Silicon in fertigation

Wim Voogt

wim.voogt@wur.nl

www.glastuinbouw.wur.nl

WAGENINGEN UR
GREENHOUSE HORTICULTURE
BLEISWIJK THE NETHERLANDS

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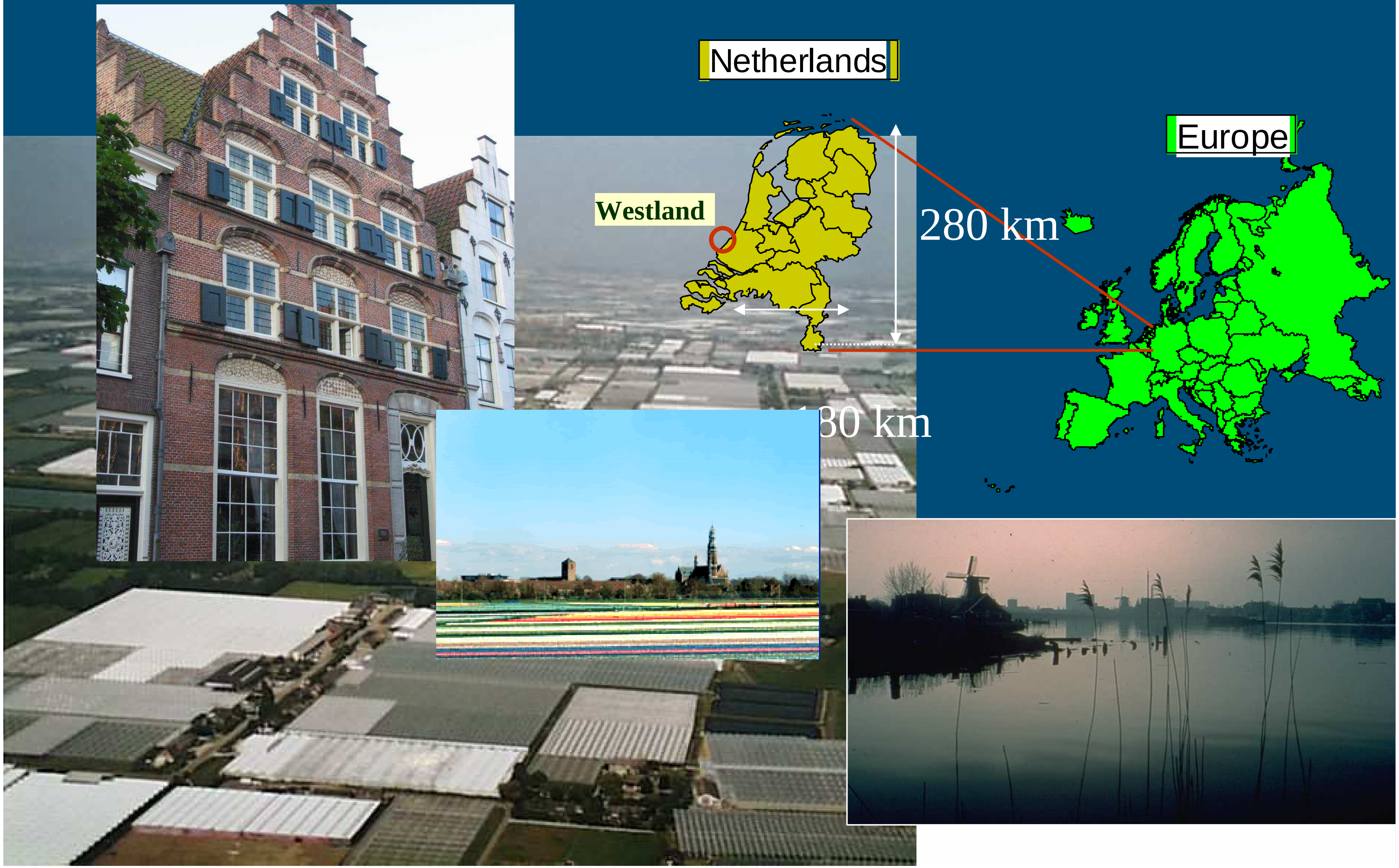
2. Si in horticulture
3. Si in the root environment
4. Si application in growing media
5. Si application in nutrient solutions
6. Performance of Si chemicals
7. Technical aspects
8. Experience in practice

