Calcium in Soil and Plant

Klaus Blankenau, PhD
Research Centre Hanninghof, Germany
Yara International

Apresentador: João Maçãs, Engº Agrº - Mestrando em Ciência do Solo – UFRGS
Desenvolvimento de Mercados - Premium Offerings, Porto Alegre/RS
Yara Brasil

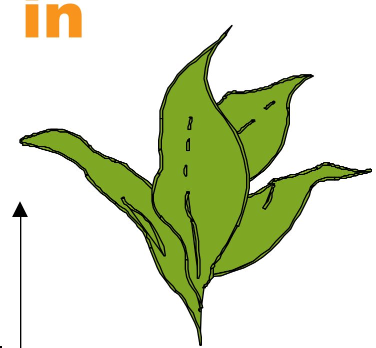
Calcium in Soil and Plant

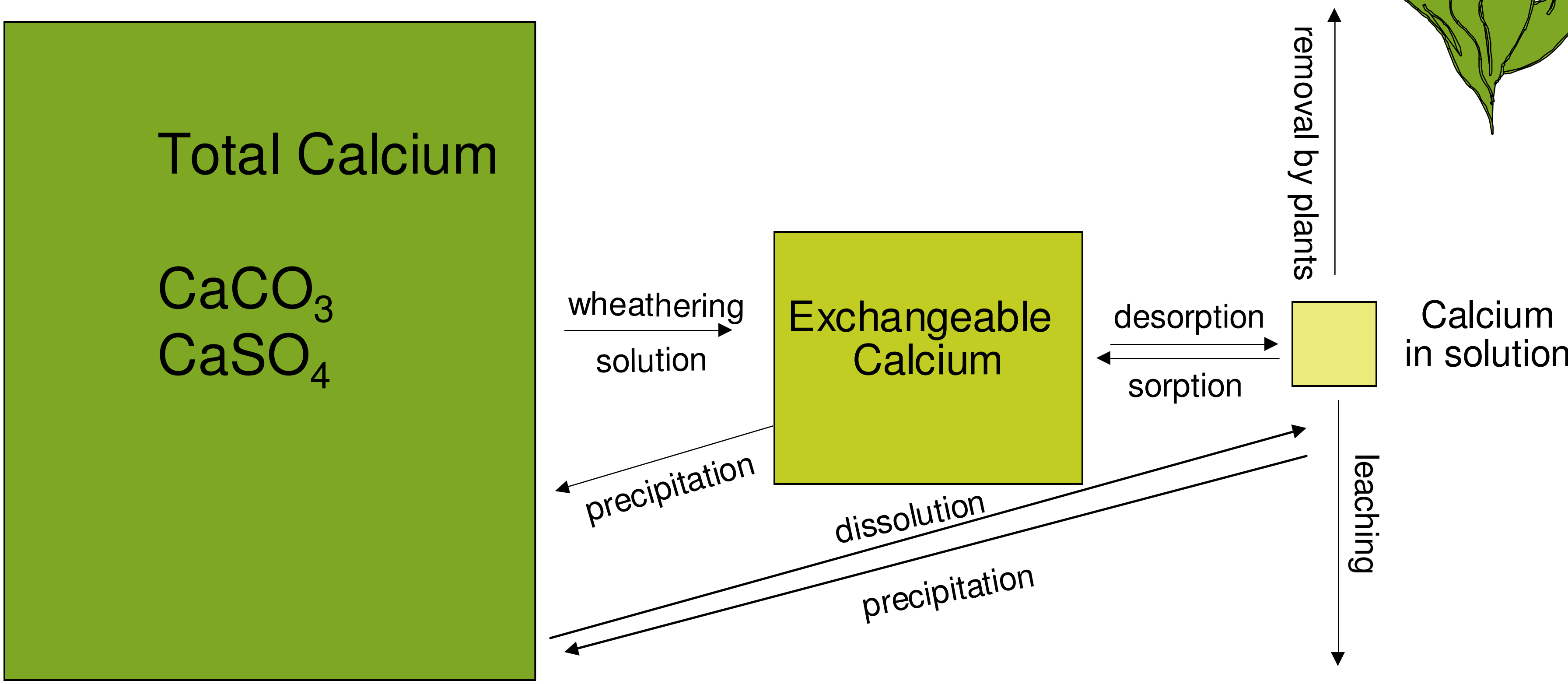
- Part 1: Background and basic facts
  - Calcium in soil
  - Calcium and plant
- Part 2: Strategies to supply Calcium to the plant

Calcium in Soil and Plant

- Part 1: Background and basic facts
  - **Calcium in soil**
  - Calcium and plant
- Part 2: Strategies to supply Calcium to the plant

Only a small part of the total soil Ca is in solution and plant available





4 000 – 55 000 kg Ca/ha (0-30 cm)

20 – 100 kg Ca/ha (0-30 cm)

Examples from Europe

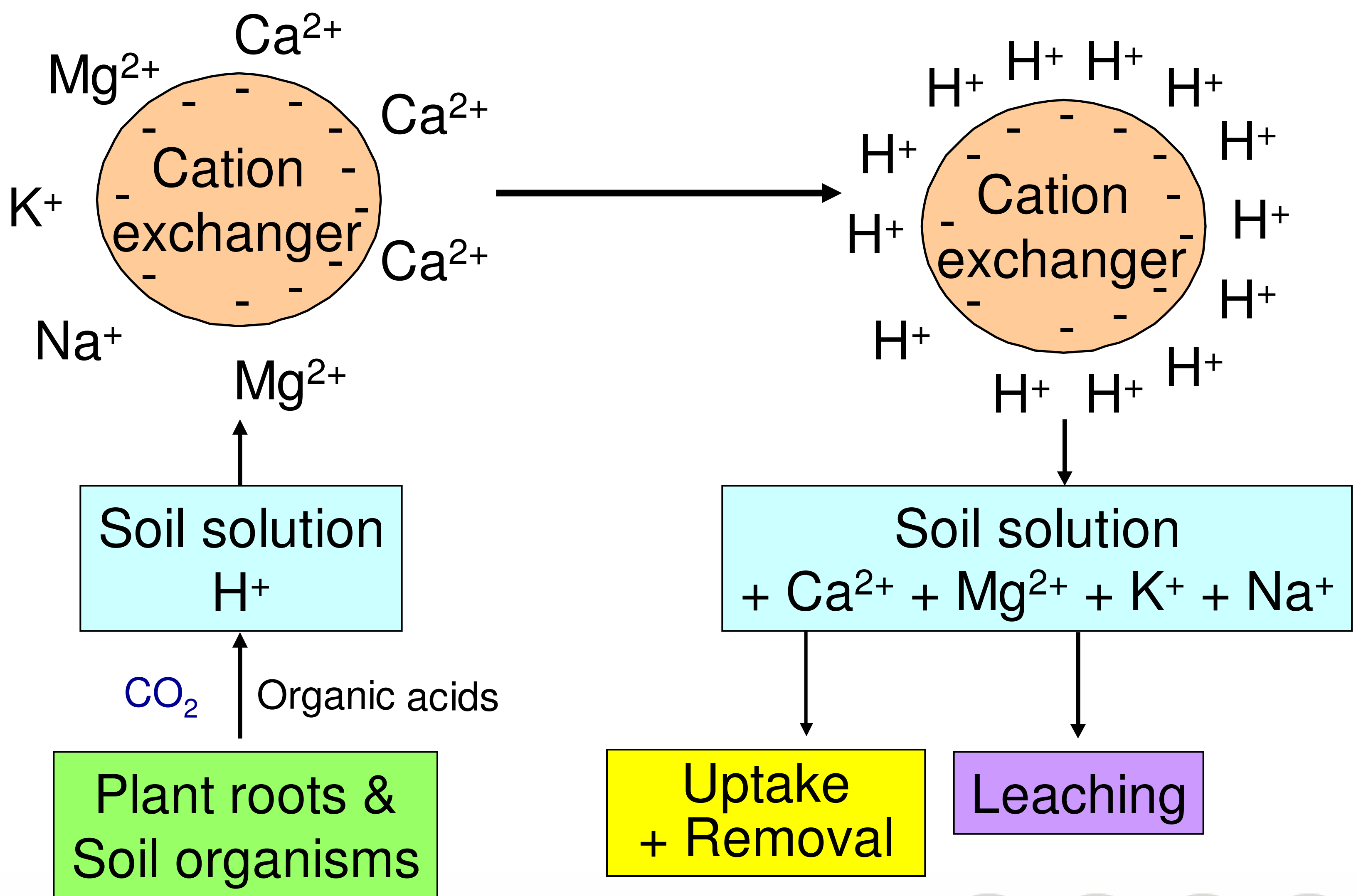
Ca export from 1 ha per year (exp. Europe)

Ca removal by crops	5 to 150 kg Cereals 20 kg/ha Sugar beet 85 kg/ha
Ca leaching	30 to 300 kg
Range of total Ca export	35 to 450 kg

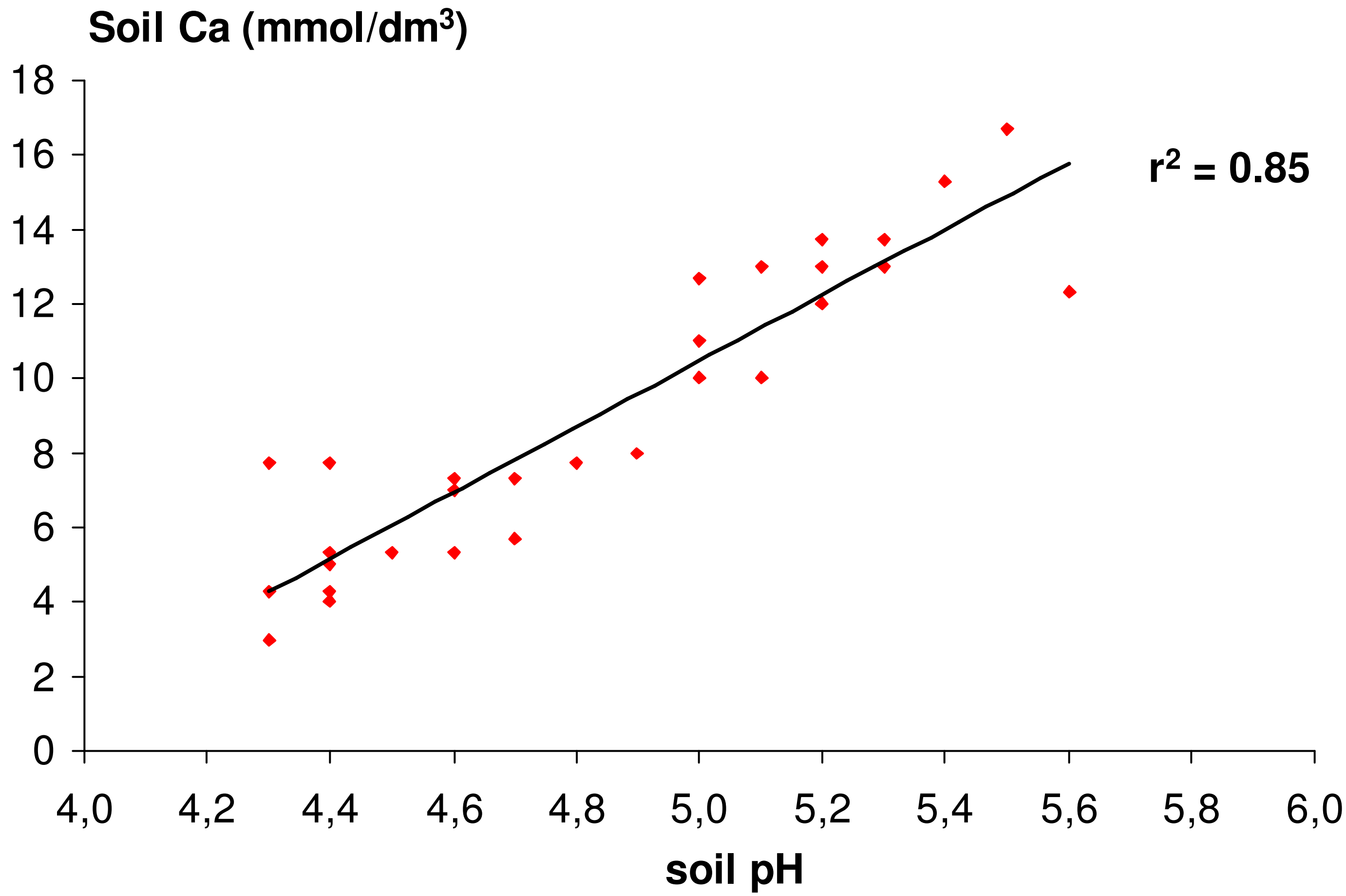
The Ca import with precipitation (rainfall, dew, ..) is only 3 - 20 kg Ca/ha.

Continuous Ca supply is necessary

Plant growth, Ca uptake and Ca leaching leads to soil acidification



The higher the soil pH the more Ca in the soil



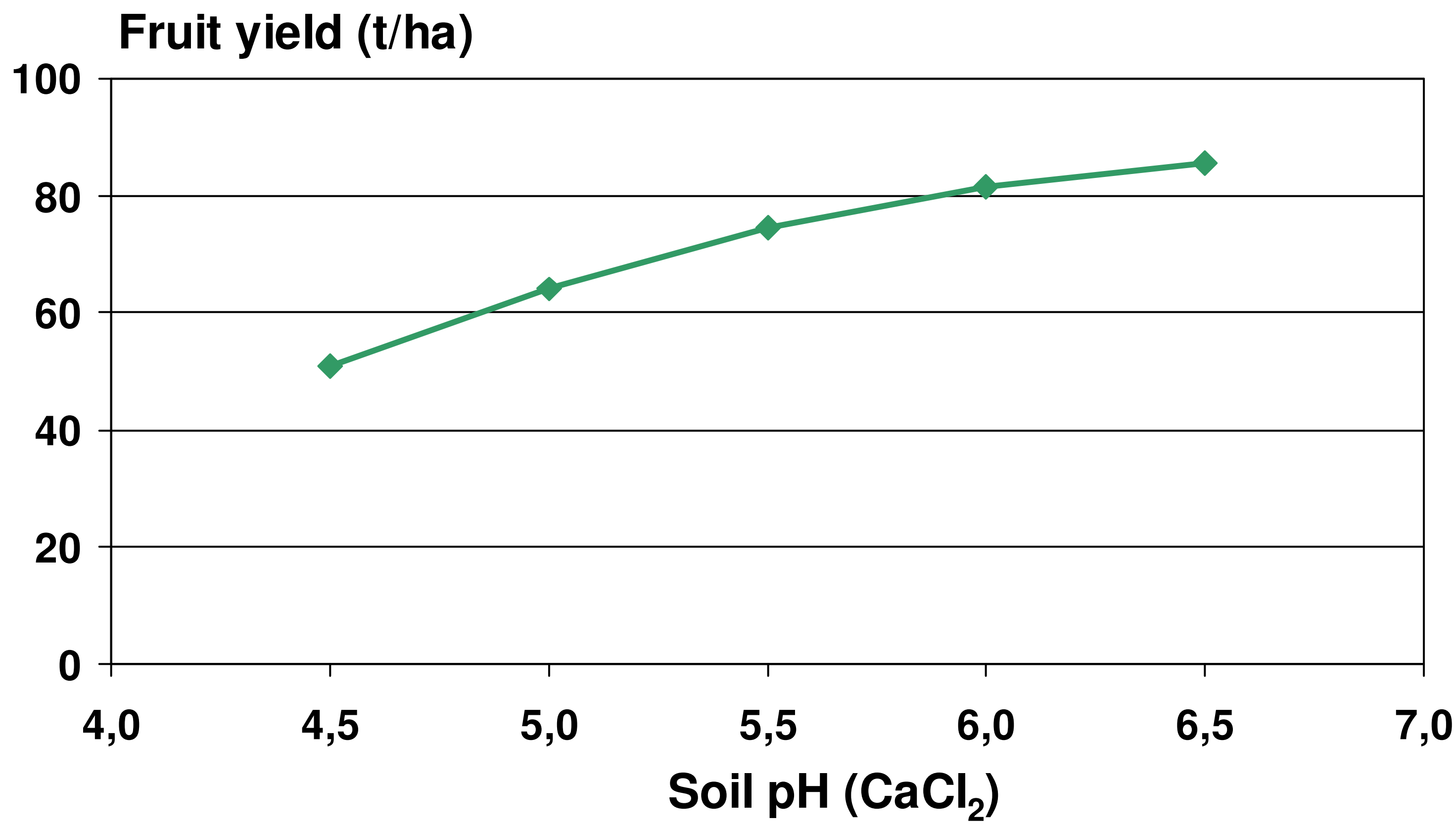
Source: Citrus orchard, Brazil (2006, unpublished)

Ca deficiency is often found on acid soils with < 0.1 to 5 mg Ca/l. - *Acid soils in the world*

	Area (million ha)	*(%)*
America	1,616	40.9
Asia	1,044	26.4
Africa	659	16.7
Europe	391	9.9
Australia and New Zealand	239	6.1
Total	3,950	100.0

Liming increases soil pH and Yield

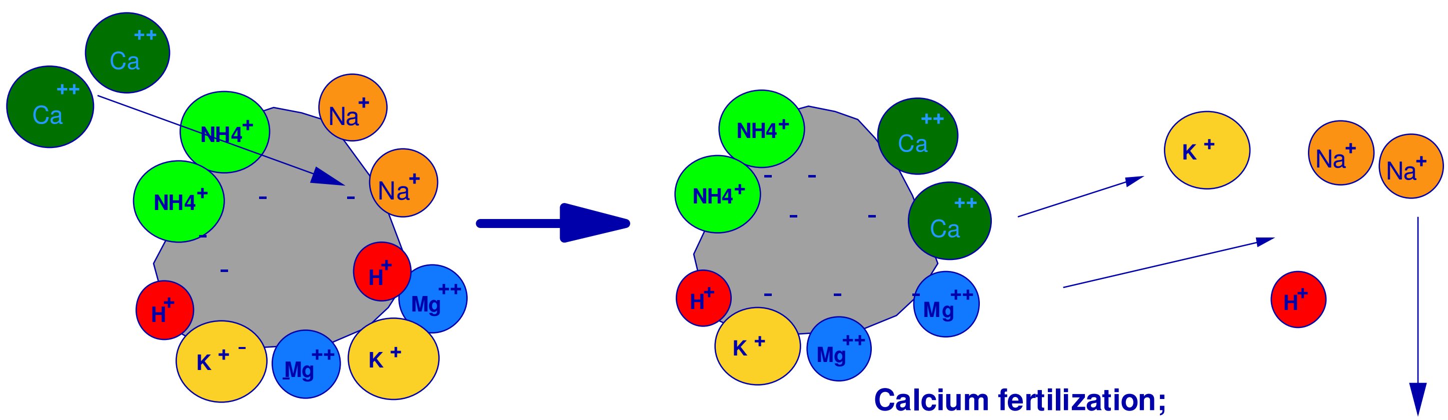
Example Oranges, cv Pera – Brazil



REF: Mattos Junior (2000)

Calcium Improves Soil Structure

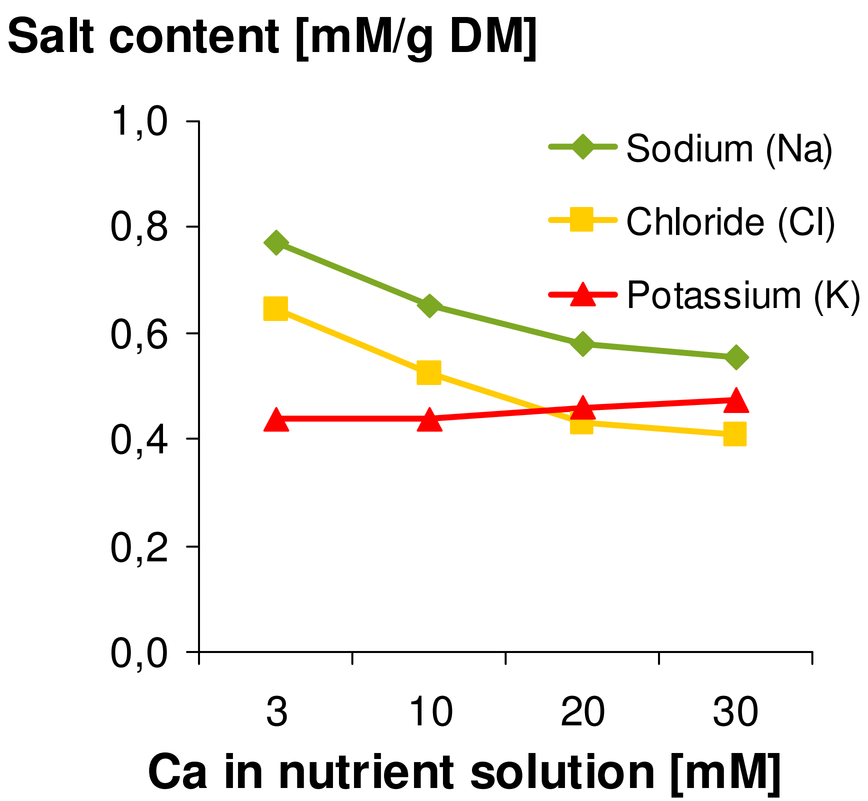
- Calcium displaces soil adsorbed Sodium and therefore improves:
  - soil structure
  - Permeability
  - Infiltration

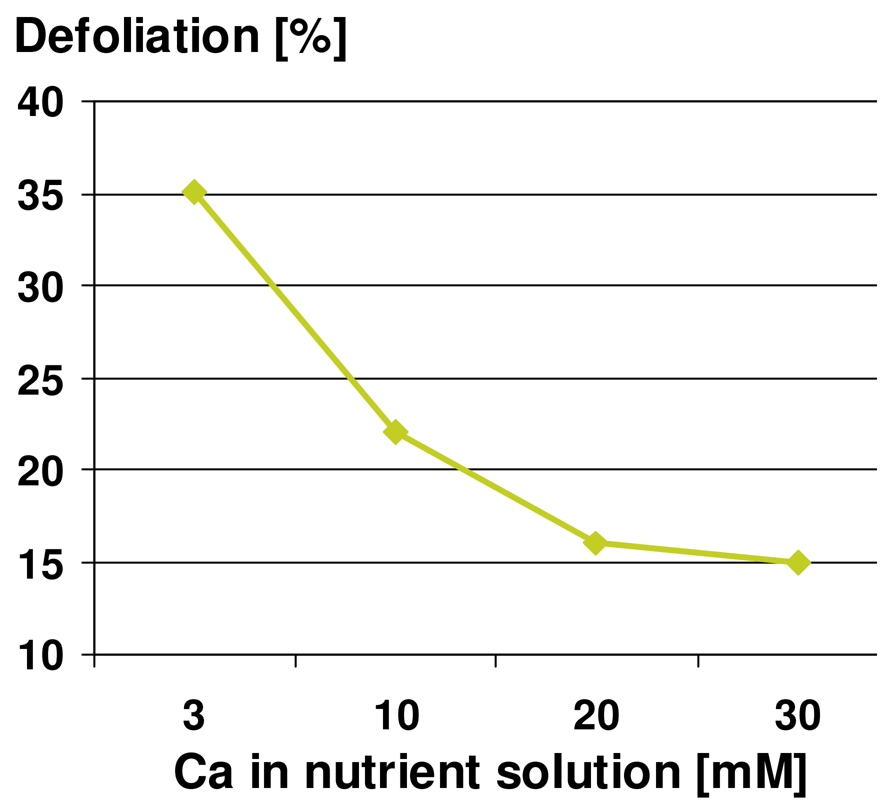


Calcium fertilization;
In saline soils more sodium can be leached
Additional benefit;
potassium becomes more available in soil solution

