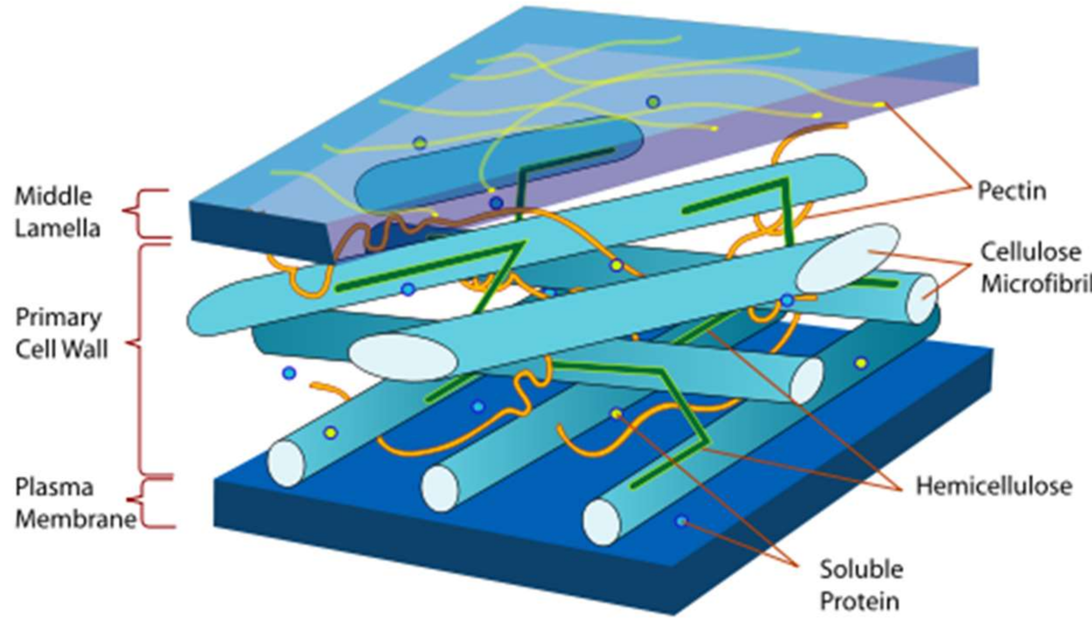
Composition of Cell Walls Differs Between Plant Species



Cellulose microfibrils form the scaffold of all plant cell walls.

Type I walls of eudicots, and some monocots, the microfibrils are tethered together by xyloglucans, and this framework is embedded in a gel of pectins. **The pectins determine the Cation Exchange Capacity.**

Type II walls of cereals the microfibrils are tethered with different sugars, such as glucuronarabinoxylan, and contain less xyloglucan and pectin.

Carpita & McCann (2000) In: *Biochemistry and Molecular Biology of Plants*, pp. 52-108

Calcium in Plant Physiology

Maintains structural integrity of cell walls and membranes

Cytosolic messenger co-ordinating cell responses
to developmental and environmental stimuli

Propagates systemic signals within the plant

Assists cation:anion balance and osmoregulation
under particular environmental conditions

White & Broadley (2003) *Annals of Botany* 92: 487-511
White & Holland (2018) *IFS Proceedings*, Cambridge 2018