Intensive horticulture in the Netherlands



Glasshouse horticulture

- 10 500 ha
- Production € 3.8 * 10^9
- Export € 2.9 *10^9

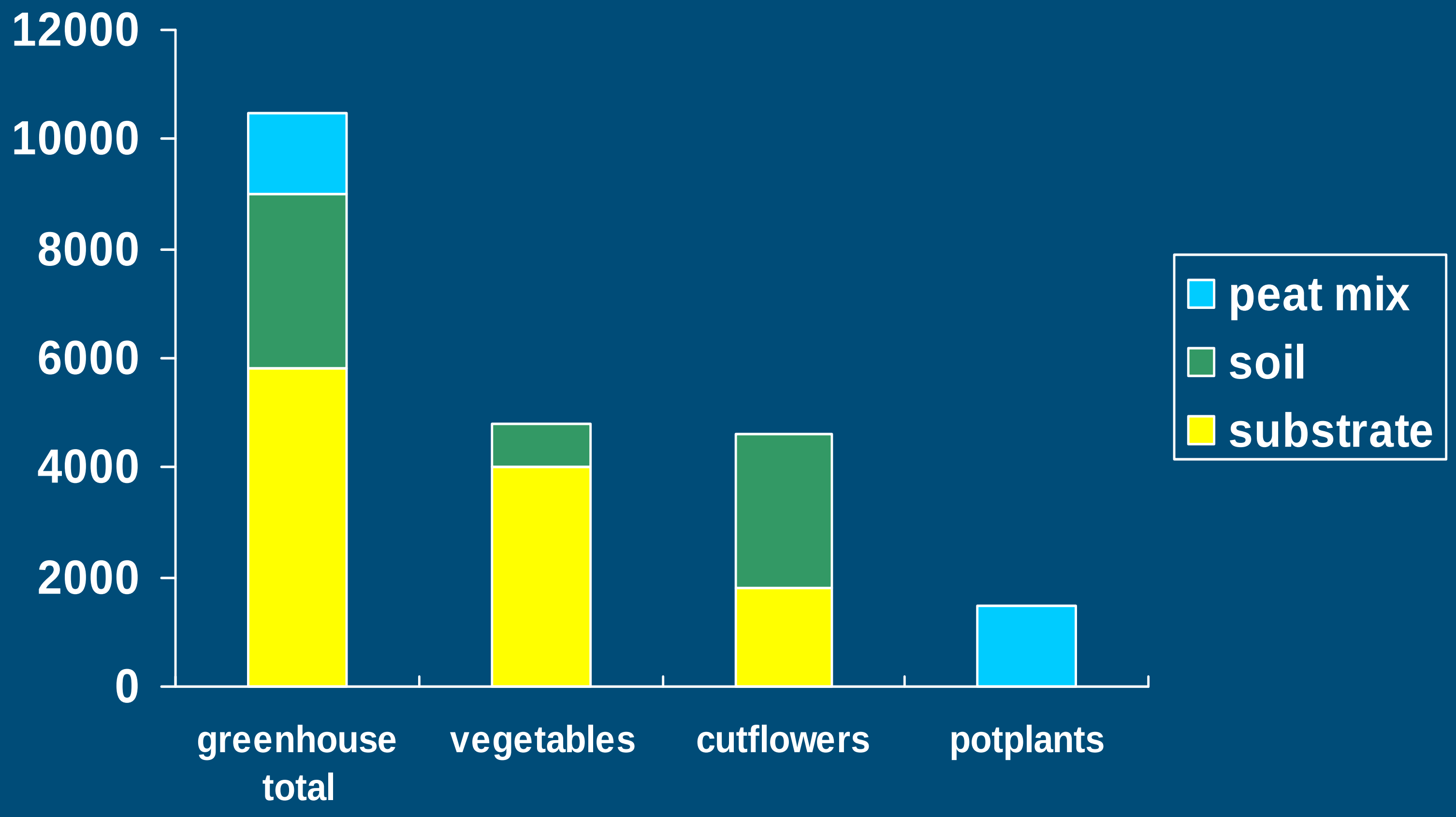
- Main crops
  - sweet pepper
  - tomato
  - cucumber
  - rose
  - chrysanthemum
  - bulb flowers








Proportion of soilless culture



Trends in Dutch Horticulture

- Increase of production scale/ intensity (units > 35 ha)
- Increasing costs (energy and labour)
- Higher demands society and consumers
- completely controllable and energy conservative greenhouses
- Systemintegration

2 Si in Horticulture

Beneficial effect of Silicon in horticulture

- Cucumber *(yield, powdry mildew)*
- Courgette *(powdry mildew)*
- Strawberry *(powdry mildew)*
- Rose *(yield powdry mildew)*
- Aster *(Aster ericoïdes)* *(powdry mildew)*
- St Paulia *(powdry mildew)*
- Lettuce *(manganese toxcicity)*

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Modern Horticulture

- Soil-less - Substrate – artificial media

Soilless culture

- Restricted volume
- High growth rate
- Closed growing systems
- adequate Si supply necessary

Methods of Si application

- In soil / amendments in growing medium
- Foliair application
- Side dressings / Fertigation

3 Si in the root environment

Greenhouse soils

	Cucumber		Rose	
	Soil sample	Tissue sample	Soil sample	Tissue sample
Plot	Si mmol l^{-1}	Si mmol kg^{-1}	Si mmol l^{-1}	Si mmol kg^{-1}
1	0.51	280	1.14	58
2	0.68	445	0.42	51
3	0.48	356	0.28	84
4	0.85	295	0.65	42
5	0.74	384	0.55	89

Figure 6 Si content in the soil extract (1:2 volume extract) and in cucumber plant tissue, collected at some greenhouse nurseries

Sufficient ?