Ca helps the plant to cope with salinity stress

Navel orange on salinity tolerant rootstock ‘Cleopatra Mandarin’

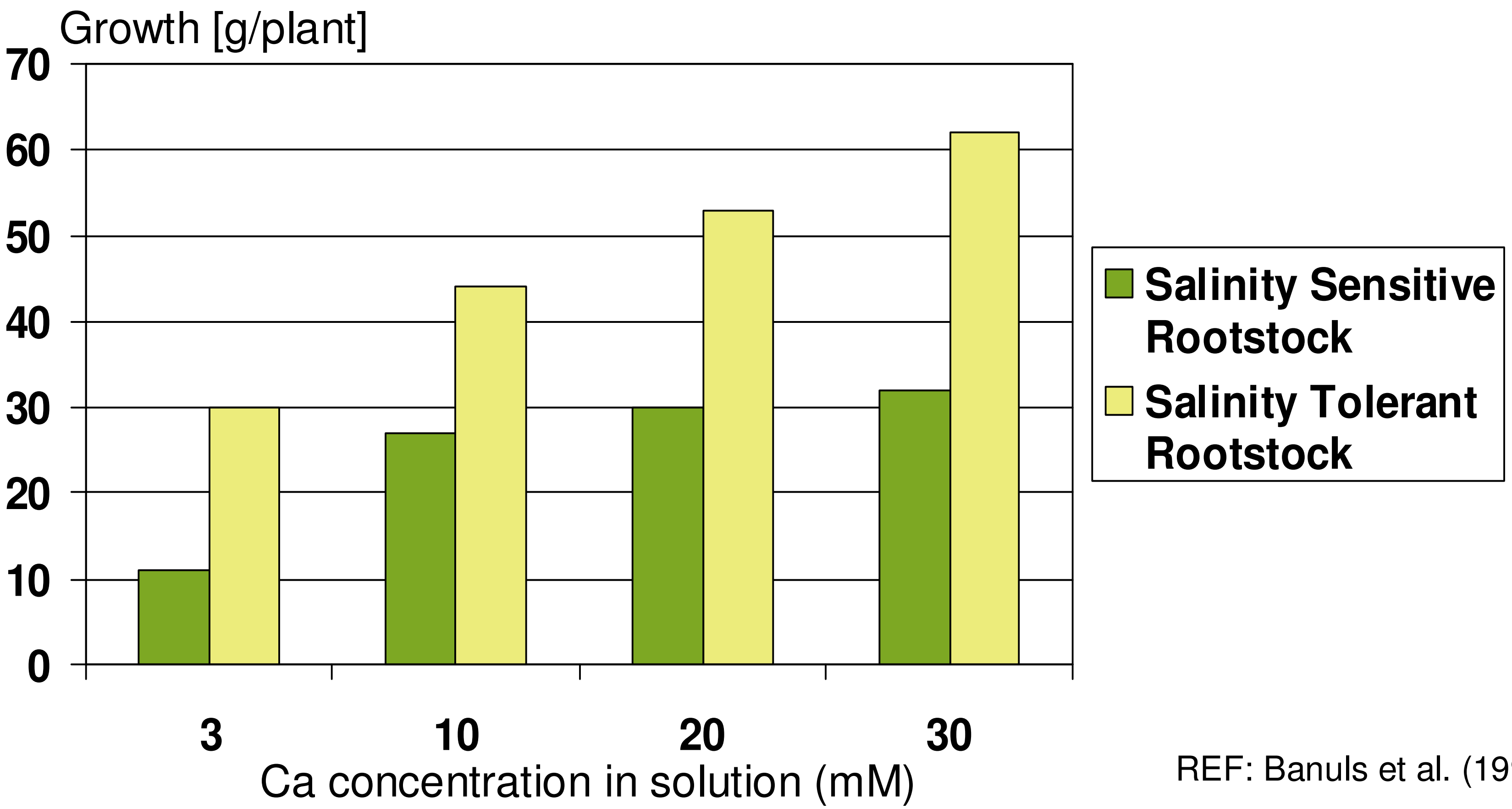




REF: Banuls et al. (1991)

Ca helps the plant to cope with salinity stress

Navel orange
- on salinity tolerant rootstock 'Cleopatra Mandarin'
- or on salinity sensitive 'Troyer citrange'

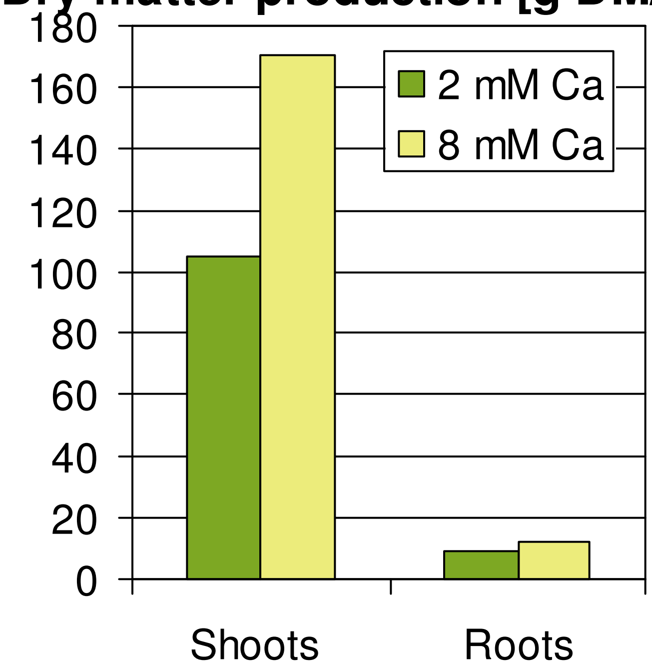


REF: Banuls et al. (1991)

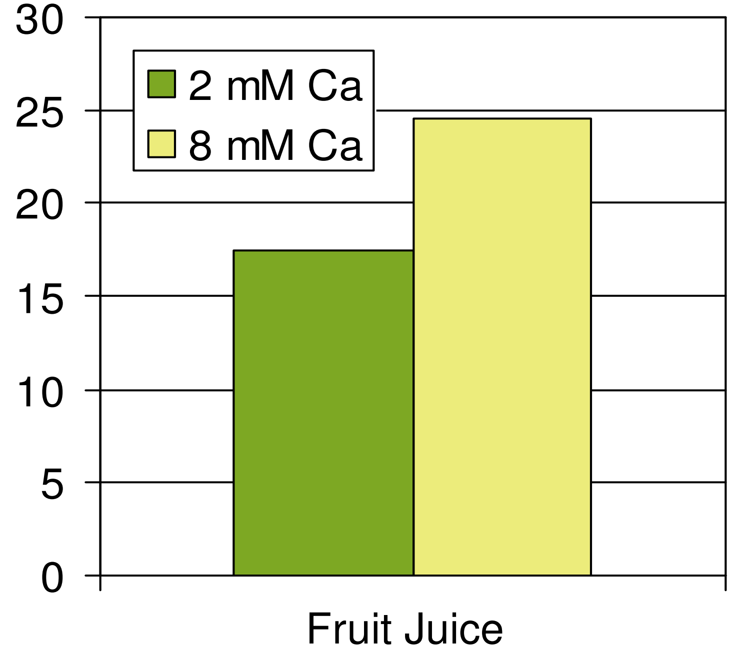
Ca helps the plant to cope with salinity stress

Galia, Muskmelon; Nutrient solution containing 80 mM NaCl

Dry matter production [g DM/pot]

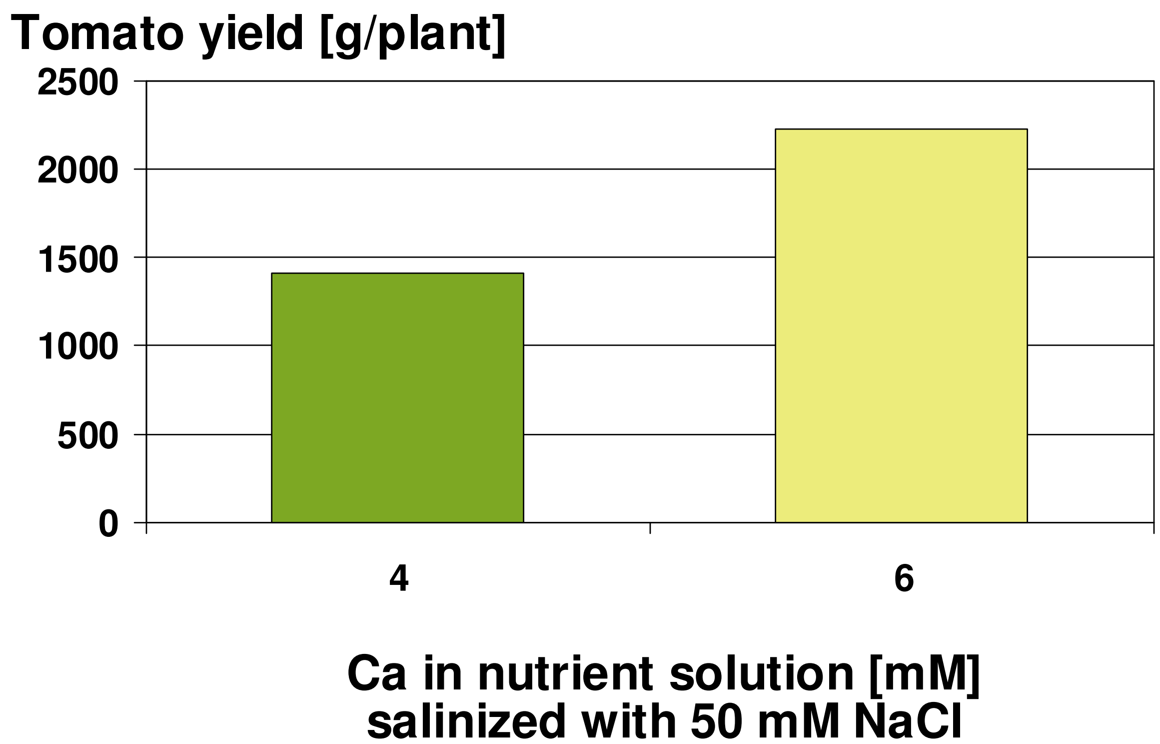


Sucrose [g/l]



REF: Navarro et al. (1999)

Ca helps the plant to cope with salinity stress



REF: Soria (2002)

Induced Ca deficiency due to antagonism

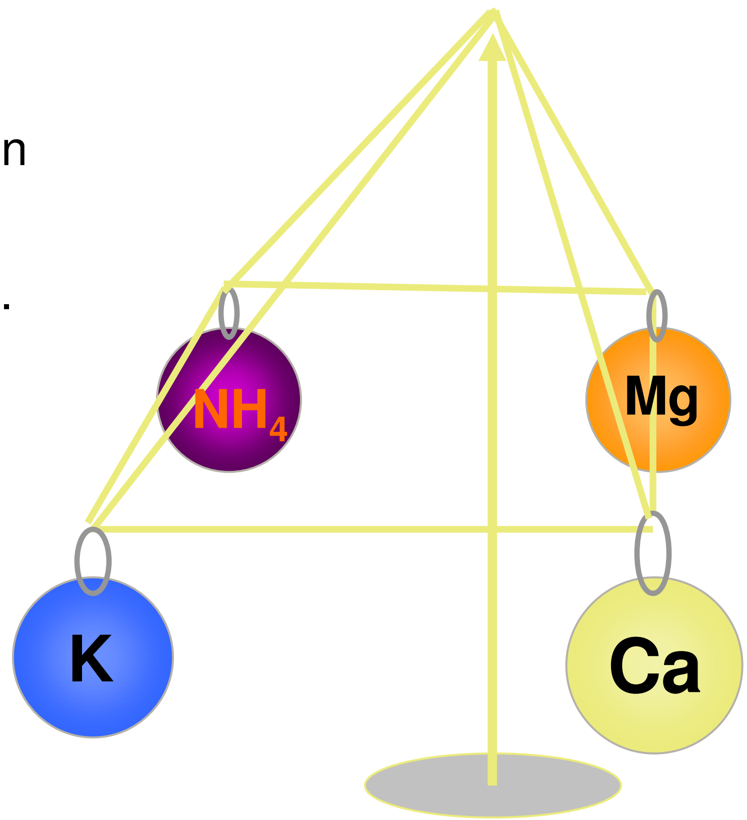
- In terms of plant uptake, Ca is in competition with other major cations such as Na^{+}, K^{+}, Mg^{2+}, NH^{4+}, Fe^{2+} and Al^{3+}.

- Therefore Ca uptake is depressed when

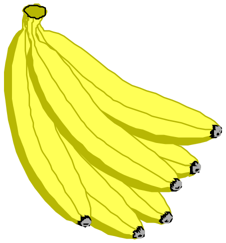
➔ Ca:K or Ca:Mg ratios are not optimum.

➔ High amount of ammonium are applied.

➔ In acid soils with free Al.



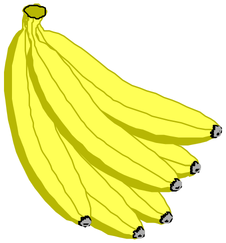
There are optimum soil Ca, K & Mg ratios
Example Banana



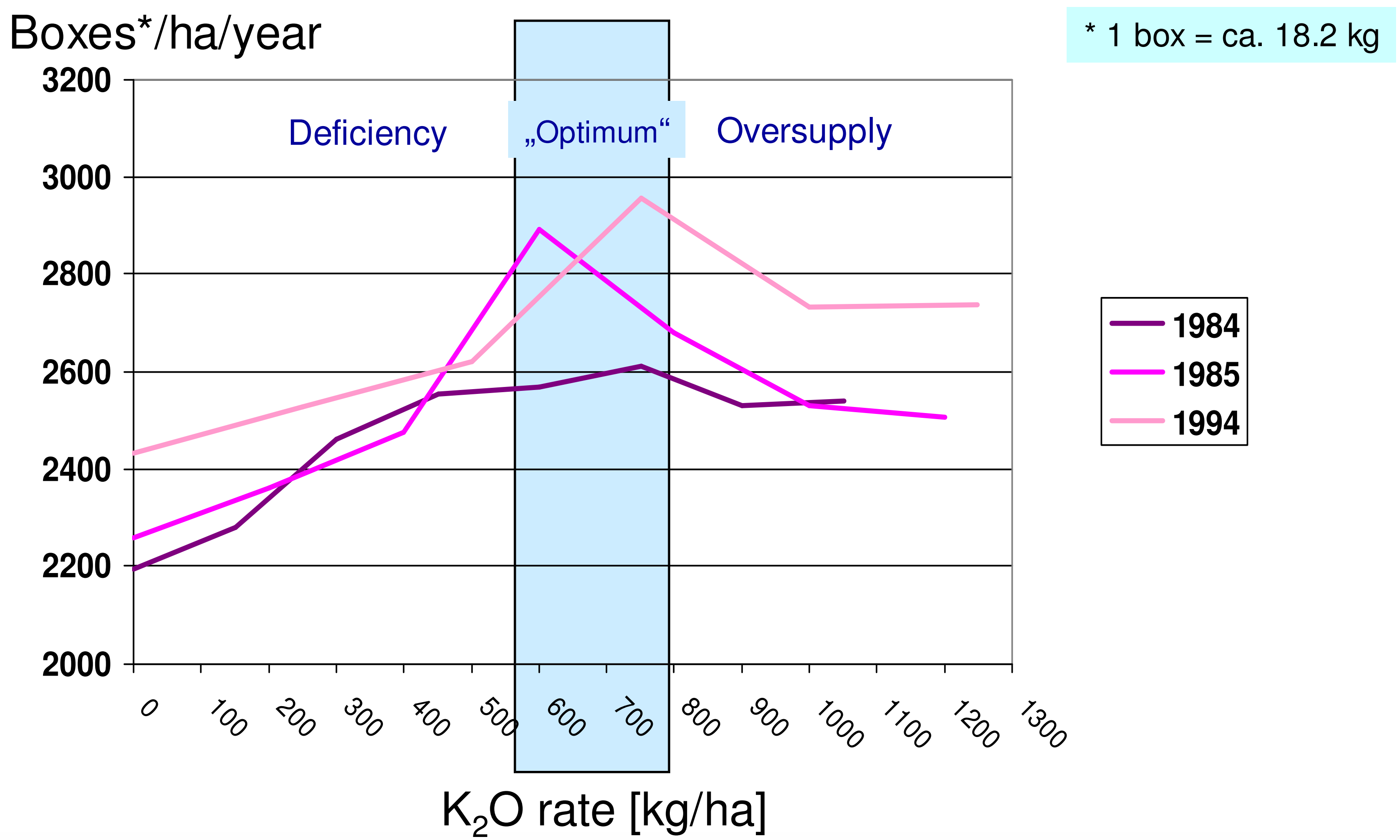
	Australia	Costa Rica
Ca / Mg	3 – 5	3.5 – 4.0
Ca / K	Approx. 12	17 – 25
Mg / K	3 - 4	8 - 15

REF: Rosero Ruano – 2000; NSW Agriculture – 1991 ; Turner et al - 1986

K oversupply causes nutritional imbalances: yield drops - *Example Banana*



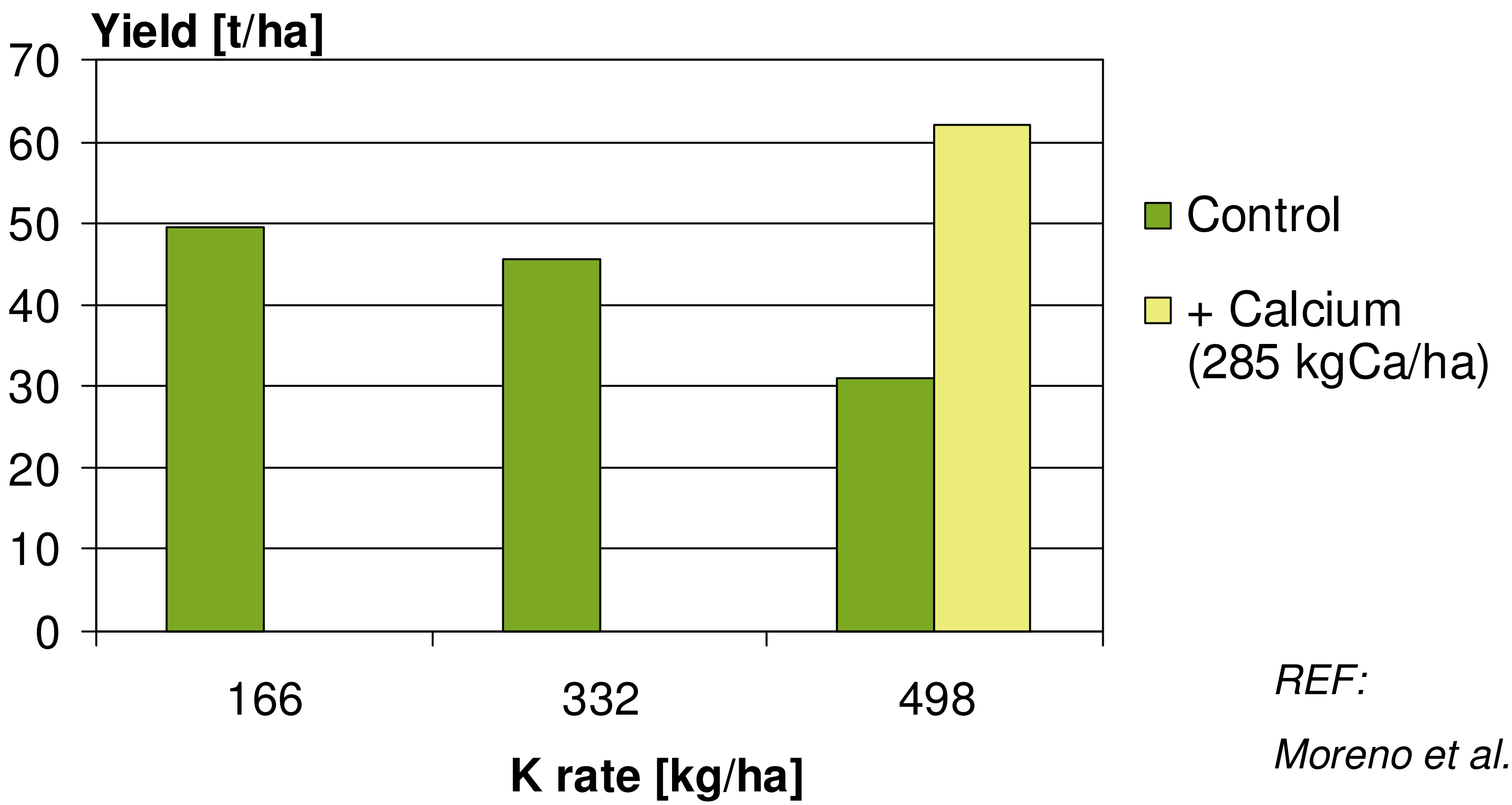
Banana - Costa Rica



REF: Lopez & Espinosa (1998)

Induced Ca deficiency due to high K rates
Example Banana

Banana - Venezuela

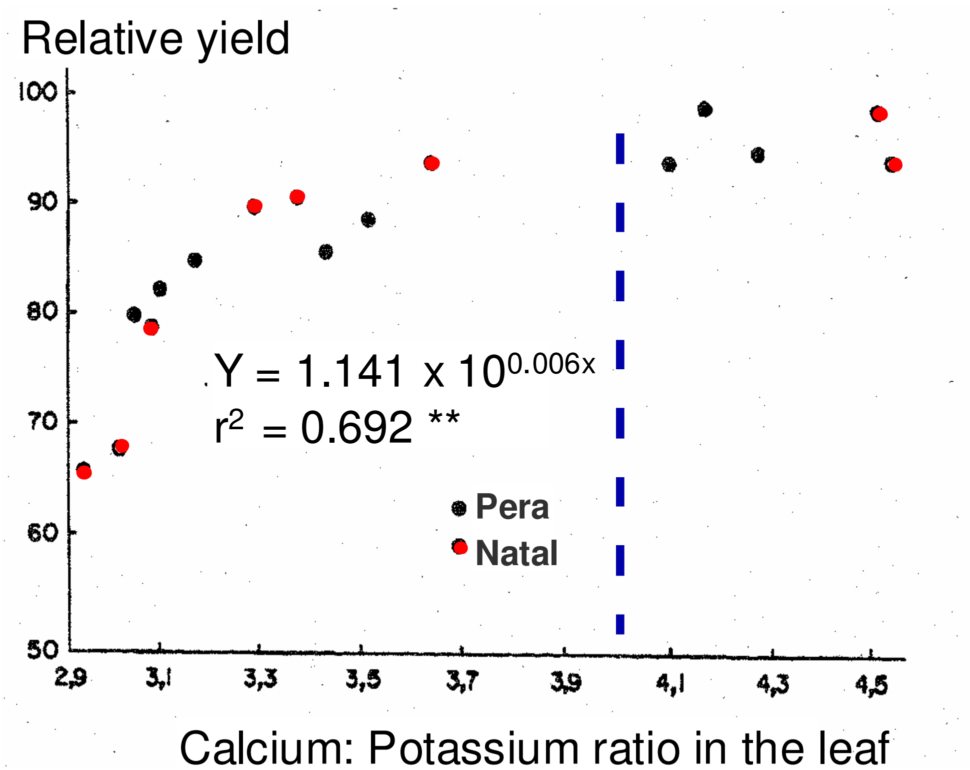


REF:

Moreno et al. (1999)

Leaf Ca/K ratio and orange production

Oranges – Brazil



REF: adapted from Malavolta (1992)

Calcium in Soil and Plant

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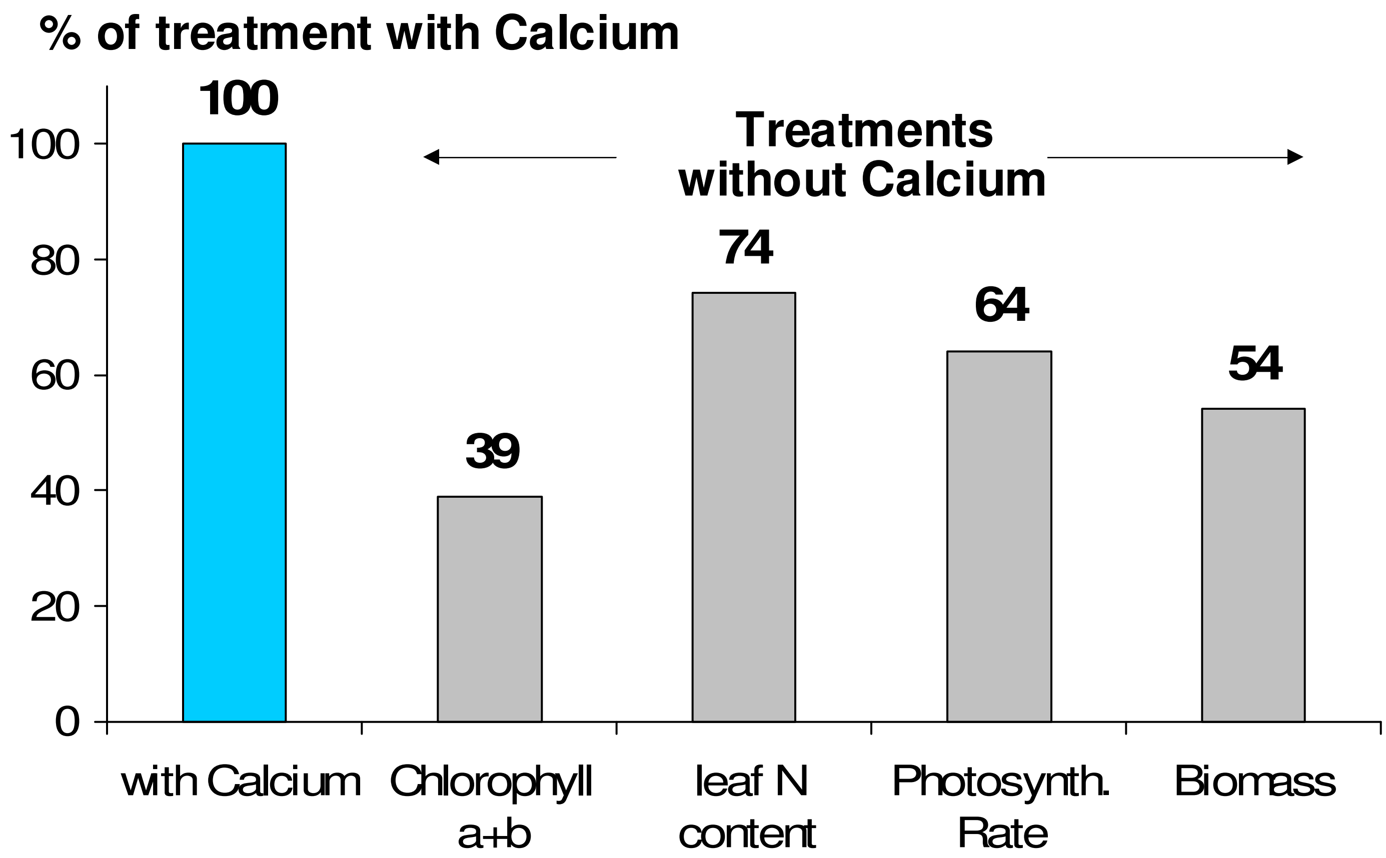
- Part 2: Strategies to supply Calcium to the plant

Calcium is important for plant growth

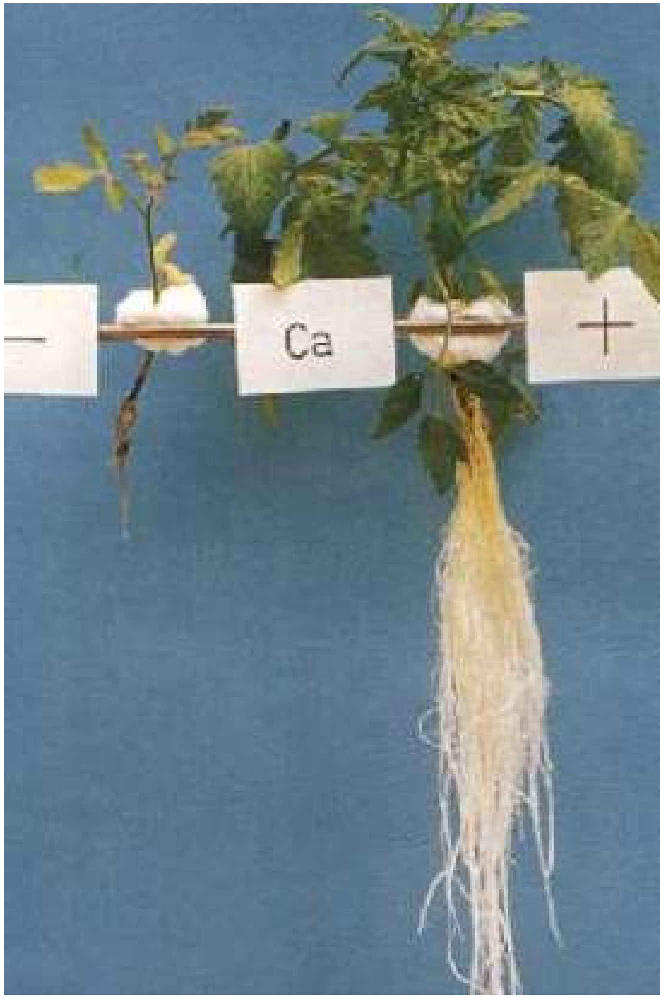
Rough Lemon – Israel



REF: Lavon et al. (1999)

Calcium is important for plant growth

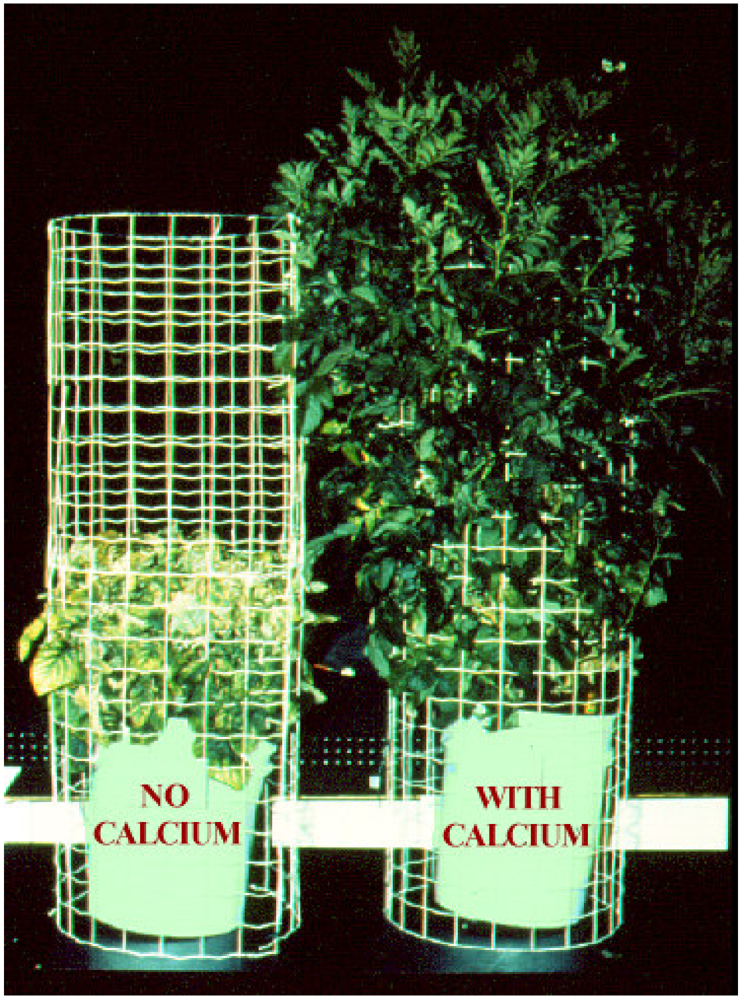
- **Without Calcium root and shoot growth fails**



Calcium improves stress tolerance

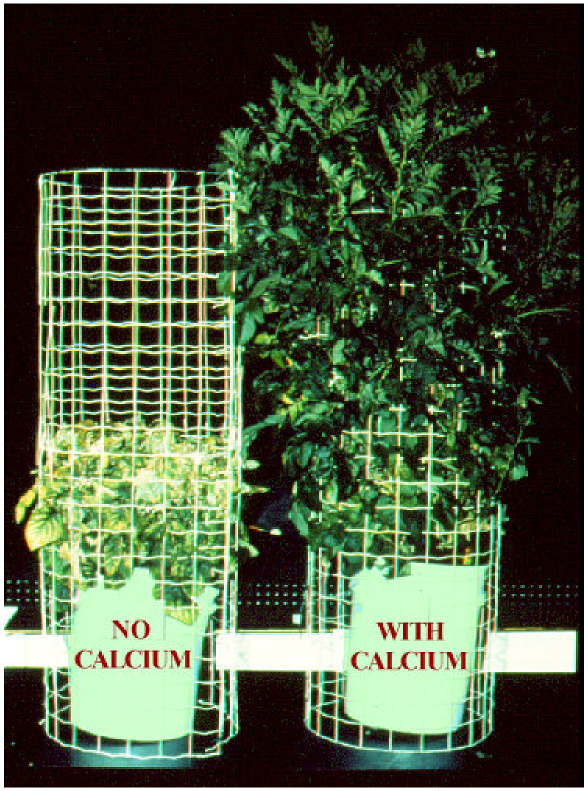
Examples

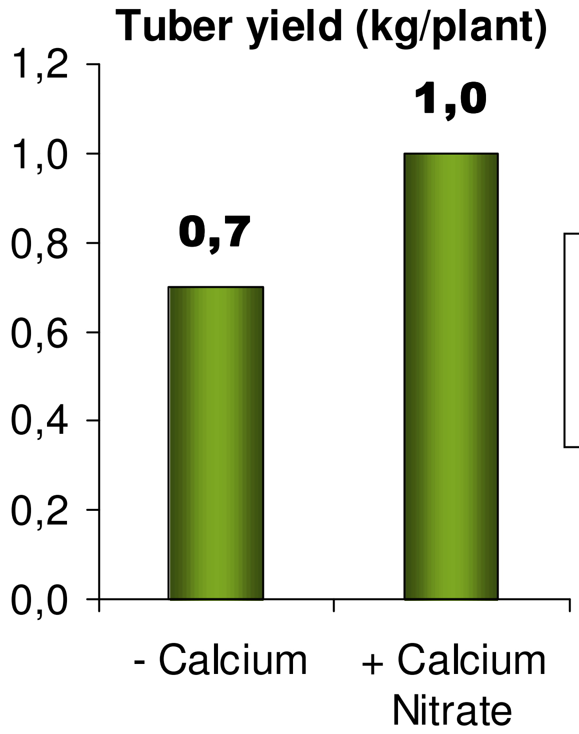
- Heat
- Wind
- Frost



Calcium improves heat stress tolerance

- **Potato – heat stress: 4 weeks 30/20°C day/night temperature.**
  Native soil Ca 550 ppm *"sufficient for normal plant growth"*



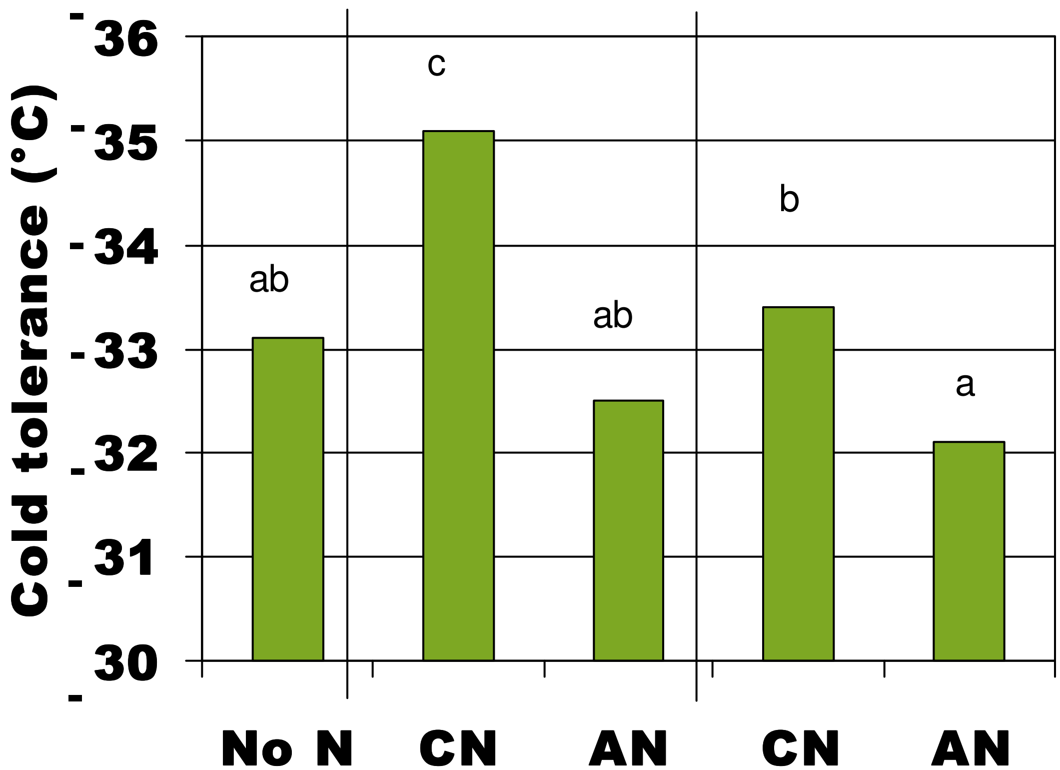


30% yield reduction under heat stress without soluble Ca

REF: Tawfik et al. (1996)

Calcium increases cold tolerance of fruit trees

Pear cv. Anjou - USA



Significance at P=0.05

Measurement of cold tolerance: T50 = temperature at which 50% of the branches experienced cold damage (no living flower buds)

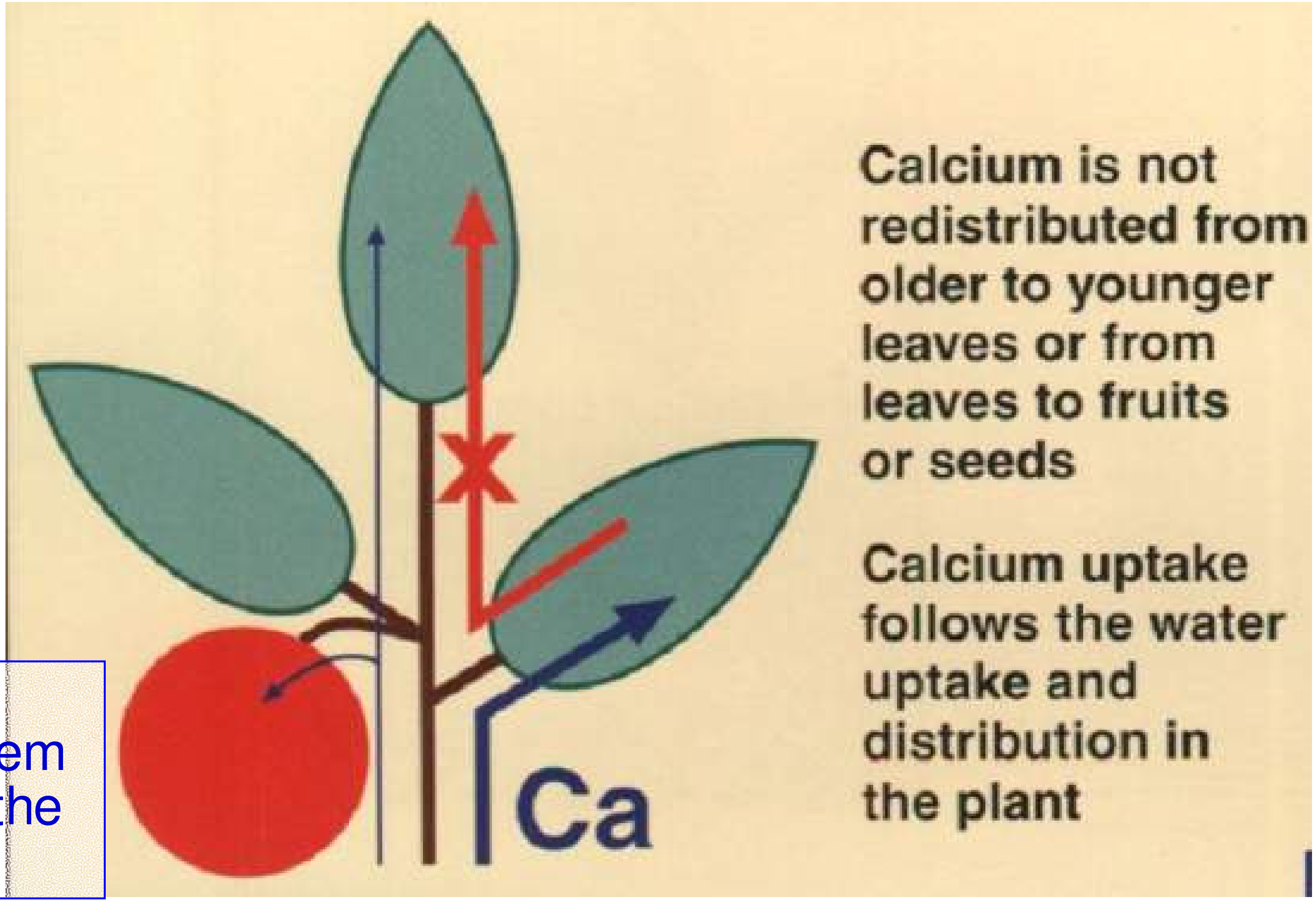
REF: Raese (1996)

Ca demand can be higher than that of P, Mg, S (total crop) - Examples, semi-arids, (sub-)tropics

Nutrients [kg/ha]	Corn [1] 9.5 t yield	Cotton [2] 2.5 t yield	Banana [3] 55 t yield	Tomato [4] 120 t yield
N	191	156	276	286
P	39	16	23	28
K	195	125	711	313
Ca	41	121	152	203
Mg	44	24	54	74
S	21	61	*50*	73

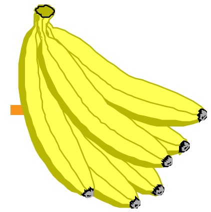
REF: [1] Barber & Olson (1968); [2] Malavolta (1987); [3] Irizarry et al. (1988); [4] Yara Greece (2005)

Calcium is mainly going to transpiring organs



Calcium:
Limited phloem transport to the fruit

Calcium is mainly going to transpiring organs - example Banana



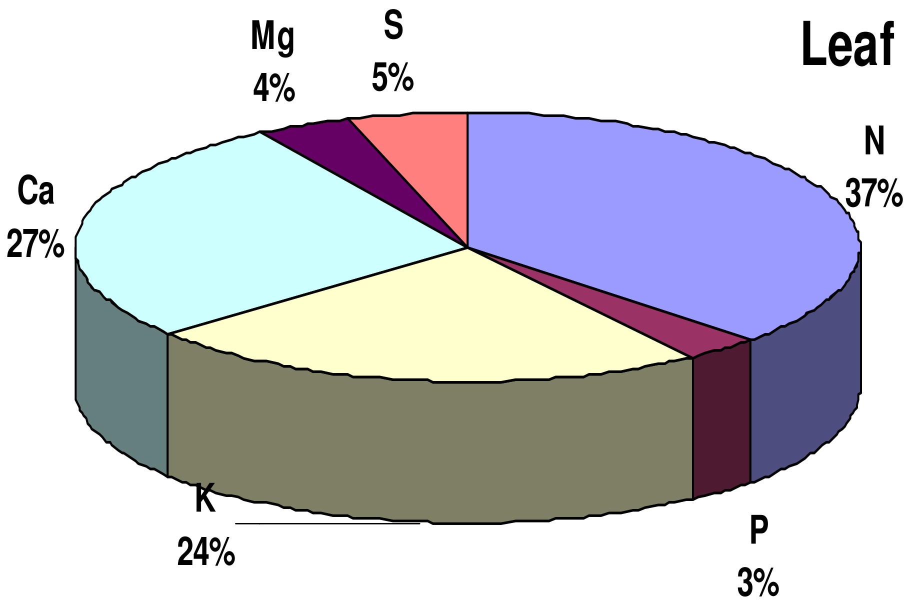
Nutrients [kg/ha]	Total crop	Pseudostem + leaves	Bunch 55 t yield
N	276	153	123
P	23	10	13
K	711	448	268
Ca	152	139	13
Mg	54	38	16

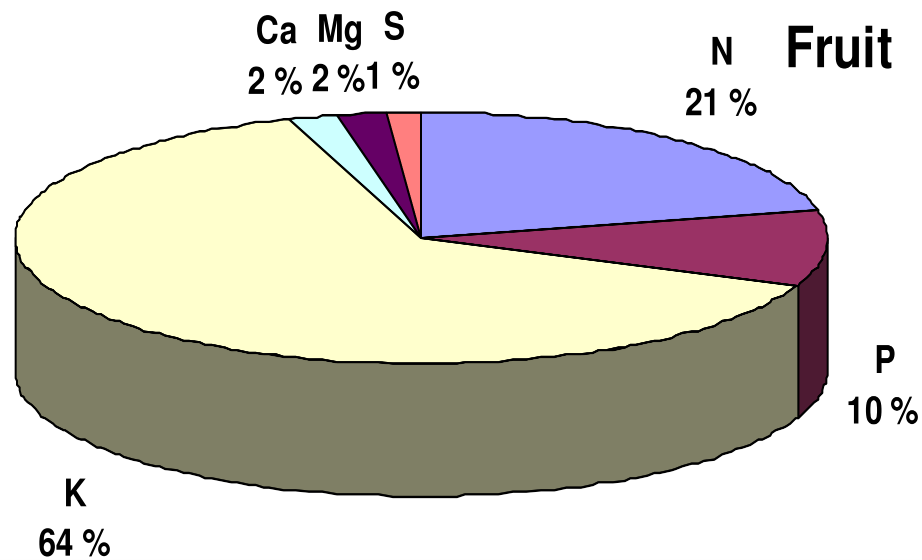
Only 10% of Ca uptake in the fruit bunch

REF: Irizarry et al. (1988)

Calcium is accumulated in leaves - low calcium flow to reproductive organs, like fruits