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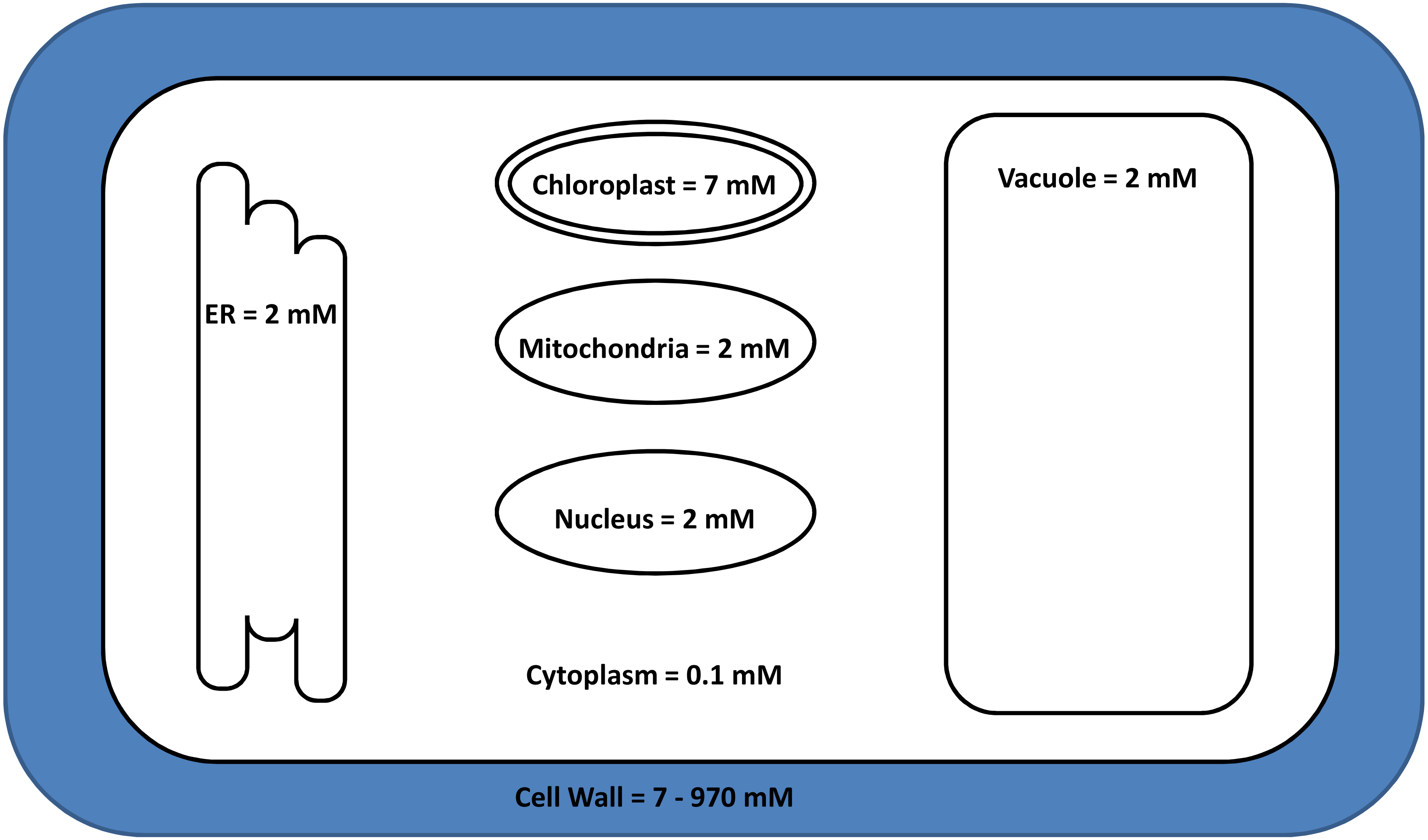
Calcium in Cellular Compartments



White and Broadley (2003) *Annals of Botany* 92: 487-511
White et al. (2018) *Annals of Botany* 122: 221-226