Si in growing media: total quantity and (potential) release

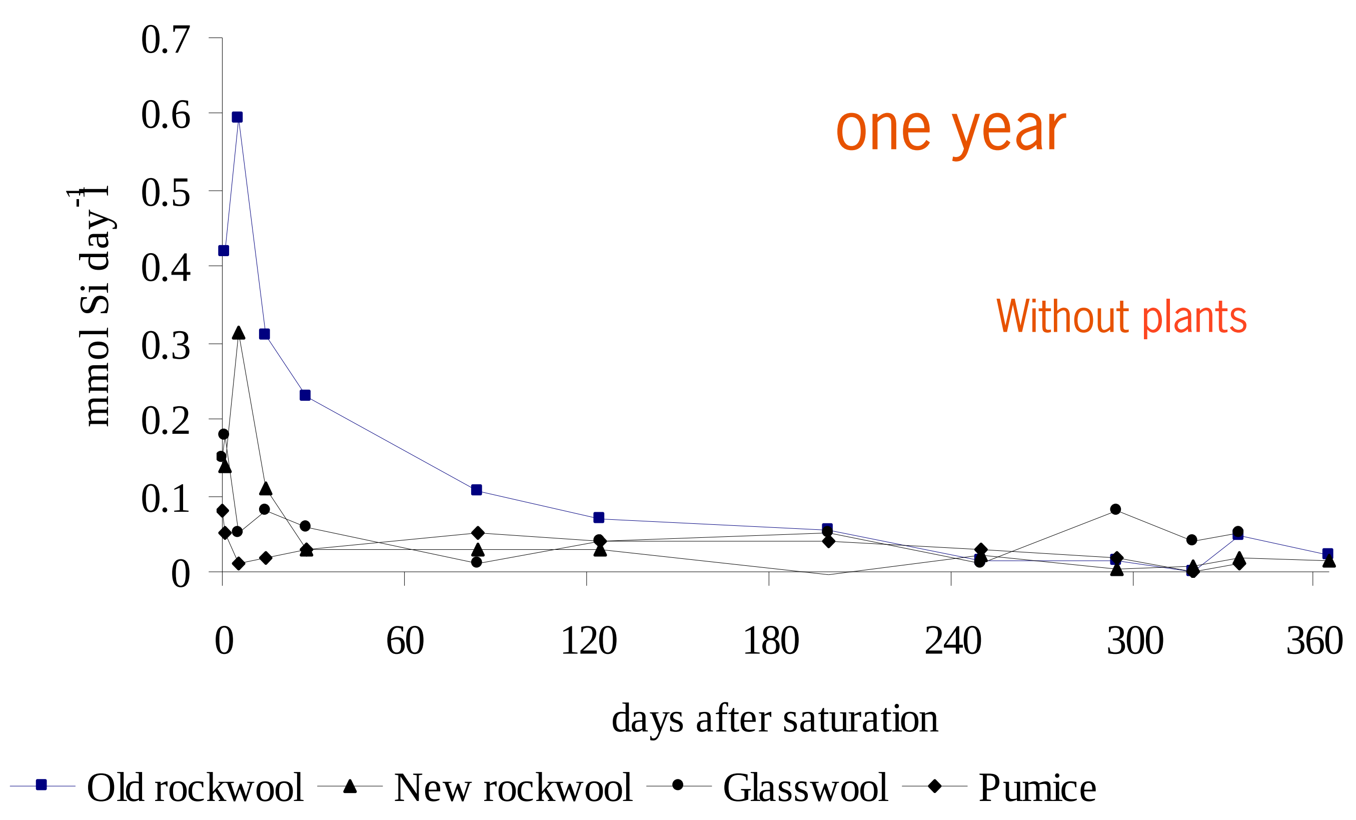
Medium	Total Si mmol kg^{-1} min	max	Si concentration)* mmol l^{-1} average	min	max
Mineral					
Rockwool new slab	7200	8000	0.2	0.1	0.4
Rockwool old slab	7200	8000	0.3	0.1	0.7
Glasswool	13300	15000	0.1	0.0	0.2
Perlite	11600	13500	0.1	0	0.2
Pumice stone	7500	8400	0.1	0.1	0.3
Expanded clay	8500	9500	0	0	0

) Saturation three times water holding capacity according to standard CEN method (Kipp et al. ; 2000)*

