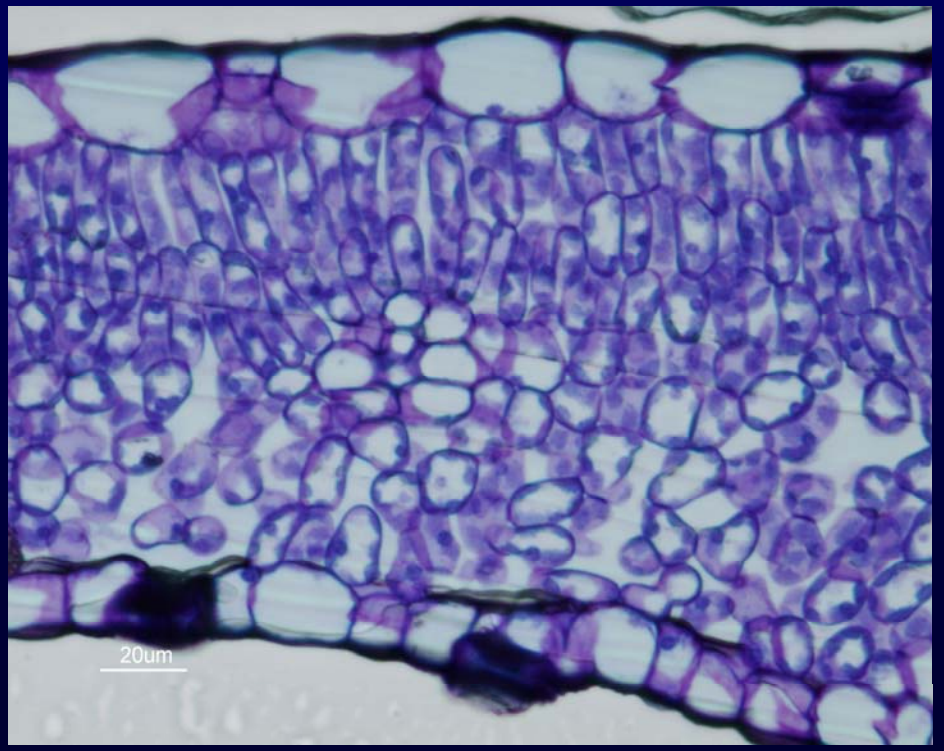
16. Tagung des AK Blattdüngung

Foliar fertilizer application has an impact on the mineral composition of the leaf



V. Fernández, A. Blanco, J. Val

October 7th, 2008

Outline

1. Foliar fertilization: significance
2. Brief theoretical background
3. Effect of foliar sprays on nutrient status
4. Conclusions

1. Significance of foliar fertilisation

- A **commonly used** agricultural practice
- Good method when **nutrient demand > root absorbing capacity**
- **Alternative** method in conditions ⇒ **insolubility/low availability**
- **Complementary** strategy to root application
- **In theory**, it can be:
  - a **more environmentally-friendly** strategy
    ⇒ limited run off & water-soil contamination risks
  - a **target-oriented** strategy
    ⇒ aerial plant organs can be directly supplied accurate doses

1. Significance of foliar fertilisation

e.g. "Recent" foliar fertilisation studies (intact leaves, fruit *spp*.)

Element	species	References
N	Apple, avocado, *Citrus,* strawberry, Peach, raspberry	Amiri et al. 2008; Carrillo-Mendoza et al. 2005; El-Otmani et al. 2004, Johnson et al. 2001; Orbovic et a. 2001; Lovatt, 1999; Reickenberg & Pritts 2006; Lea-Cox & Syverten, 1995; Ali & Lovatt, 1994
K	Muskmelon, grape, *Prunus,* apple	Lester et al. 2006, 2005; Knoll et al. 2006; Vebercs et al. 2005; outhwick et al. 1996
P	Apple, tomato, *Citrus*	Ahn et al. 2005; Vebercs et al. 2005; Lovatt, 1999
Mg	Peach, plum	Alcazar-López et al. 2004; 2003
Ca	Blueberry, strawberry, peach, plum, apple	Stückrath et al. 2008; Singh et al. 2007; Lanauskas et al. 2006; Alcazar-López et al. 2004, 2003; Wojcik and Lewandowski, 2003; Wojcik and Szwonek, 2002

1. Significance of foliar fertilisation

e.g. “Recent” foliar fertilisation “agronomic” studies (intact leaves, fruit *spp*.)

Element	Species	References
B	Coffee, strawberry, avocado, raspberry, apple, pear, *Prunus*	Leite et al. 2007; Singh et al. 2007; Wojcik 2005; Wojcik and Lewandowski, 2003; Torres et al. 2003; Nyomora et al. 2000; Picchioni et al. 1995
Fe	Peach, *Citrus*, pear	Fernández et al. 2008, 2006; Papadakis et al. 2007; Álvarez-Fernández et al. 2004
Mn	*Citrus*	Papadakis et al. 2007, 2005
Zn	Apple, pistachio, walnut	Amiri et al. 2008; Torres et al. 2003; Zhang & Brown, 1999

1. Significance of foliar fertilisation

However, still **many factors** relating to e.g. **penetration, translocation & physiological effect** of sprays not clear

⇒ **variable results** obtained after application, e.g.:

- **Defoliation** (e.g. Fe & *Citrus*, Stewart & Leonard, 1967)
- **Leaf burn** (K, P & tomato, Chapagain & Wiesman, 2004)
- **No significant effects** (some Fe sprays & peach; Fernández et al., 2006)
- **Positive effects** (N & peach; Johnson et al., 2001; K & muskmelon; Lester et al., 2006)

Foliar fertilisation: a complex scenario

Many factors rule the effectiveness of a leaf-applied fertiliser, e.g.:

Leaf structure: e.g. leaf surface (stomata, cuticle,…)

