Phylogenetic Effects On Shoot Magnesium Concentrations

Philip J. White

Helen Bowen, Emily Farley,
Emma Shaw, Jacqueline Thompson,
Gladys Wright & Martin R. Broadley

IAPN - Magnesium Symposium
5th November 2014

Outline of Talk

1. An Introduction to Angiosperm Phylogenies

2. Molecular Physiology of Group II Elements
   - Magnesium, Calcium, Strontium

3. Elemental Stoichiometries - Mg : Ca : Sr

4. Phylogenetic and Environmental Effects
   on Shoot Ca & Mg Concentrations

5. Consequences for Diets and Ecology

Phylogenetics
Genetics at a Higher Level of Classification

Phylogenetics is the study of the relationships among groups of organisms (e.g. families, species, populations) based on DNA sequencing.

The result of phylogenetic studies are hypotheses about the evolutionary history of taxonomic groups.

Angiosperms – flowering plants.

Phylogenetics Angiosperm Phylogeny

Volume 85
Number 4
1998

Annals
of the
Missouri
Botanic
Garden

AN ORDINAL CLASSIFICATION FOR THE FAMILIES OF FLOWERING PLANTS

The Angiosperm Ph

ABSTRACT

Recent cladistic analyses are revealing the phylogeny of flowering plants in increasin
for the monophyly of many major groups above the family level. With many elements of
of phylogeny established, a revised suprafamilial classification of flowering plants becom
Here we present a classification of 462 flowering plant families in 40 putatively mon
number of monophyletic, informal higher groups. The latter are the monocots, commeli
rosids including eurosids I and II, and asterids including euasterids I and II. Under th
also listed a number of families without assignment to order. At the end of the system i
of uncertain position for which no firm data exist regarding placement anywhere within

Botanical Journal of the Linnean Society, 2009, **161**, 105–121. With 1 figure

An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering

Botanical Journal of the Linnean Society, 2003, **141**, 399–436. With 1 figure

An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG II

THE ANGIOSPERM PHYLOGENY GROUP*

Received June 2002; accepted for publication December 2002

A revised and updated classification for the families of the flowering plants is provided. Newly adopted orders include Austrobaileyales, Canellales, Gunnerales, Crossosomatales and Celastrales. Pertinent literature published since the first APG classification is included, such that many additional families are now placed in the phylogenetic scheme. Among these are Hydnoraceae (Piperales), Nartheciaceae (Dioscoreales), Corsiaceae (Liliales), Triuridaceae (Pandanales), Hanguanaceae (Commelinales), Bromeliaceae, Mayacaceae and Rapateaceae (all Poales), Barbeuiaceae and Gisekiaceae (both Caryophyllales), Geissolomataceae, Strasburgeriaceae and Vitaceae (unplaced to order, but included in the rosids), Zygophyllaceae (unplaced to order, but included in eurosids I), Bonnetiaceae, Ctenolophonaceae, Elatinaceae, Ixonanthaceae, Lophopyxidaceae, Podostemaceae (Malpighiales), Paracryphiaceae (unplaced in euasterid II), Sladeniaceae, Pentaphylacaceae (Ericales) and Cardiopteridaceae (Aquifoliales). Several major families are recircumscribed. Salicaceae are expanded to include a large part of Flacourtiaceae, including the type genus of that family; another portion of former Flacourtiaceae is assigned to an expanded circumscription of Achariaceae. Euphorbiaceae are restricted to the uniovulate subfamilies; Phyllanthoideae are recognized as Phyllanthaceae and Oldfieldioideae as Picrodendraceae. Scrophulariaceae are recircumscribed to include Buddlejaceae and Myoporaceae and exclude several former members; these are assigned to Calceolariaceae, Orobanchaceae and Plantaginaceae. We expand the use of bracketing families that could be included optionally in broader circumscriptions with other related families; these include Agapanthaceae and Amaryllidaceae in Alliaceae *s.l.*, Agavaceae, Hyacinthaceae and Ruscaceae (among many other Asparagales) in Asparagaceae *s.l.*, Dichapetalaceae in Chrysobalanaceae, Turneraceae in Passifloraceae, Erythroxylaceae in Rhizophoraceae, and Diervillaceae, Dipsacaceae, Linnaeaceae, Morinaceae and Valerianaceae in Caprifoliaceae *s.l.* © 2003 The Linnean Society of London, *Botanical Journal of the Linnean Society*, 2003, **141**, 399–436.

ADDITIONAL KEYWORDS: angiosperms – gene sequences – phylogenetics.

; compiled by Birgitta Bremer, Kåre Bremer,
las E. Soltis, Pamela S. Soltis and Peter F.
ı alphabetical order only, with contributions
Olmstead, Paula J. Rudall, Kenneth J.
Xiang and Sue Zmarzty (in alphabetical
ıt the Royal Swedish Academy of Sciences, PO
Vice Chancellor, Stockholm University, SE-106
Laboratory, Royal Botanic Gardens, Kew,
ıiley Hortorium, Department of Plant Biology,
53-4301, USA; D. E. Soltis, Department of
11–8525, USA; P. S. Soltis, Florida Museum of
rida, 32611–7800, USA; and P. F. Stevens,
and Missouri Botanical Garden, PO Box 299,

2009

ering plants is provided. Many recent studies have
rmerly unplaced families, resulting in a number of
les, Bruniales, Buxales, Chloranthales, Escalloniales,
ramniales, Trochodendrales, Vitales and Zygophylla-
included here in orders, greatly reducing the number
ıaeales), Haptanthaceae (Buxales), Peridiscaceae
afflesiaceae (both Malpighiales), Aphloiaceae, Geisso-
Picramniaceae (Picramniales), Dipentodontaceae
s), Balanophoraceae (Santalales), Mitrastemonaceae
nember of lamiid clade). Newly segregated families
gnized families include Petermanniaceae (Liliales),
eae (both Brassicales), Schoepfiaceae (Santalales),
ae and Talinaceae (all Caryophyllales) and Linder-
keted families is abandoned because of its unpopu-
tained; these include Amaryllidaceae, Asparagaceace
pighiales), Primulaceae (Ericales) and several other
with a new linear order for APG, subfamilial names
lidaceae *s.l.*, Asparagaceace *s.l.* and Xanthorrheaceae
s.l. (all Asparagales) and a formal supraordinal classification for the flowering plants. © 2009 The Linnean Society
iety, 2009, **161**, 105–121.

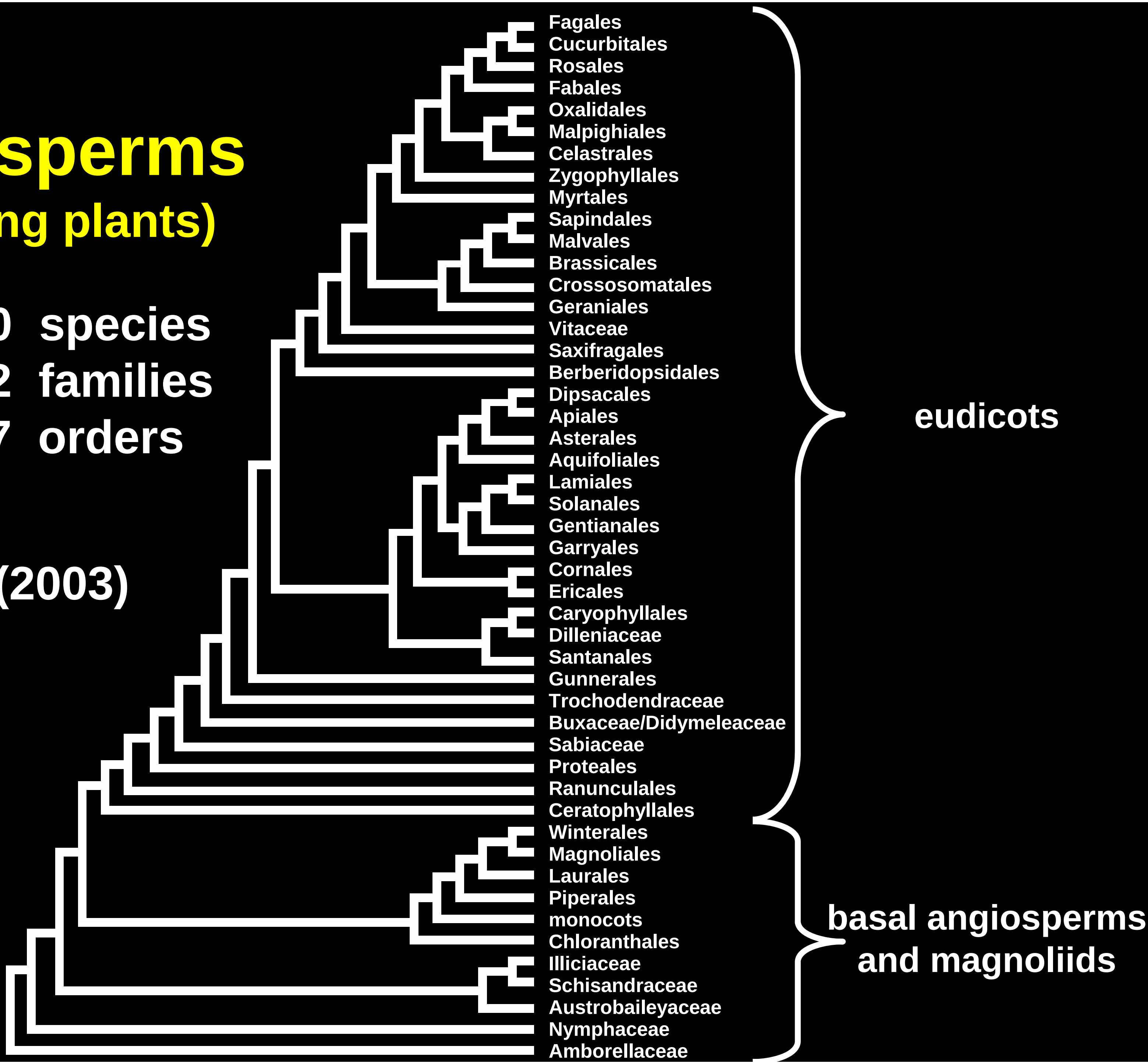
sification – phylogenetic classification – DNA phylogenetics –

The Angiosperm Phylogeny Group (1998, 2003, 2009)

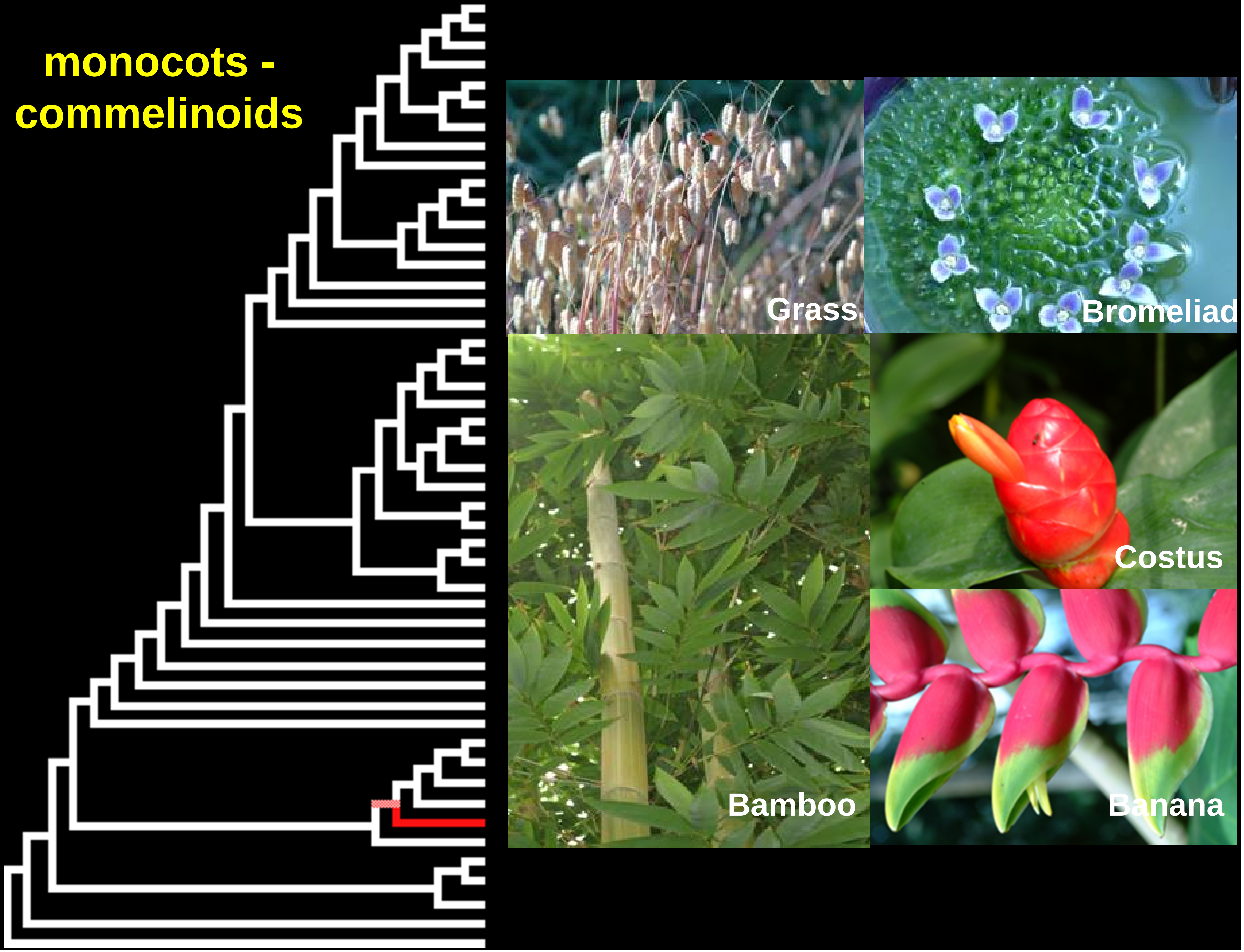
Angiosperms
(flowering plants)