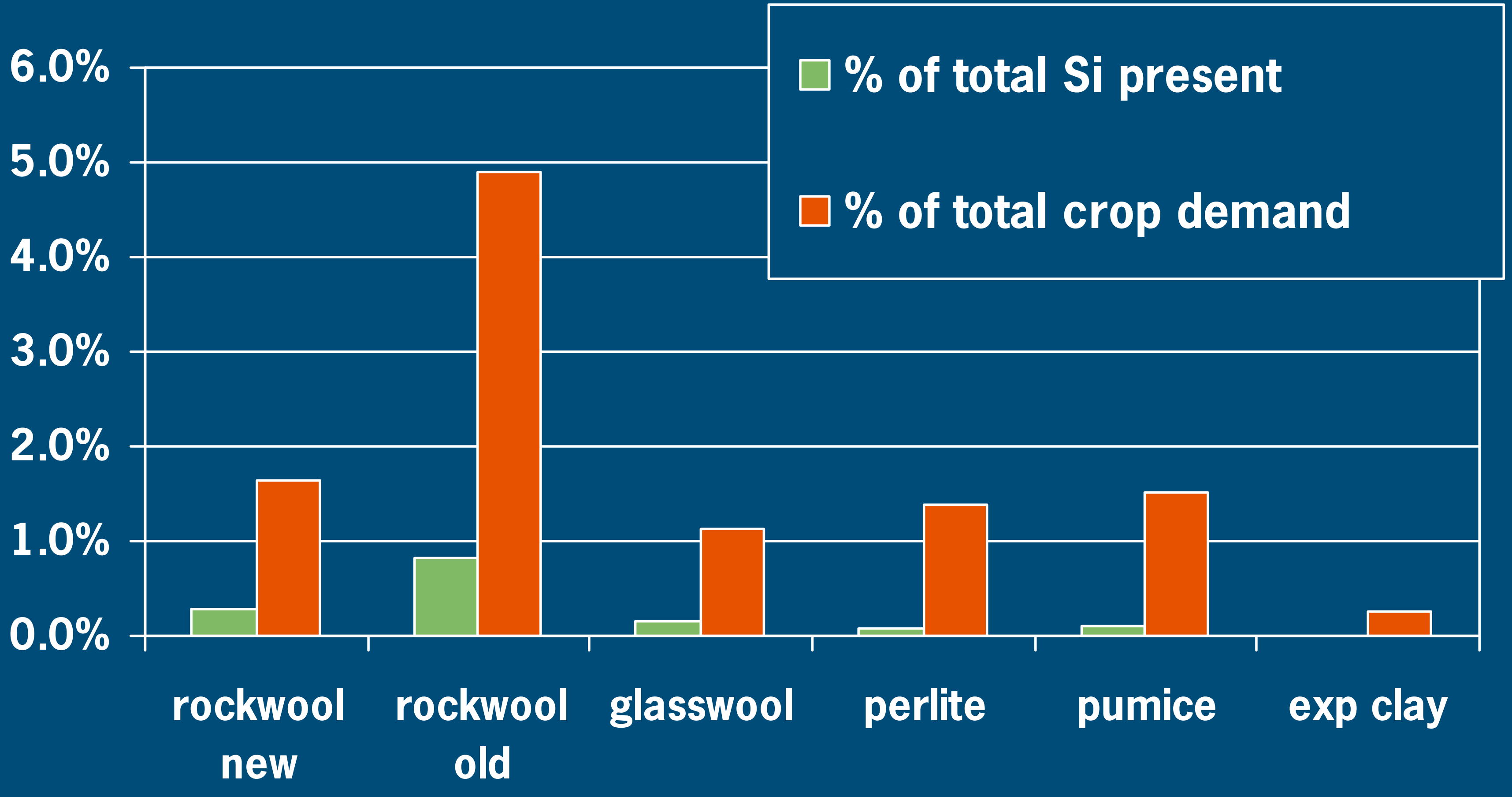
Si in growing media II

Medium	Total Si mmol kg^{-1}		Si concentration)* mmol l^{-1}		
	min	max	average	min	max
Organic					
Wood fibre	100	1800	0.1	-	-
Peat	15	220	0.1	0.0	0.2
Bark	76	850	0.1	-	-
Rice Hull	2200	2600	0.8	1.1	2.5
Compost	2000	4500	0.2	0.1	0.7
Coir chips	1200	1250	0.0	-	-
Coir dust	1200	1250	0.1	-	-
Artificial					
Polyurethane	0	0			

Si release from substrates



Relative release of Si from growing media



4 Si application in growing media

Substrate amendments

- Substrate / potting soil mixtures
  - Rice hull
  - Compost
  - Clay
  - Calcium silicate slag
  - Silicate limestone

Substrate mixtures

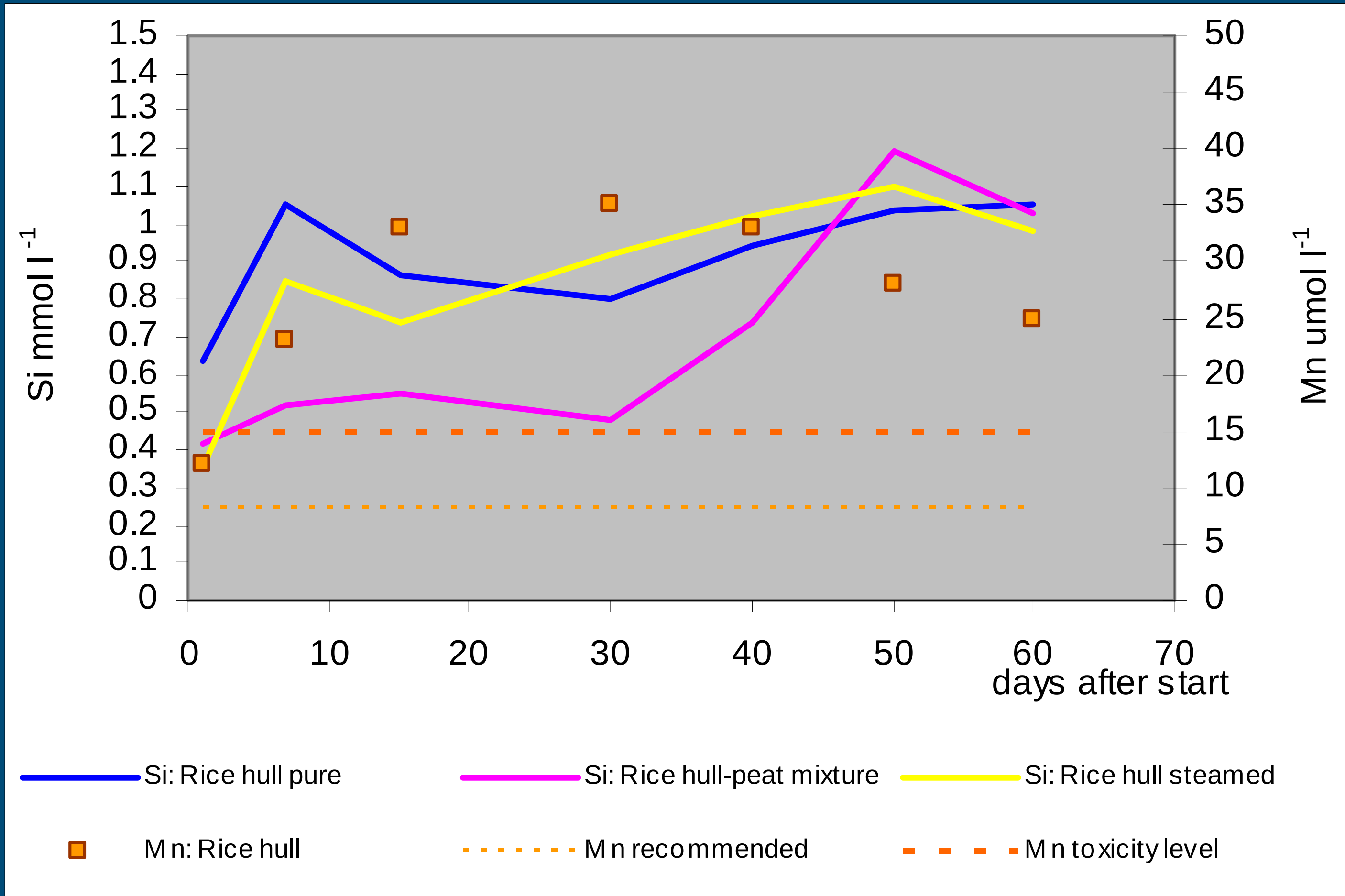
- Rice hull

Rice Hull

Medium	Total Si mmol kg^{-1} min	max	Si concentration)* mmol l^{-1} average	min	max
Organic					
Wood fibre	100	1800	0.1	-	-
Peat	15	220	0.1	0.0	0.2
Bark	76	850	0.1	-	-
Rice Hull	2200	2600	0.8	1.1	2.5
Compost	2000	4500	0.2	0.1	0.7
Coir chips	1200	1250	0.0	-	-
Coir dust	1200	1250	0.1	-	-
Artificial					
Polyurethane	0	0			