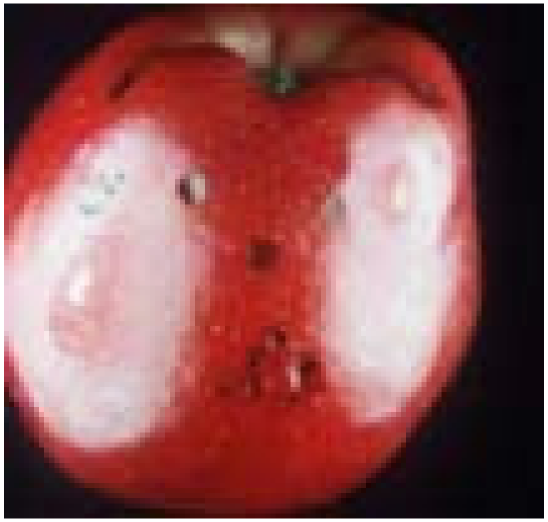
Apple



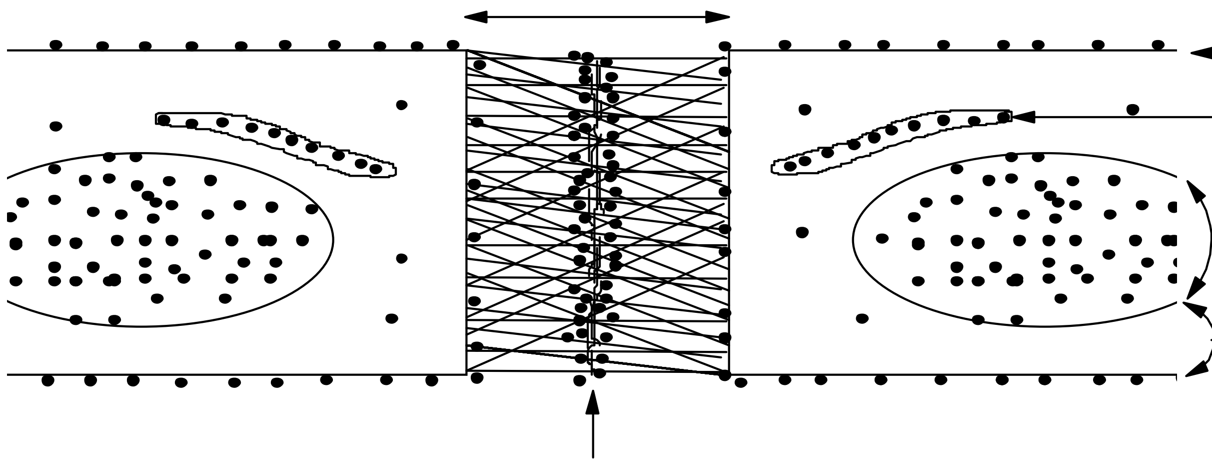


Insufficient calcium flow to the fruit results in disorders

Bitter Pit - Apples



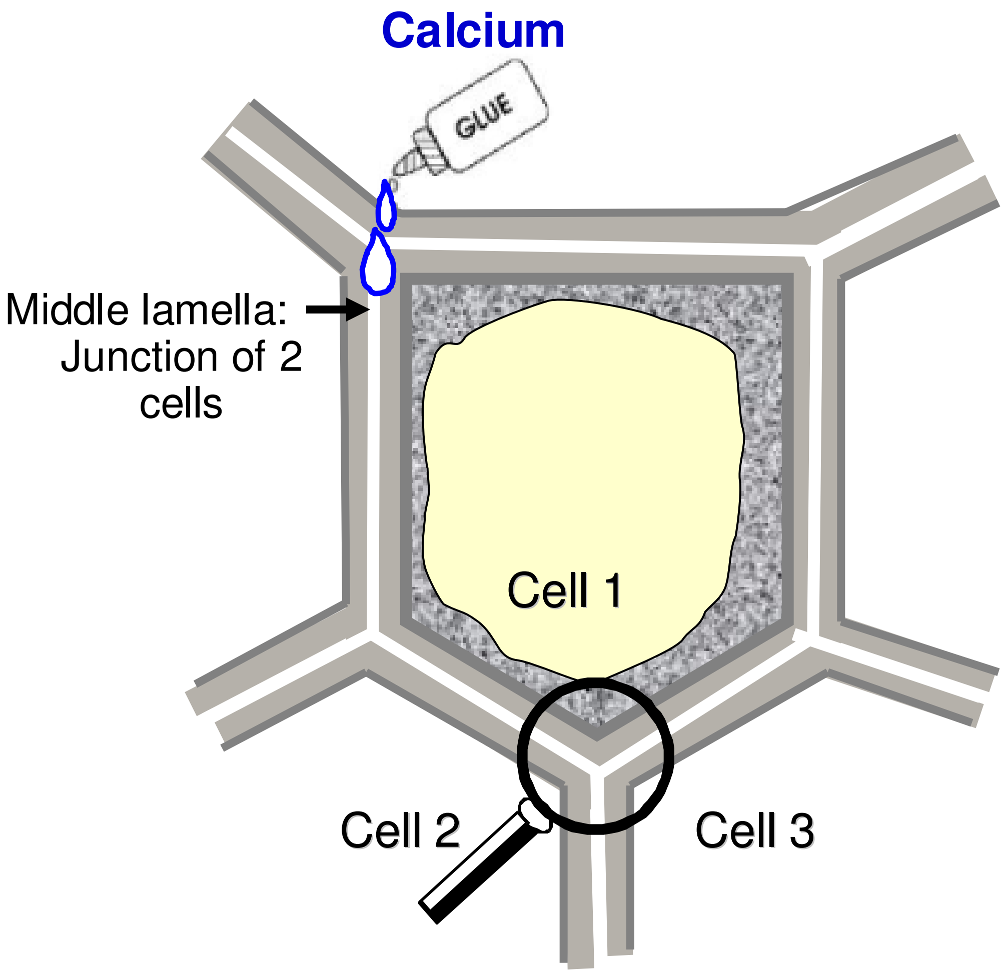
Up to 90% of the total cell Ca is in cell walls.
Ca deficiency results in cell disintegration

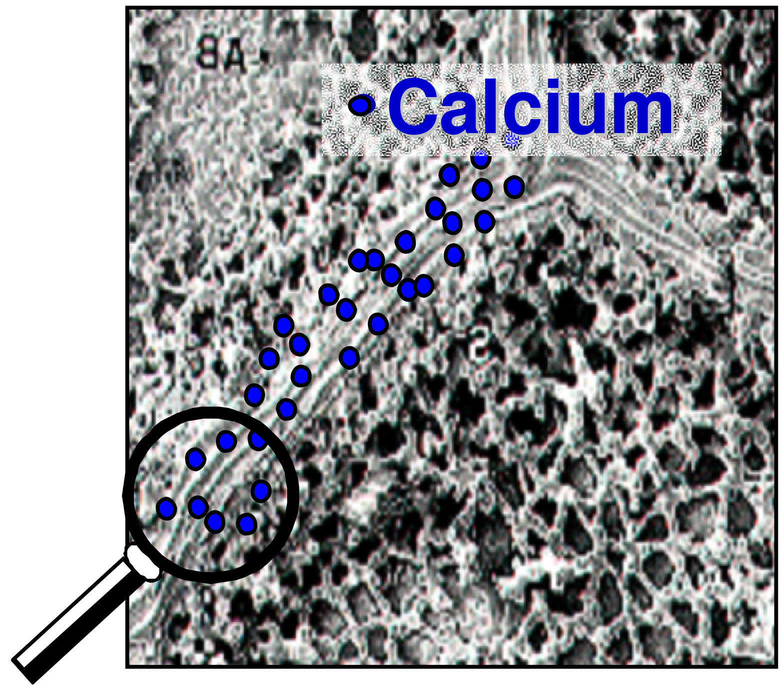


Calcium: (●)

REF: adapted from Marschner (1995)

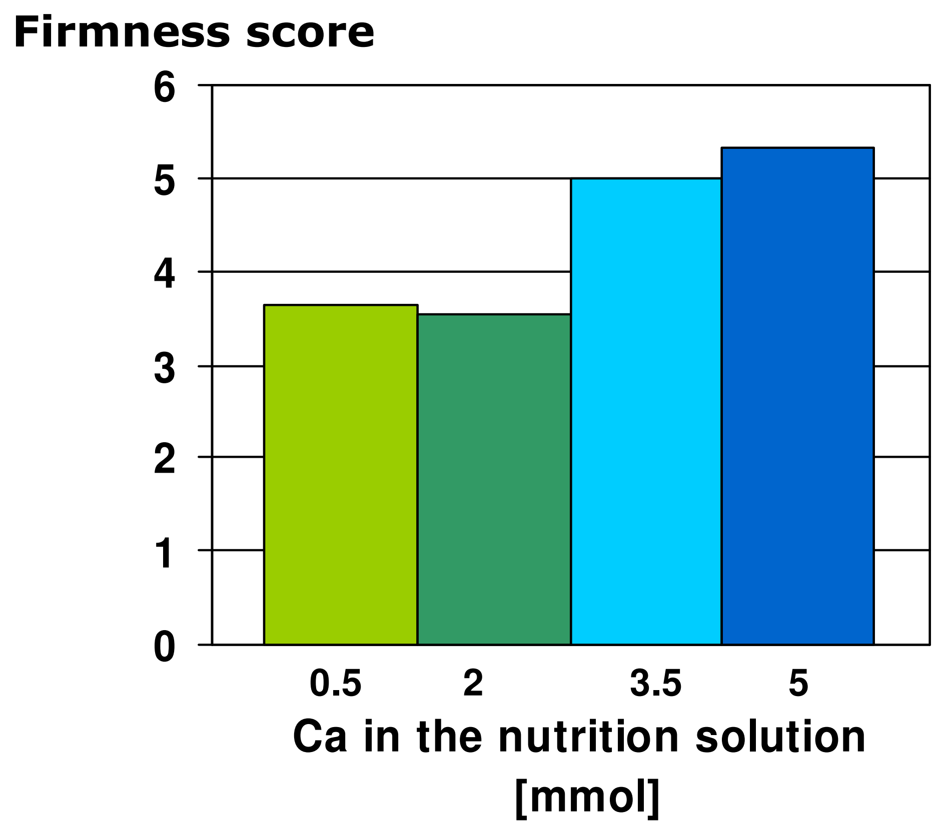
In the middle lamella, Calcium is binding the cells together - like a glue





Calcium makes firmer fruit

Melon – South Africa



REF Combrink et al. (1995)

Calcium reduces Internal Rust Spot in potato

Ca	IRS [%]	Peel Ca [%]
nil	60	0,11
84	37	013
252	17	0,15

Insufficient calcium flow to the fruit results in disorders

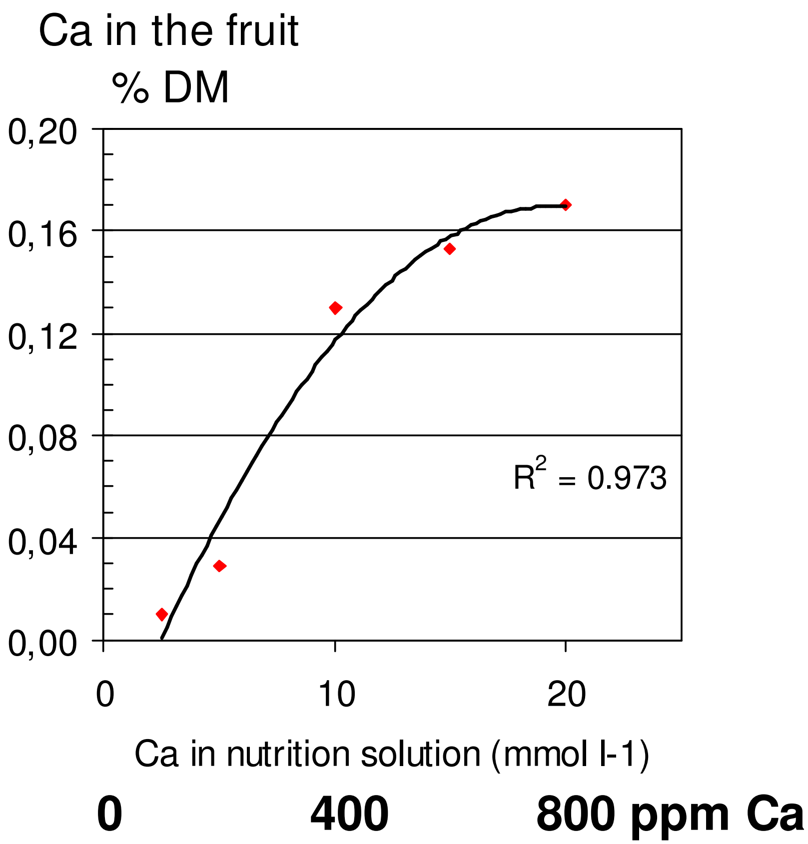
Blossom End Rot (BER) - Tomato

- Physiological disorder
  - Disintegration of cell membrane
  - Increased ion permeability

- Attributed to Calcium deficiency

- Pronounced under stress
  - Soil water deficit
  - High salinity
  - High Ammonium presence

Calcium in the tomato fruit is directly linked to the Ca content of the nutrition solution



REF: Paiva et al. (1998)

- Ensure a sufficient Ca supply to avoid quality problems like blossom end rot.
- As a general rule, tomato fruit with a Ca concentration > 0.12% don't develop BER.

Insufficient calcium flow to the fruit results in disorders

Citrus - Splitting

Citrus - Creasing (Albedo breakdown)

Calcium and Potassium levels in the albedo tissue of creased and non-creased orange fruits

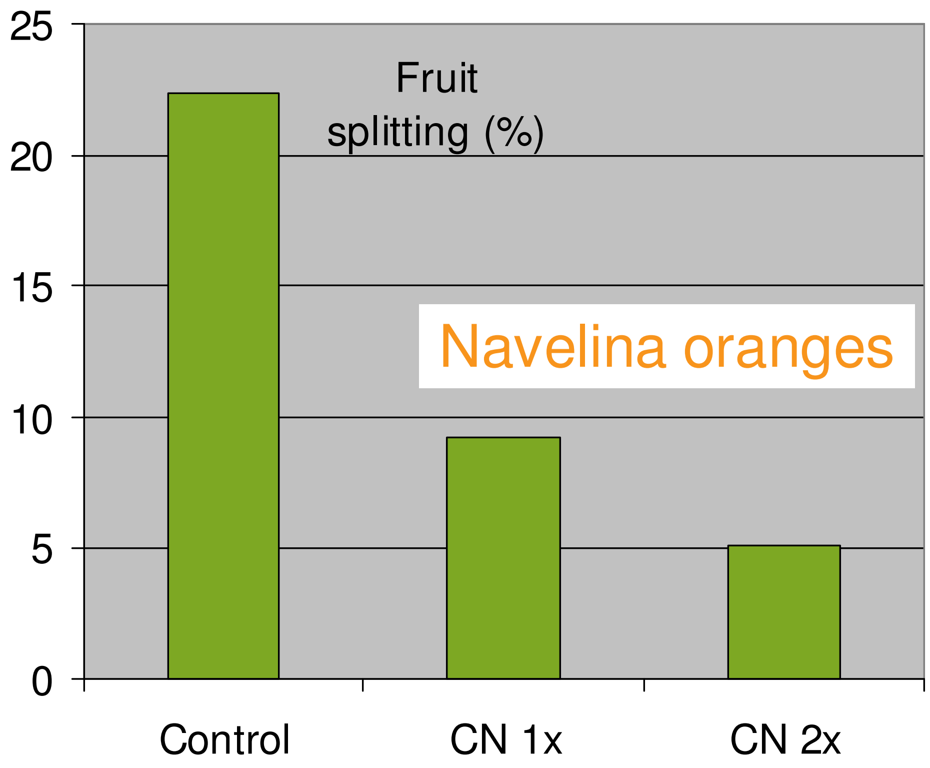
At commercial K rates, creasing is the result of Ca deficiency!

	Leng navels (Navel orange)		Valencias (Common orange)	
	Non-creased	Creased	Non-creased	Creased
Calcium (Ca) [mg/g albedo DM]	9.9	6.1 **	9.0	6.7 **
Potassium (K) [mg/g albedo DM]	1.5	2.1 **	2.2	2.1

** statistically significant difference; $p < 0.01$)

REF: Storey et al. (2002)

Calcium Nitrate sprays reduce "splitting" in oranges



Calcium reduces splitting

REF: Serrano and Primo-Millo (1989)

Calcium improves shelf-life (long term storage)

- ***Example: apples***

- Bitter pit develops with storage time
  - With Ca 3.5%
  - No Ca 23%

- Fruit firmness improves
  - With Ca 7.3 kpa
  - No Ca 5.9 kpa

Ca & Tuber Storage

- Ca in the peel
  - Resistance against disease

Peel Ca [%]	Surface area decayed [%]
0,1	90
0,2	50
0,3	20
0,5	nil

(McGuire & Kelman, 1984)

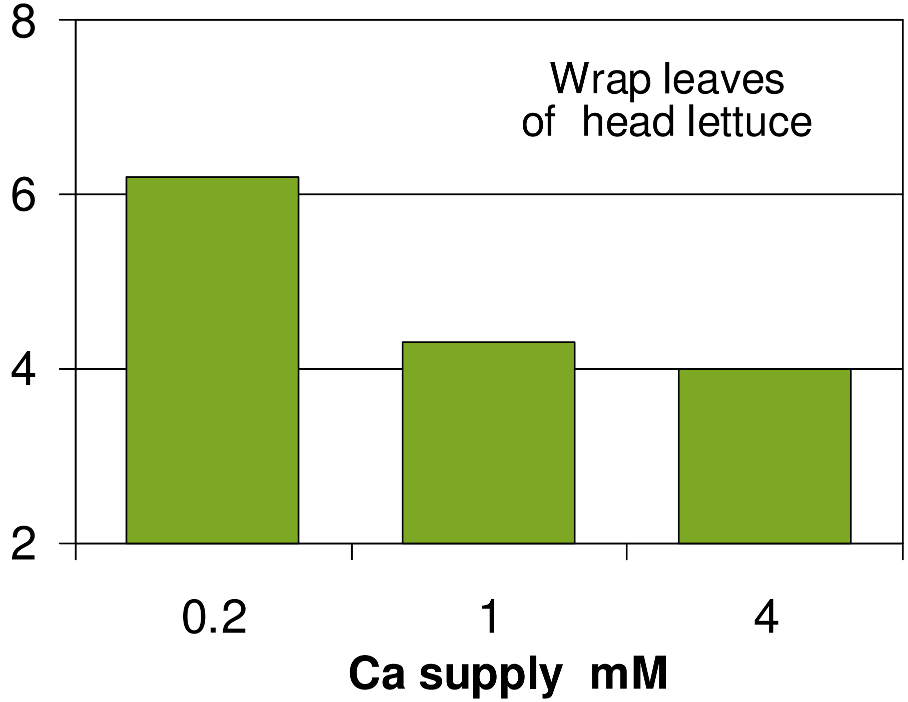
Soft rot

A good Ca status reduces the water losses during storage

- **Ca helps the plant to reduce transpiration losses during the night**

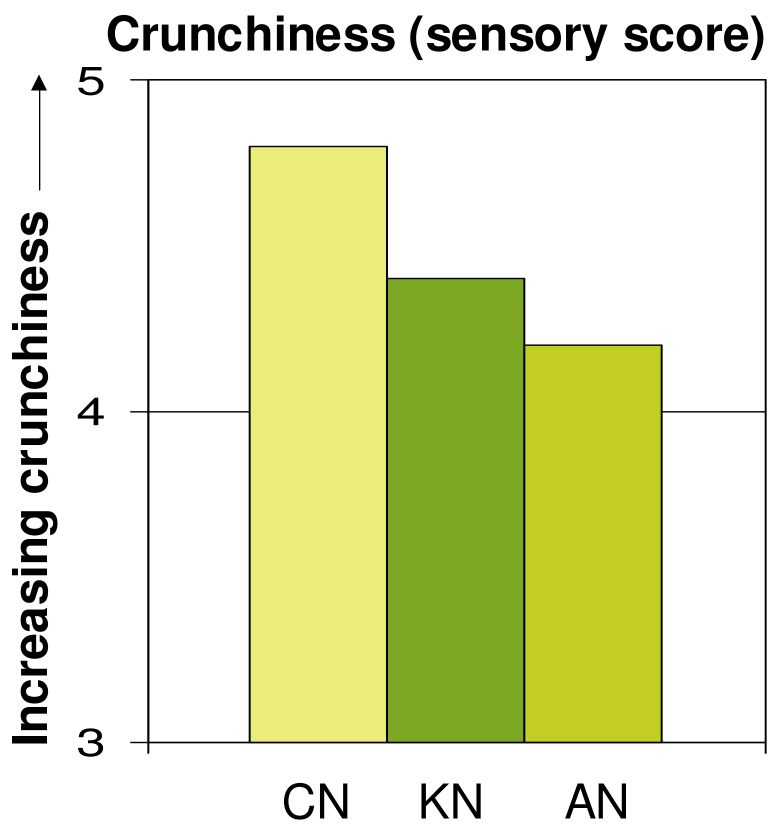
  ⇨ **Indicating a higher storage quality.**

Transpiration in relation to leaf area [g H_2O/m^2xh]



(Wissemeyer, 1996)

Calcinit makes lettuce more crunchy



Mean of 3 lettuce types

CN = calcium nitrate
KN = potassium nitrate
AN= ammonium nitrate

(Simonne et al., 2001)

Part 1: Background and Basic facts - Summary

Calcium in the Soil:

- Only a small fraction of the total soil Ca is in solution and directly plant available
- Calcium uptake and Calcium leaching enhances soil acidification
- Calcium application improves base saturation
- Calcium application can alleviate salinity stress
- There is an optimum Ca, Mg, K ratio for crop growth. Over-application of K and Mg can induce Calcium deficiency (e.g. banana plantations)

Calcium and Plant:

- Calcium demand can be higher than that of P, Mg, S
- Calcium helps against heat and cold stress
- Calcium improves crop firmness and thereby fruit quality and fruit storage

Calcium in Soil and Plant

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  - Calcium and plant
- **Part 2: Strategies to supply Calcium to the plant**

Calcium in Soil and Plant

- Part 2: Strategies to supply Calcium to the plant

- Application of lime – $CaCO_3$
- Application of gypsum – $CaSO_4$
- Application of Calciumnitrate – $Ca(NO_3)_2$

Calcium in Soil and Plant

- Part 2: Strategies to supply Calcium to the plant

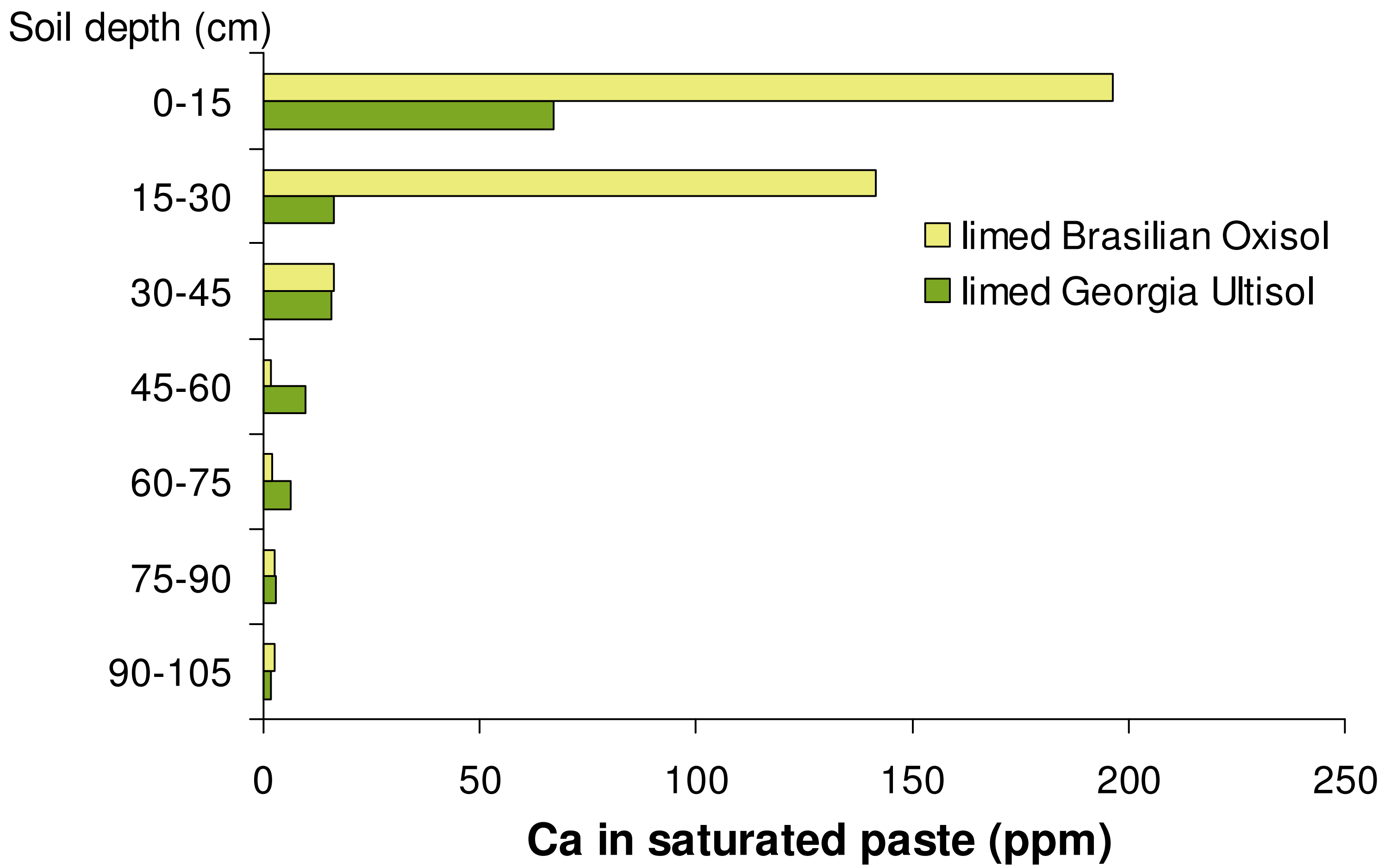
- **Application of lime – $CaCO_3$**
- **Application of gypsum – $CaSO_4$**
- Application of Calciumnitrate – $Ca(NO_3)_2$

Why should we lime soils ?