250,000 species
462 families
47 orders

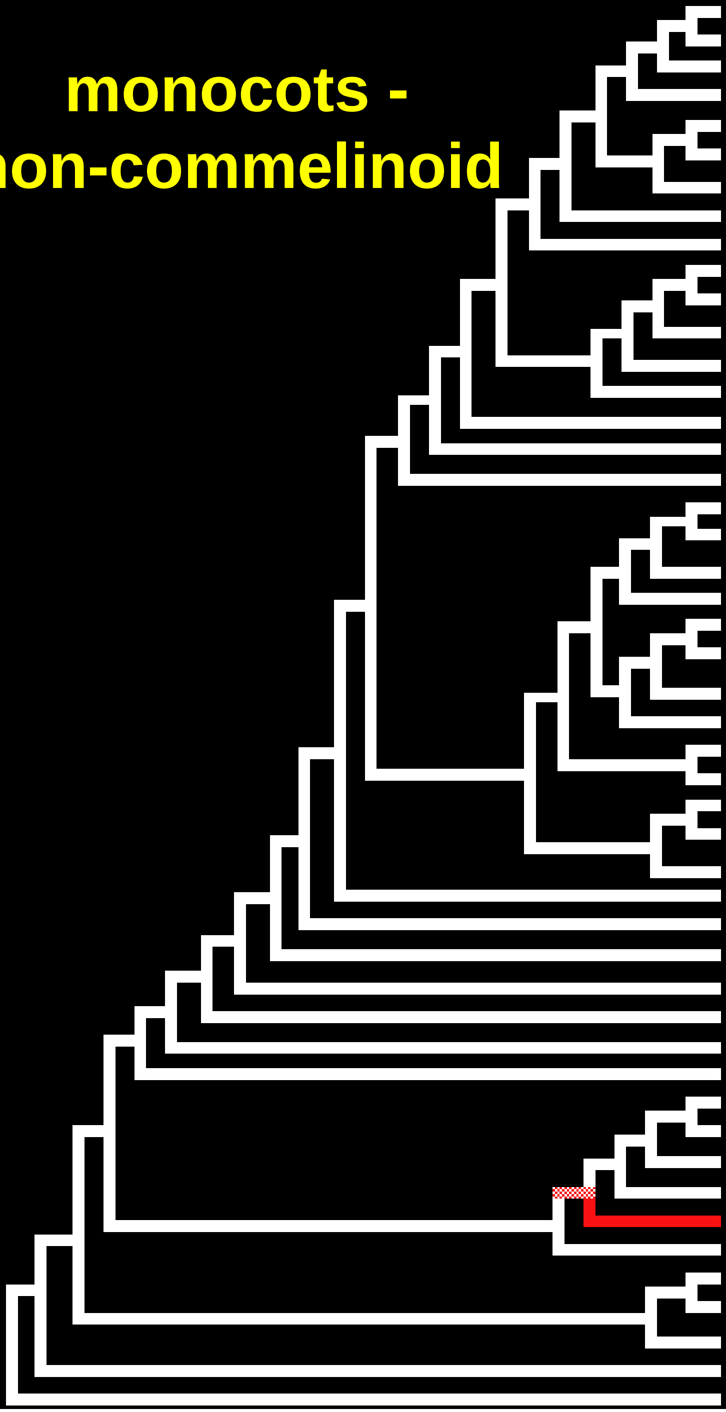
APG II (2003)



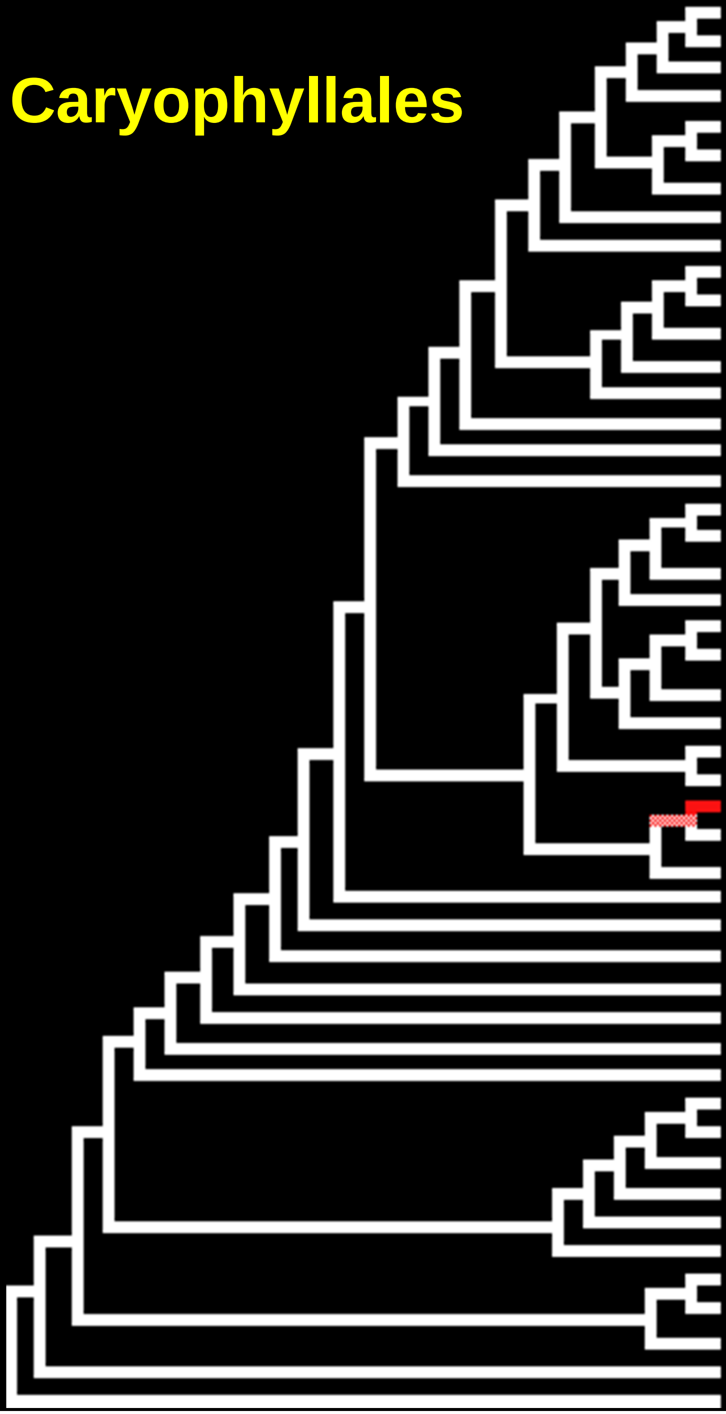
monocots - commelinoids



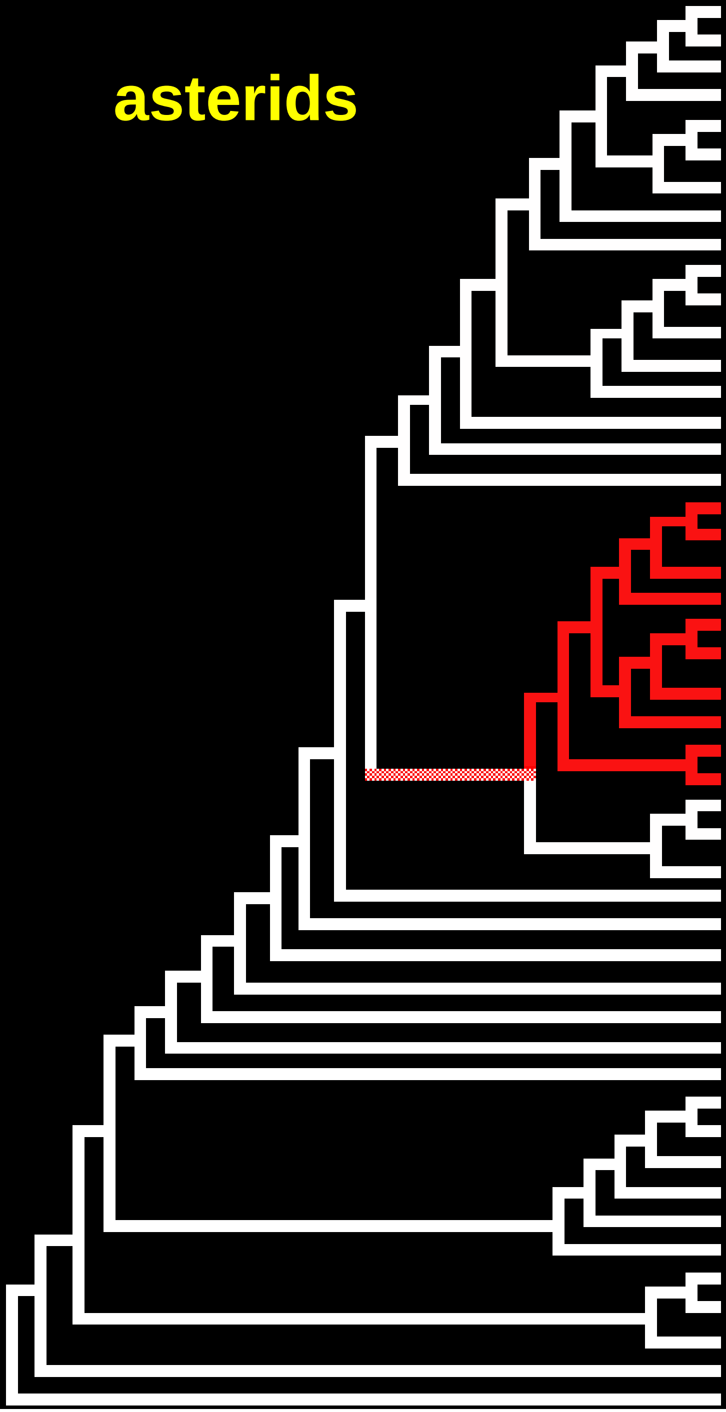
monocots - non-commelinoid

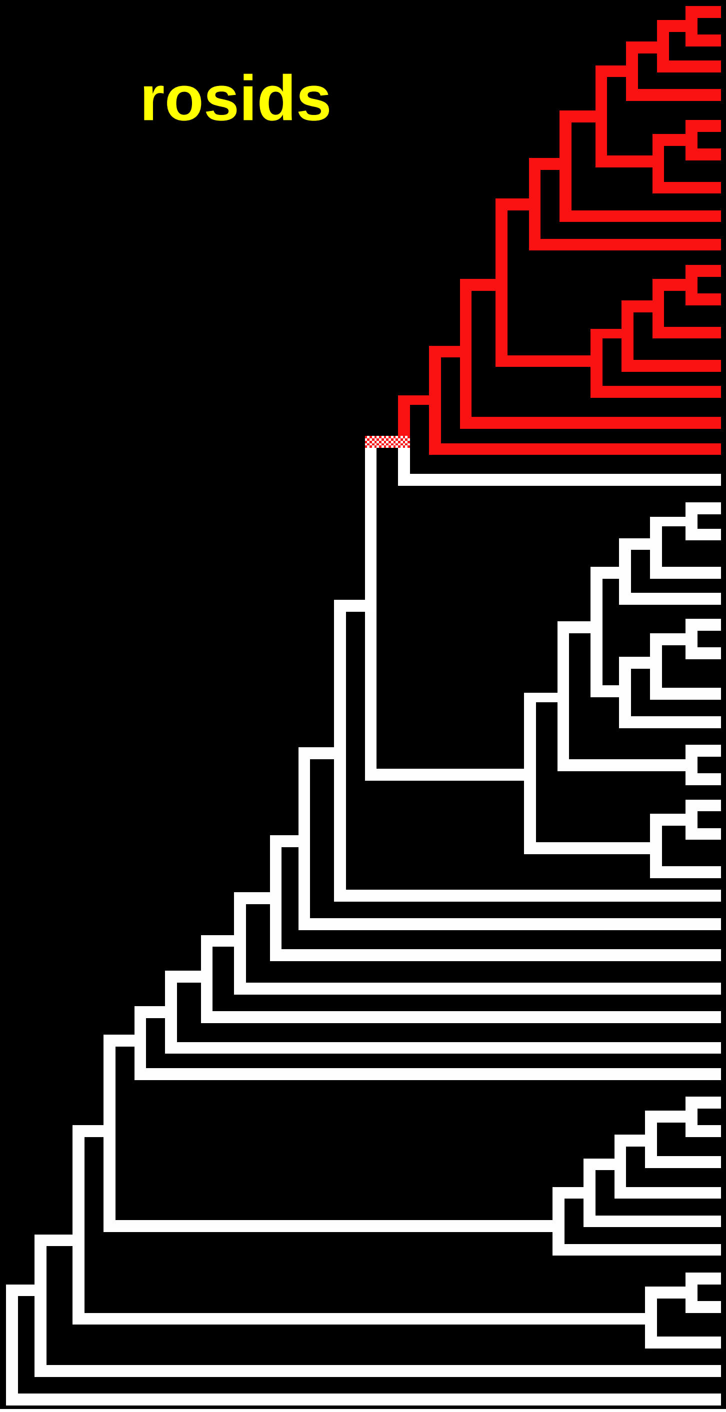


Caryophyllales

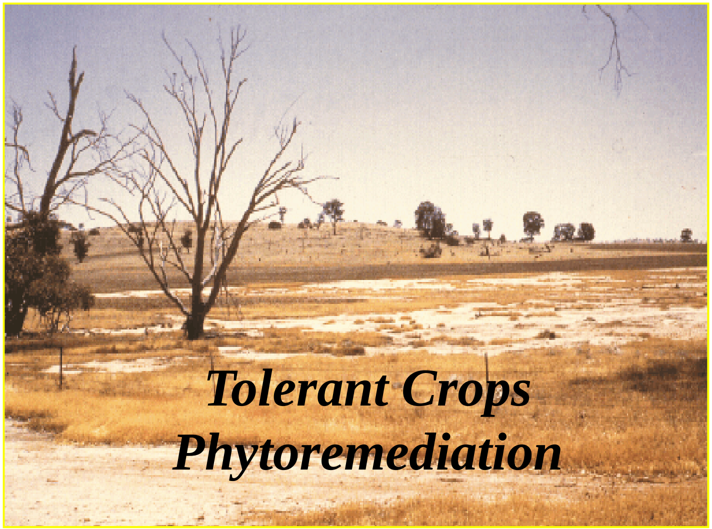


asterids

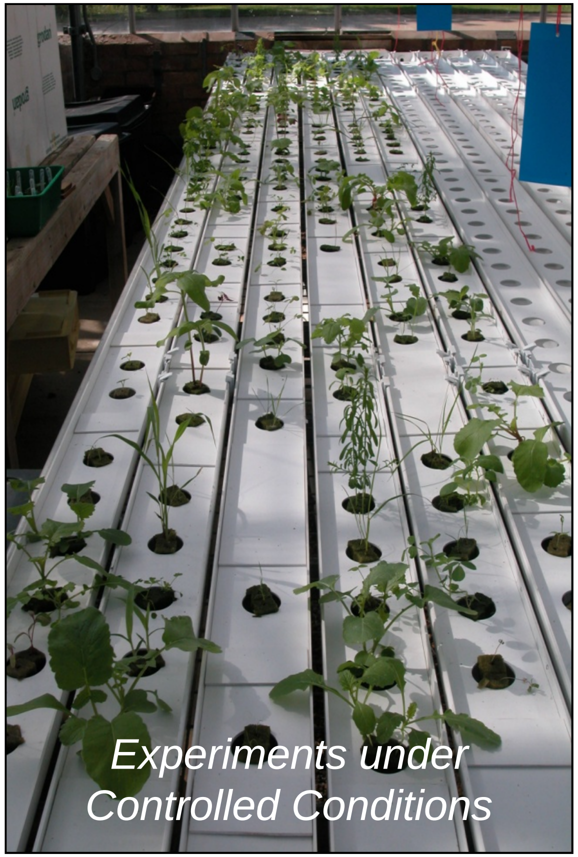



rosids

Plant Species Differ In Their Shoot Elemental Composition (Ionome)