Plant physiology: e.g. plant water & nutrient status,…

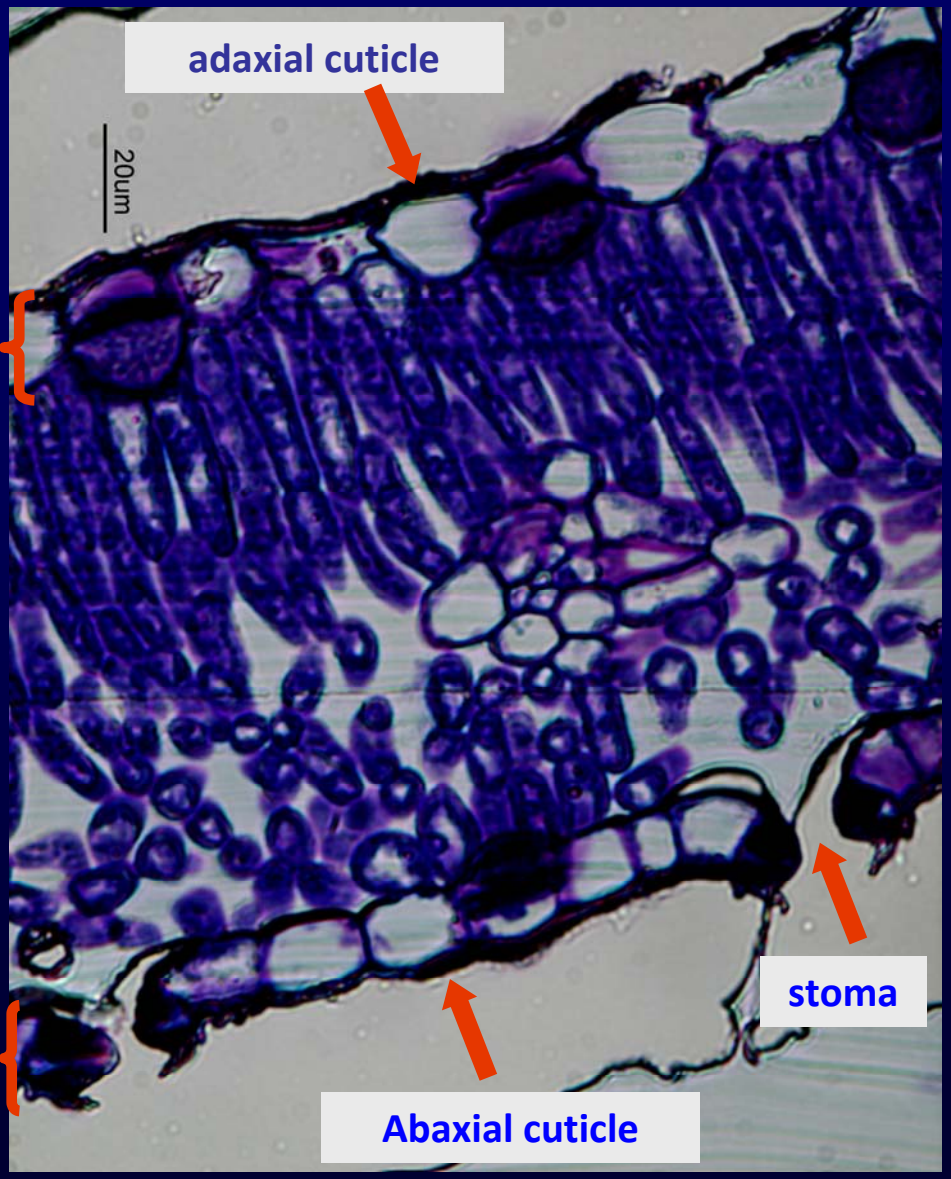
Environmental factors. Conditions in phyllosphere and rhyzosphere,…

Physical-chemical properties of compounds

Focus of the presentation:

Leaf nutrient status

2. Brief theoretical background



May occur through (Tuckey et al., 1961):

- Cuticle
- Cuticular cracks & imperfections
- Stomata
- Thrichomes & specialised epidermal cells

2. Brief theoretical background

Progress in foliar penetration & related affairs, last 40 years:

- **Mechanistic approach** to foliar penetration based on **cuticles (astomatous)**:

  - Characterisation of cuticular penetration of **lipophillic** compounds (Riederer & Friedmann, 2006)

  - Attempts to characterise penetration of **water & electrolytes**: "aqueous pores" (Schönherr, 1976, 2001, 2006) & estimation of pore sizes (summ. Schönherr, 2006; Eichert & Goldbach, 2008)

- Characterisation of **structure & composition** of the plant **cuticle** (summ. Jeffree, 2006)

- Characterisation of **leaf surfaces** and significance of **epicuticular waxes** on water & "dirt" repellence ("Lotus effect") (Barthlott & Neinhuis, 1997; summ. Jeffree, 2006)

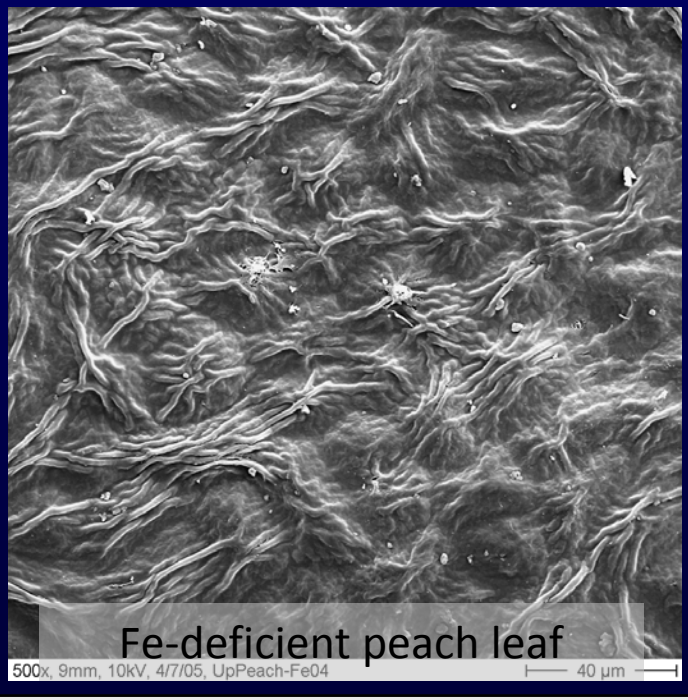
- Attempts characterise **stomatal penetration** mechanisms (Schönherr & Bukovac, 1972; Eichert et al., 1998, 2008)

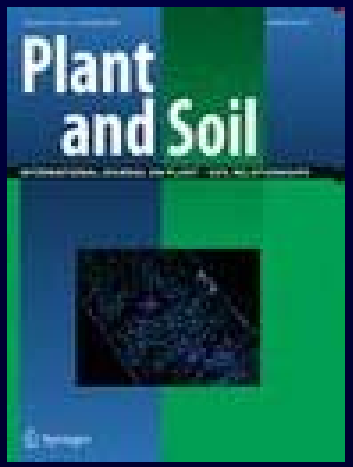
- Mechanisms of **cuticle formation**; new findings on **cuticular wax formation** (Samuels et al., 2008) & **cutin synthesis** (Heredia-Guerrero et al., 2008)

2. Theoretical background: Effect of nutrient deficiencies on leaf structure

Adaxial leaf surfaces

Effect Fe deficiency on soluble cuticular lipids (Fernández, Eichert et al., 2008)