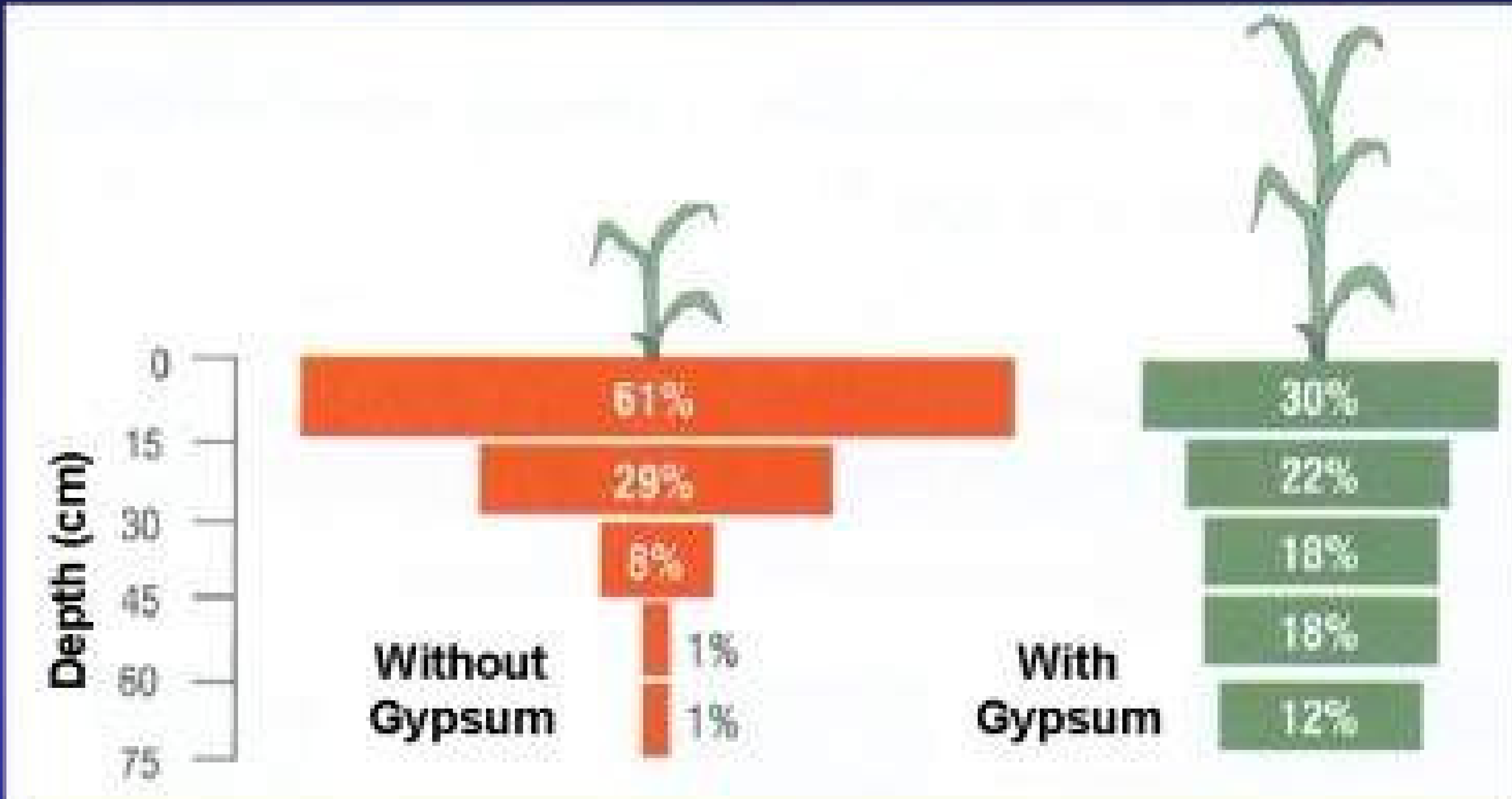
- Eliminate toxicities of Al^{3+} and Mn^{2+}
- Supply adequate levels of Ca^{2+} and Mg^{2+}
- Facilitate the utilization of water
- Create conditions which maximize the availabity and uptake of essential nutrients and
- Create conditions which control soil pathogens

Slide taken from „Yamada: The Cerrado of Brazil“ (www.Potafos.org)

Liming increases the Ca content of the topsoil, but subsoil Ca remains very low



REF: McCray and Sumner (1990)



Distribution of corn root system in the profile of a clay latosol with and without gypsum application

Source: Sousa et al. (1995)

Slide taken from „Yamada: The Cerrado of Brazil“ (www.Potafos.org)

Calcium in Soil and Plant

- Part 2: Strategies to supply Calcium to the plant

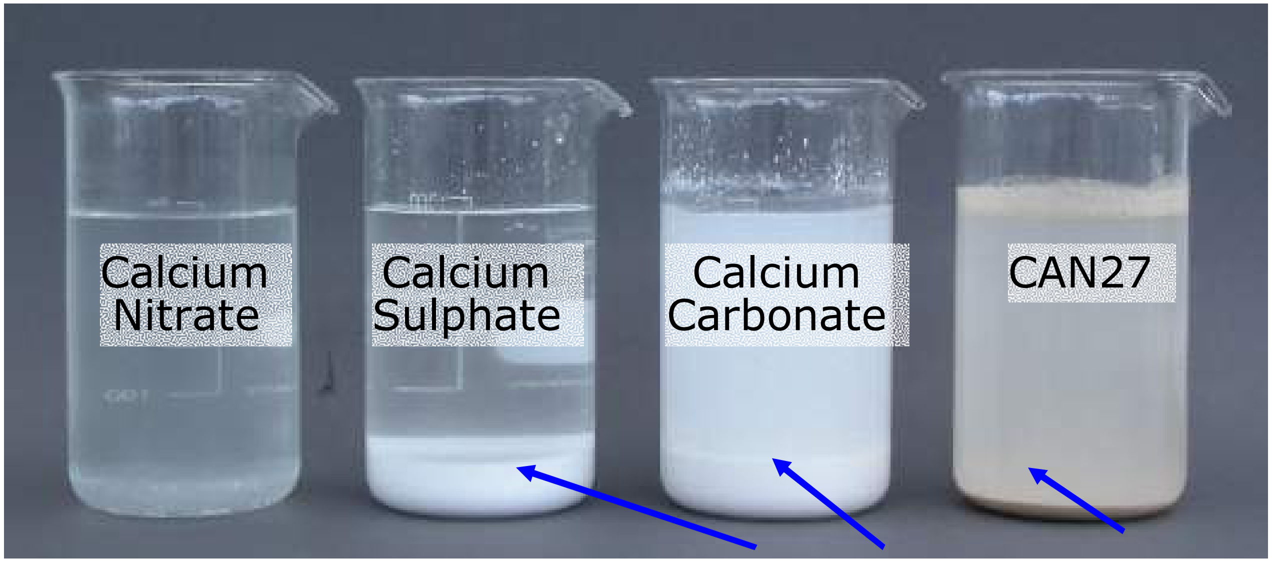
- Application of lime – $CaCO_3$
- Application of gypsum – $CaSO_4$
- **Application of Calciumnitrate – $Ca(NO_3)_2$**

Calciumnitrate is delivering quickly available Calcium

Source	Ca %	Litres of water to dissolve one kg product
Calcium nitrate	19	1
Calcium chloride	36	1,3
MCP	16	55
Calcium sulphate	23	415
Calcium oxide	71	760
Calcium carbonate	40	* 66000

* Measured in CO_2-free water. At presence of realistic CO_2 levels may 10 000 l are needed

Solubility of calcium sources

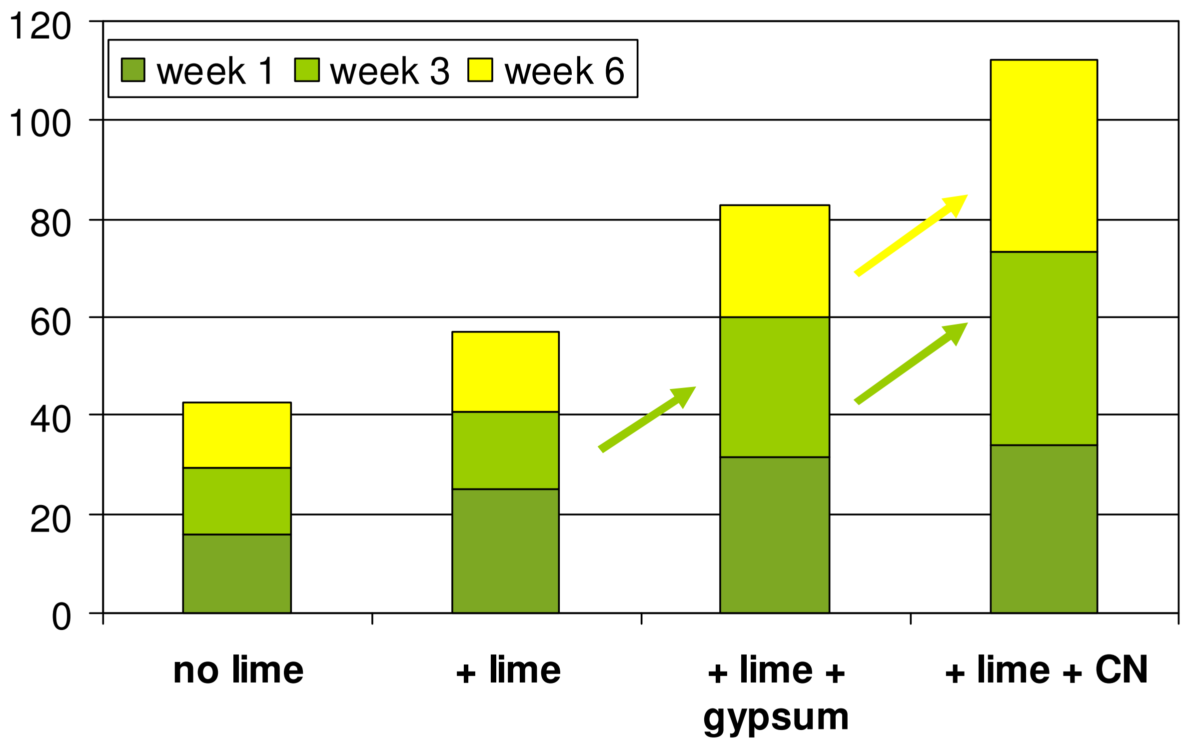


insoluble calcium

Plants require soluble calcium for uptake

Higher Ca contents in the soil solution with Calciumnitrate > gypsum > lime

Ca removed from soil by leaching events (soil solution) – mg/pot



CN vs gypsum:
Ca in soil solution higher till week 6

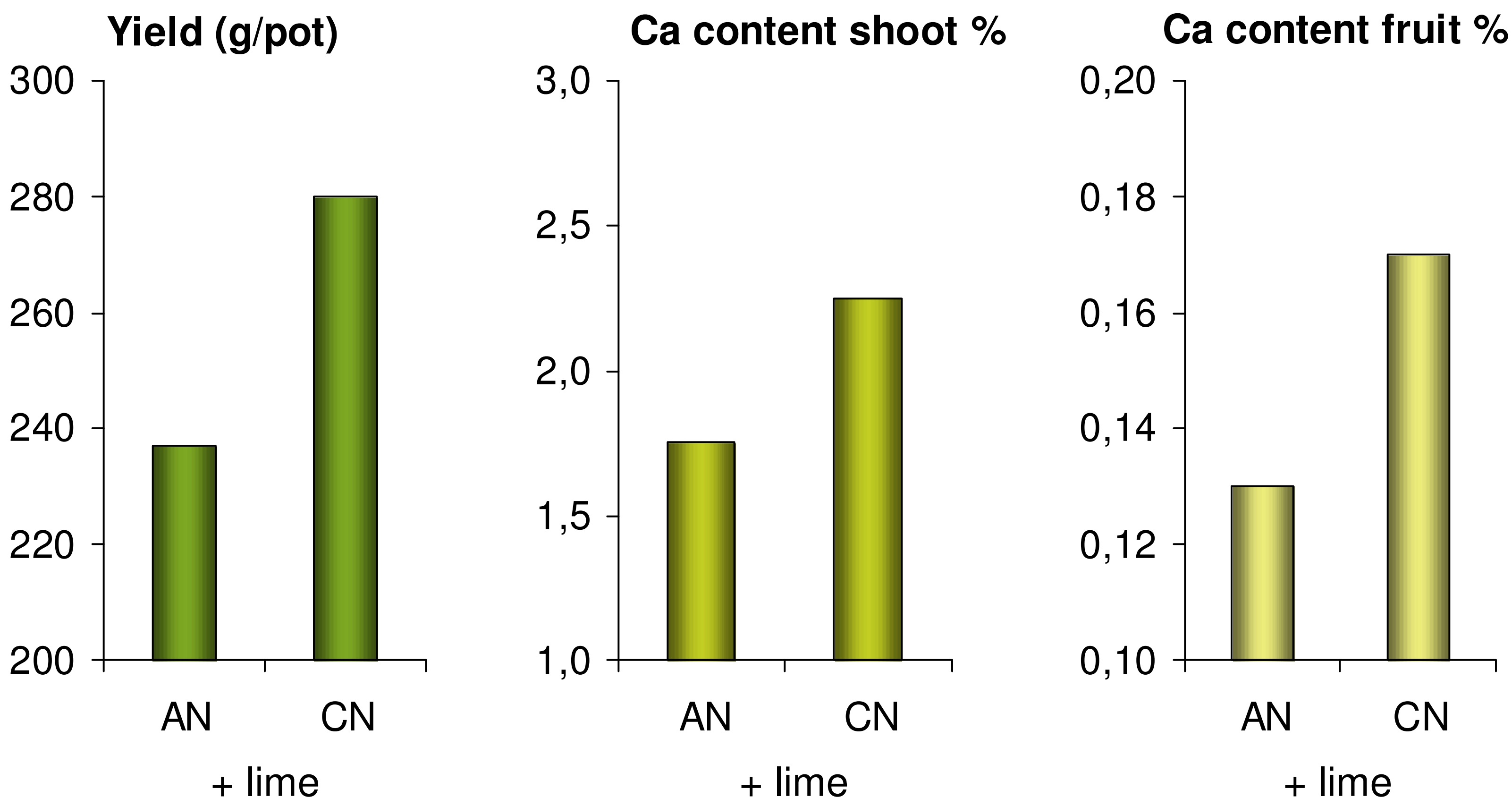
Gypsum vs lime:
Ca in soil solution higher in week 3

Gypsum + Calciumnitrate: Calcium application of 73 mg Ca/pot

REF: Research Centre Hanninghof (2004)

Fertigation: Soluble Calcium improves yield and quality of bell pepper

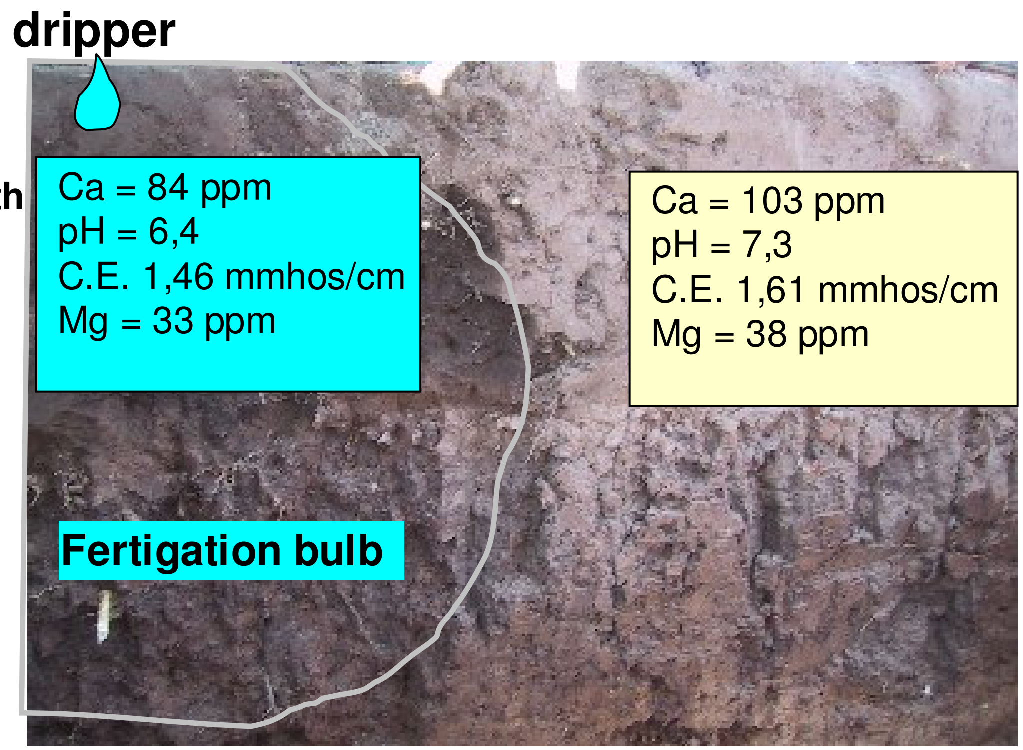
Greenhouse trial



REF: Research Centre Hanninghof (2000)

Ca deficiency is often found under fertigation: *Soil Ca depletion is enhanced by fertigation*

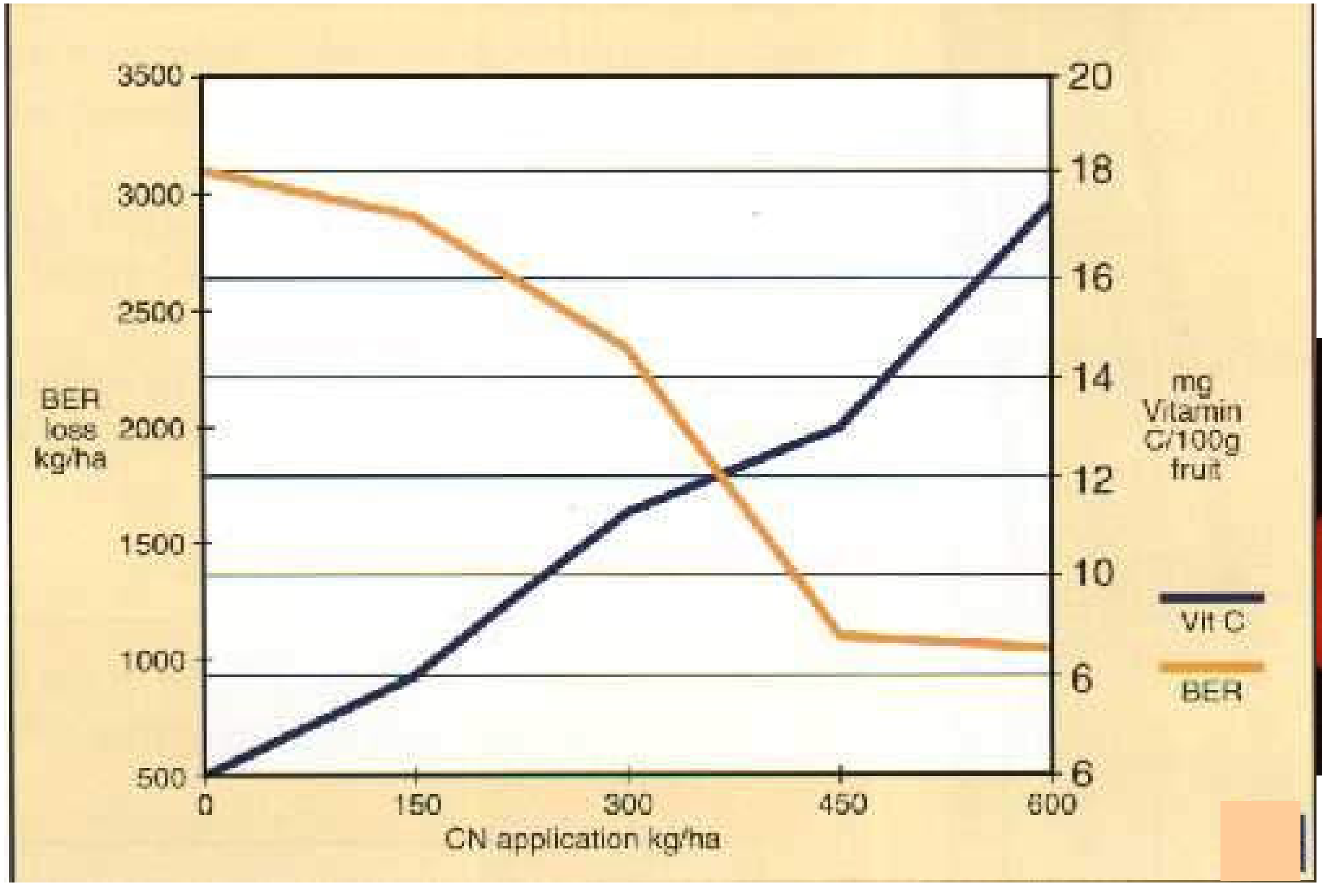
Result after one year of fertigation with a Ca free solution



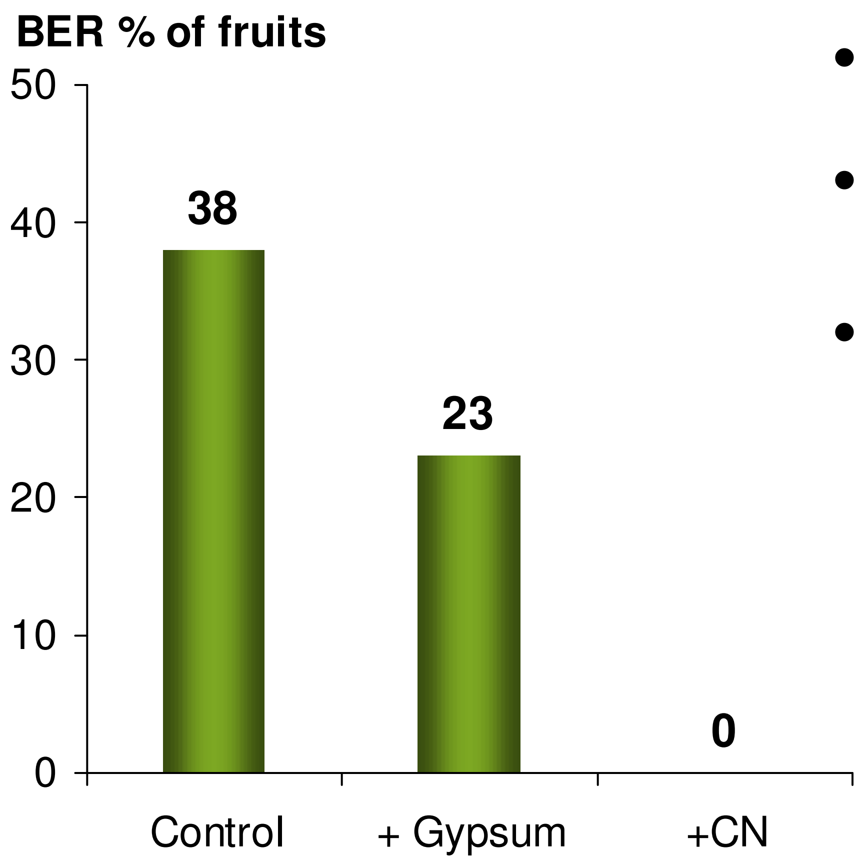
(Lemon orchard in Argentina, 2004)

Fertigation:
Calcium Nitrate reduces incidence of disorders

Blossom End Rot - Tomato



Fertigated crops need soluble Calcium
Best results with Calciumnitrate



REF: Gárate et al. (1991)

- Greenhouse trial (200 l pots)
- Continuous Ca supply via fertigation can help to decrease BER incidence.
- Regular supply of soluble Ca is more efficient that release of Ca from the insoluble fraction of the soil substrate.