Evolution of the Angiosperm Ionome
Data Sources



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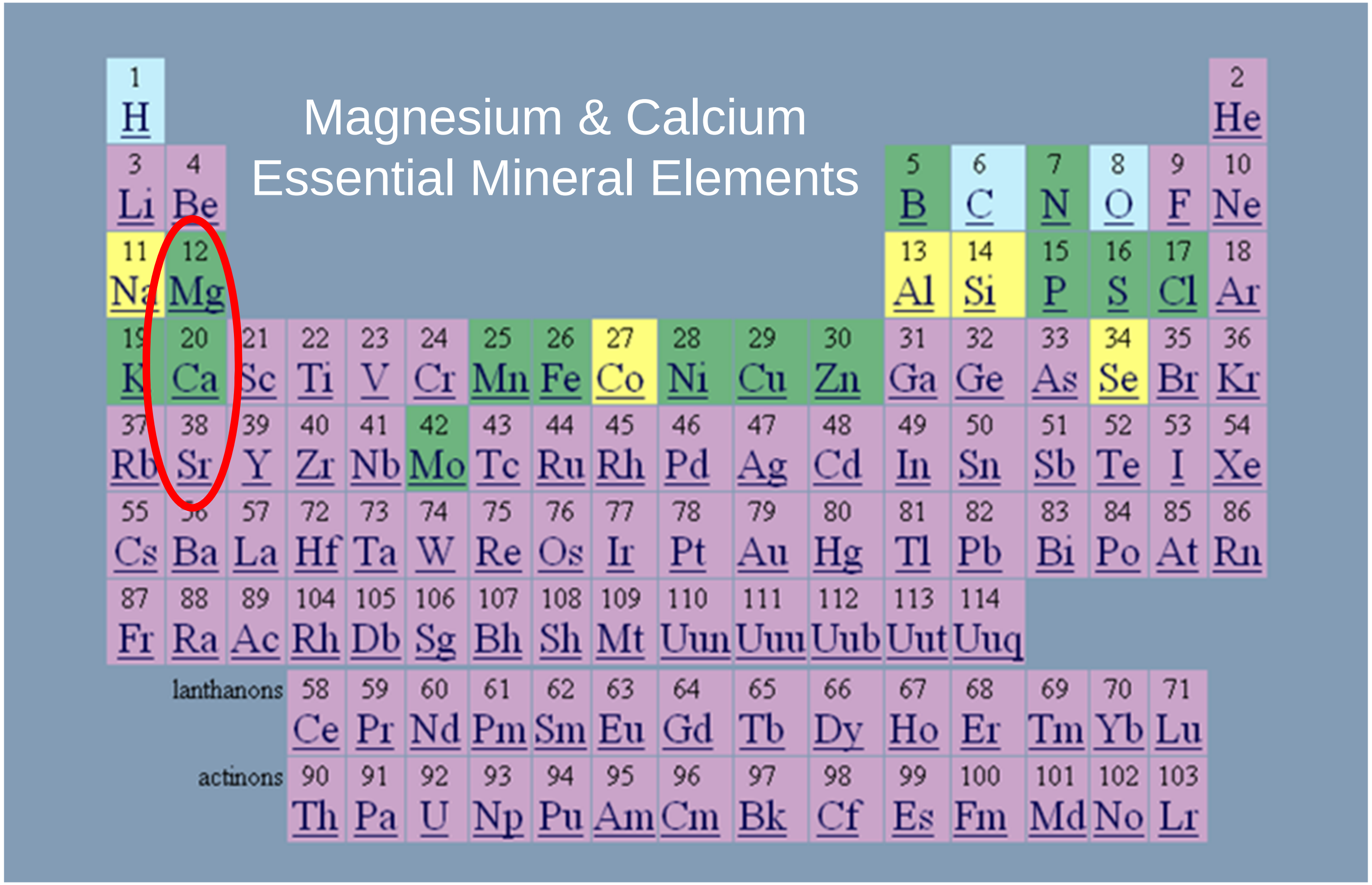
Phylogenetic Effects on Shoot Concentrations of Group II Elements



Broadley et al. (2003) *J. Exp. Bot.* 54: 1431-1446
Broadley et al. (2004) *J. Exp. Bot.* 55: 321-336

Magnesium in Plant Physiology

Proteins – chlorophyll (5-50%)
Enzyme activities (photosynthesis, energy metabolism, protein synthesis)
Bound to cell wall components (5-10%)

TABLE 6.11 Concentration and binding form of Mg in one-year-old needles of Norway spruce growing on two soil types

		Proportion of total Mg		
Soil type	Total Mg concentration ($mg\ g^{-1}$ dw)	Water-soluble	Pectate, phosphate	Chlorophyll
Rendzina	1.47	91.2	2.6	6.2
Podsol	0.31	64.8	10.0	25.2

Based on Fink (1992a).

Marschner's Mineral Nutrition of Higher Plants, 2012

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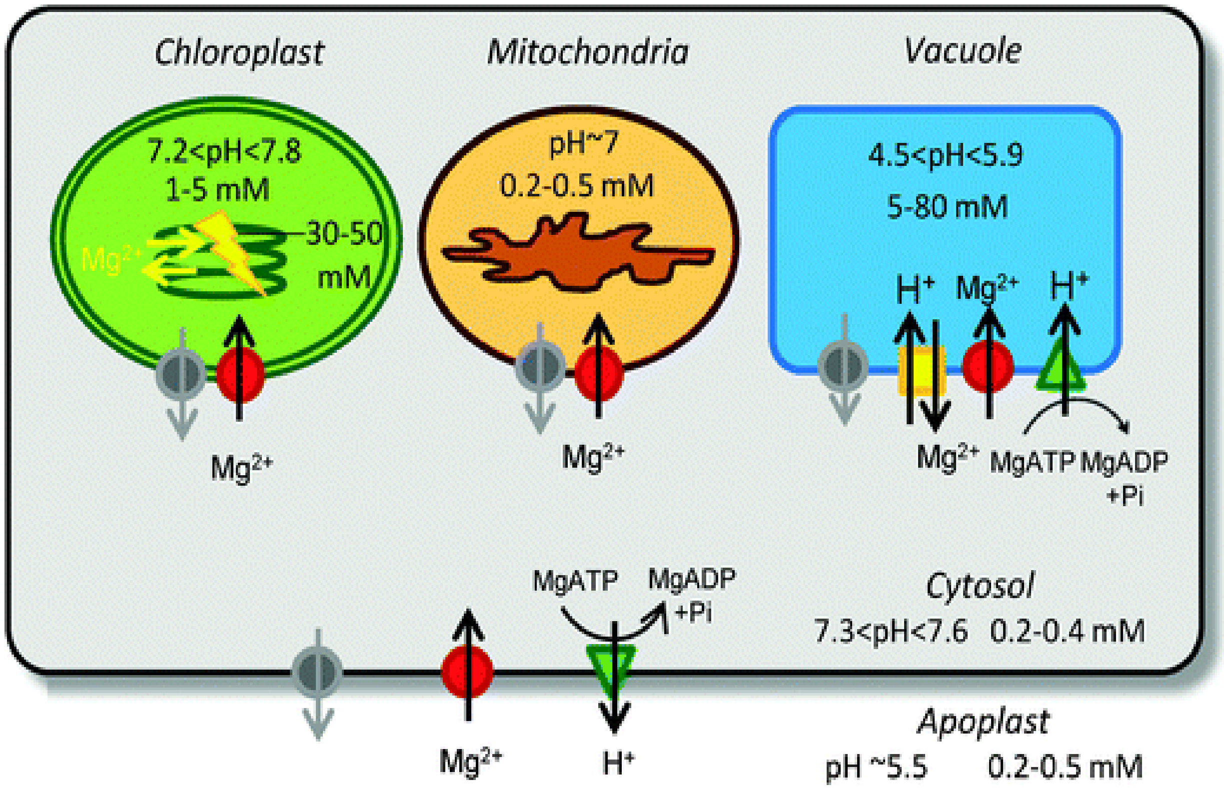
Magnesium Transport Within A Plant



MRS/MGT ● MHX (Mg/H⁺ exchanger) ■

Hermans et al. (2013) *Metallomics* 5: 1170-1183

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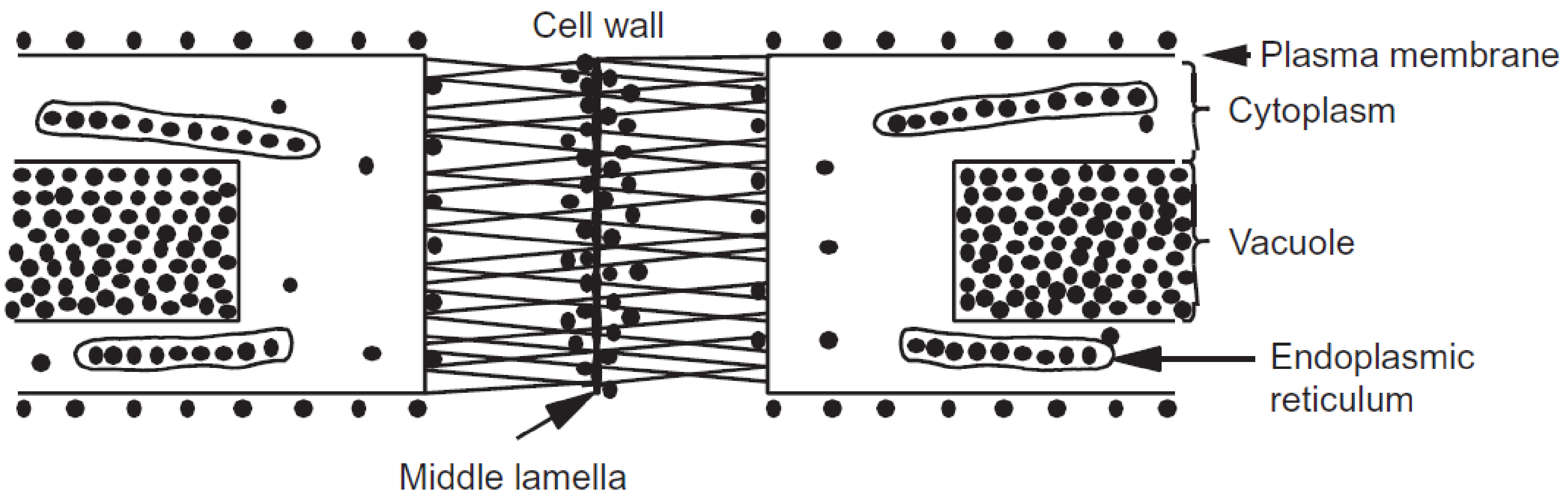
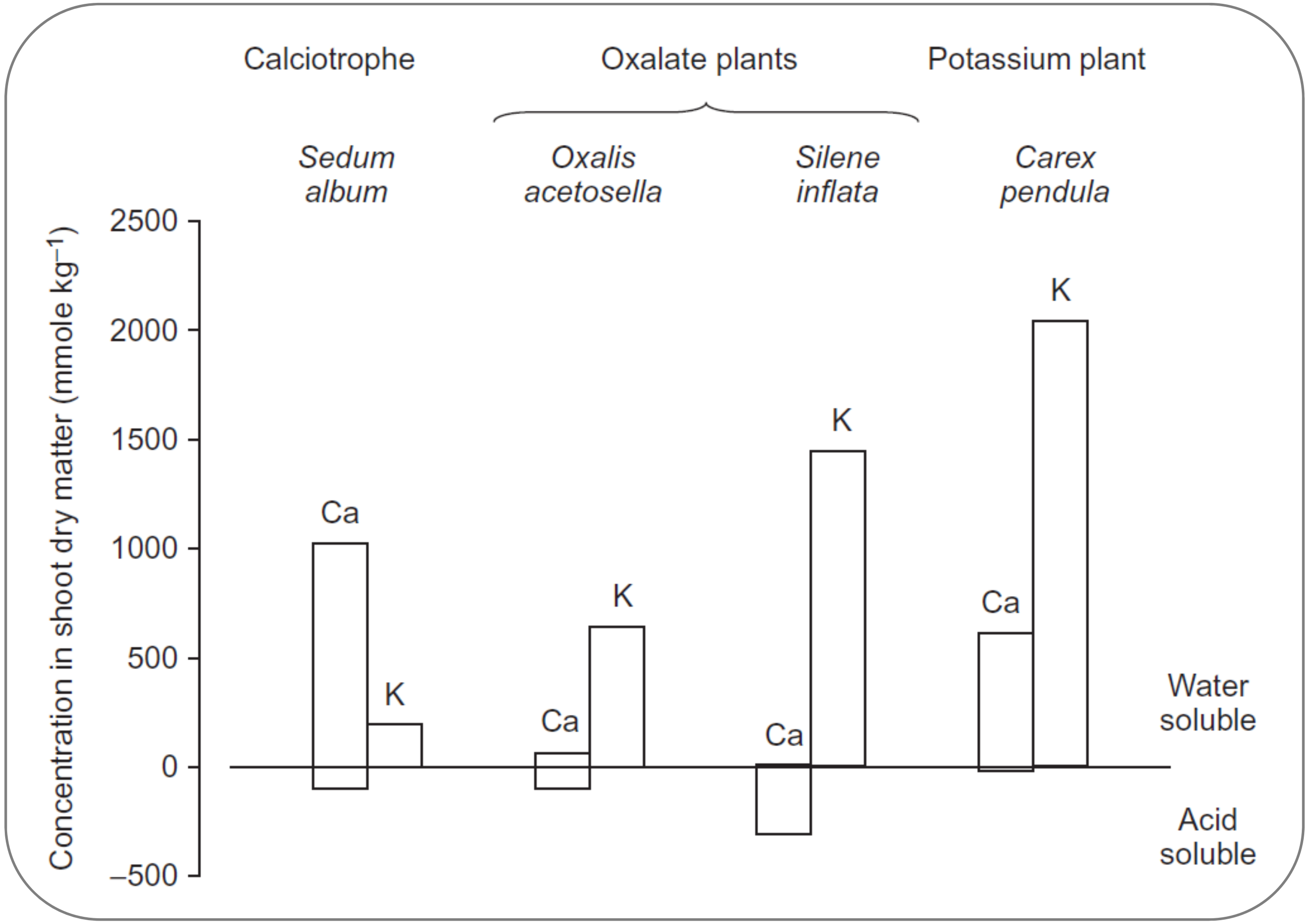
Calcium in Plant Physiology

Stability of cell walls and membranes
Signal transduction through cytosolic Ca^{2+} concentration
Cation/anion balance and osmoregulation



Marschner's Mineral Nutrition of Higher Plants, 2012

Calcium in Plants



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

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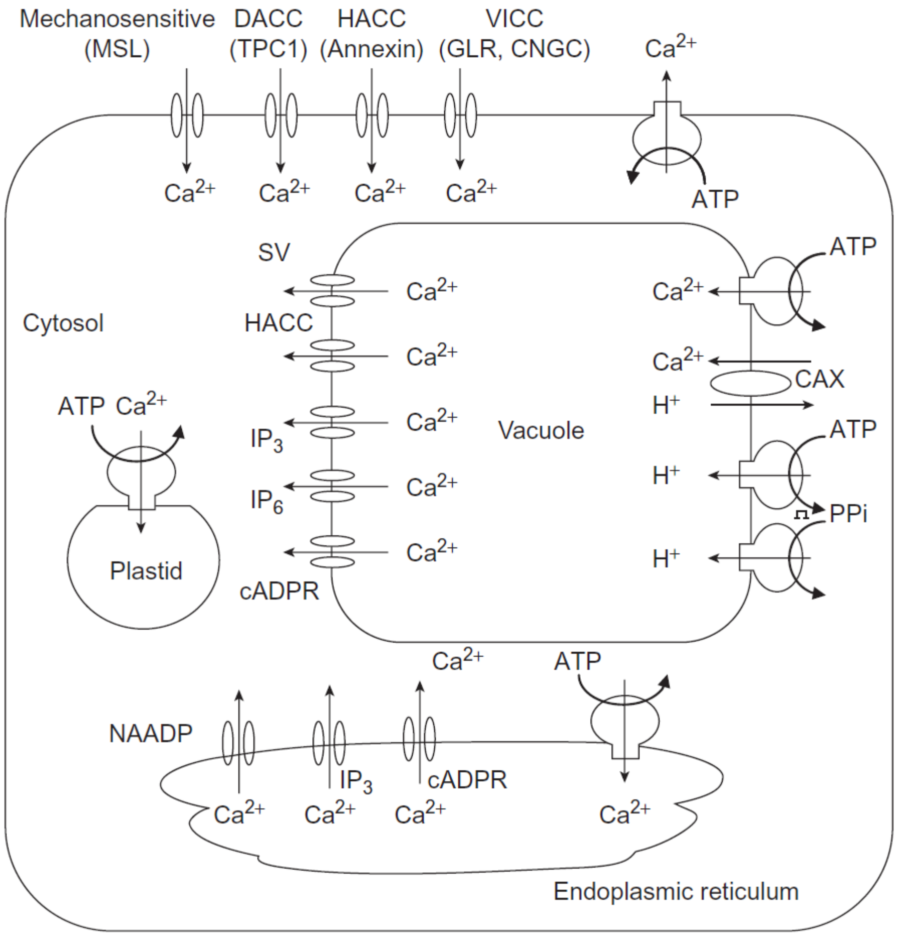
Calcium Transport in Plant Cells