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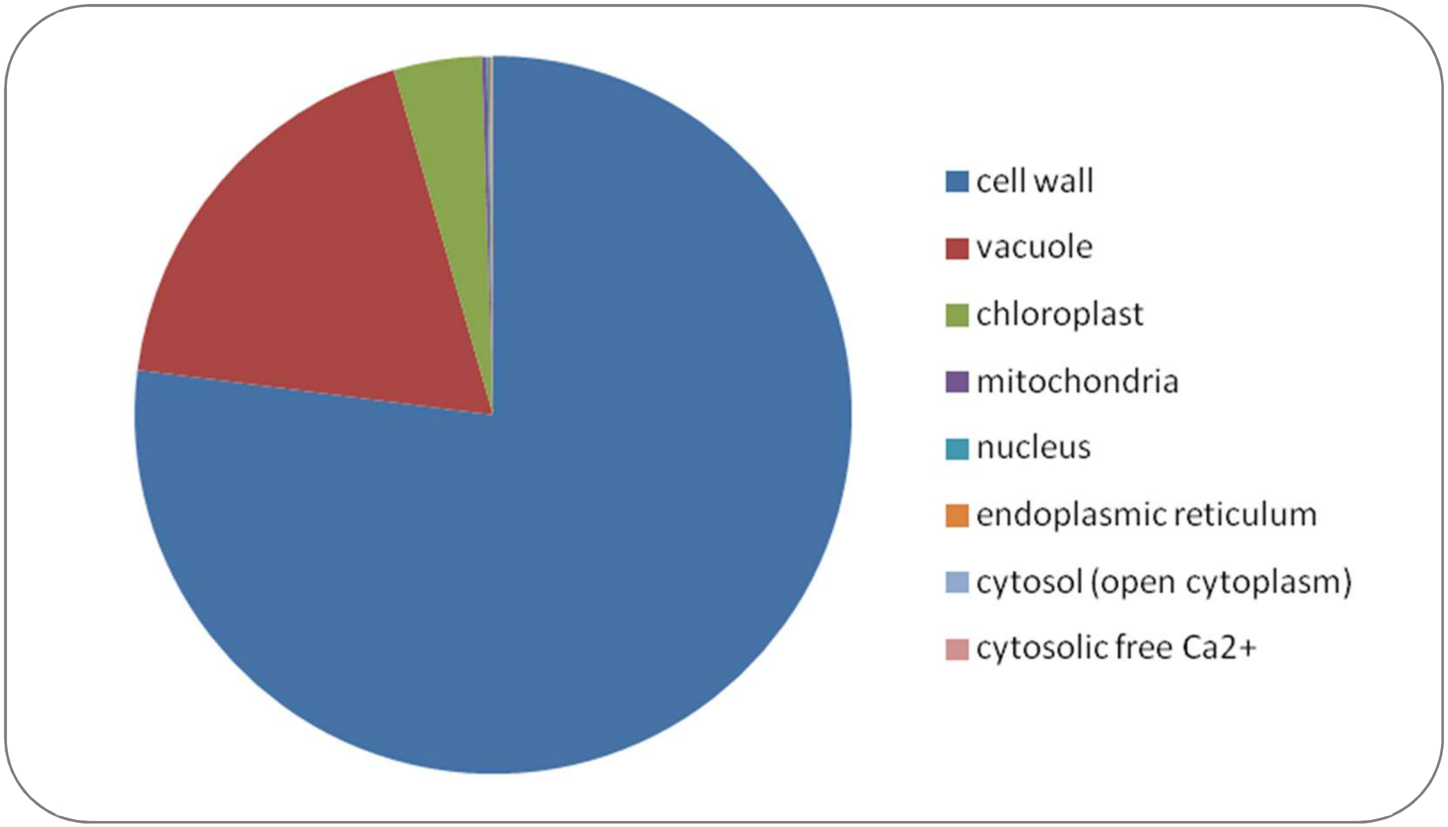
Apportionment of Calcium in Wheat Leaves



White and Broadley (2003) *Annals of Botany* 92: 487-511
White et al. (2018) *Annals of Botany* 122: 221-226