Calciumnitrate is delivering quickly available Calcium – *not only in fertigation systems*

- Soluble Calcium for Starter Effect – e.g. cotton
- Soluble Calcium for fast growing crops – e.g. vegetables
- Soluble Calcium for times of high Ca demand

- Calciumnitrate contains Nitrate, which has benefits over ammonium and Urea

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Calciumnitrate as a starter in cotton – *Cotton has a relatively high Ca demand*

Nutrients [kg/ha]	Corn [1] 9.5 t yield	Cotton [2] 2.5 t yield	Banana [3] 55 t yield	Tomato [4] 120 t yield
N	191	156	276	286
P	39	16	23	28
K	195	125	711	313
Ca	41	121	152	203
Mg	44	24	54	74
S	21	61	*50*	73

REF: [1] Barber & Olson (1968); [2] Malavolta (1987); [3] Irizarry et al. (1988); [4] Yara Greece (2005)

Calciumnitrate as a starter in cotton
Challenges

<u>Avoid too much N after bloom:</u>

- vegetative growth, improper boll development and delayed maturity

<u>Avoid too little N during stand development and seedling growth:</u>

- reduced plant development, fruit set and fiber yield

<u>Avoid medium to high NH_4^+ application:</u>

- reduced cotton germination
- NH_4^+ causes temporary Calcium deficiency (cation competition)
- On acidic soils, nitrification is reduced, so this effect is even prolonged

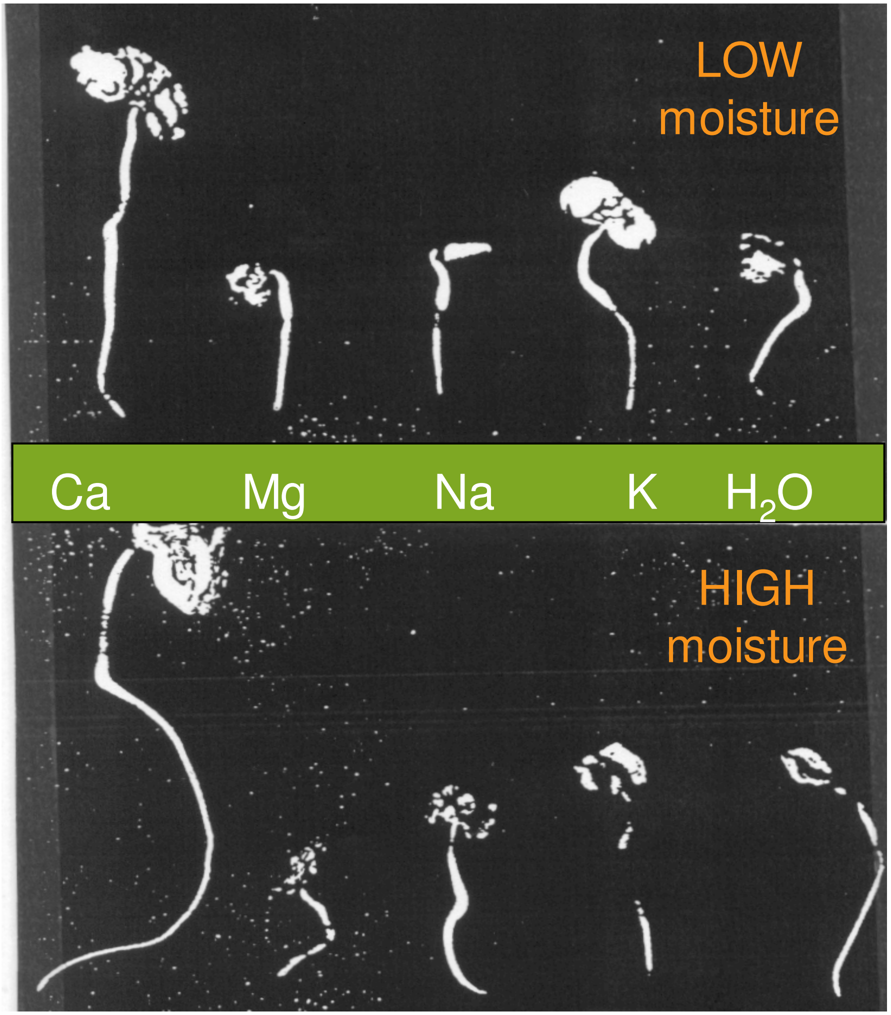
<u>Observations from fields:</u>

- Calciumnitrate produces strong healthy crop that can better resist early season disease, insects and harsh weather

Calcium is important for cotton emergence

Cotton seedlings germinated at low and high moisture levels (3 cc and 6 cc) five days after being placed in distilled water and single salt solution containing cations.

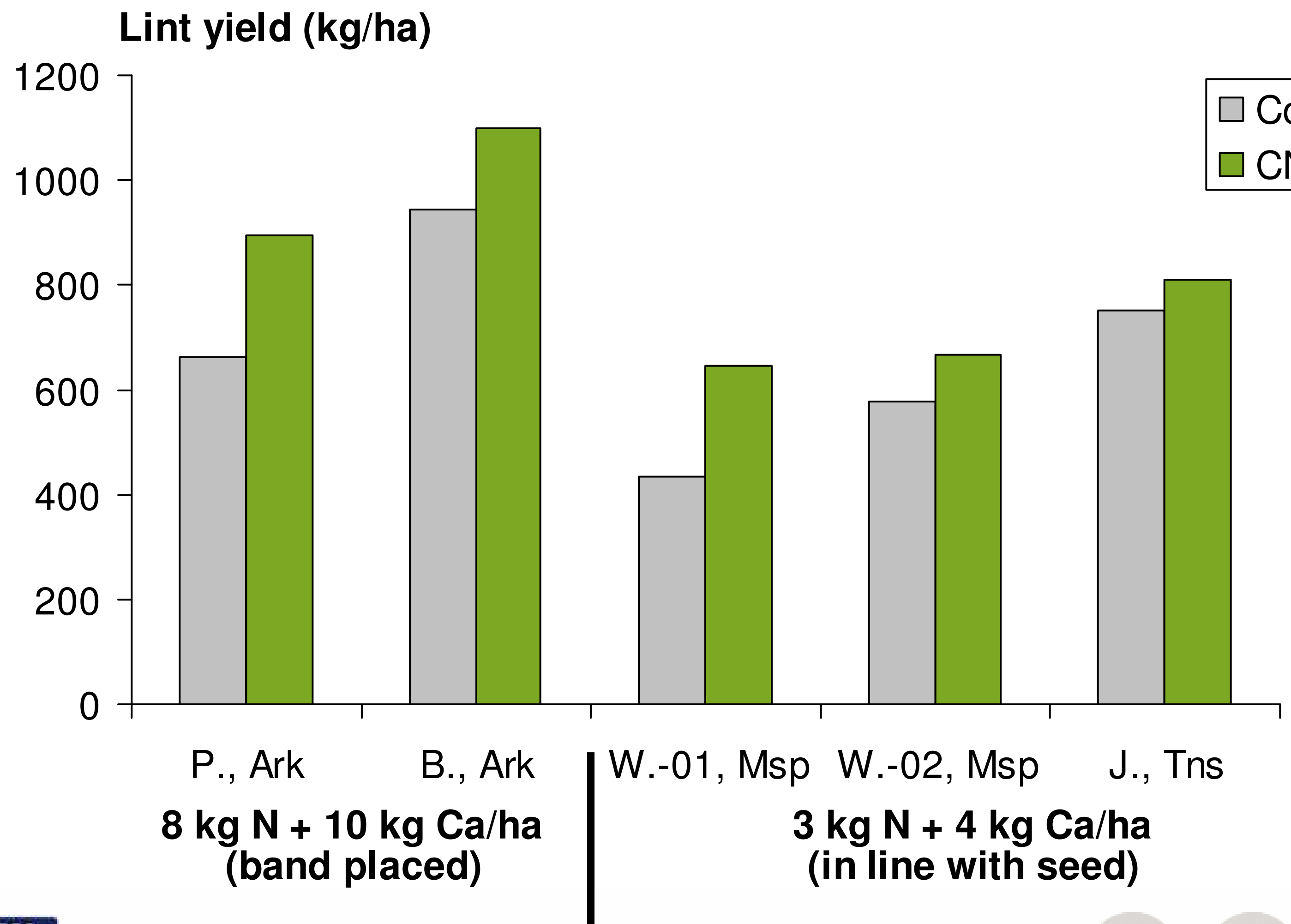
Note the beneficial effect of Calcium



Source: SQM (2005)

Calciumnitrate as a starter in cotton

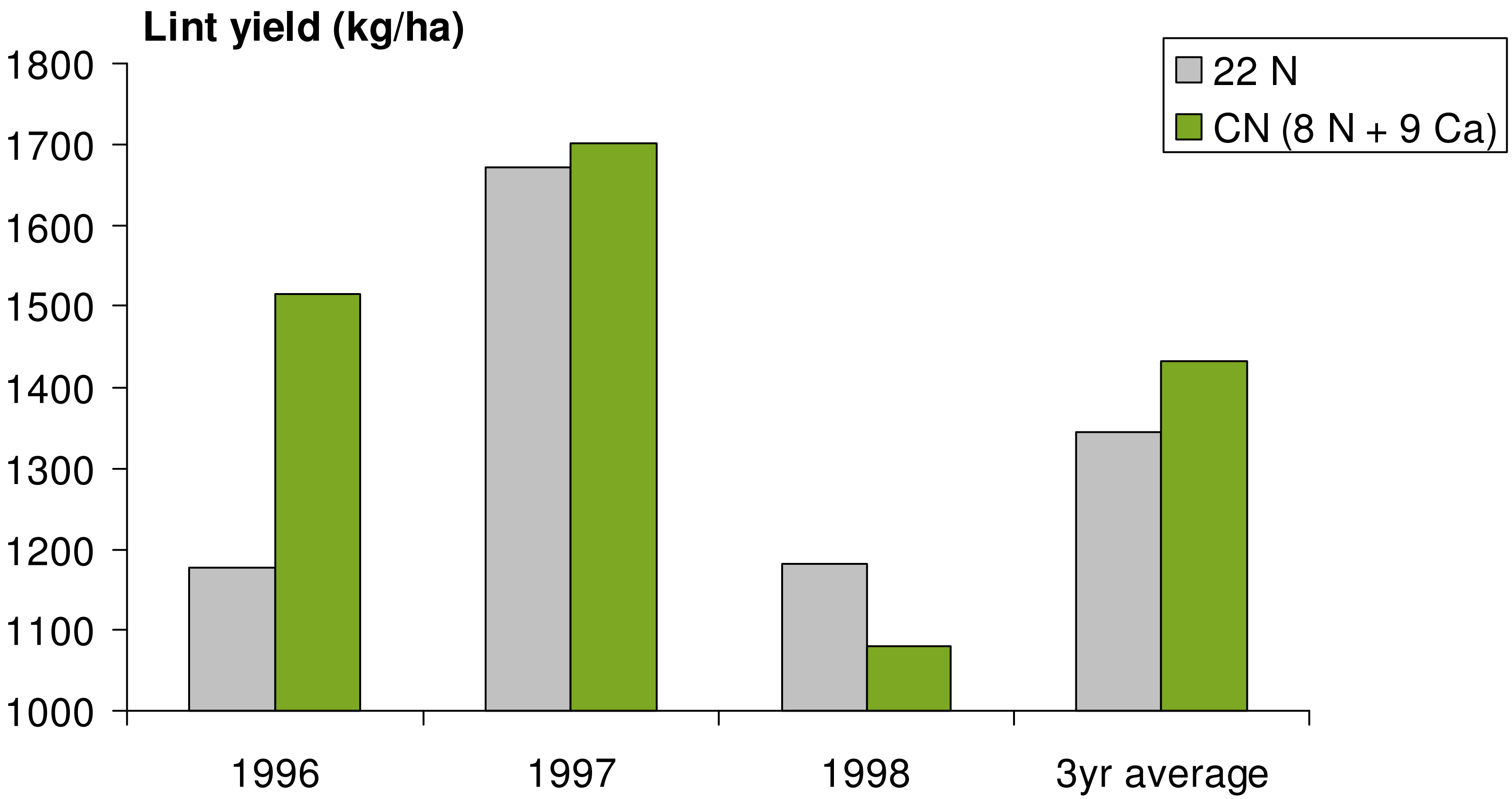
Demo trials on farms, USA



REF:
Yara (1998)

Calciumnitrate as a starter in cotton

Same field, 3 years trial - North Carolina



REF:
Yara (1998)

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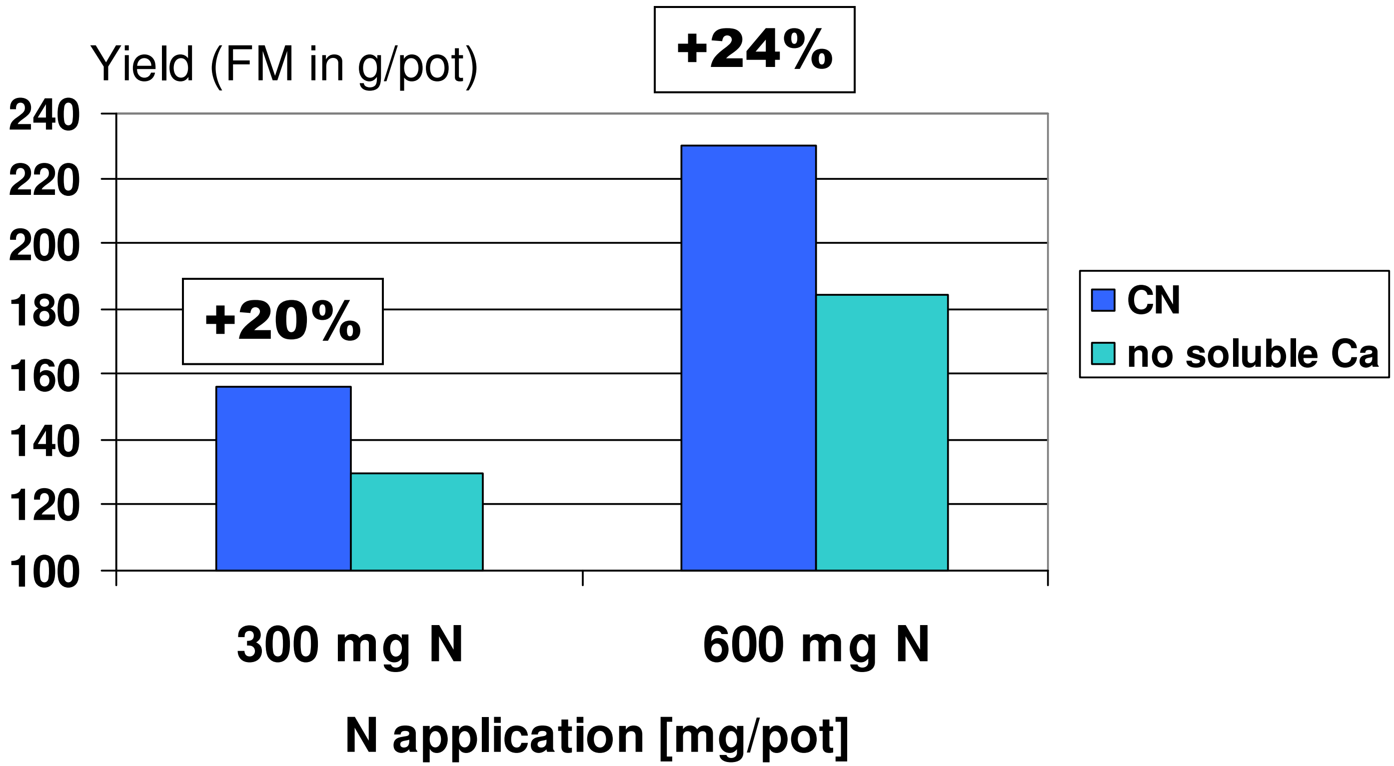
Higher yield with Calciumnitrate than with N application without soluble Calcium

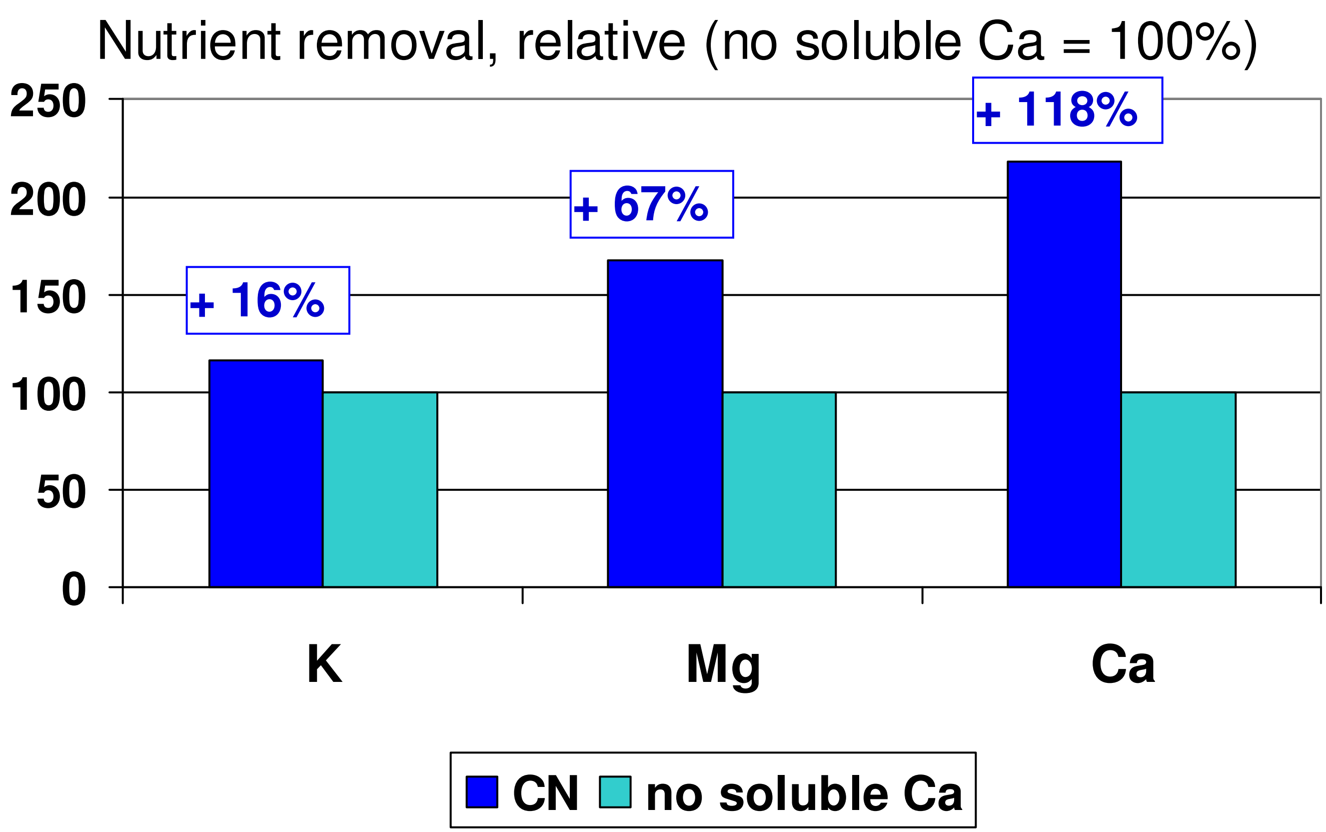
Pot trial, spinach; limed soil



REF: Research Centre Hanninghof (2005)

Higher cation uptake with Calciumnitrate than with N application without soluble Calcium