)* *As extracted by 1:1.5 volume extract*

Silicon release from rice hull substrate



Silicate amendments

- Limestone Si
- Silicate slag

Table 2 Si concentrations in the soil solution, the leachate and in the tissue of cucumber plants in a control treatment, a treatment with Si in the nutrient solution and two levels of Silica slag ('bermix') in potting soil (Voogt and van Winkel, 2005).

	Treatment			
	Control 0 Si	Si in nutrient solution 1.5 mmol l^{-1}	Bermix 0.5 kg m^{-3}	Bermix 2.5 kg m^{-3}
Si Peat soil mmol l^{-1} (1:1.5 volume extract)	0.05	0.35	0.22	0.25
Si Leachate mmol l^{-1}	0.12	1.44	0.59	0.74
Plant weight g $plant^{-1}$	100	99	99	101
Si plant tissue mmol kg^{-1} d.m.	22	602	663	700

Effect of different Si sources and application methods on yield, Si in root environment and Si in the plant

Treatment	Yield	Si Root environment		Si tissue	
		2 months	6 months	3 months	6 months
Control, zero Si	38.2[a]	0.12	0.15	68	125
Si supplied in nutrient solution	40.1[b]	0.41	0.68	425	625
Rice hull-peat mixture	36.1[c]	0.75	0.48	459	602
Slab with silica gel	38.9[a,b]	0.63	0.25	380	420
Prepared slab	39.2[a,b]	0.38	0.32	289	302