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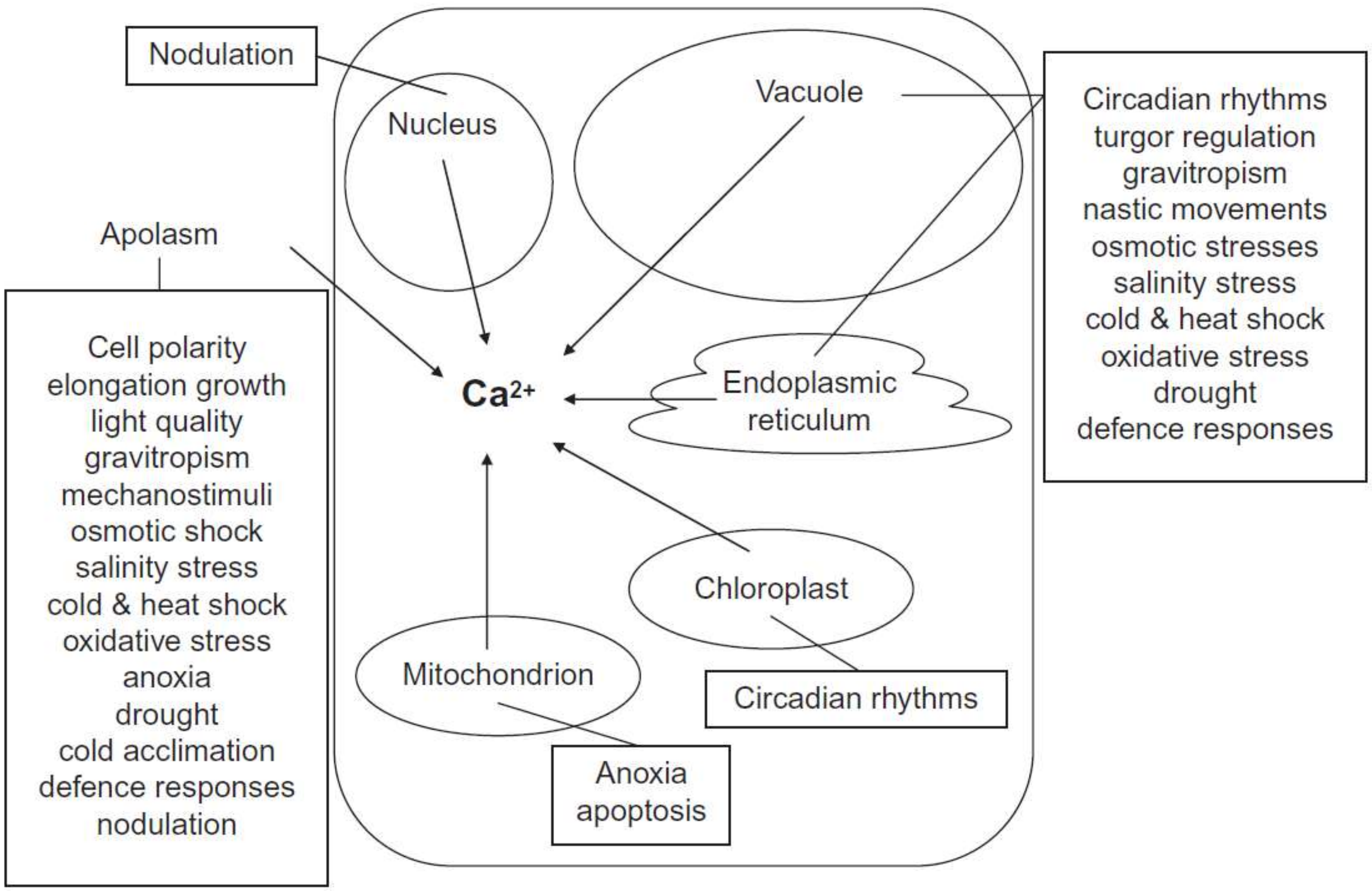
Calcium Signals in Plant Cells



Hawkesford et al. (2012) In: *Marschner's Mineral Nutrition of Higher Plants*, pp. 135-189