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

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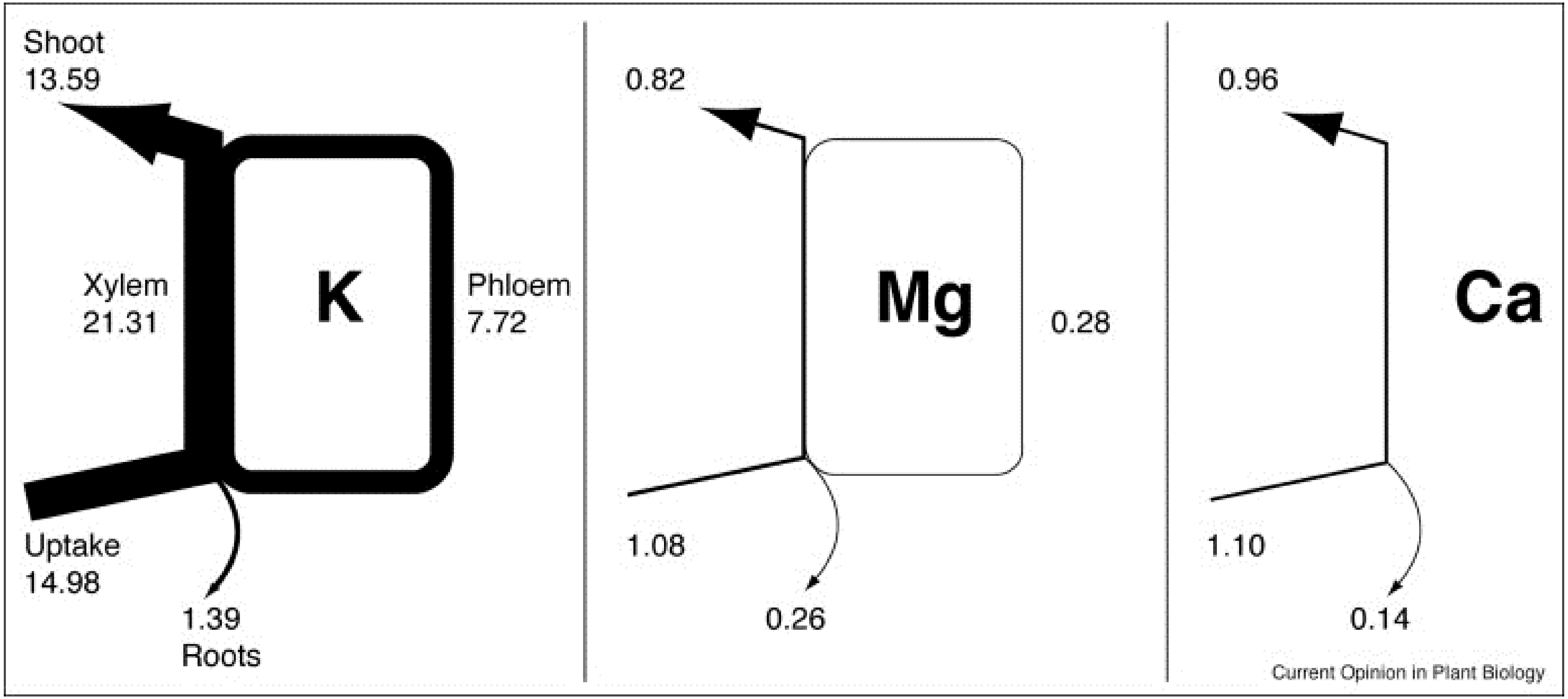
Cation Transport Within A Plant



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

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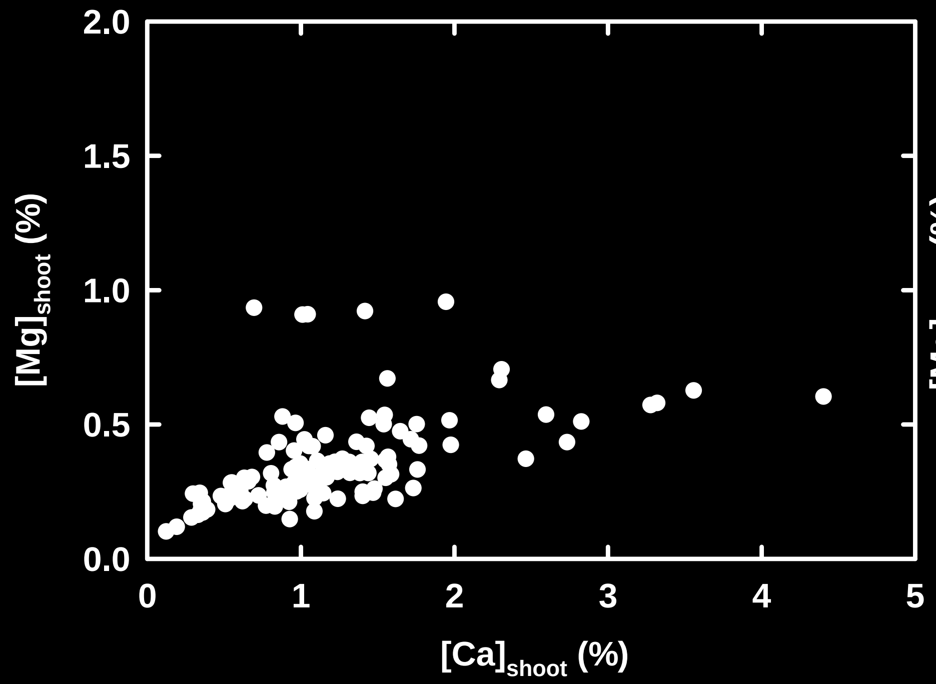
Magnesium : Calcium Ratios in Shoot Tissues

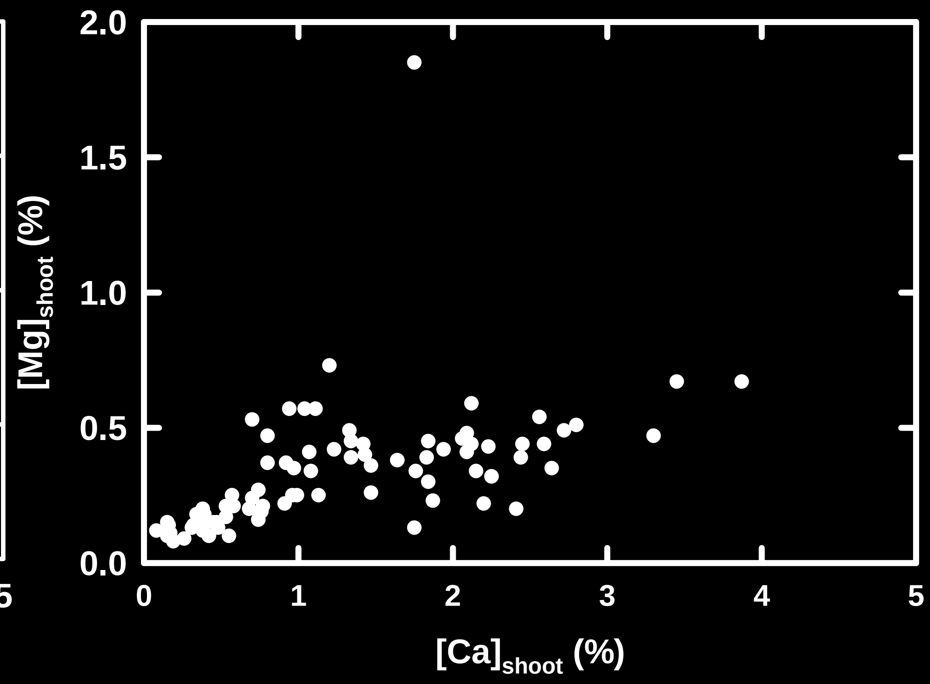
Hydroponics

Broadley et al. (2004)



Sampled from the field

Thompson et al. (1997)



Magnesium : Calcium Ratios in Shoot Tissues

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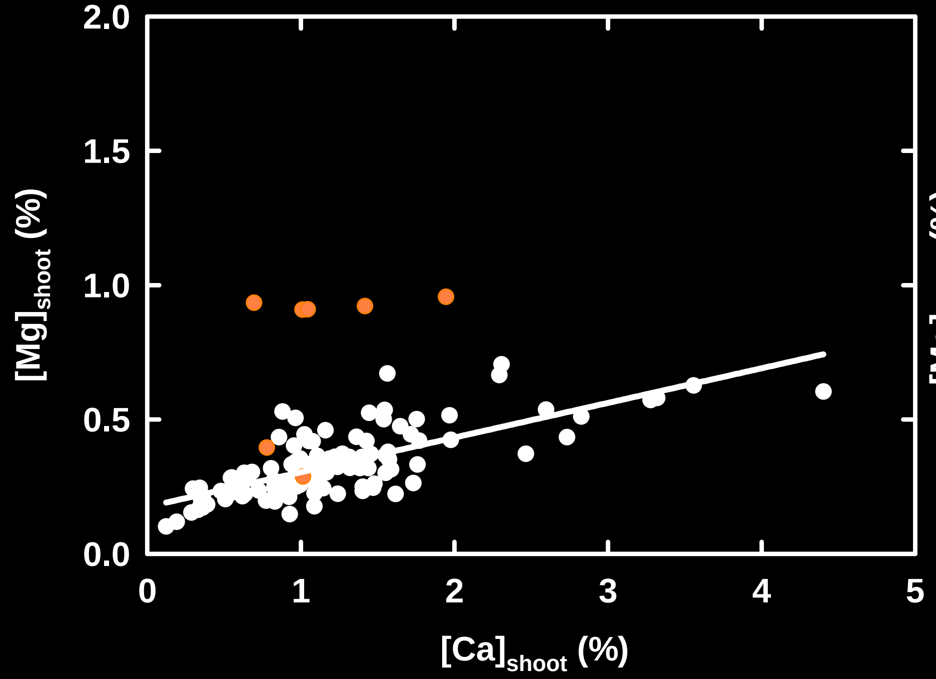
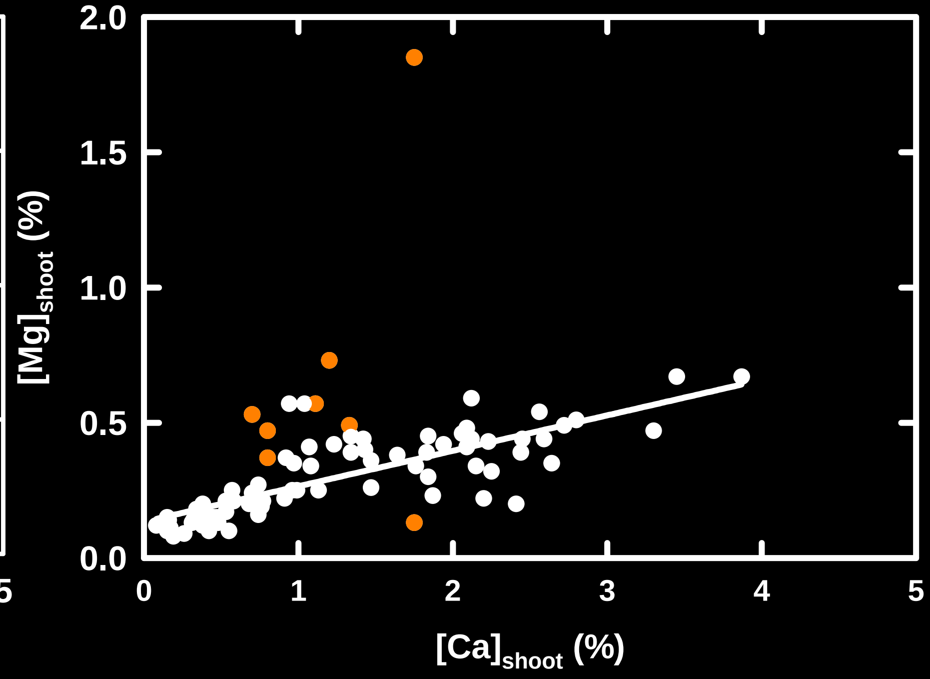


Sampled from the field

Thompson et al. (1997)

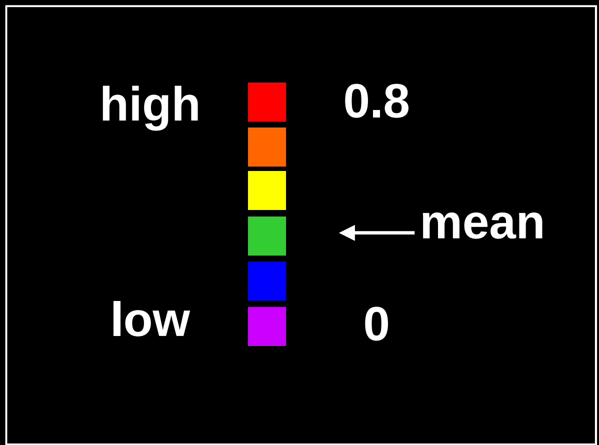


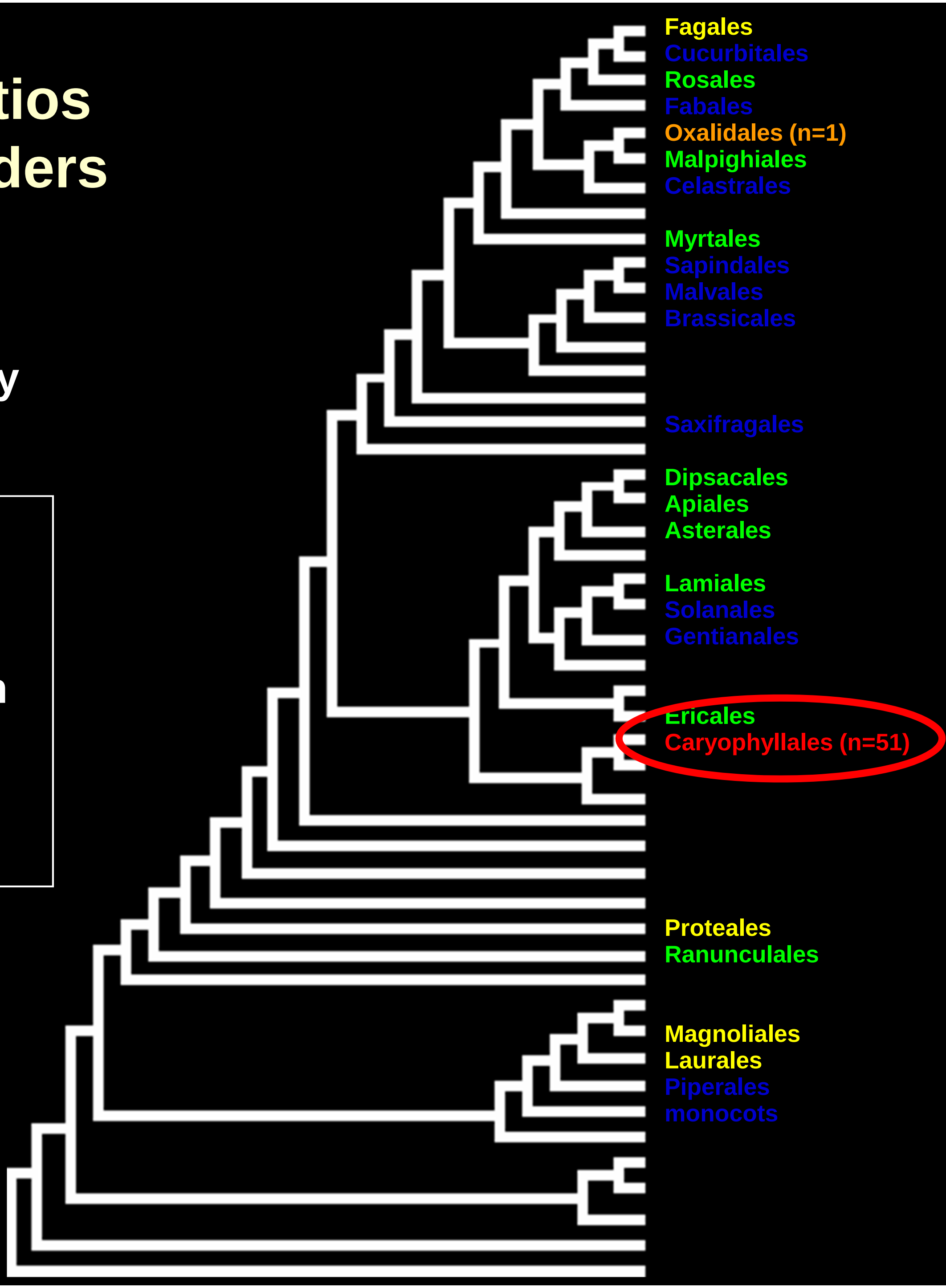
- All other taxa
- Caryophyllales (e.g. sugar beet, carnation)