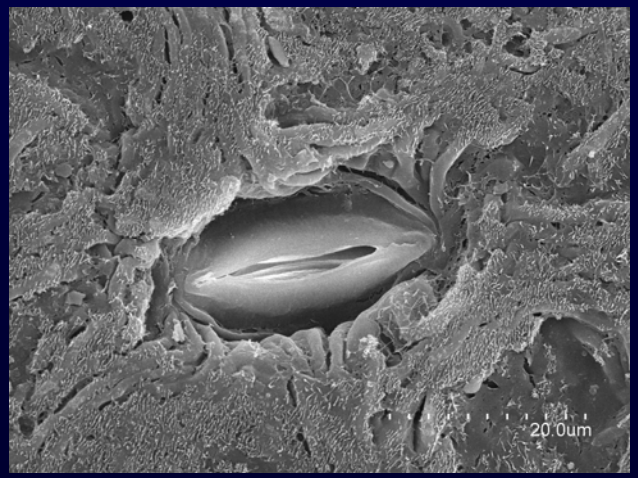
(1 min extraction in 2:1 chloroform:methanol)

	Green leaves	Chlorotic leaves
Soluble cuticular lipids (µg cm^{-2})	176.5 ± 13.3***	103.6 ± 7.9***

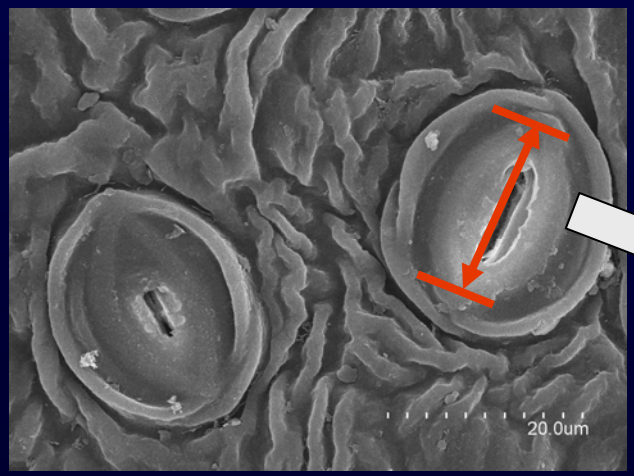
2. Theoretical background: Effect of nutrient deficiencies on leaf structure

Effect Fe deficiency on stomata (Fernández, Eichert et al., 2008)

Species	Leaf type	Stomatal density (stomata mm^{-2})	Pore length (µm)
Peach	green	221±18 ns	26.1±0.4***
	chlorotic	233±11 ns	19.9±0.4***
Pear	green	160±9 ns	24.4±0.3***
	chlorotic	156±12 ns	20.3±0.3***



Pear leaf stoma (+ Fe)

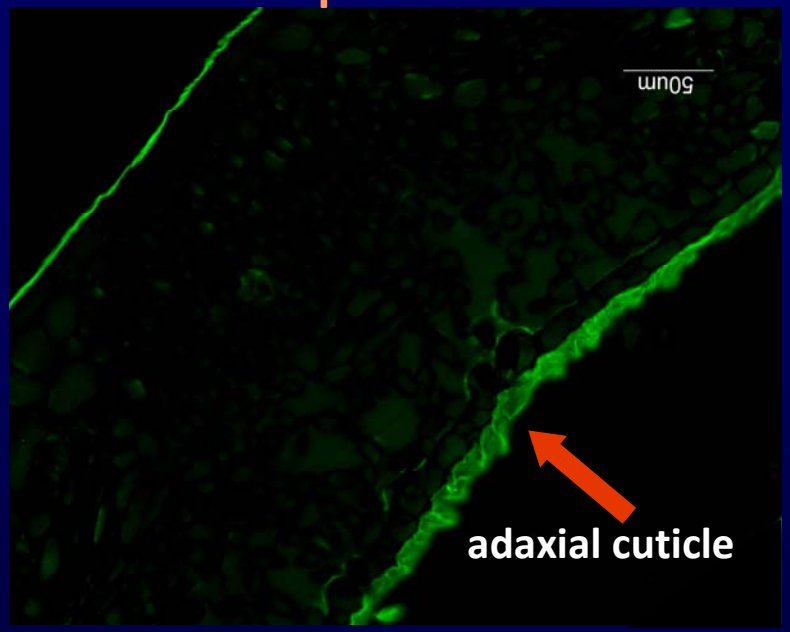


Peach leaf stomata (- Fe)

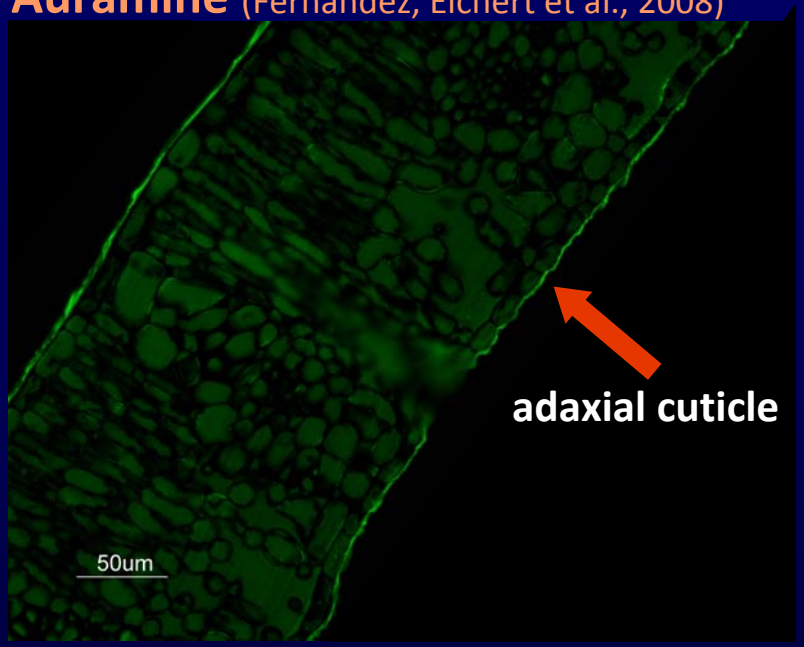
Length decreased

2. Theoretical background: Effect of nutrient deficiencies on leaf structure

Cross-section of pear leaf stained with Auramine (Fernández, Eichert et al., 2008)



Fe-sufficient



Fe-deficient

	Cuticle weight (µg cm^{-2})	
Leaf surface	Fe-sufficient	Fe-deficient
abaxial	513.6 ± 20.8 ***	332.9 ± 21.2***

3. Effect of foliar sprays on mineral status

- Foliar fertilisers applied (in general):
  - To avoid occurrance of deficiencies
  - To correct / control deficiencies
- Common ingredients: micronutrients, Ca, K, N, Mg
- Many factors rule success:

  dropplet size, environmental conditions, plant physiology, physical-chemistry of solutions,...