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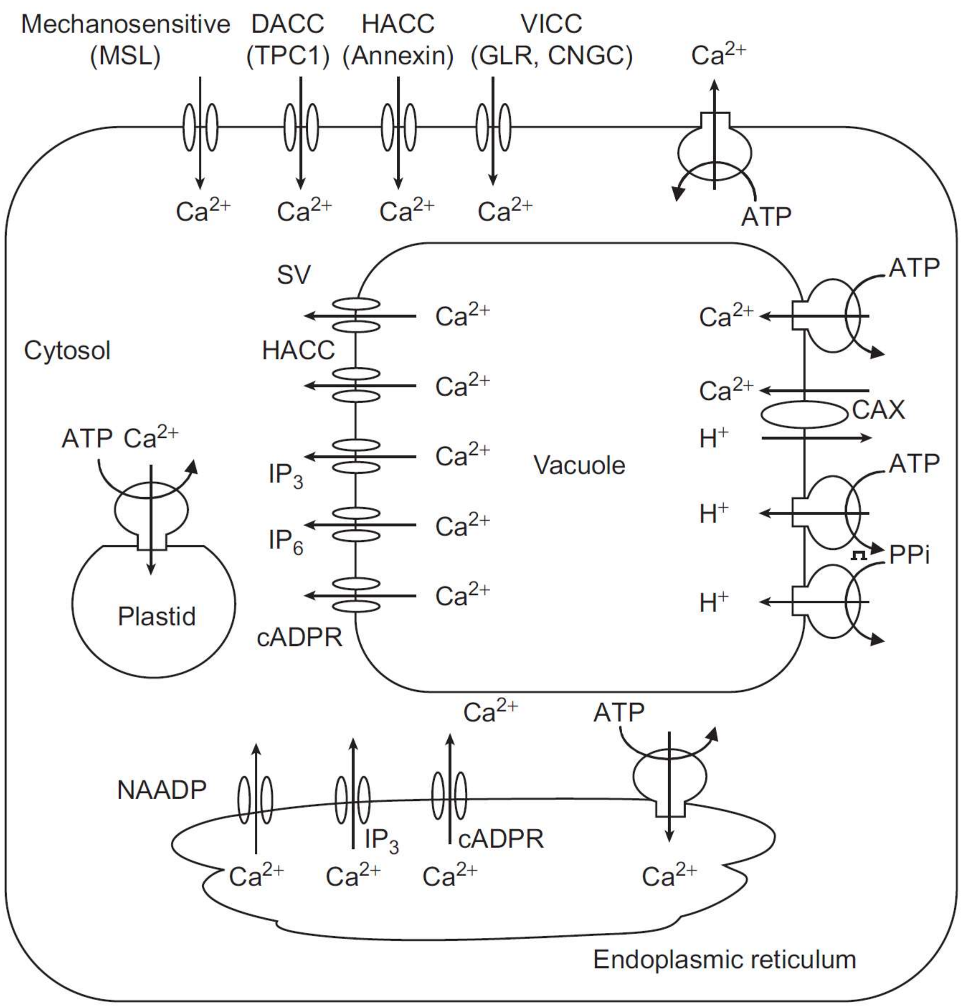
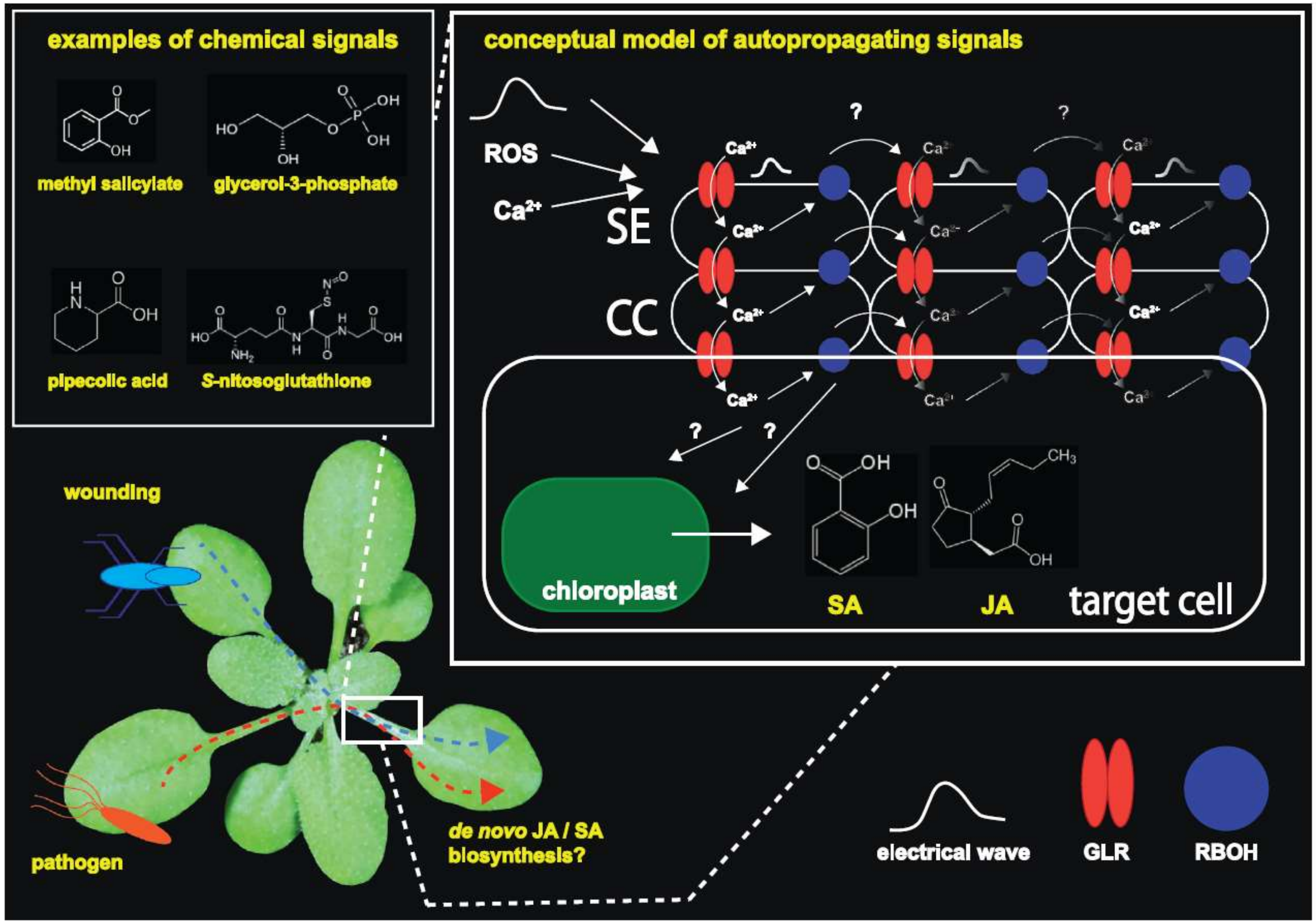
Calcium Transport in Plant Cells