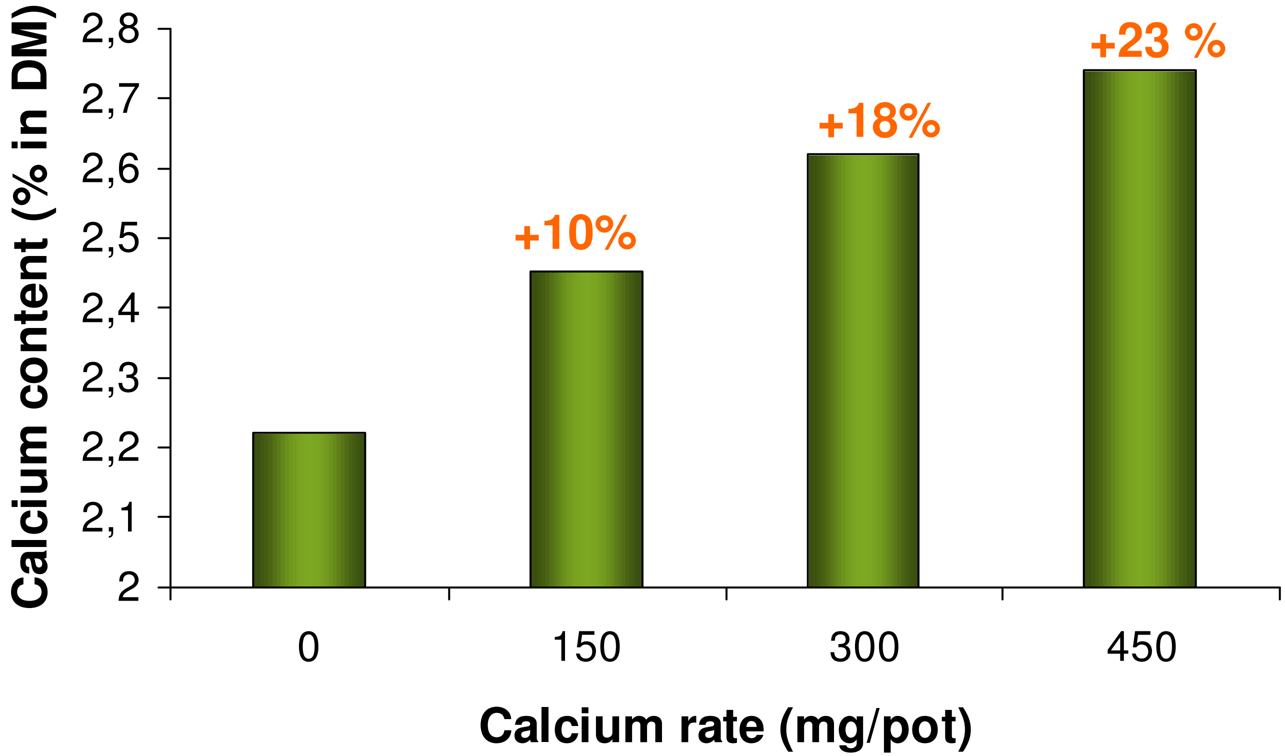
Pot trial, spinach; limed soil



REF: Research Centre Hanninghof (2005)

Significant increase of calcium content in leaf tissue of Pak choi by calcium application

Pot trial, Loamy Sand, pH 6.2, initial Ca in soil solution ~100 mg/L
Calcium applied as Tropicote (19% Ca, 15.5 % N) at 3-4 leaf stage



Pak choi is an important Ca source for the human diet in Asia

REF: Yara (2005)

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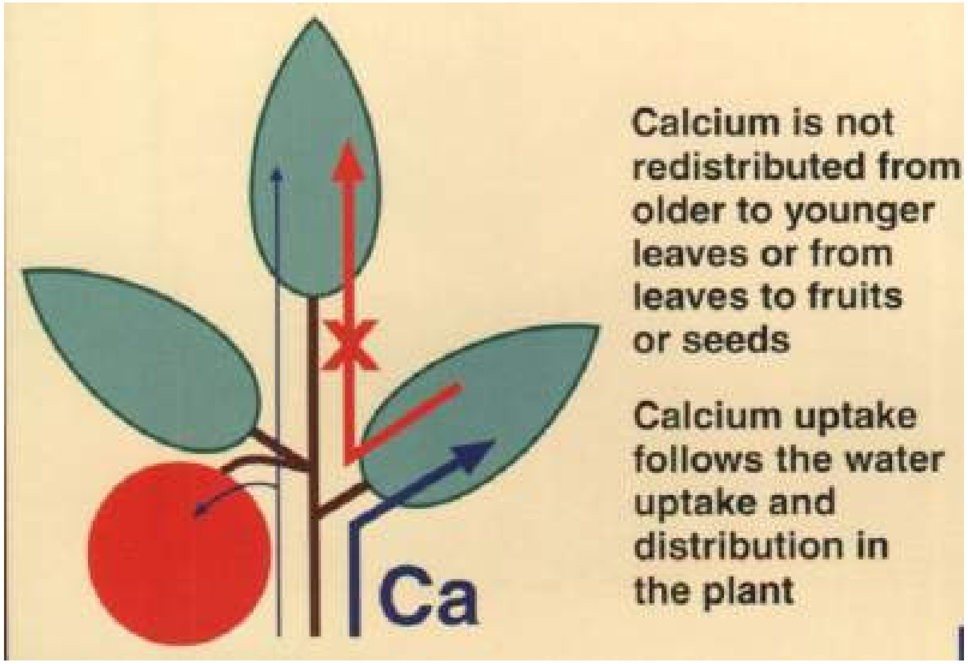
Calcium is mainly going to transpiring organs

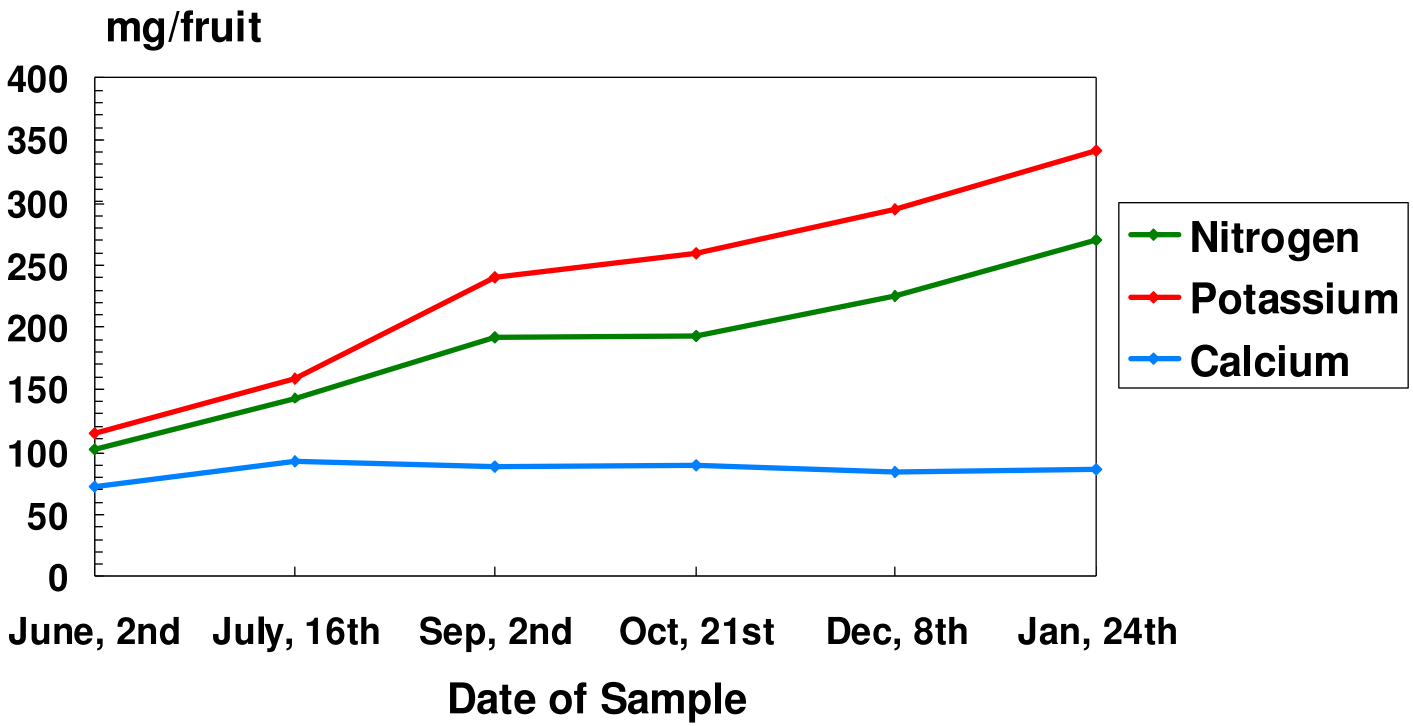


- Calcium transport in xylem
- Calcium is phloem immobile
- Fruits can show Ca deficiency even at soils tested high in Ca
- Fruit trees:

  Soil applied Ca should be concentrated pre-flowering

Why Calcium application pre-flowering?
Ca uptake from the soil into the fruits is low

- Valencia Oranges – Florida



(Northern hemisphere)

Source: Yara (1999)

Calcium timing is important: Tropicote™ during flowering increases yield of fruits, juice, solids

- Valencia Oranges – Florida
- During flowering: Ammoniumnitrate (90 kg/ha) or Tropicote™ (200 kg/ha); = 30 kg N/ha with both fertilizers !

Extra application (flowering)	Yield Boxes/ha	Fruit number/ha	Juice content [%]	Total juice [t/ha]	Solids [lbs/box]
No (control)	942	184 618	60.9	23.4	6.62
+ Ammonium Nitrate	939	190 269	61.6	23.6	6.81
+ Tropicote™ **(15.5-00-00+19%Ca)**	1059	224 703	62.5	27.1	6.94

REF: Yara (2002)

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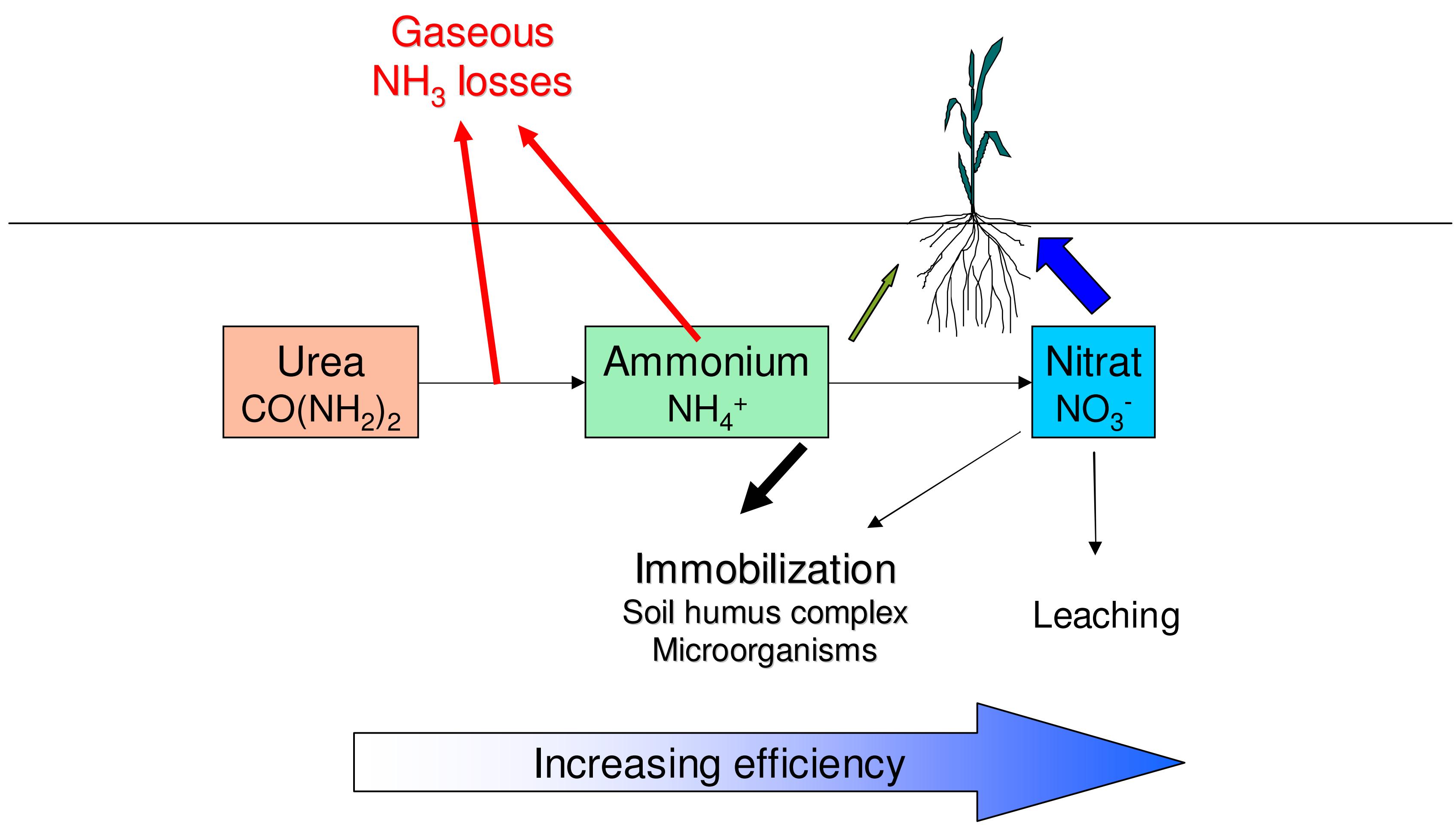
Nitrogen losses reduce the N supply for the crop and reduce the N use efficiency

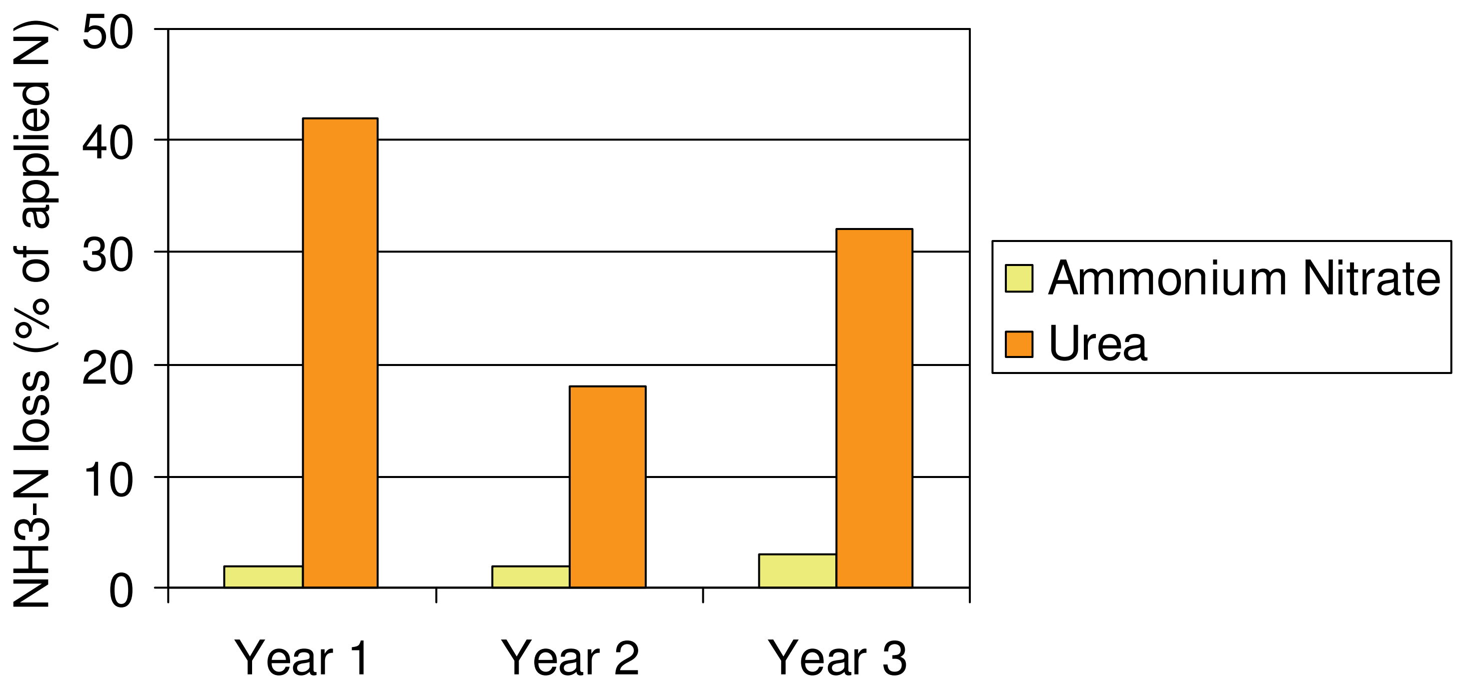


Nitrate has a high N use efficiency

- No volatile NH_3 losses
- No soil acidification
- Lower risk for phytotoxicity than Urea and ammonium
- Lower microbial immobilization versus ammonium and urea

NH_3 losses from Urea reduce the N availability

- N loss measurements in field trials - Valencia Oranges - Brazil

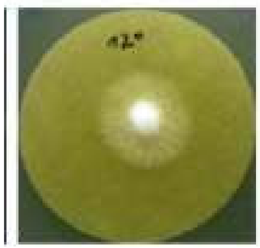


REF: Mattos Junior (2000)

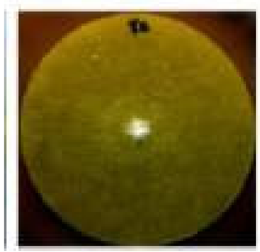
Preferential microbial immobilization of urea and ammonium vs. nitrate

Ammonium

Urea



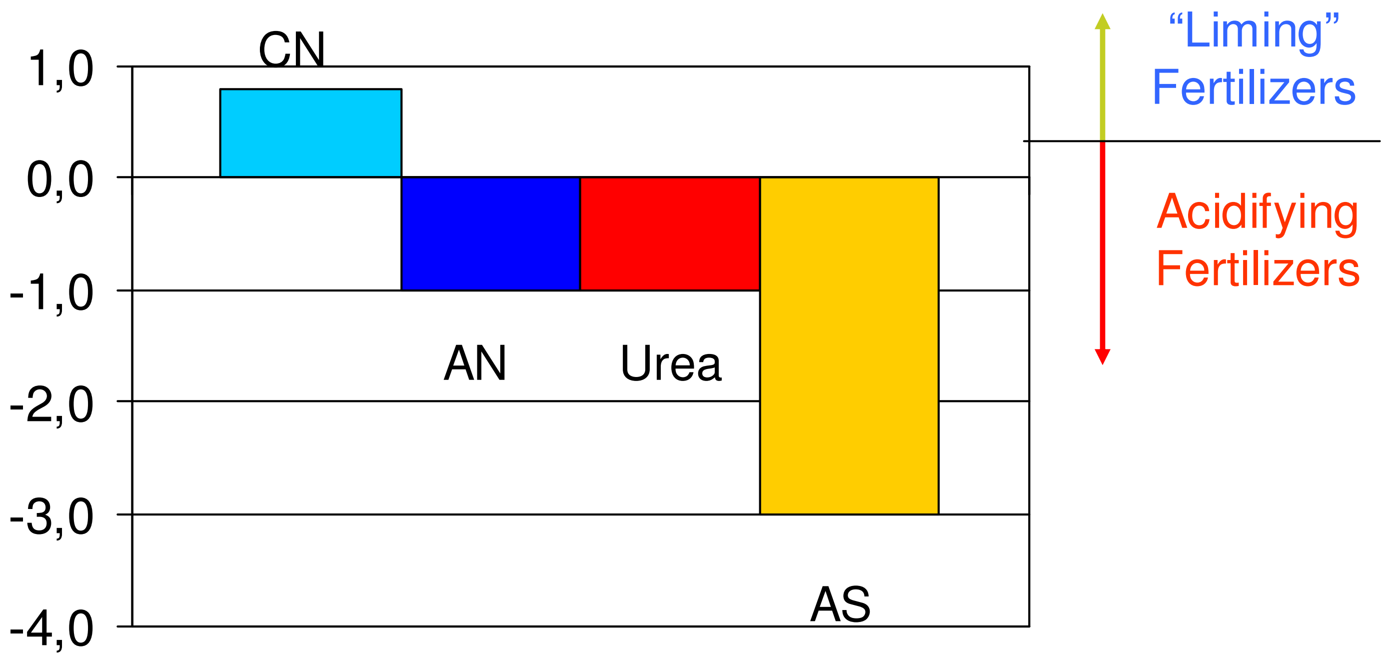
Nitrate



- 10 – 40% of fertilizer N is locked up by microbes until harvest
  - E.g. 11% in orange, Spain; 39% in corn, India
- Soil microbes grow better on urea & ammonium vs. nitrate
- More N available for crops with nitrate fertilizers
- Example: Laboratory trials with fungus Fus. oxysporum

No soil acidification from Nitrate

Lime consumption (kg CaO) per application of 1 kg Nitrogen

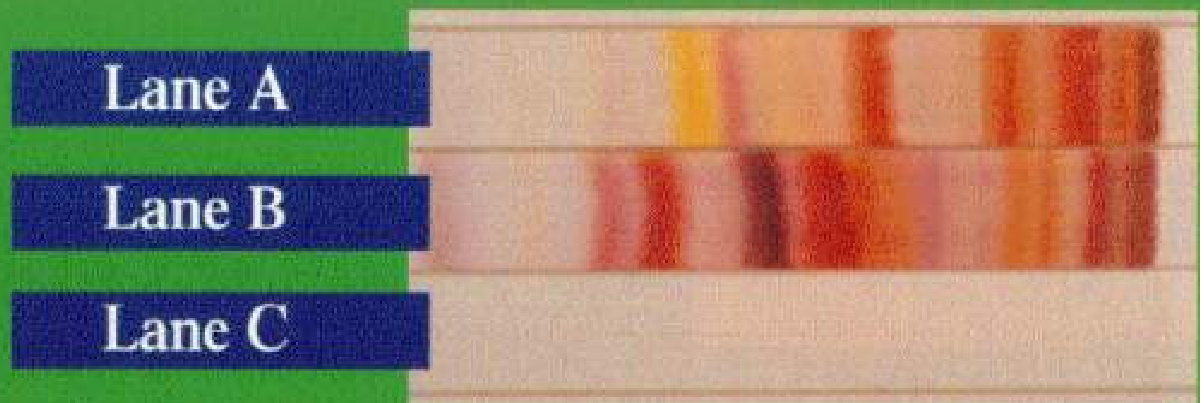


Important: most fungi grow best under acidic conditions

Fusarium solani causes fibrous root rot - No Fusarium toxins with Calciumnitrate

- Ammonium-containing fertilizers, including Ammonium Nitrate, support Fusarium growth

Fibrous root rot symptoms caused by Fusarium solani *in a citrus grove at Bartow, FL.*