Assuming penetration took place, the plant must:

- Adjust to new nutrient balance

- Maybe overcome new stress situation (specially Micronutrients; Sanz, 2008; person, comm.)

3. Effect of foliar sprays on mineral status

- **e.g. 1** (extreme case):
  - 35% $ZnSO_4$ applications to fruit trees in California to avoid Zn deficiency (peach & nectarine; Castagnoli et al., 1990) ⟹
    - premature defoliation
    - limited N use efficiency
    - limited N remmobilisation

3. Effect of foliar sprays on mineral status. e.g. 2

- e.g. 2. 1% $CaCl_2$ treatment to apple trees in Spain (Val et al., 2008):

	Ca spray programmes			
	Control	May and June	July and August	May to August
	(0 spray)	(2 sprays)	(2 sprays)	(4 sprays)
Macroelements (% DW)				
Ca	1.90 a	2.41 b	2.18 ab	2.46 b
N	2.78 a	2.66 ab	2.75 a	2.56 b
P	0.18 a	0.16 b	0.20 c	0.16 a
K	1.19 ab	1.05 a	1.31 b	1.12 a
Mg	0.33	0.34	0.34	0.32
Microelements (mg kg $^{-1}$ DW)				
Fe	121.9	121.4	114.0	130.3
Mn	42.8	43.3	40.6	44.2
Cu	7.51	7.62	8.09	7.52
Zn	12.2	11.3	12.6	10.6

All elements at normal range (Westwood, 1978)

Leaf tissue element concentrations after $CaCl_2$ sprays (Jul. Smoothee Golden Delicious; 0.05% Tween 20)

3. Effect of foliar sprays on mineral status. e.g. 2

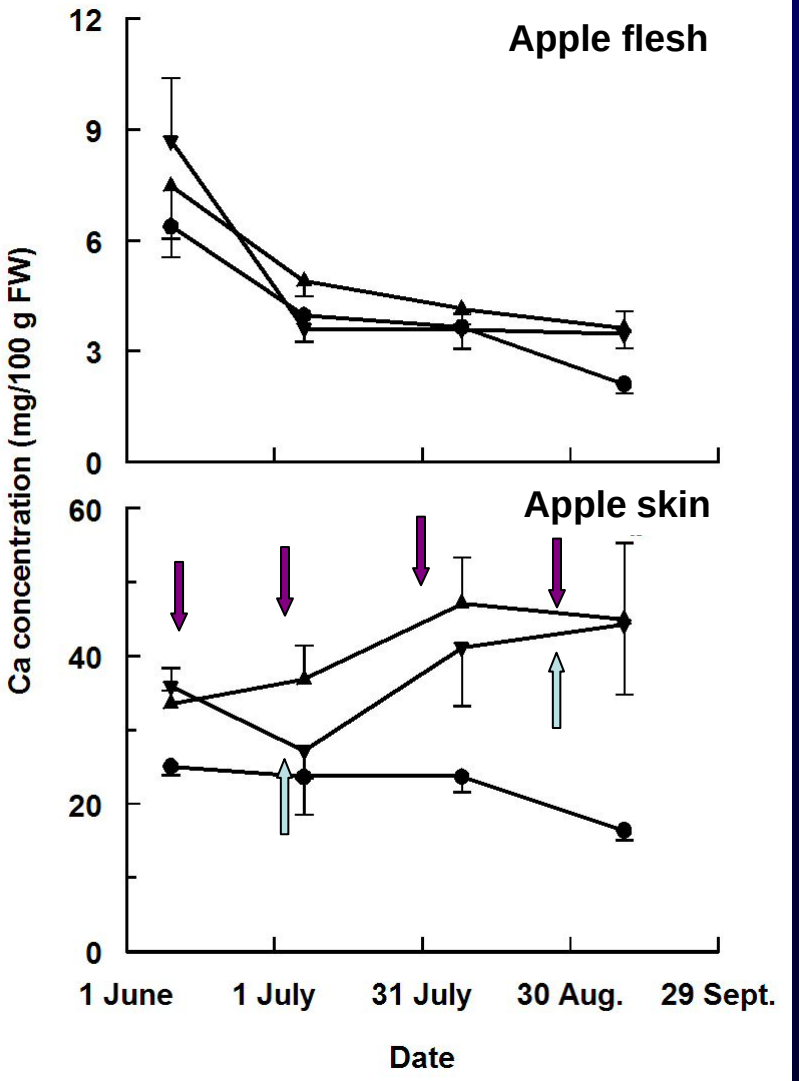
- e.g.2: Foliar treatment with 1% $CaCl_2$ to apple trees in Spain (Val et al., 2008):

	Ca spray programmes			
	Control	May and June	July and August	May to August
	(0 spray)	(2 sprays)	(2 sprays)	(4 sprays)
Macroelements (% DW)				
Ca	1.90 a	2.41 b	2.18 ab	2.46 b
N	2.78 a	2.66 ab	2.75 a	2.56 b
P	0.18 a	0.16 b	0.20 c	0.16 a
K	1.19 ab	1.05 a	1.31 b	1.12 a
Mg	0.33	0.34	0.34	0.32
Microelements (mg kg $^{-1}$ DW)				
Fe	121.9	121.4	114.0	130.3
Mn	42.8	43.3	40.6	44.2
Cu	7.51	7.62	8.09	7.52
Zn	12.2	11.3	12.6	10.6