5 Si in fertigation

Si in the nutrient solution

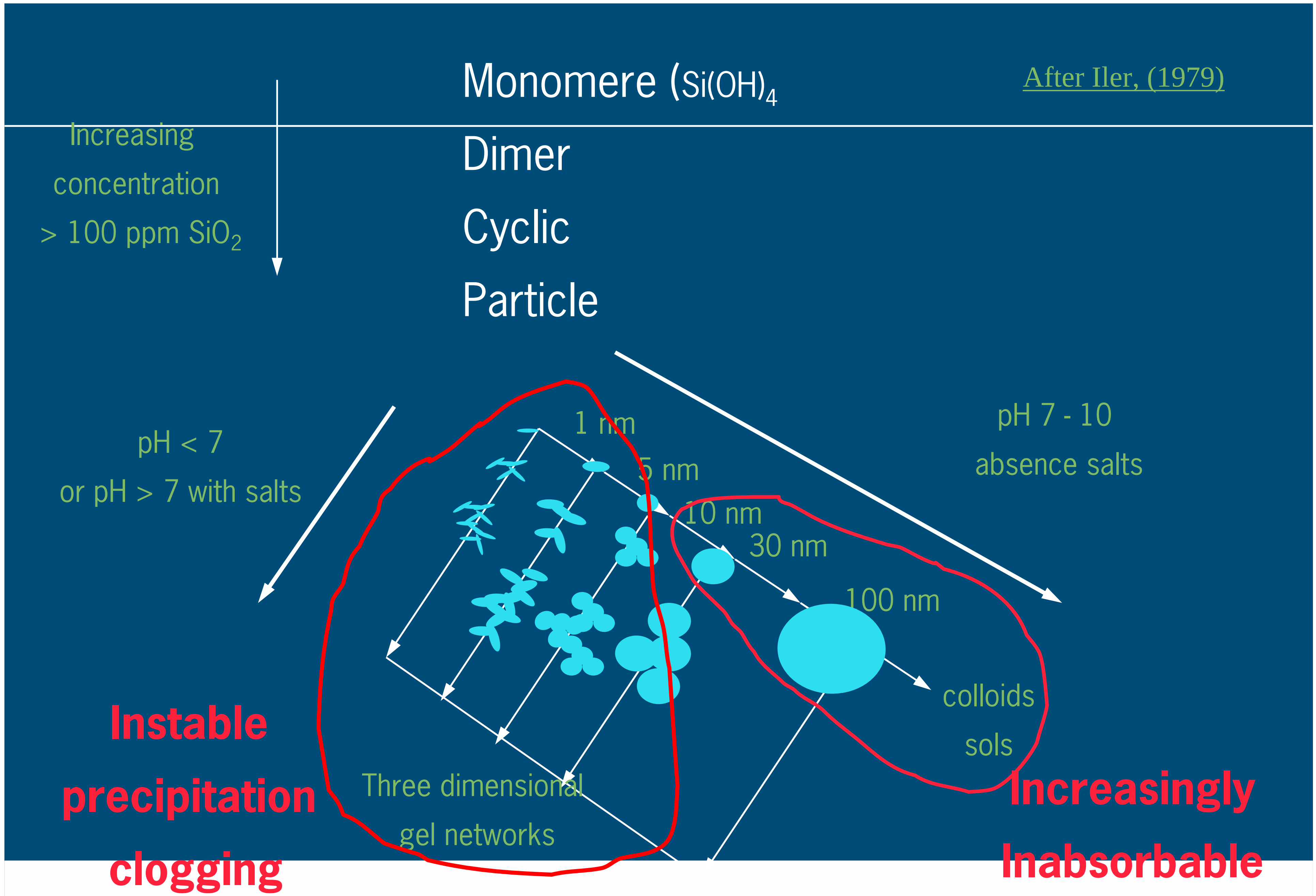
i.e. Fertigation

- Controlled supply
- Fits with fertilizer supply

Preconditions Si fertilizers

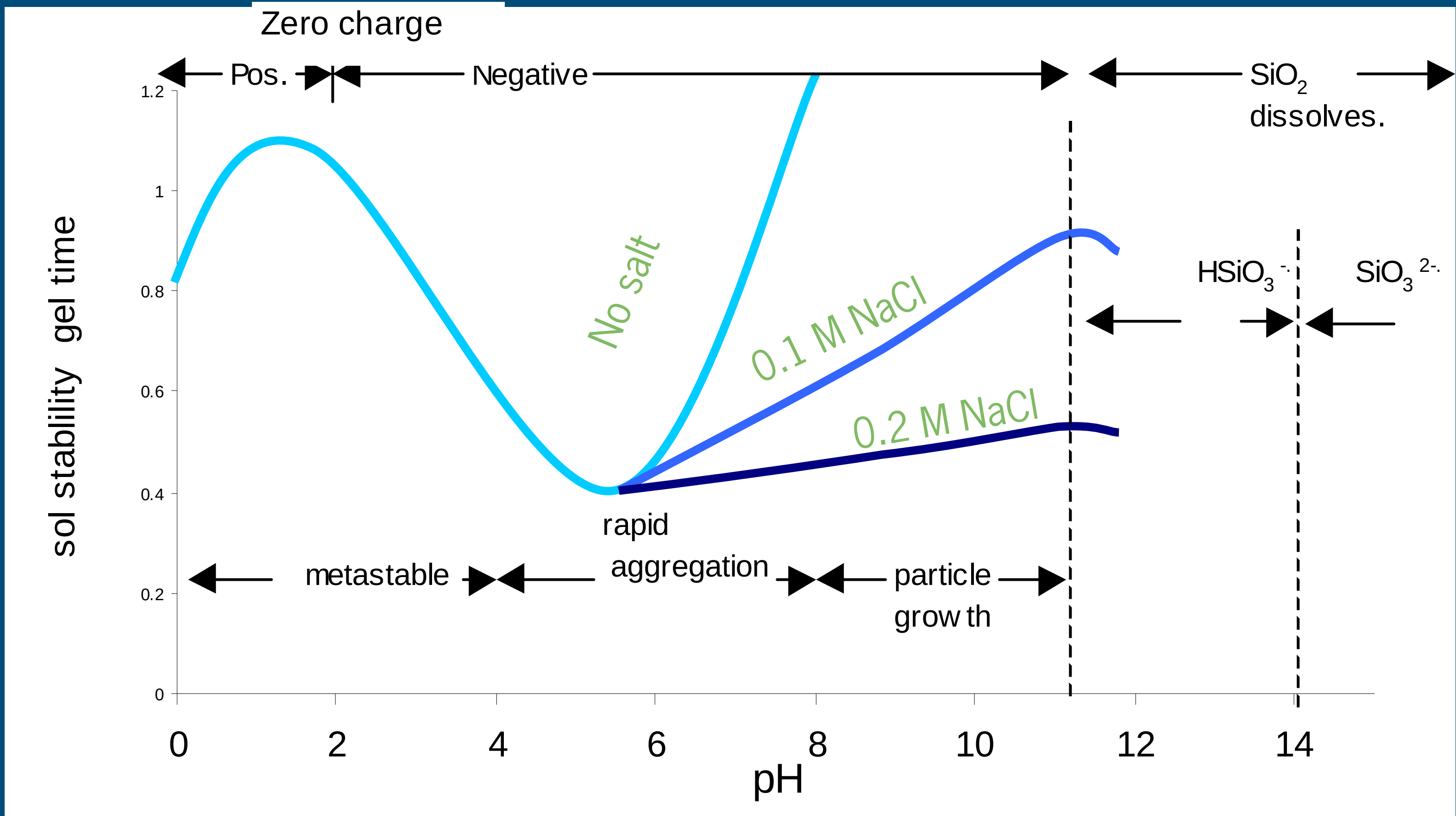
- Completely soluble
- Stable in nutrient solution
  - in stock solution
  - in nutrient solution supplied
  - in root environment
- Applicable in fertiliser supply system
- pH under control
- No interference with other nutrients
- not expensive

Chemical aspects of silicon in solution



Monomere (Si(OH)4
After Iler, (1979)
Increasing
concentration
> 100 ppm SiO2
Dimer
Cyclic
Particle
pH < 7
or pH > 7 with salts
1 nm
5 nm
10 nm
30 nm
100 nm
pH 7 - 10
absence salts
colloids
sols
Three dimensional
gel networks
Instable
precipitation
clogging
Increasingly
Inabsorbable

Effect of pH in the colloidal silica water system,
(after ***Iler*** *, 1979) The chemistry of silica)*



Candidate soluble silicon sources

Si source/compound	
Li_2SiO_3	monomeric $Si(OH)_4$
Na_2SiO_3	monomeric $Si(OH)_4$
K_2SiO_3	monomeric $Si(OH)_4$
Waterglass	oligomeric
Silica sol	colloidal silica
Silica sol	colloidal silica
Silica sol	colloidal silica

Plant recovery

Si source/compound		particle size	Si content mmol kg^{-1} dry matter
Rainwater		-	60
Well-water		-	210
Li_2SiO_3	monomeric $Si(OH)_4$	-	308
Na_2SiO_3	monomeric $Si(OH)_4$	-	392
K_2SiO_3	monomeric $Si(OH)_4$	-	368
Waterglass	oligomeric	-	420
Silica sol	colloidal silica	10 nm	177
Silica sol	colloidal silica	15 nm	75
Silica sol	colloidal silica	20 nm	45

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Li_2SiO_3	monomeric $Si(OH)_4$	-	308
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Silica sol	colloidal silica	20 nm	45

Problem of clogging

Effect of Si form on clogging of the trickle irrigation system in a long-term trial with rockwool grown cucumber. Average water delivery (l m^{-2} hr^{-1}) and variation coefficient (V.C.) of the trickle nozzles after 6 months and the number of necessary cleanings.