Shoot Mg / Ca Ratios of Angiosperm Orders

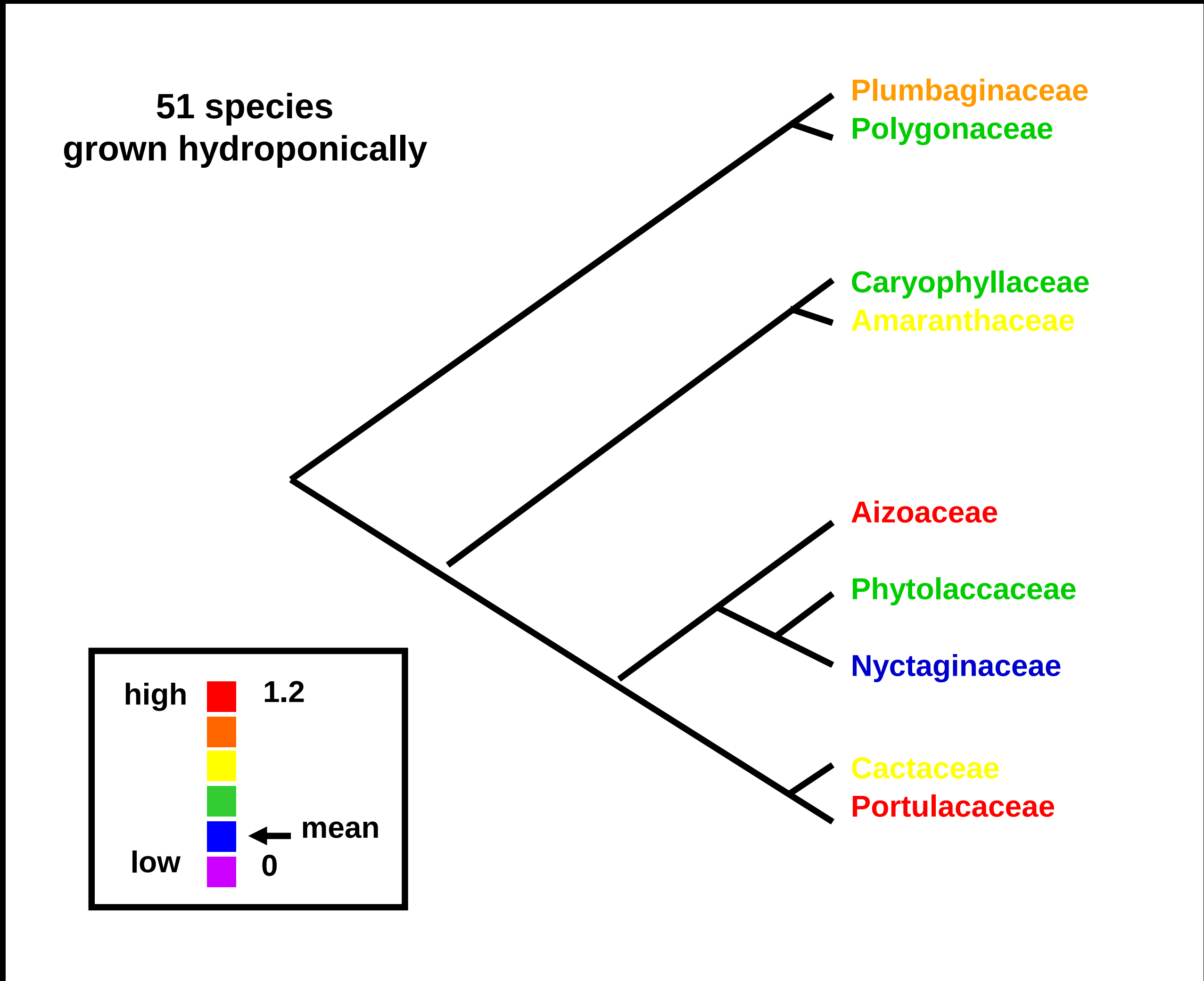
> 200 species

grown hydroponically

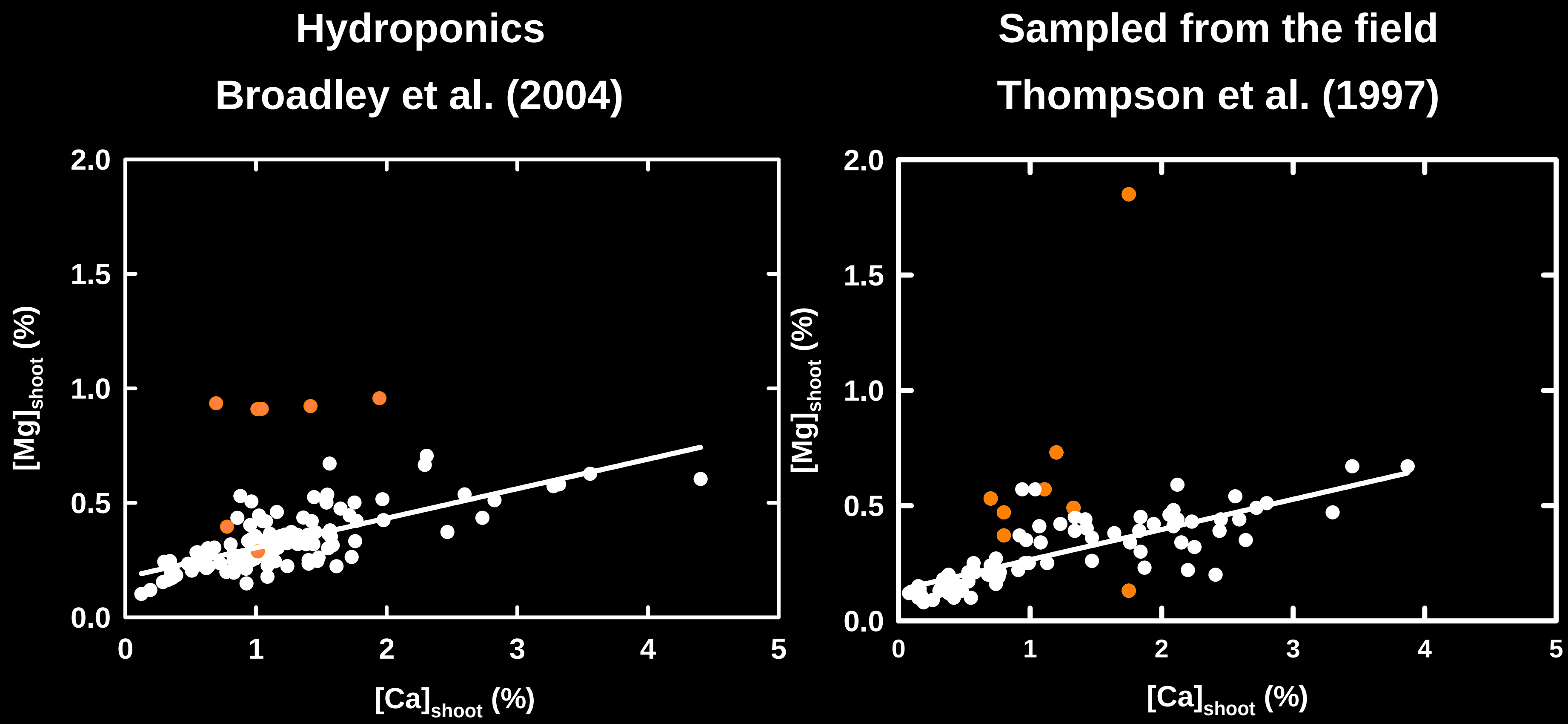




Shoot Mg / Ca Ratios in the Caryophyllales

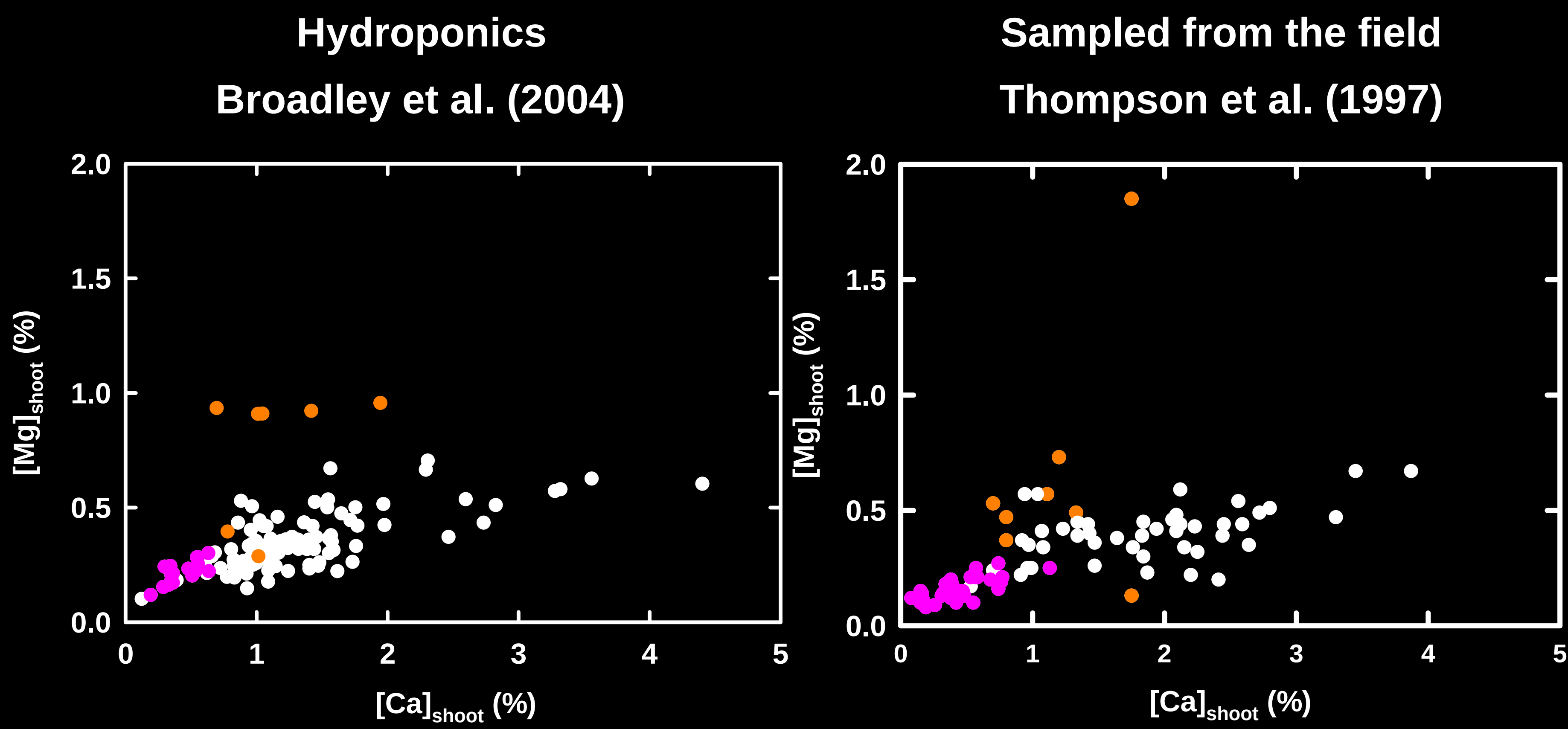


Magnesium : Calcium Ratios in Shoot Tissues



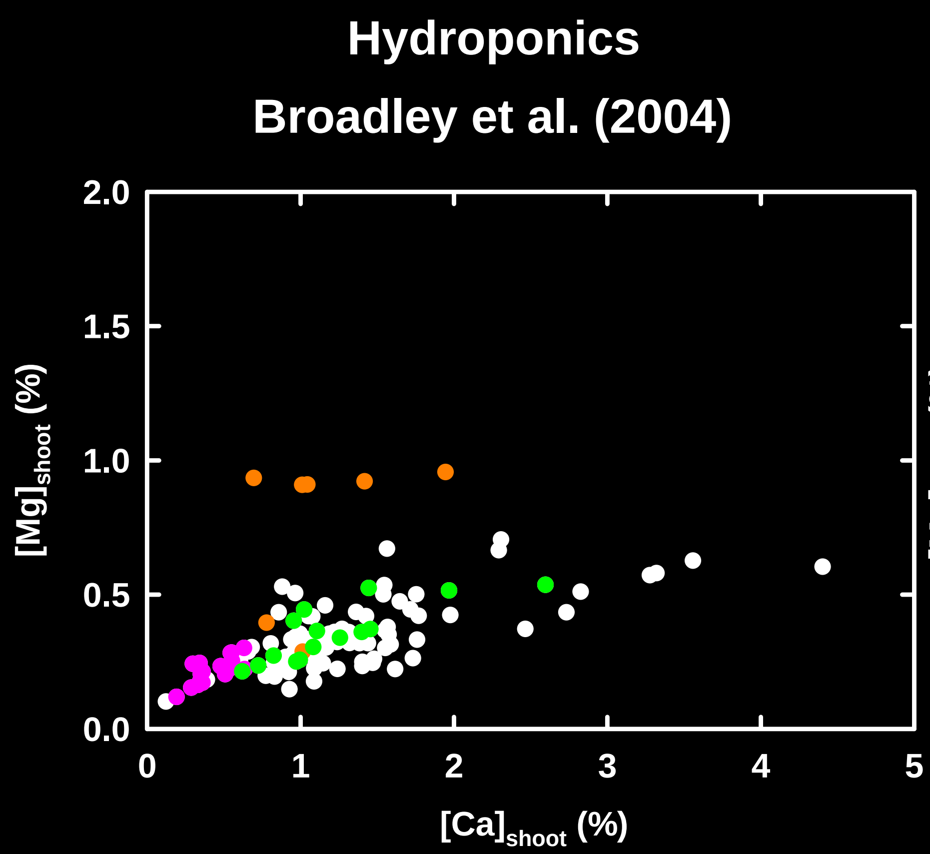
- All other taxa
- Caryophyllales (e.g. sugar beet, carnation)