- Ca sprays ⇒ leaf Ca ↑
- No major ≠ other elelements

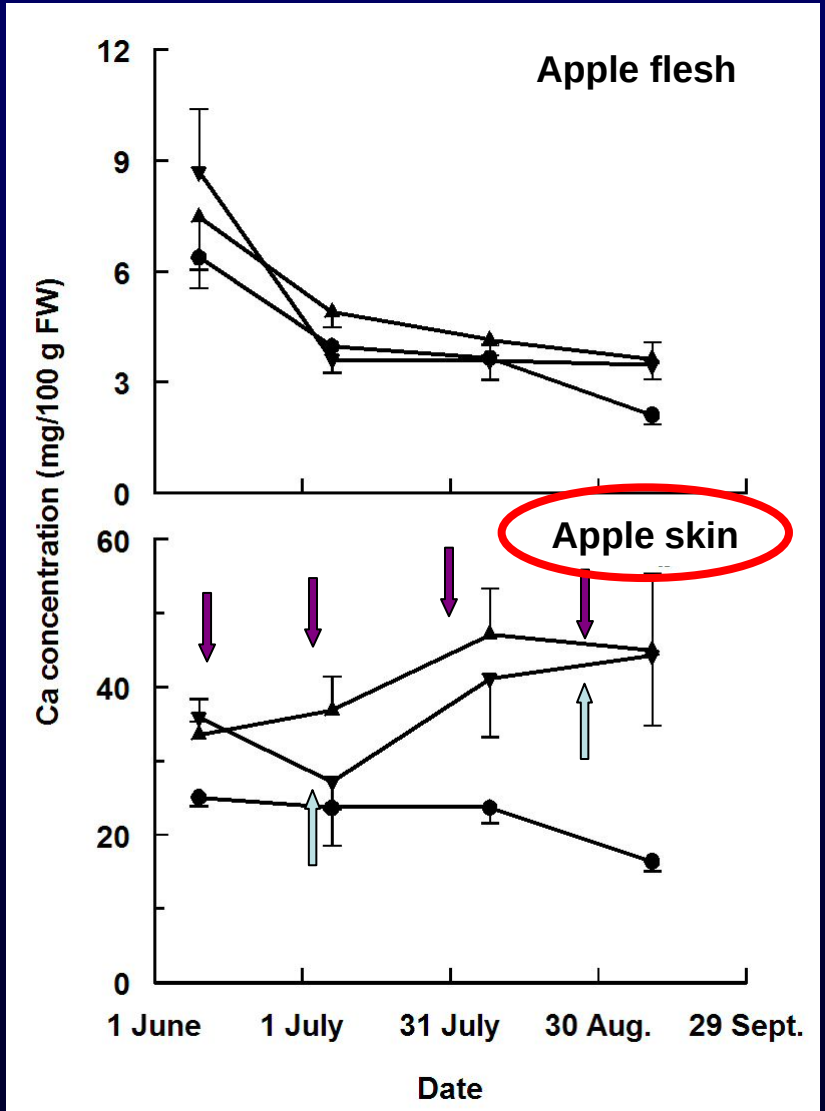
Leaf tissue element concentrations after 1% $CaCl_2$ sprays (Jul. Smoothee Golden Delicious, 0.05% Tween 20)

e.g. 2. [Ca] in skin & flesh of Smoothee Golden Delicious apples after 1% $CaCl_2$ + 0.05% Tween 20 sprays (Val et al., 2008)



- Sprayed 4 times from Jun - Aug
- Sprayed on 30 June and on 29 August
- Untreated

e.g. 2. [Ca] in skin & flesh of Smoothee Golden Delicious apples after 1% $CaCl_2$ + 0.05% Tween 20 sprays (Val et al., 2008)



▲ Sprayed 4 times from Jun - Aug

▼ Sprayed on 30 June and on 29 August

● Untreated

- Significant Ca ↑ only in apple skin (carefully scrubbed, 0.1 % deterg.)
- No major [mineral element] changes

3. Effect of foliar sprays on mineral status. e.g. 3

- e.g. 3. Foliar sprays of $MgSO_4$ (EpsoTop, K+S Kali) plus 0.1% Texapon applied to peach leaves in Spain

Treatment	Peach leaf tissue element concentration after 1 month							
	Macronutrients (%)				Micronutrients (ppm)			
	P	Ca	Mg	K	Fe	Mn	Cu	Zn
Non-treated	0.25	1.95	0.60	3.03	121.98	26.12	9.15	22.43
1% EPSOTop	0.22	4.38	0.79	2.10	143.88	25.52	8.92	21.28
2% EPSOTop	0.22	4.15	0.72	2.11	135.59	23.49	11.35	19.68
3% EPSOTop	0.20	4.30	0.78	1.94	159.98	28.62	12.04	25.09

3. Effect of foliar sprays on mineral status. e.g. 3

$MgSO_4$ (EpsoTop) ⇒ ↑ Mg

Treatment	Peach leaf tissue element concentration after 1 month							
	Macronutrients (%)				Micronutrients (ppm)			
	P	Ca	Mg	K	Fe	Mn	Cu	Zn
Non-treated	0.25	1.95	0.60	3.03	121.98	26.12	9.15	22.43
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$MgSO_4 \Rightarrow \uparrow Mg; \uparrow Ca;$

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3. Effect of foliar sprays on mineral status. e.g. 3

$MgSO_4 \Rightarrow \uparrow Mg; \uparrow Ca; \downarrow K$

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3. Effect of foliar sprays on mineral status

- e.g. 4. Values chlorotic vs. green peach leaves. Alkaline soils, Spain (Belkhodja et al. 1998; Sanz & Montañés, 1993)

	% DW						mg Kg $^{-1}$ DW		
	N	P	Ca	Mg	K	Fe	Mn	Cu	Zn
Green leaves	3,4	0,15	2,41	0,9	2,44	150	20	15	18
Chlorotic leaves	3,47	0,236	2,77	0,523	3	89,24	60,349	24,73	24,49

Chlorotic leaves { Lower than usual: Fe, Mg

3. Effect of foliar sprays on mineral status. e.g. 4

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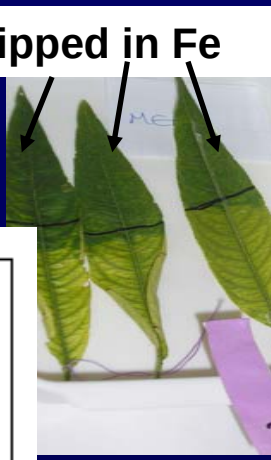
	% DW						mg Kg $^{-1}$ DW		
	N	P	Ca	Mg	K	Fe	Mn	Cu	Zn
Green leaves	3,4	0,15	2,41	0,9	2,44	150	20	15	18
Chlorotic leaves	3,47	0,236	2,77	0,523	3	89,24	60,349	24,73	24,49