Treatment		Average water delivery l m^{-2} hr^{-1}	V.C.	total cleanings
No silicon		1.6	9.3	4
Potassium waterglass	1.5 mM	1.1	17.3	11
Potassium metasilicate	1.5 mM	1.5	6.6	5
Silica sol	1.5 mM	1.5	8.4	4
Silica sol	3.0 mM	1.5	14	5

Effect of Si on the yield of cucumber, as found in six consecutive experiments with and without application of Si using different Si sources and with different cropping periods, P value for the total yield (kg m^{-2}).

Experiment	Yield							Si		Remarks
	- Si			+ Si						
	fruits m^{-2}	kg m^{-2}	fruit weight g	fruits m^{-2}	kg m^{-2}	fruit weight g	P	source	supply mmol l^{-1}	
1		32.6			33.4		n.s.	Silica sol	1.5	Poor Si uptake
2		28.9			29.4		n.s.	waterglass	1.5	Severe clogging
3		33.4			39.4		< 0.05	waterglass	1.5	clogging
4		32.4			36.1		< 0.05	waterglass	1.0	clogging
5		31.8			36.8		< 0.05	K_2SiO_3	1.0	
6		8.2			10.9		<0.05	K_2SiO_3	0.75	short autumn crop, severe mildew

Si source/compound		particle size	Si content mmol kg^{-1} dry matter
Li_2SiO_3	monomeric $Si(OH)_4$	-	308
Na_2SiO_3	monomeric $Si(OH)_4$	-	392
K_2SiO_3	monomeric $Si(OH)_4$	-	368
Waterglass	oligomeric	-	420
Silica sol	*colloidal silica*	*10 nm*	*177*
Silica sol	*colloidal silica*	*15 nm*	*75*
Silica sol	*colloidal silica*	*20 nm*	*45*

“undesired” components

- Lithiumsilicate = toxic effects
- Sodiumsilicate: to much Na

Si source/compound		particle size	Si content mmol kg^{-1} dry matter
Li_2SiO_3	monomeric $Si(OH)_4$	-	308
Na_2SiO_3	monomeric $Si(OH)_4$	-	392
K_2SiO_3	monomeric $Si(OH)_4$	-	368
Waterglass	*oligomeric*	-	*420*
Silica sol	*colloidal silica*	*10 nm*	*177*
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Na_2SiO_3	*monomeric $Si(OH)_4$*	-	*392*
K_2SiO_3	**monomeric $Si(OH)_4$**	**-**	**368**
Waterglass	*oligomeric*	-	*420*
Silica sol	*colloidal silica*	*10 nm*	*177*
Silica sol	*colloidal silica*	*15 nm*	*75*
Silica sol	*colloidal silica*	*20 nm*	*45*

Potassium meta silicate

- $Si(OH)_4$ + KOH molar ratio 1 : 2
  - uptake efficient
  - stable
    - transport and storage
    - nutrient solution……. ?
    - root environment →
  - fit in fertiliser system +/-
  - other elements K
  - relatively expensive

Supply in nutrient solutions

- Practical implications
  - Introduction in the nutrient solution
  - high pH (KOH)
  - Potassium input

Performance trials : cucumber

Effect of Si supply on Si concentrations in the root environment (RE), on yield (fruits m^{-2}, kg m^{-2} , fruit weight) and on tissue contents of cucumber grown in rockwool.

	Supply	Root	Yield				Tissue contents		
		Environment	fruits	kg	fruit	%	young	old	fruits
	mmol l^{-1}	mmol l^{-1}	m^{-2}	m^{-2}	weight g	1st class	laminae	laminae	
1	0	0.04	75^{a}	33.4^{a}	444^{a}	97^{a}	84	244	20
2	0.5	0.47	89^{b}	40.1^{b}	448^{a}	94^{a}	347	665	55
3	1.0	0.95	87^{b}	39.4^{b}	455^{a}	95^{a}	544	1114	78
4	2.0	1.71	88^{b}	39.6^{b}	450^{a}	95^{a}	691	1419	118
5	4.0	2.37	86^{b}	38.4^{b}	448^{a}	95^{a}	776	1421	110

Yield components in each column followed by the same letter are not significantly different according to Duncan's multiple range test at $P < 0.05$

However:

Bloom !

Performance trials: Rose

Si concentration			Yield			Si content laminae mmol kg^{-1} d.m.	
	Supply	R.E.	Stems m^{-2}	stem weight g	kg m^{-2}	young	old
- Si	0.02	0.06	144	40	5.8	32	69
+ Si	0.7	1.6	159	38	6.0	108	220

7 Technical aspects of Si fertilizer application

Nutrient solution calculation

Basic composition in mmol l^{-1}

		NH_4	K	Ca	Mg	NO_3	SO_4	H_2PO_4
	mmol l-1	1.25	8	4	1.375	16	1.375	1.25
Fertiliser								
KH_2PO_4	1.25		1.25					1.25
$Ca(NO_3)_2$	4			4		8		
NH_4NO_3	1.25	1.25				1.25		
$MgSO_4$	1.375				1.375		1.375	
KNO_3	6.75		6.75			6.75		