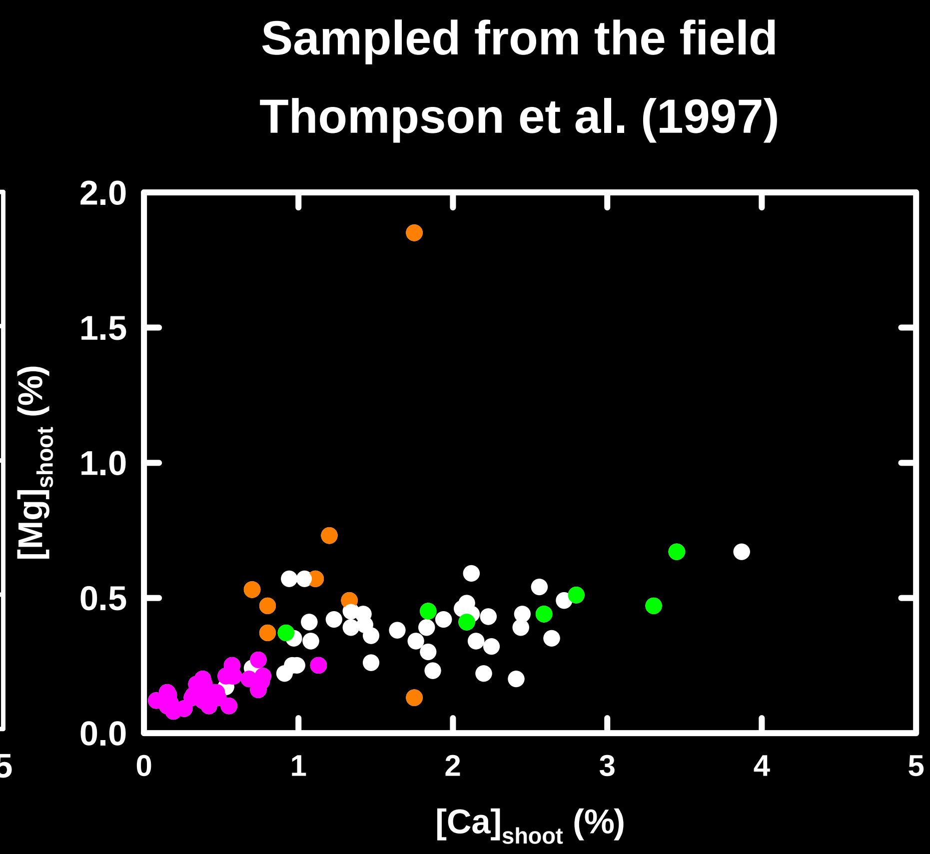
Magnesium : Calcium Ratios in Shoot Tissues



- All other taxa
- Caryophyllales (e.g. sugar beet, carnation)
- Poales (e.g. the grass / cereal family, Poaceae)

Magnesium : Calcium Ratios in Shoot Tissues

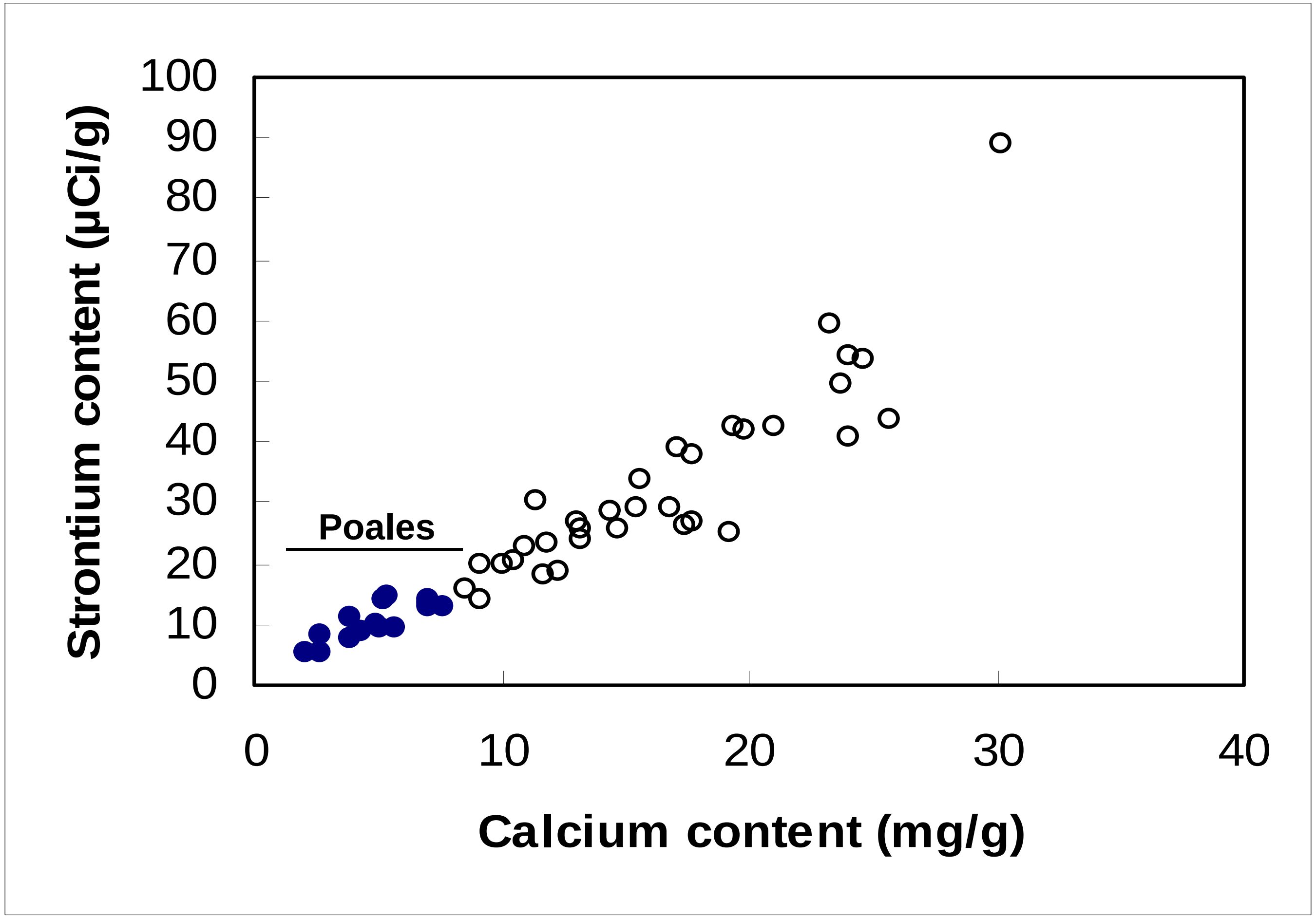




- All other taxa
- Caryophyllales (e.g. sugar beet, carnation)
- Poales (e.g. the grass / cereal family, Poaceae)
- Asterales (e.g. the daisy / sunflower family Asteraceae)

Strontium : Calcium Ratios

In Shoots of 44 Plant Species



Andersen AJ (1967) *Risö Report 170*

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Phylogenetic Variation In Shoot Mineral Concentrations

	Proportion of Genetic Variation		
	Ca	Mg	Sr
order and above (%)	64	65	76
within order (%)	36	35	24

Ancient evolutionary origin of variation
in Ca, Mg & Sr concentrations

Broadley et al. (2004) *J. Exp. Bot.* 55: 321-336

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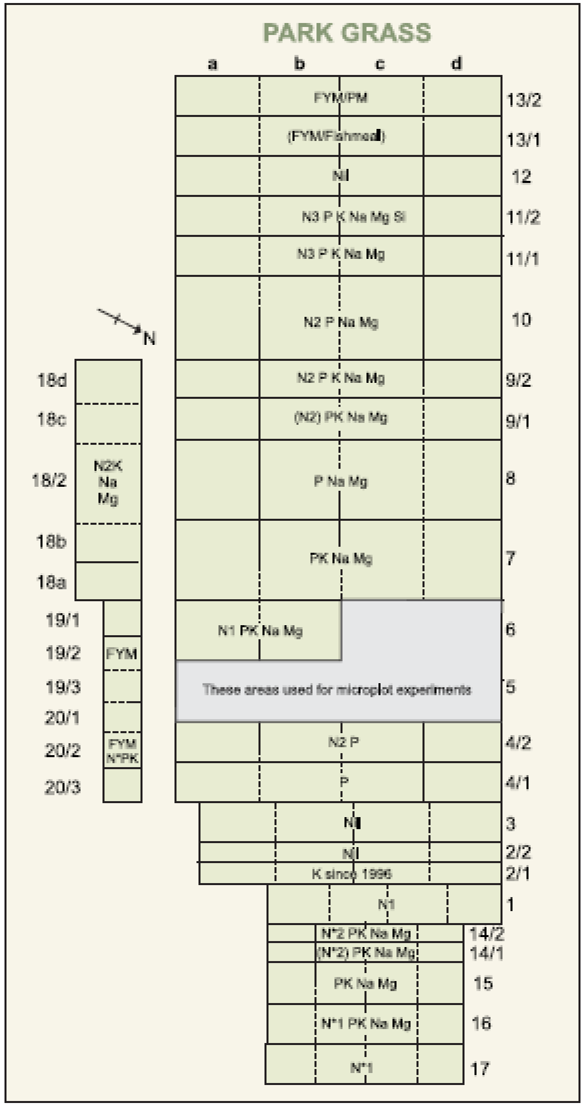
Phylogenetic and Environmental Effects on the Plant Ionome



Park Grass, Rothamsted
1856-2014

Botanical Composition of Park Grass Plots (Crawley *et al.*, 1991-2000)

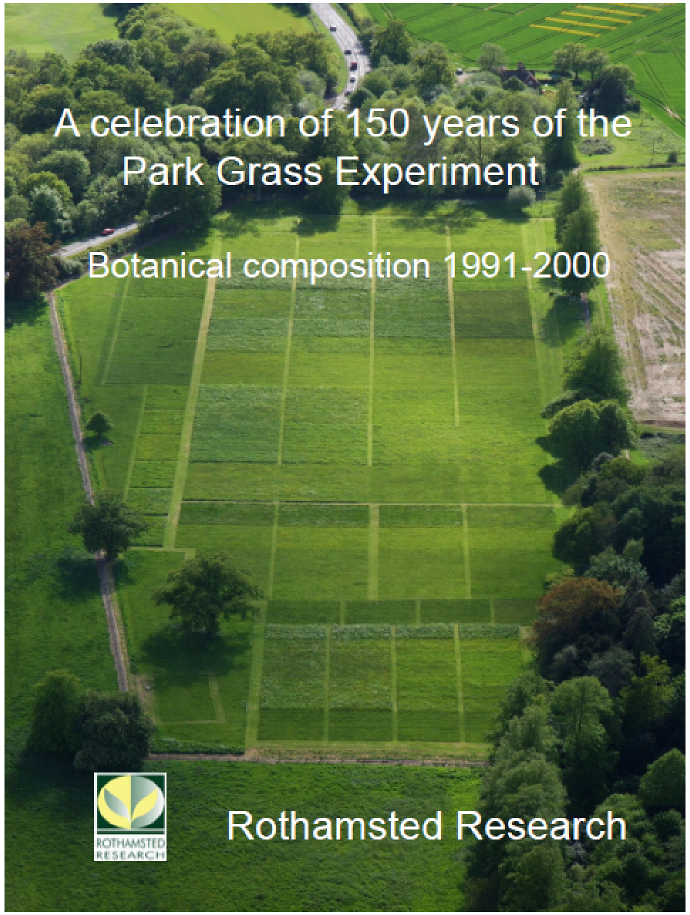


Table 3. Species comprising at least 10% of herbage, and total number of species; mean 1991-2000.

Treatment	Plot	Soil pH 1995-02	AC	AP	AO	AE	DG	FR	HP	HL	LoP	LaP	TP	AS	CN	HS	LH	PL	RaA	RuA	SM	Total no. of species
			Percentage of dry matter (Species names are listed below)																			
Nil	3a	7.2	10	+	+	+	+	20	+	+	+	+	+	–	10	+	15	+	+	+	10	38
	b	6.4	10	+	+	+	+	20	+	+	–	+	+	–	10	–	15	10	+	+	+	38
	c	5.3	30	–	+	–	+	30	+	+	–	+	+	–	+	+	15	+	+	+	+	37
	d	5.2	45	+	+	+	+	30	+	+	–	+	+	–	10	–	+	+	+	+	+	36
P	4/1a	6.9	+	+	+	+	+	20	+	+	+	+	10	–	+	+	15	10	+	+	+	34
	b	6.1	+	+	+	+	+	20	+	+	+	+	+	–	+	–	10	15	10	+	+	34
	c	5.2	30	+	+	+	+	25	+	+	+	+	+	–	+	–	10	+	+	+	+	29
	d	5.3	25	+	+	+	+	25	+	+	+	+	+	–	+	–	15	+	+	+	+	32
PKNaMg	15a	5.7	+	+	+	10	+	10	+	+	+	20	10	+	+	+	–	+	+	+	–	28
	b	5.9	+	+	+	15	+	10	+	+	+	+	20	+	+	+	+	10	+	+	–	27
	c	5.0	20	+	+	+	+	10	+	+	+	+	20	–	15	+	–	+	+	+	–	28
	d	4.9	40	+	+	+	+	10	+	+	+	+	10	–	+	+	+	+	+	+	–	27
N*1	17a	7.1	10	+	+	+	+	15	+	+	+	–	+	–	+	+	25	10	+	+	+	32
	b	6.4	15	+	+	+	+	+	+	+	+	+	–	–	+	+	30	15	+	+	+	34
	c	5.8	25	+	+	+	+	10	+	+	+	–	–	–	+	+	25	10	+	+	+	34
	d	5.6	25	+	+	+	+	10	+	+	+	–	+	+	10	+	10	+	+	+	–	34
N*2PKNaMg	14/2a	6.9	+	20	–	50	+	+	+	–	+	+	–	10	–	+	–	+	+	+	–	24
	b	6.4	+	30	+	40	+	+	–	+	+	–	+	10	–	+	–	–	+	+	–	24
	c	6.1	+	20	+	40	+	+	–	+	+	+	–	+	–	+	–	+	+	+	–	21
	d	5.9	+	25	–	30	10	+	+	+	+	+	–	+	–	10	–	+	+	+	–	22
N1	1a	7.1	+	+	+	+	10	25	10	+	–	+	+	–	+	–	10	+	+	+	+	33
	b	6.2	20	+	+	+	10	25	+	+	+	+	+	–	10	–	+	+	+	+	+	31
	c	5.3	35	–	+	+	+	45	+	+	+	+	+	–	+	–	–	–	+	+	–	30
	d	4.1	65	–	30	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	10
N2KNaMg	18a	7.1	15	+	+	+	10	15	+	+	+	–	+	–	10	+	10	+	–	+	–	30
	b	6.3	30	+	+	+	+	15	+	+	+	–	–	–	25	+	+	+	–	+	–	29
	c	5.4	35	+	+	+	15	20	+	+	10	–	–	–	+	+	–	–	–	+	–	21
	d	3.6	60	–	25	+	–	–	–	+	–	–	–	–	–	–	–	–	–	+	–	6
N2P	4/2a	6.9	10	+	+	+	+	55	+	10	+	–	–	–	+	–	–	+	+	+	–	22
	b	6.2	15	10	+	+	+	65	+	10	+	–	–	–	–	–	+	–	–	+	–	14
	c	5.2	30	+	+	+	+	55	+	+	+	–	–	–	–	–	–	+	–	10	–	18
	d	3.7	30	–	75	+	–	+	–	+	–	–	–	–	–	–	–	–	–	+	–	10
N2PKNaMg	9/2a	6.9	+	15	+	25	10	+	–	15	+	+	+	+	–	10	–	+	+	+	–	22
	b	6.3	+	25	+	35	+	+	+	15	–	+	+	+	–	+	–	–	–	+	–	17
	c	5.0	30	10	10	+	+	15	–	+	–	+	+	+	–	+	–	–	–	+	–	18
	d	3.7	15	–	65	–	–	–	–	20	–	–	–	–	–	–	–	–	–	–	–	4
N3PKNaMg	11/1a	6.5	+	20	–	40	10	+	+	10	+	–	–	+	–	+	–	–	+	+	–	14
	b	6.2	+	20	+	35	20	+	+	10	+	–	–	+	–	+	–	–	–	+	–	15
	c	4.9	+	30	+	20	+	–	–	30	–	–	–	+	–	+	–	–	–	+	–	13
	d	3.6	–	–	+	–	–	–	–	100	–	–	–	–	–	–	–	–	–	–	–	3
FYM/PM	13/2a	6.8	30	+	+	+	10	15	+	+	10	–	–	–	+	+	–	–	–	+	–	28
	b	6.1	+	15	+	20	10	+	–	+	+	+	–	+	+	10	–	+	+	+	–	38
	c	5.3	20	+	+	+	+	+	+	10	–	+	+	+	+	+	+	10	+	+	–	32
	d	5.1	35	10	+	+	+	10	+	10	+	+	+	–	+	+	+	+	+	+	–	34

After Crawley et al., 2005, American Naturalist, 165, 179-192.
Data are from surveys immediately before hay harvest; rounded to the nearest 5% of dry matter, mean 1991-2000. (Selected plots only)
+, species present at less than 10%; –, species not identified on that plot.
Species that do not occur at 10%, or more, on any one plot are not shown.