Hawkesford et al. (2012) In: *Marschner's Mineral Nutrition of Higher Plants*, pp. 135-189

Calcium Propagates Systemic Signals



Current Opinion in Plant Biology

Hilleary & Gilroy (2018) *Curr. Opin. Plant Biol.* 43, 57-62

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Calcium (Ca^{2+})
(charge balance, osmoticum, detoxicant)

	Ammonium	Nitrate
K^+	55	99
Ca^{2+}	43	85
Mg^{2+}	22	28
total cations	*120*	*212*
NO_3^-	0	44
$H_2PO_4^-$	23	18
SO_4^{2-}	33	11
Cl^-	5	2
organic acids	59	137
total anions	*120*	*212*

ionic balance in shoots of castor oil plants supplied with different forms of nitrogen

Van Beusichem et al. (1988) *Plant Physiol.* 86: 914-921

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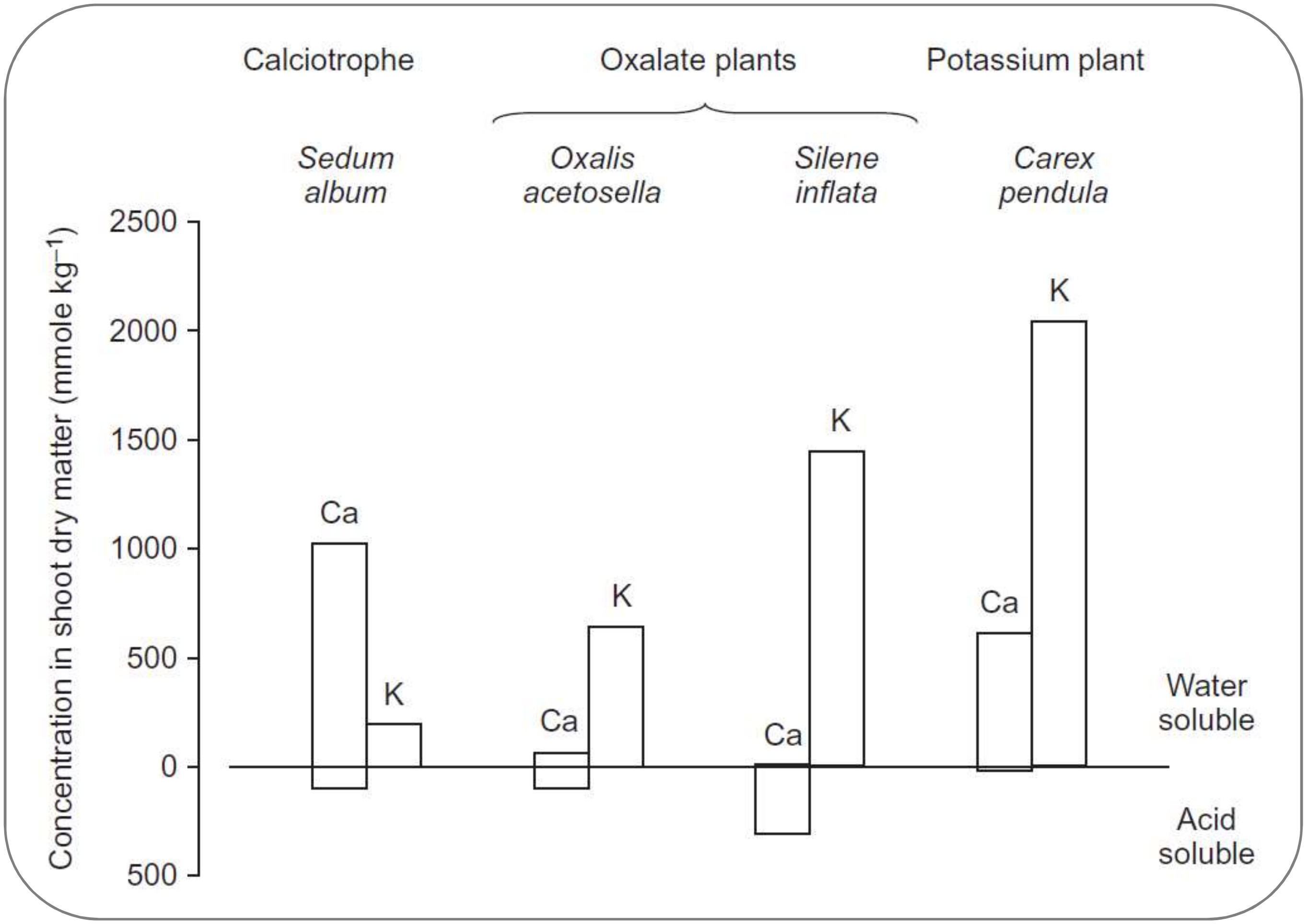
Calcium Sequestration Differs Between Angiosperm Species



White (2005) In: *Plant Nutritional Genomics*, pp. 66-86

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Symptoms of Calcium Deficiency

White & Broadley (2003) *Annals of Botany* 92: 487-511

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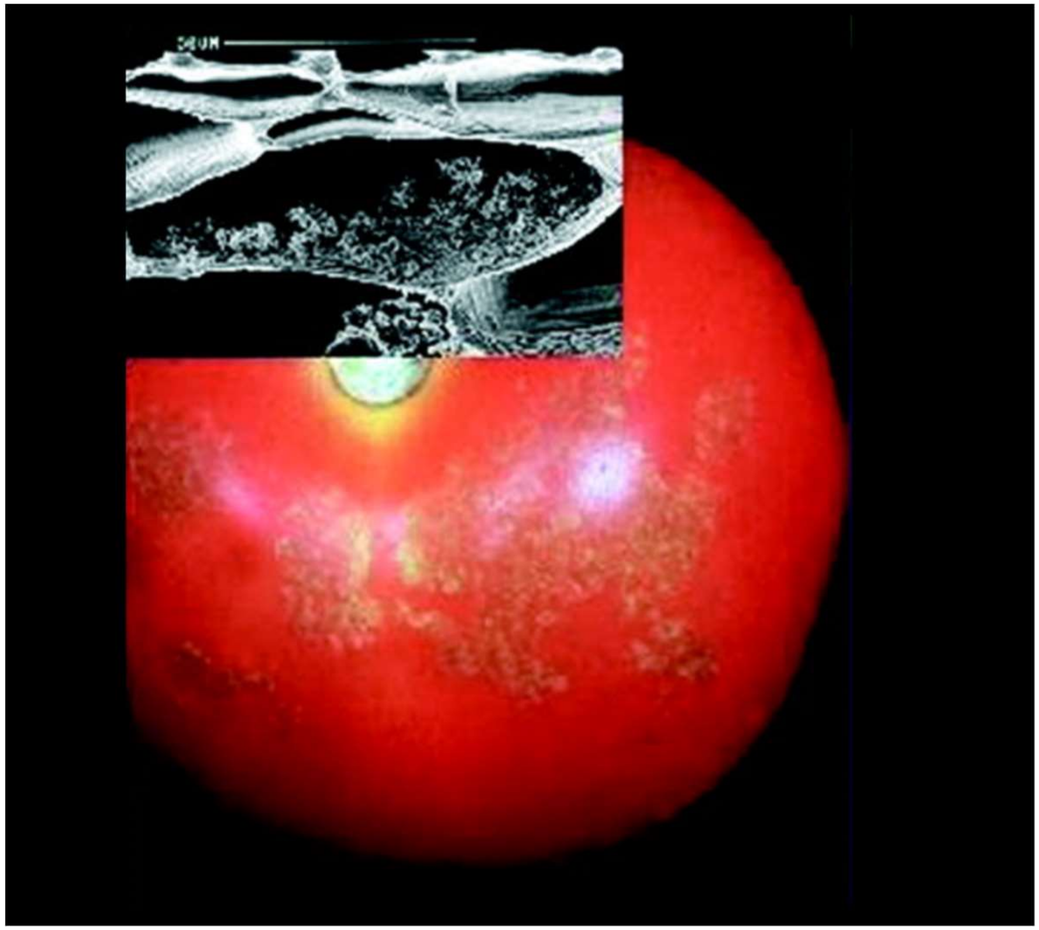
Symptoms of Calcium Toxicity