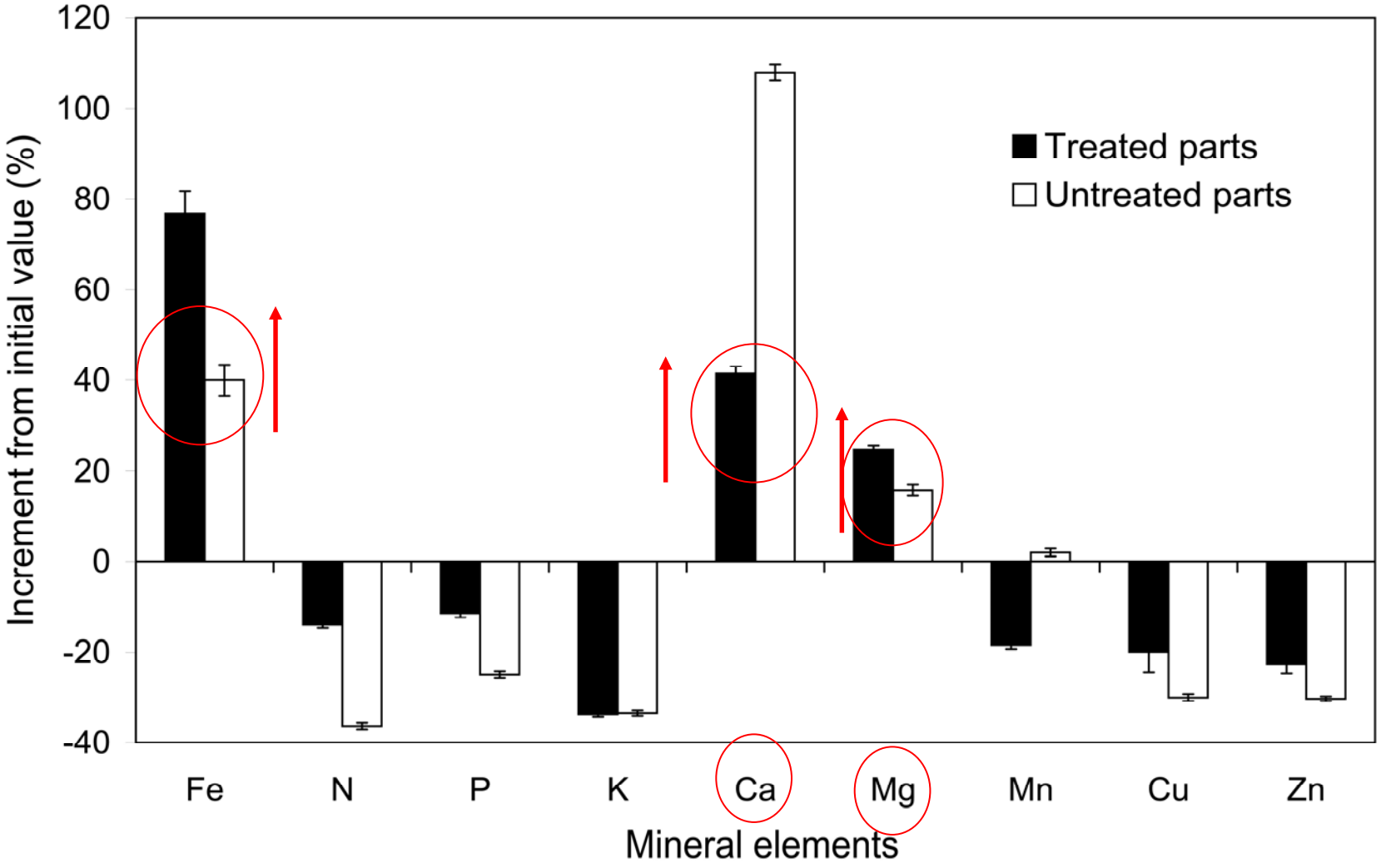
Chlorotic leaves
- Lower than usual: Fe, Mg
- Higher than usual: K, P, Micro-nutrients

4. Effect of foliar sprays on mineral status. e.g. 4

- e.g. 4. 2 mM Fe application to chlorotic peach leaves

(Fernández et al., 2008b)

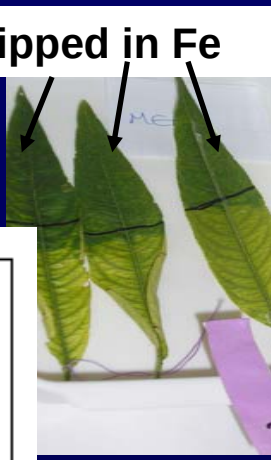


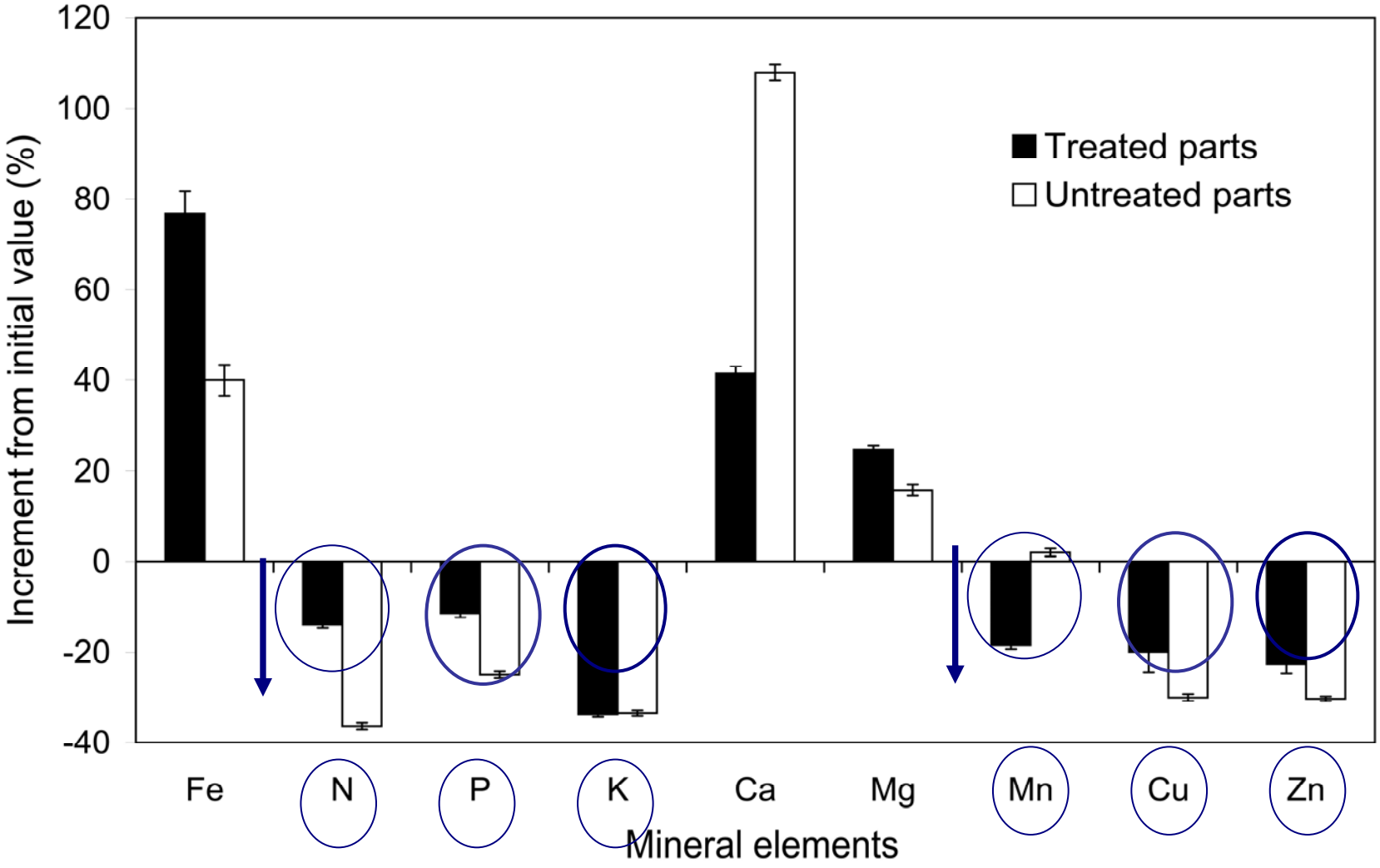


3. Effect of foliar sprays on mineral status. e.g. 4

- e.g. 4. 2 mM Fe application to Fe-chlorotic peach leaves

(Fernández et al., 2008b)