Grasses:
- *Agrostis capillaris* – Common Bent
- *Alopecurus pratensis* – Meadow Foxtail
- *Anthoxanthum odoratum* – Sweet Vernal Grass
- *Arrhenatherum elatius* – False Oat Grass
- *Dactylis glomerata* – Cock's-foot
- *Festuca rubra* – Red Fescue
- *Helictotrichon pubescens* – Downy Oat-grass
- *Holcus lanatus* – Yorkshire Fog
- *Lolium perenne* – Perennial Ryegrass

Legumes:
- *Lathyrus pratensis* – Meadow Vetchling
- *Trifolium pratense* – Red Clover

Forbs:
- *Anthriscus sylvestris* – Cow Parsley
- *Centaurea nigra* – Common Knapweed
- *Heracleum sphondylium* – Hogweed
- *Leontodon hispidus* – Rough Hawkbit
- *Plantago lanceolata* – Ribwort Plantain
- *Ranunculus acris* – Meadow Buttercup
- *Rumex acetosa* – Common Sorrel
- *Sanguisorba minor* – Salad Burnet

Crawley et al. (2005) *American Naturalist* 165, 179-192

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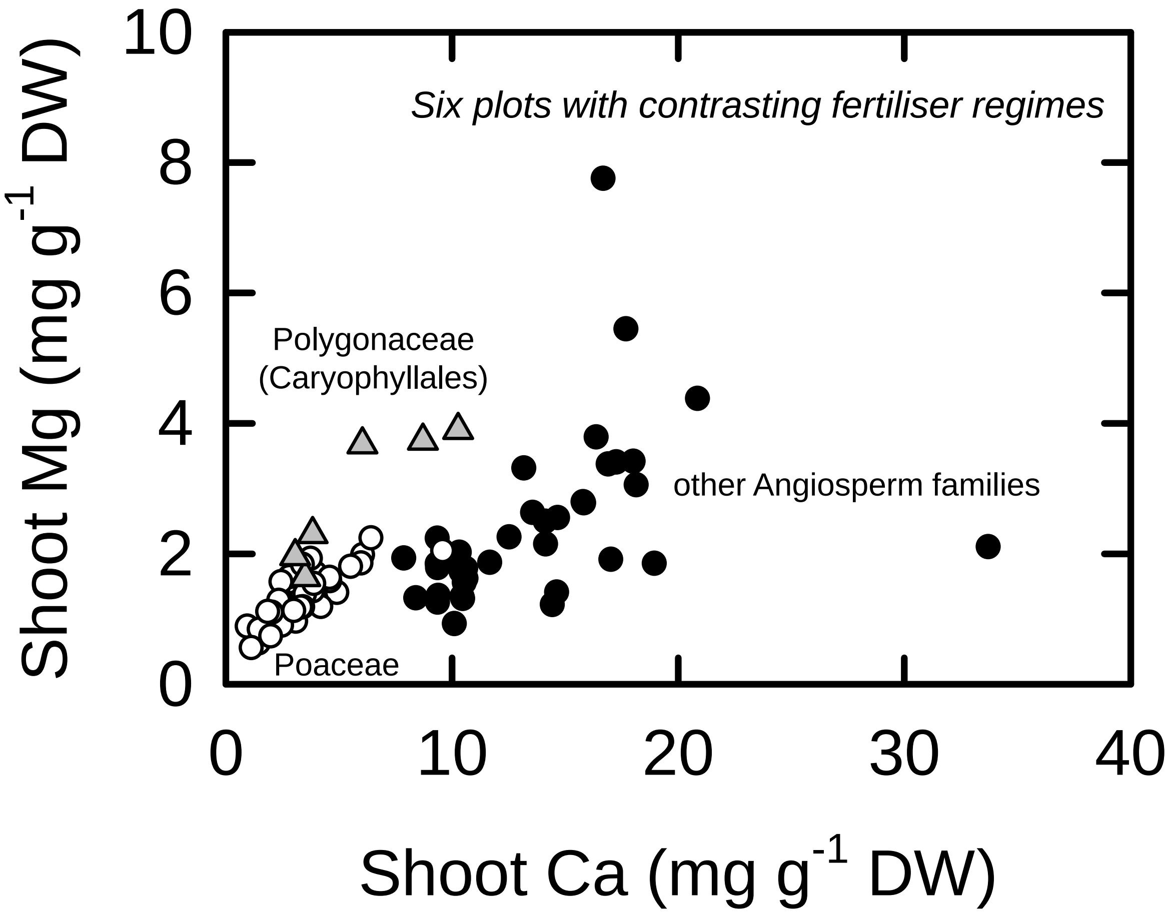
Calcium : Magnesium Ratios
In Plants Receiving Contrasting Fertilisers



White et al. (2012) *New Phytologist* 196: 101-109

Phylogenetic and Environmental Effects on the Plant Ionome

Ecological Survey

% Variance	Species	Site
Calcium	81.4	18.6
Magnesium	62.6	37.4

Rothamsted Park Grass Experiment (six plots)

% Variance	Species	Treatment	Residual
Calcium	70.8	8.2	21.0
Magnesium	32.8	19.9	47.3

Thompson et al. (1997) *New Phytologist* 136, 679-689
White et al. (2012) *New Phytologist* 196, 101-109

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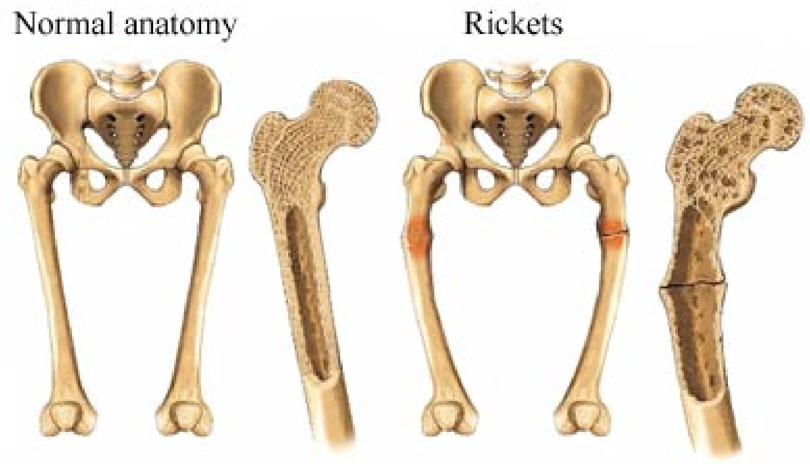
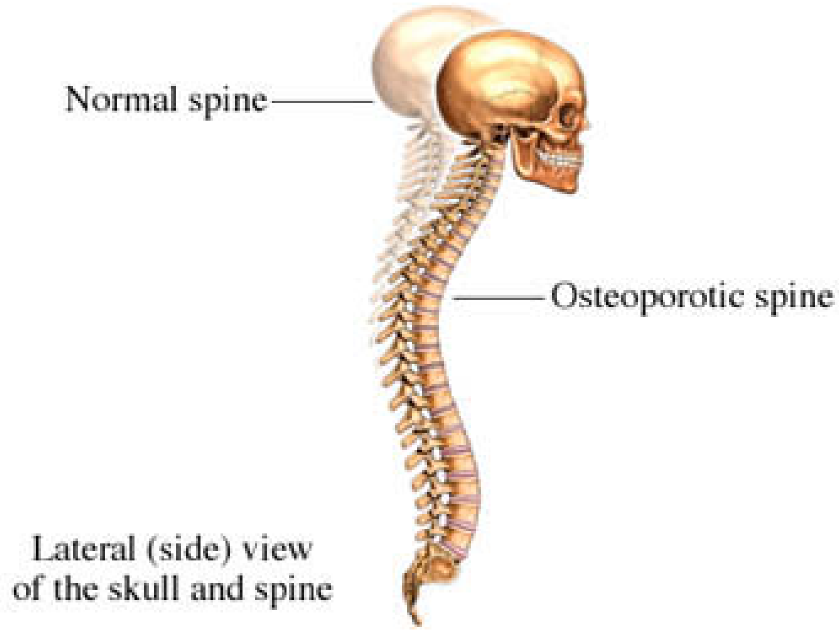
Plant Calcium - Dietary Consequences

calcium deficiency disorders arise
when populations change from
bean-rich to cereal-rich diets





Thacher (2006) *Ann. Trop. Paediatrics* 26, 1-16
White & Broadley (2009) *New Phytol.* 182, 49-84

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Ecological Implications - Serpentine Flora

name is derived from the mineral serpentine
($(Mg,Fe)_3Si_2O_5(OH)_4$)

high Mg and Fe; low Ca
high Ni, Cr and Co; low organic matter; little water; low N, P and K

Edmonstons Chickweed - *Cerastium nigrescens* (Caryophyllaceae).
World distribution restricted to the serpentine debris on Unst

Proctor J (1999) Toxins, nutrient shortages and droughts: the serpentine challenge. *Trends in Ecology and Evolution*, 14, 334-335

Growth & Survival in Solutions With Large Mg/Ca Quotients

65 plant species:
26 Caryophyllales
16 serpentine flora
23 other angiosperms

2 treatments:
0.75 & 10 mM Mg

measured:
survival & shoot biomass
$[Mg]_{shoot}$, $[Ca]_{shoot}$

White, Shaw, Thompson & Wright, unpublished data

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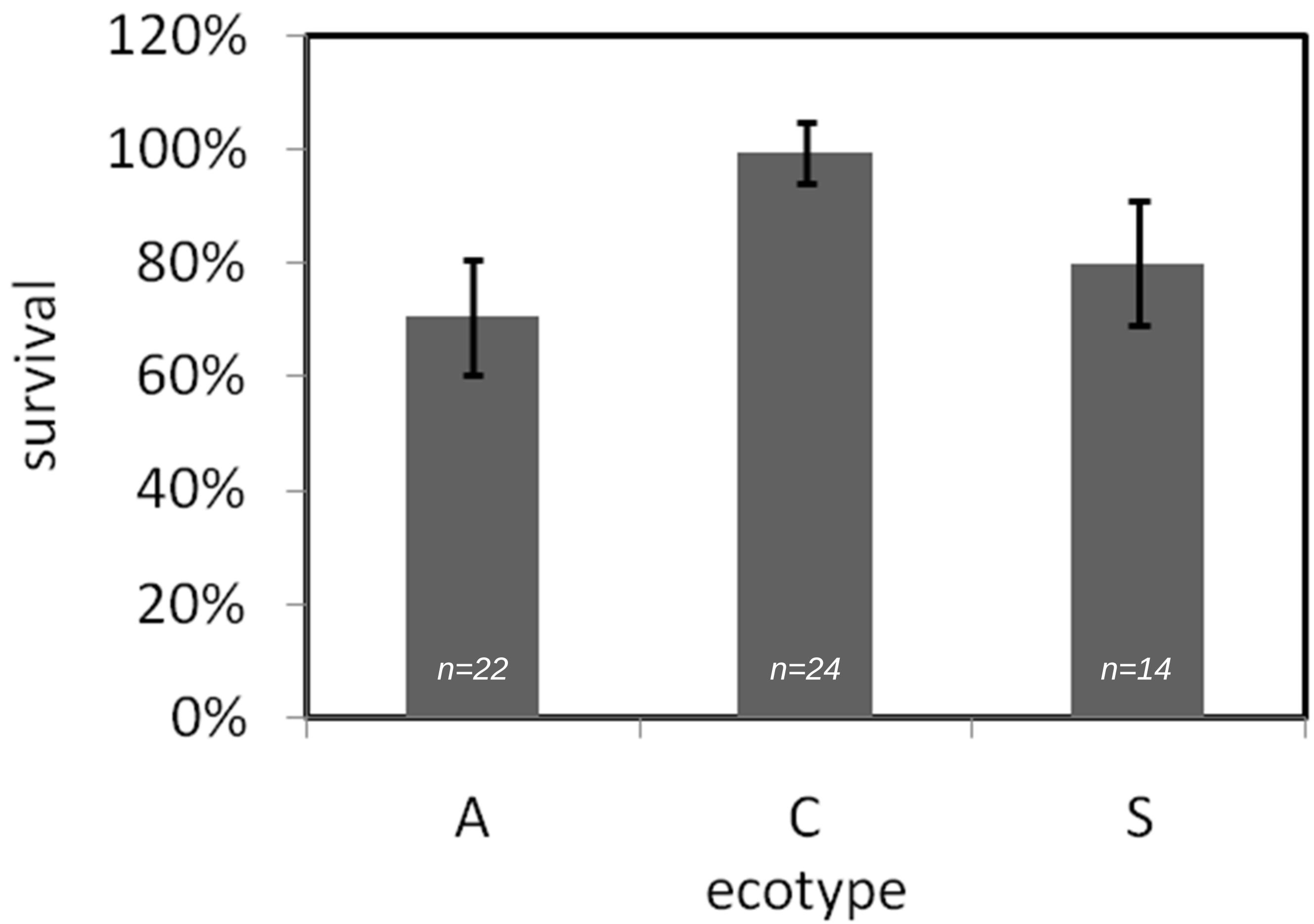
Growth & Survival in Solutions With Large Mg : Ca Ratios