White & Broadley (2003) *Annals of Botany* 92: 487-511

Occurrence Calcium Deficiency

rarely observed

soils with low Ca content
(low cation exchange capacity, high precipitation, high offtakes)

acid soils, saline & sodic soils
(competition with other cations, osmotic effects)

dry soils
(reduced transpiration & mass flow to roots, restricted root growth)

rapidly growing crops
when instantaneous demand exceeds supply

White & Broadley (2003) *Annals of Botany* 92: 487-511
White (2015) *Handbook of Plant Nutrition*, pp. 165-198

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Sources of Calcium for Agriculture

Group	Common name	Formula	Composition (%)
1. N-fertilisers	Calcium nitrate	$Ca(NO_3)_2.4H_2O$	11-12 Ca, 8-9 N
	Calcium cyanamide	$CaCN_2$	50 Ca, 35 N
	Calcium ammonium nitrate	$H_4CaN_2O_3$	8-14 Ca, 21-27 N
2. P-fertilisers	Rock phosphate	$Ca_5FO_{12}P_3$	30-37 Ca, 11-16 P
	Single superphosphate	$Ca(H_2PO_4)_2 + 2 CaSO_4$	18-21 Ca, 7-9 P, 11-12 S
	Triple superphosphate	$Ca(H_2PO_4)_2.H_2O$	16 Ca, 25 P
3. S-fertilisers	Gypsum	$CaSO_4.2H_2O$	24 Ca, 10-18 S
	Polysulphate	$K_2Ca_2Mg(SO_4)_4.2H_2O$	12 Ca, 12 K, 19 S, 4 Mg
4. Liming materials	Calcium carbonate	$CaCO_3$	40 Ca
	Dolomite	$CaMg(CO_3)_2$	16-21 Ca, 8-13 Mg
	Hydrated lime	$Ca(OH)_2$	55 Ca
	Burnt lime	CaO	70 Ca
	Sugar beet lime	-	25 Ca, <1 P, <1 S, <1 Mg
	Basic slag	$CaSiO_3$	16-40 Ca
5. Amendments	Wood ash	25-40% $CaCO_3$	10-16 Ca, <1[illegible]
	Shell sands	-	20-30 Ca
	Blood and bone	-	8-15 Ca, 4-7 N, 3-9 P

White & Holland (2018) *IFS Proceedings*, Cambridge 2018

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Summary

calcium is abundant in the earth's crust
soil Ca concentrations reflect pedogenesis

calcium is acquired by roots
from the soil solution as Ca^{2+}

calcium is essential for plants

most plant Ca is used for cell wall structure
small amounts of Ca are involved in signalling
Ca can also act in cation:anion balance and osmoregulation

symptoms of Ca deficiency and toxicity
reflect phloem-immobility and functions of Ca

calcium deficiency is rare
deficiencies can be corrected by application of Ca-materials

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