3. Effect of foliar sprays on mineral status. e.g. 5

- e.g. 5. 2% Epso- sprays in combination with 0.1% $FeSO_4$ (plus 0.1% Texapon) applied to chlorotic peach leaves (Spain)

Epso-Top

16 % MgO	water-soluble magnesium oxide	(= 9 % Mg)
32 % SO_3	water-soluble sulphur trioxide	(= 13 % S)

Epso-Microtop

15 % MgO	water-soluble magnesium oxide	(= 9 % Mg)
31 % SO_3	water-soluble sulphur trioxide	(= 12 % S)
1 % **B**	water-soluble boron	
1 % **Mn**	water-soluble manganese	

Epso-Combitop

13 % MgO	water-soluble magnesium oxide	(= 8 % Mg)
33 % SO_3	water-soluble sulphur trioxide	(= 13 % S)
4 % **Mn**	water-soluble manganese	
1 % **Zn**	water soluble zinc	

3. Effect of foliar sprays on mineral status. e.g. 5

- e.g. 5. 2% Epso- sprays in combination with 0.1% $FeSO_4$ (plus 0.1% Texapon) applied to chlorotic peach leaves in Spain

2% $MgSO_4 \Rightarrow \uparrow$ Mg

Treatment	[leaf mineral element] after 1 month							
	P (%)	Ca (%)	Mg b(%)	K (%)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)
Non-treated	0.25	1.95	0.60	3.03	121.98	26.12	9.15	22.43
EPSOTop	0.16	5.41	0.85	1.71	257.59	58.44	9.19	14.24
Combitop	0.16	5.59	0.97	2.02	241.57	231.0	9.94	47.40
Microtop	0.19	4.31	0.82	2.77	220.05	114.29	10.90	16.72

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2% $MgSO_4$ + 0.1% Fe $\Rightarrow$ ↑ Mg; ↑ Fe; ↑ Ca

Treatment	[leaf mineral element] after 1 month							
	P (%)	Ca (%)	Mg b(%)	K (%)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)
Non-treated	0.25	1.95	0.60	3.03	121.98	26.12	9.15	22.43
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2% $MgSO_4$ + Fe ⇒ ↑ Mg; ↑ Ca; ↑ Fe

Micro-Top: 1% Mn - Combi-Top: 4% Mn + 1% Zn

Treatment	[leaf mineral element] after 1 month							
	P (%)	Ca (%)	Mg b(%)	K (%)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)
Non-treated	0.25	1.95	0.60	3.03	121.98	26.12	9.15	22.43
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- e.g. 5. 2% Epso- sprays in combination with 0.1% $FeSO_4$ (plus 0.1% Texapon) applied to chlorotic peach leaves (Spain)

2% $MgSO_4$ + 0.1% Fe ⇒ ↓ K; ↓ P; ↓ Zn

Treatment	[leaf mineral element] after 1 month							
	P (%)	Ca (%)	Mg b(%)	K (%)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)
Non-treated	0.25	1.95	0.60	3.03	121.98	26.12	9.15	22.43
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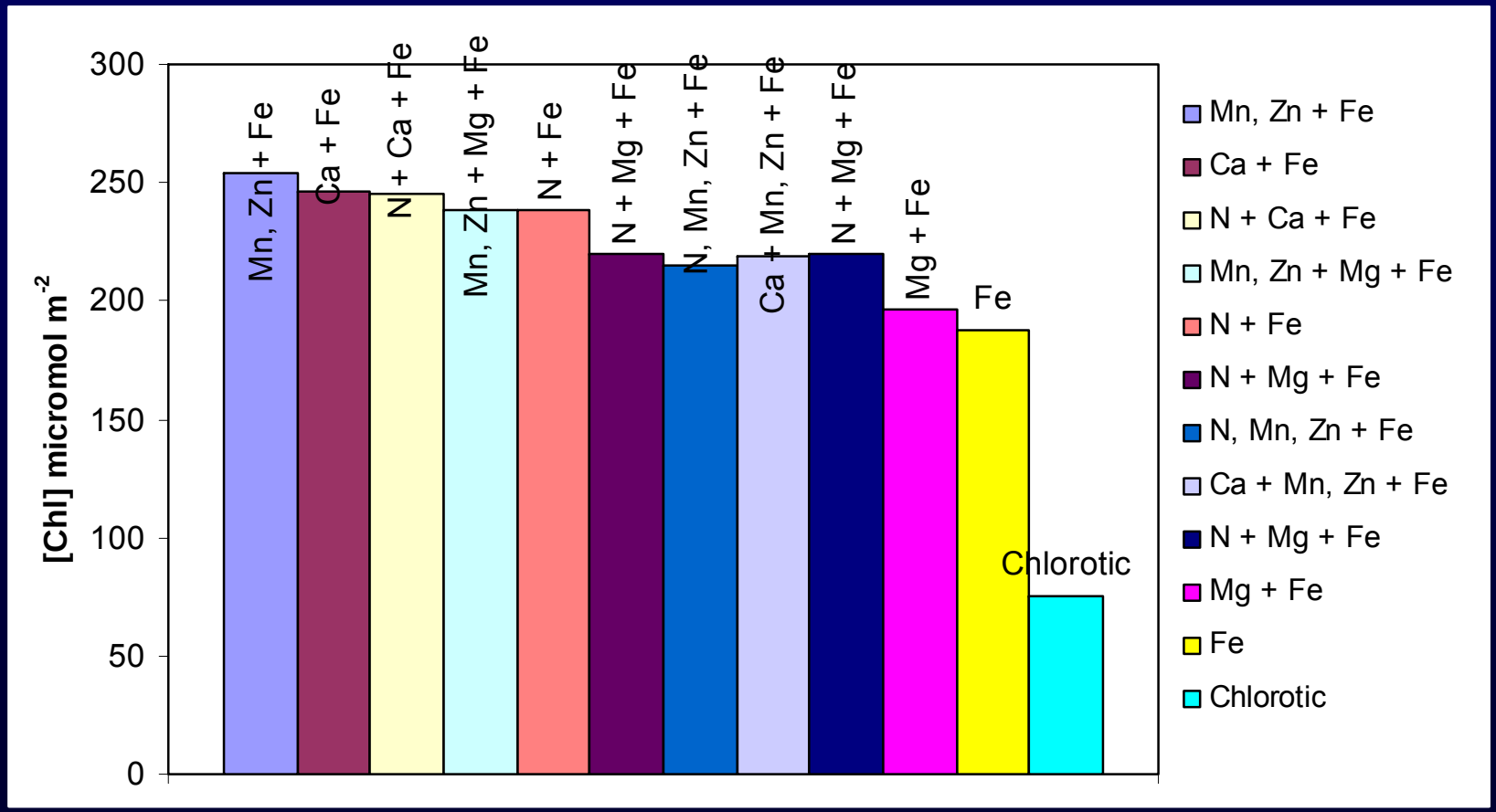
3. Effect of foliar sprays on mineral status. e.g. 6