White, Shaw, Thompson & Wright, unpublished data

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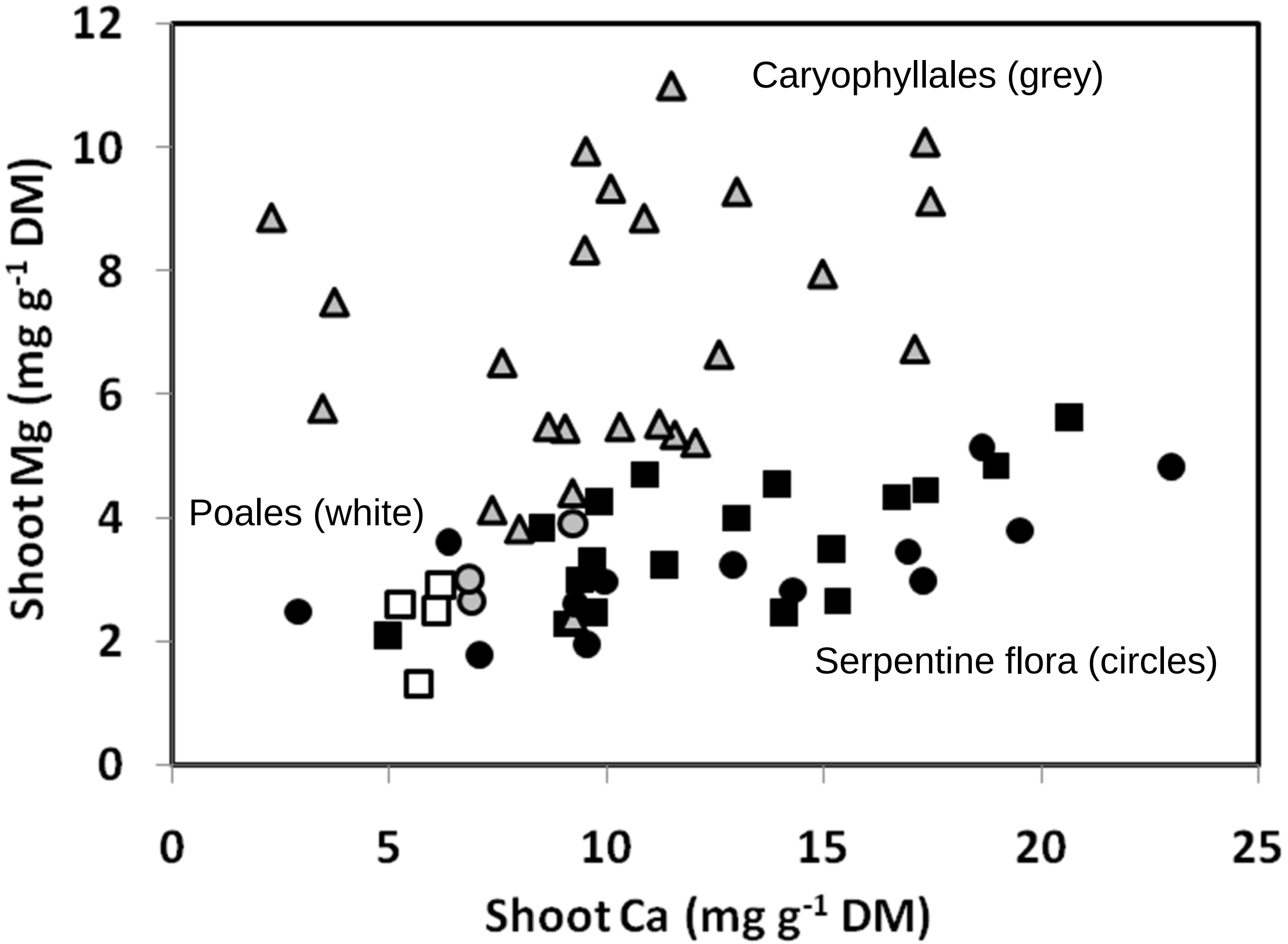
Shoot Mg : Ca Ratios
In Plants Supplied Non-Serpentine Solution



White, Shaw, Thompson & Wright, unpublished data

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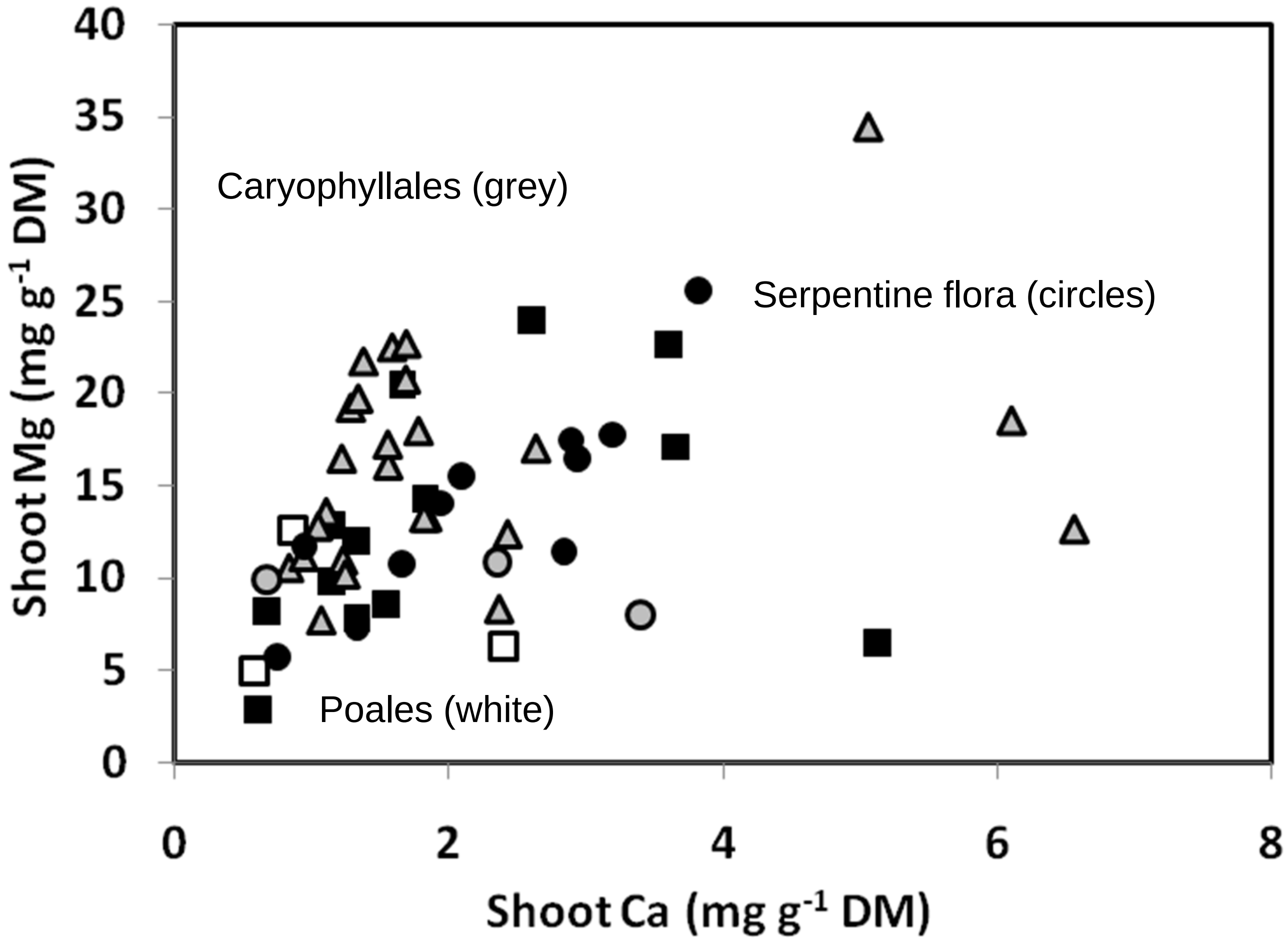
Shoot Mg : Ca Ratios
In Plants Supplied Serpentine Solution



White, Shaw, Thompson & Wright, unpublished data

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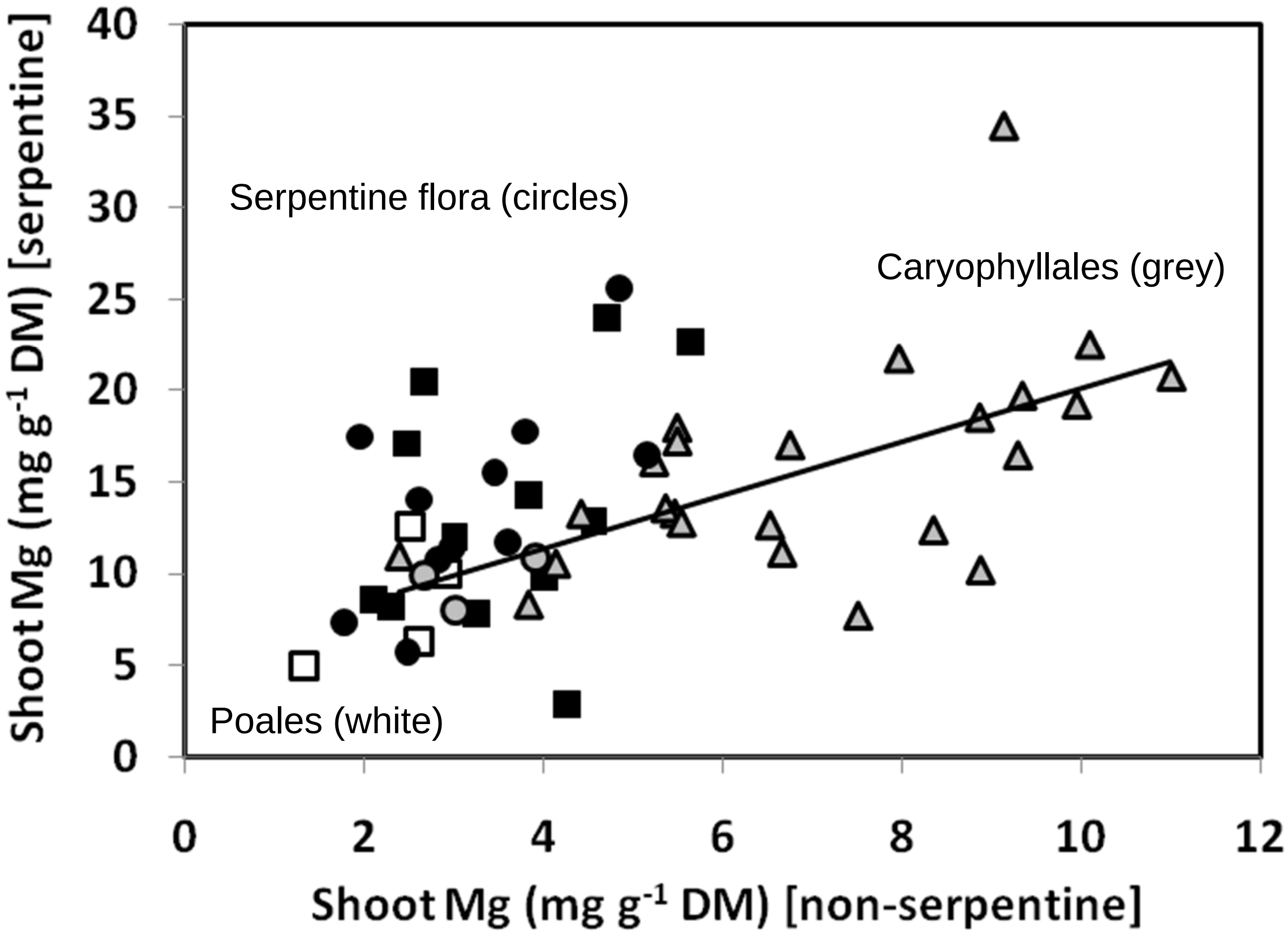
Shoot Magnesium Concentration In Plants Supplied Non-Serpentine Solution



White, Shaw, Thompson & Wright, unpublished data

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Phylogenetic Effects On Shoot Magnesium Concentrations

Species differ in their shoot Mg and Ca concentrations

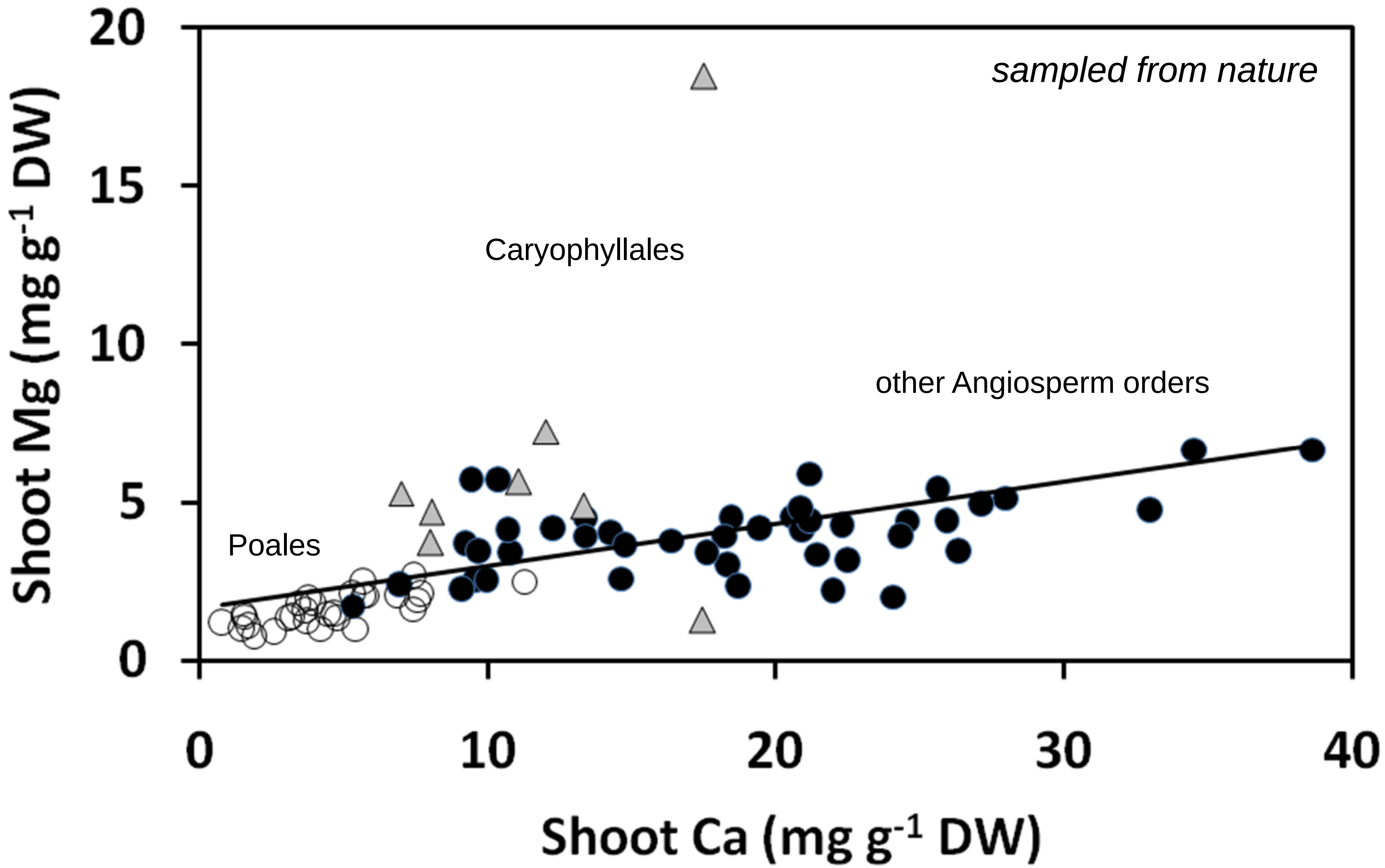
Differences attributed to ancient evolutionary events

Shoot Mg and Ca concentrations are correlated among many species

Commelinoid monocots - low shoot Mg and Ca concentrations
Caryophyllales - high Mg / Ca quotients

(Phylo)genetic variation can exceed environmental variation

Calcium : Magnesium Ratios
In Plants Sampled From An Herbaceous Flora



Thompson et al. (1997) *New Phytologist* 136: 679-689

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