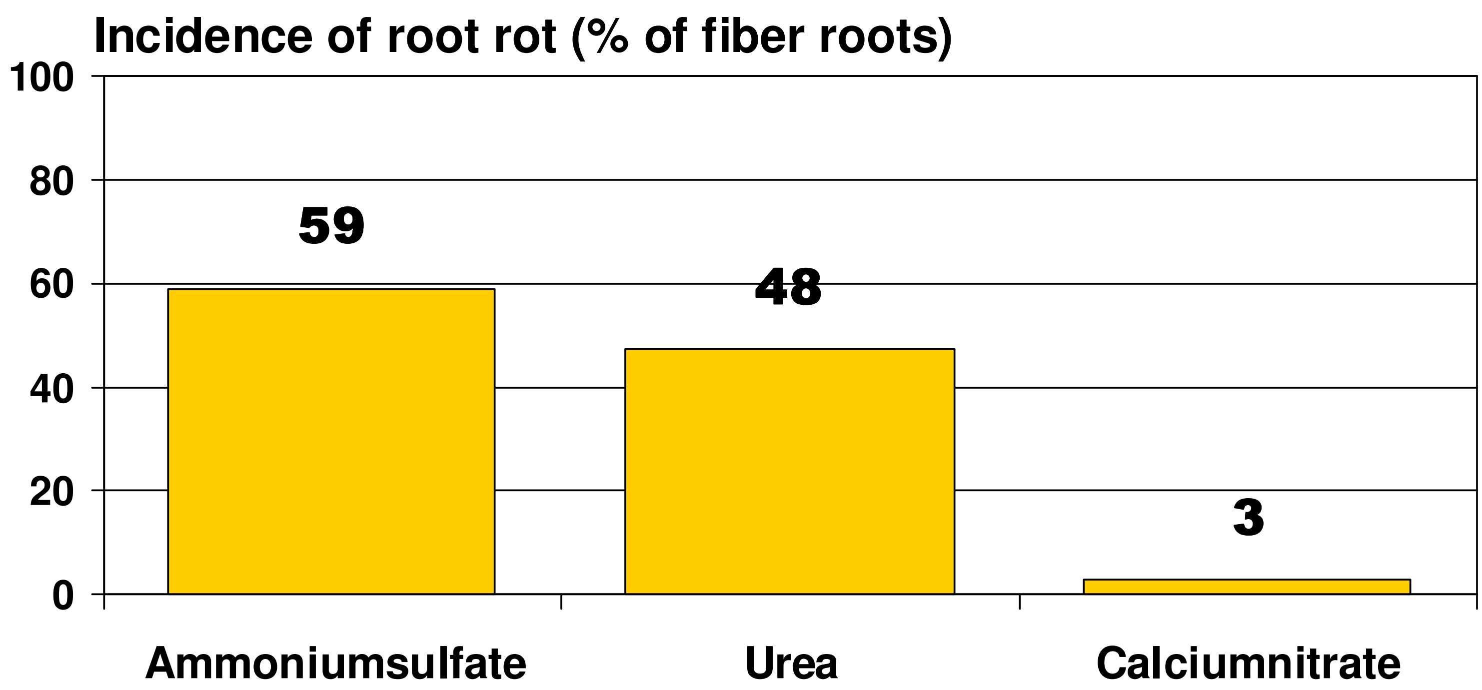


Fusarium *naphthazarium toxins extracted from cultures grown with ammonium nitrate (Lanes A and B) and cultures grown with Calcium Nitrate (Lane C), and developed on thin layer chromatography plates. Note the absence of toxin in the Calcium Nitrate-produced cultures.*

REF: Nemec (2000 - cited in “Quality Counts” [ed. Yara])

Calciumnitrate reduces citrus fiber root rot compared to urea and ammonium

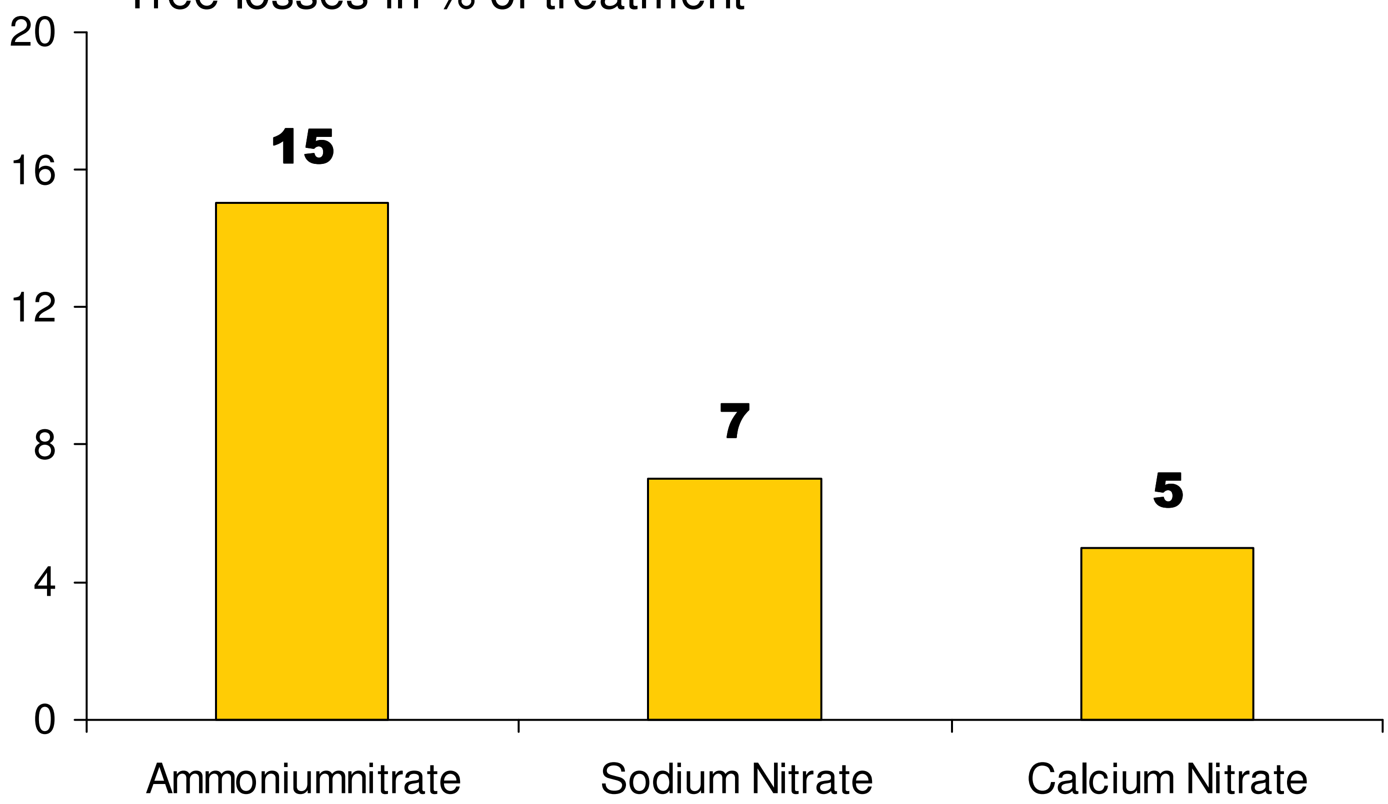
- ✓Pot experiment with seedlings of sweet Oranges ('Homosassa')
- ✓Phytophtora ssp. can cause root rot at fiber roots



REF: Klotz et al. (1958)

Nitrate reduces losses of young citrus trees by citrus blight

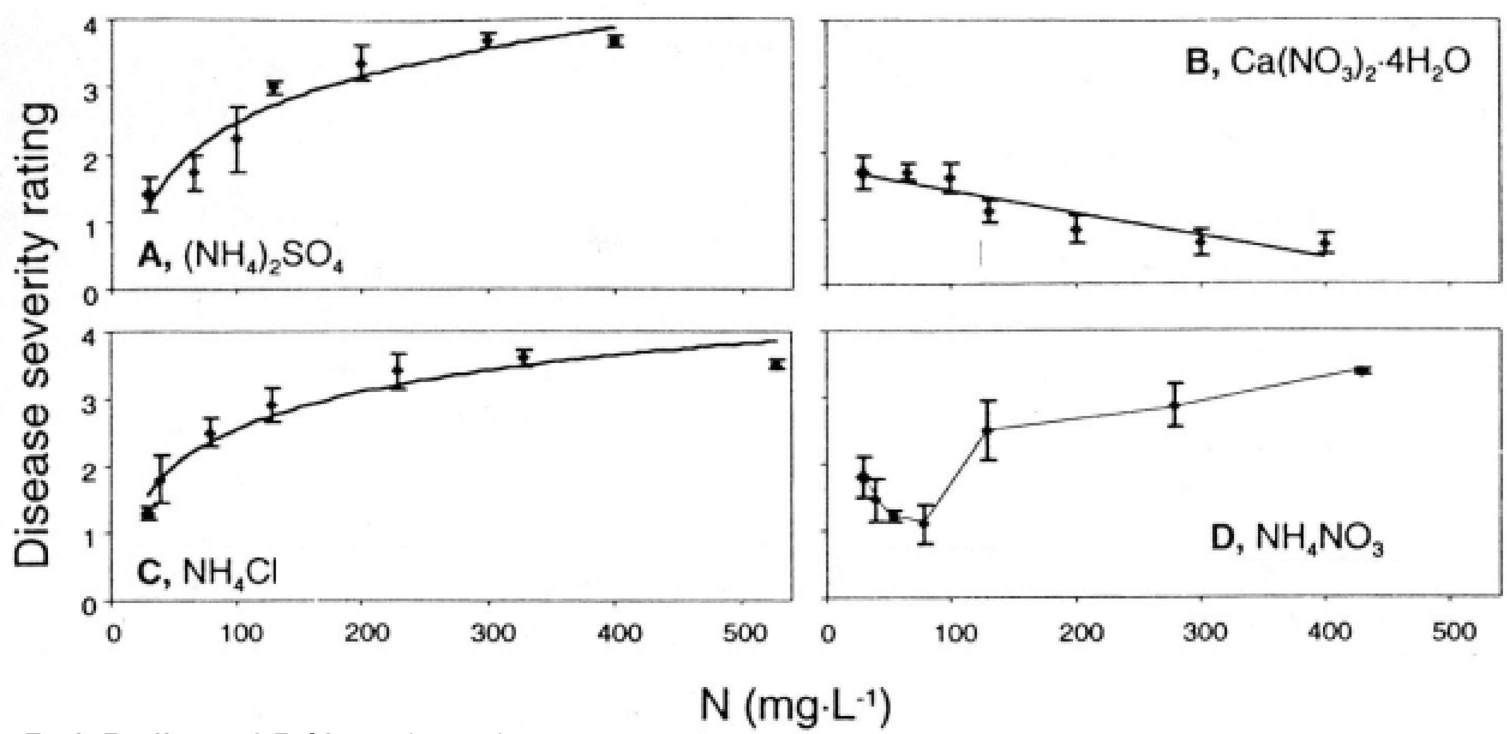
- Oranges, Florida



REF:
Seymour (1976)

Calciumnitrate reduces severity of Fusarium attack of tomatoes

- Nitrate inhibits sporulation and spore germination of *Fusarium oxysporum*
- Nitrate decreases the sensitivity of tomato to fusaric acid, a toxin released by the pathogen.

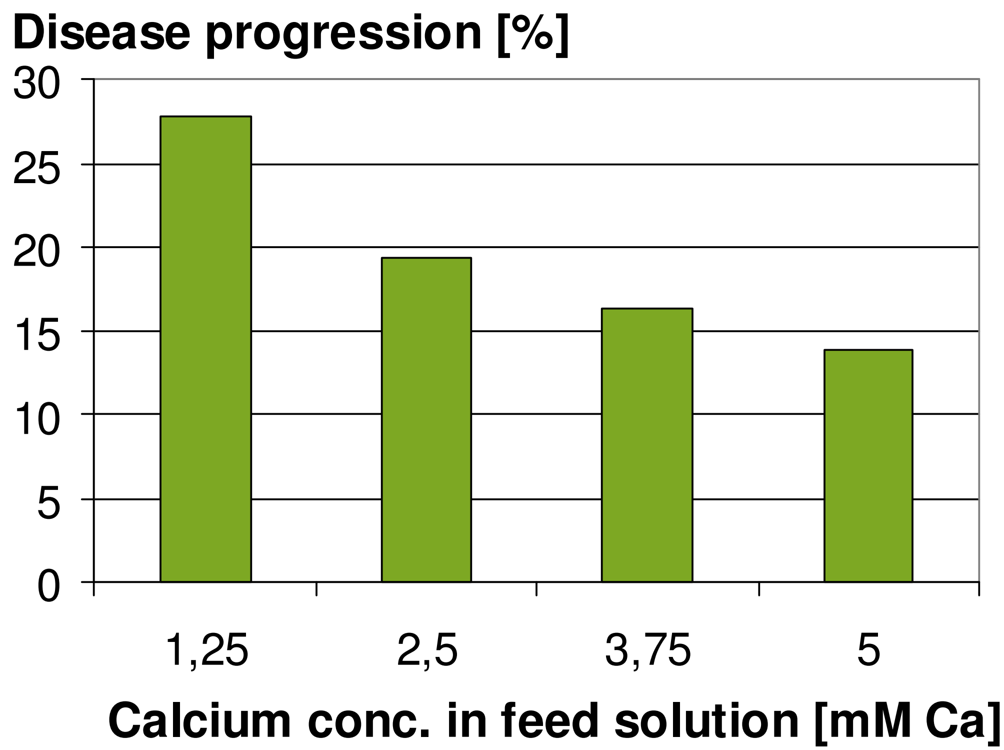


Ref: Duffy and Défago (1999)

Calcium effects on disease pressure:
Ca reduces the risk of grey mould in roses

Increasing calcium content in roses can significantly reduce susceptibility to
grey mould (botrytis)

Susceptibility to grey mould in rose



REF: Bar-Tal et al. (2001)

How does Calcium inhibit Botrytis growth?

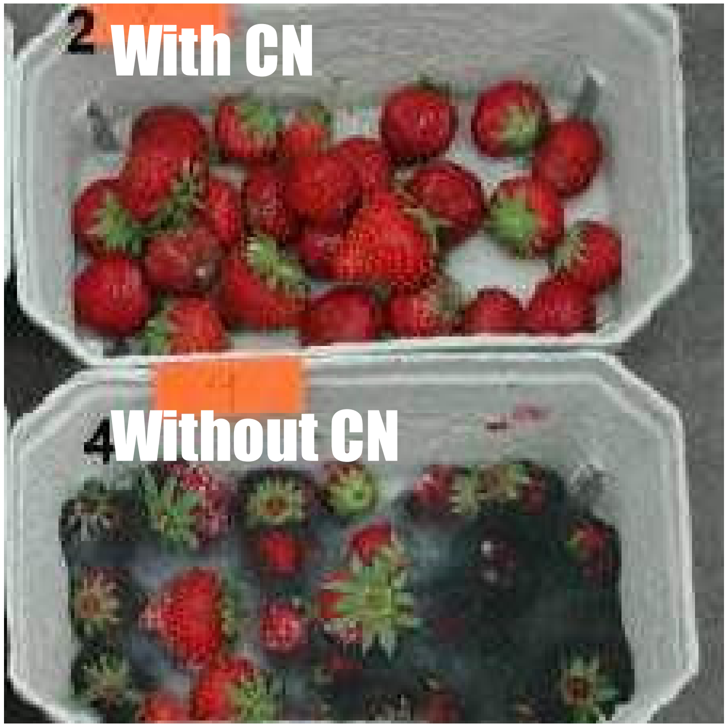
- Calcium may produces stronger plant cell walls, hence less solute leakage.
- Botrytis uses polygalacturonase enzymes to break down pectate, an important compound of the cell walls.
- In presence of Ca, the enzyme activity and hence the pectate breakdown is significantly reduced.

mMol Ca	Botrytis Enzyme activity	Botrytis Hyphal growth
0.0	0.43	3.4
0.5	0.19	4.0
3.0	0.0	2.0

REF: Volpin and Elad (1991)

Calciumnitrate reduces susceptibility to Botrytis

Strawberries – United Kingdom



Number of days before Botrytis occurs
Storage at 15^{O}C

% Botrytis	without CN	plus CN
25	3.1	3.7
50	4.8	5.6
75	6.7	7.8

Calcium is important to build strong cell walls, increasing the tolerance to botrytis (grey mould).

Ref : Yara (1997)

Calcium effects on disease pressure:
Calcium reduces Erwinia rot disease

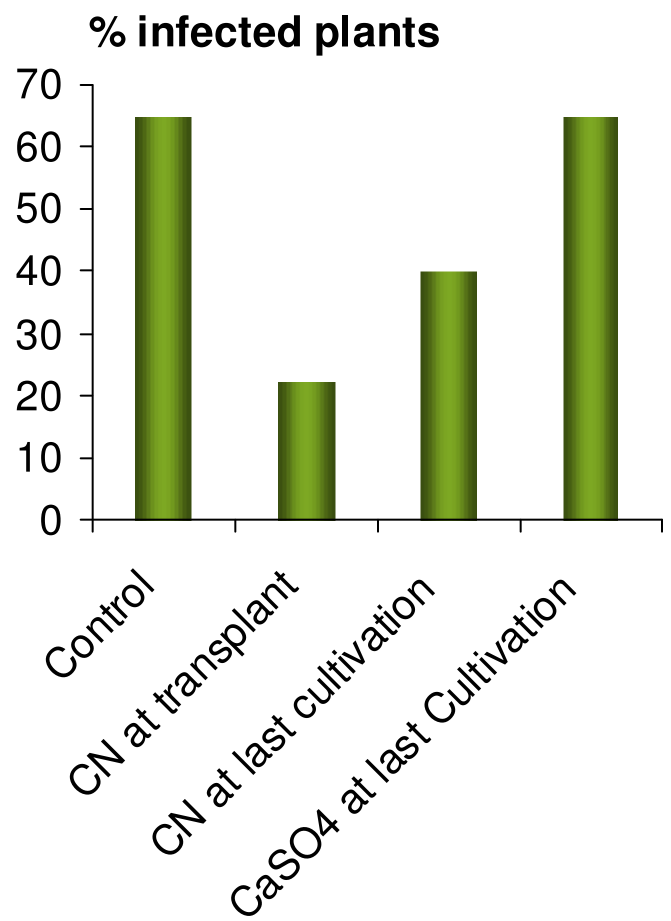
- Infection of host plant tissue depends on enzymes:
  - polygalacturonases
  - pectolytic enzymes
- Enzyme activity is reduced by Ca.

Erwinia rot in potatoes

Ca Content mg/g dry weight	Polygalacturonases activity	Pectolytic activity	*Erwinia carot,* symptoms *
6.8	62	7,2	4
16	48	4,5	4
34	21	0	0
*4=complete decay of plants within 6 days		0=no symptoms	
Platero and Tejerina, in Marschner (1995)			

Calciumnitrate improves disease resistance

Tomato



- Southern Blight (*Sclerotium rolfsii*)

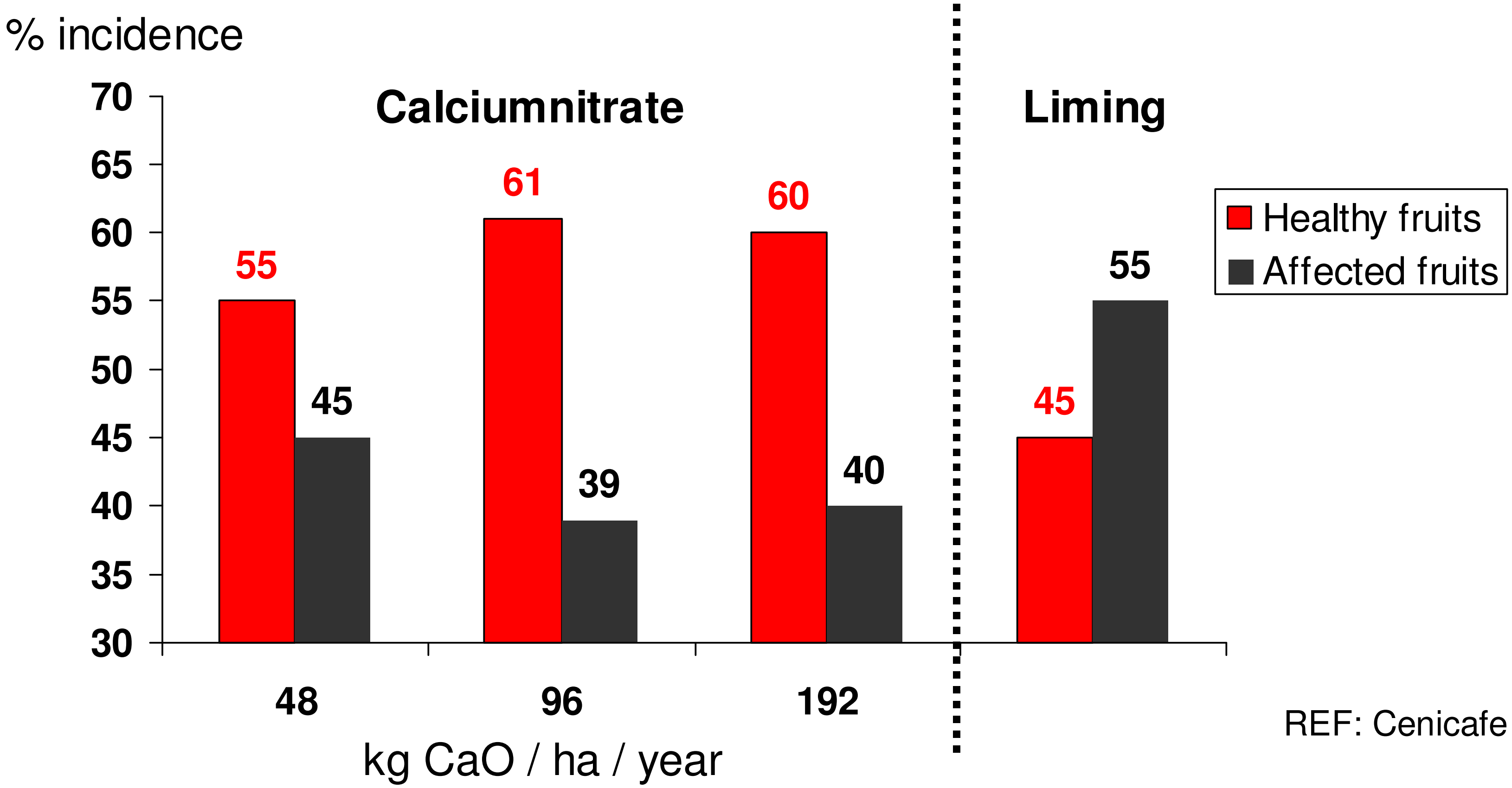
<u>The Calciumnitrate effect can be:</u>

- Calcium effect: readily available Ca from CN is more efficient than from less soluble $CaSO_4$
- Nitrate effect on soil pH or on reduced microbial growth
- Both, Calcium and Nitrate effect?

REF: Sitterly (1962)

Calciumnitrate reduces incidence of *Cercospora coffeicola*

Coffee - Colombia



REF: Cenicafe (2005)

All treatments with same total N rates (also valid for previous examples)

Part 2: Strategies to supply Calcium to the plant - Summary

- Application of lime ($CaCO_3$) is essential to establish an optimum soil pH for crop growth. Calcium delivery from lime is very slow
- Calcium from gypsum ($CaSO_4$) is more soluble and mobile in soil than lime
- Calciumnitrate ($Ca(NO_3)_2$) is the most soluble Ca source
- Because of that Calciumnitrate is the standard Ca source in fertigation
- Also rain-fed crops achieved higher yields with Calciumnitrate, especially if soluble Ca is needed in short periods of growth
- Examples are Calciumnitrate as a starter for cotton and Calciumnitrate for pre-flowering application to citrus (e.g. same approach works for coffee, too)
- Synergy effects of Calcium and Nitrate in reducing disease pressure:
  - Calcium strengthens the cell walls *(physical barrier against pathogens)*
  - Bad development of microbial pathogens on Nitrate compared to urea, ammonium or ammoniumnitrate *(no acidification, less microbial growth)*


YARA
Muito Obrigado