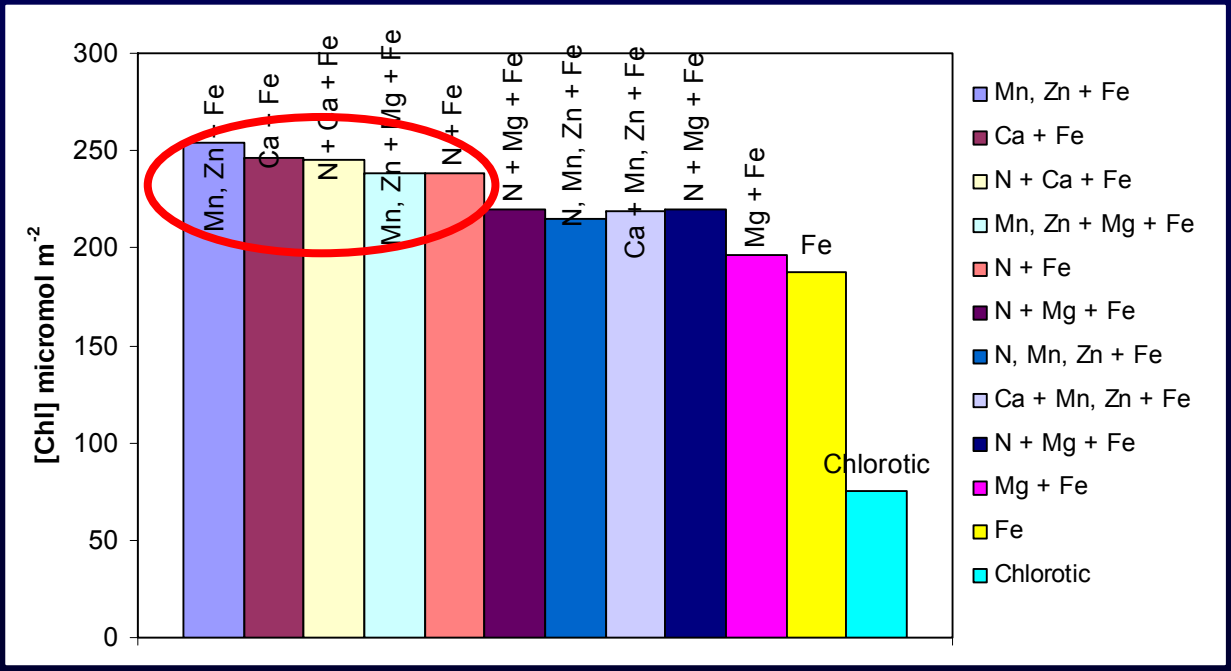
- e.g. 6. Treatment with ***multi-element*** (N, Ca, Mg, Zn-Mn) + **Fe** sprays to Fe-chlorotic leaves



[Chl] of chlorotic peach leaves 1 month after treatment with foliar sprays

3. Effect of foliar sprays on mineral status. e.g. 6

- **e.g. 6.** Treatment with multi-element (N, Ca, Mg, Zn-Mn) + Fe sprays to Fe-chlorotic leaves
  - Improved effect of Fe-sprays via addition of:
    - N, Mn-Zn, Ca
    - Also beneficial effect of Mg
  - No Fe ⇒ no re-greening



[Chl] of chlorotic peach leaves 1 month after treatment with foliar sprays

3. Effect of foliar sprays on mineral status. e.g. 6

- **e.g. 6.** Treatment with multi-element (N, Ca, Mg, Zn-Mn) + Fe sprays to Fe-chlorotic leaves
  - Potential mechanisms involved on improving effect of Fe sprays:

a) Urea, $MnSO_4$-$ZnSO_4$, $CaCl_2$ (to a lower extent $MgSO_4$) increase $FeSO_4$ foliar penetration rates via, e.g.:

⇒ lowering salt deposit POD (humectants), synergism,…

b) Fe-chlorosis ⇒ nutrient imbalance / { ↑ (K, Mn, Zn, P); ↓ (Mg, Fe)

- Adding Fe sprays (Fernández et al., 2008b) ⇒ ↓ (K, Mn-Zn, P, Mg)
- Adding Fe sprays + N, Ca, Mg, Zn-Mn ⇒
  - may help plant reach nutrient balance
  - improve Fe bioavailability (uptake & distribution)

4. Conclusions

Nutrient deficiencies ⇒

- Cause imbalances on mineral status
- Element deficient if present, maybe at [low] or not available (e.g., Fe-chlorosis)

Foliar sprays ⇒

- Immediate availability of nutrients and rapid response (Weinbaum, 1996)
- Increase concentration of the applied nutrient
- May lead to mineral element readjustments in the plant (e.g., nutritional status of Fe-deficient leaves as shown)

4. Conclusions

For better performance of element sprays (e.g., Fe or micronutrients):

- assess **consecuences** of rising concentration of **applied element**
- maybe **supply** simultaneously or complementary some **key elements** to help plant reach appropriate balance
  - e.g. 6: improved preformance of Fe-sprays containing N, Mn-Zn, Ca & Mg

- Search fo fertiliser management strategies to benefit from foliar fertilisation (multiple treatments, appropriate timing, etc.)
- More multidisciplinary research required to e.g., understand nutrient relationships, foliar penetration principles, distribution and uptake etc...

Thank you very much for your attention!!!

Vielen dank für Ihre Aufmerksamkeit!!!

Muchas gracias por su atención!!!