Fertilizer recipe

Fertiliser formula for concentrated stock tanks

	1 m3	*100 times concentrated*		
A tank				
Calciumnitrate	72 kg			
Ammoniumnitrate *(liquid)*	19.5 kg	or	15.7	l
B tank				
Monopotassiumphosphate	17 kg			
Magnesiumsulphate	33.4 kg			
Potassiumnitrate	68 kg			

Fitting in silicon fertilizer

		NH_4	K	Ca	Mg	NO_3	SO_4	H_2PO_4	Si	OH
	mmol l-1	1.25	8	4	1.375	16	1.375	1.25		
Fertiliser										
KH_2PO_4	1.25		1.25					1.25		
$Ca(NO_3)_2$	4			4		8				
NH_4NO_3	1.25	1.25				1.25				
$MgSO_4$	1.375				1.375		1.375			
KNO_3	6.75		6.75			6.75				
$Si(OH)_2$ + KOH	0.75		1.5						0.75	1.5
		1.25	**9.5**	4	1.375	16	1.375	1.25	0.75	**1.5**

Settlement base - acid

		Standard composition									
		NH_4	K	Ca	Mg	NO_3	SO_4	H_2PO_4	Si	*OH^-*	*H^+)**
fertiliser	mmol l-1	1.25	8	4	1.375	16	1.375	1.25	0.75		
pot. meta silicate KOH +$Si(OH)_2$	0.75		1.5						0.75	***1.5***	
HNO_3	1.5					1.5					***1.5***
KH_2PO_4	1.25		1.25					1.25			
$Ca(NO_3)_2$	4			4		8					
NH_4NO_3	1.25	1.25				1.25					
$MgSO_4$	1.375				1.375		1.375				
KNO_3	5.25		5.25			5.25					

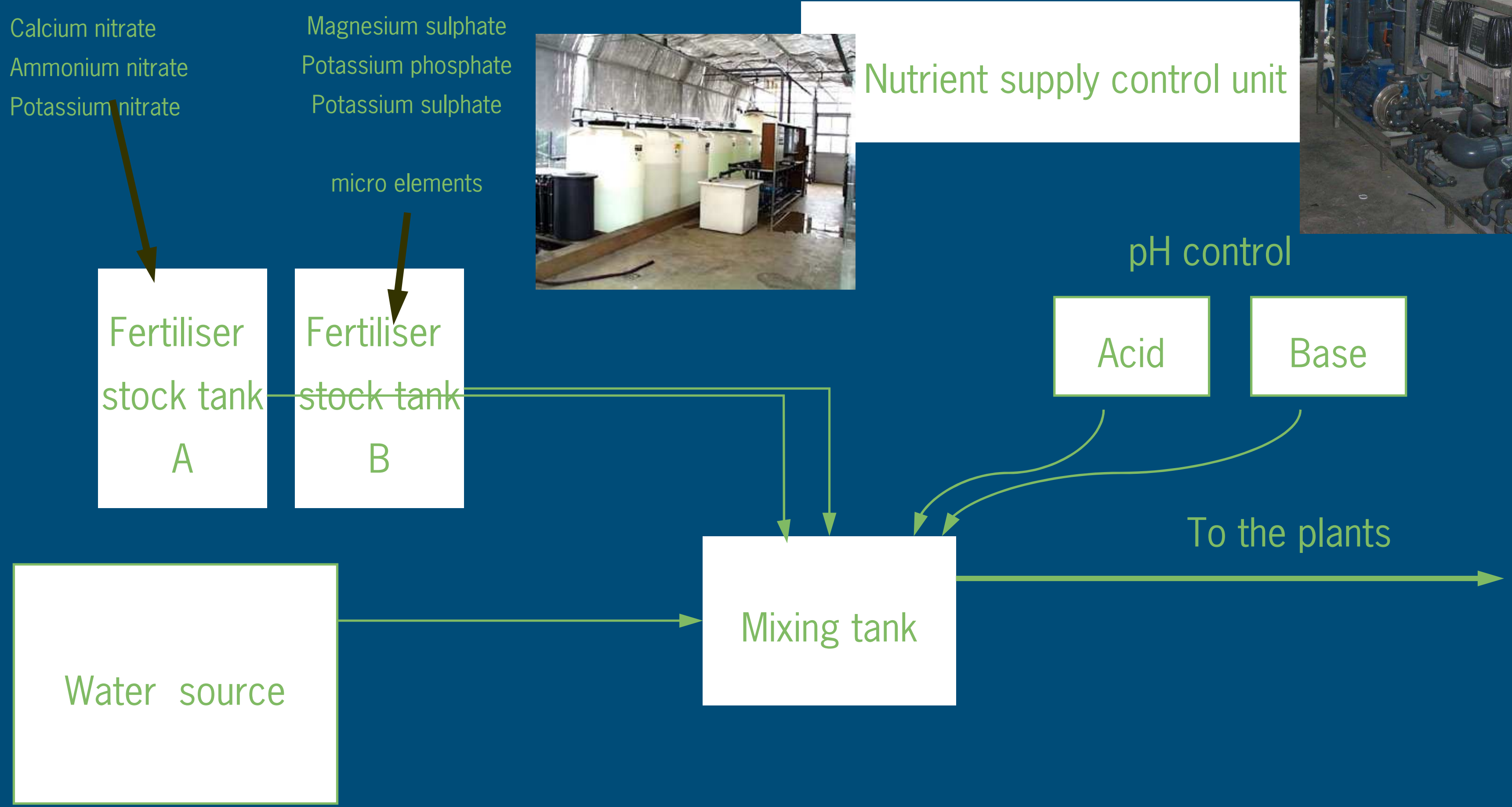
In other words

Addition of Potassium silicate =

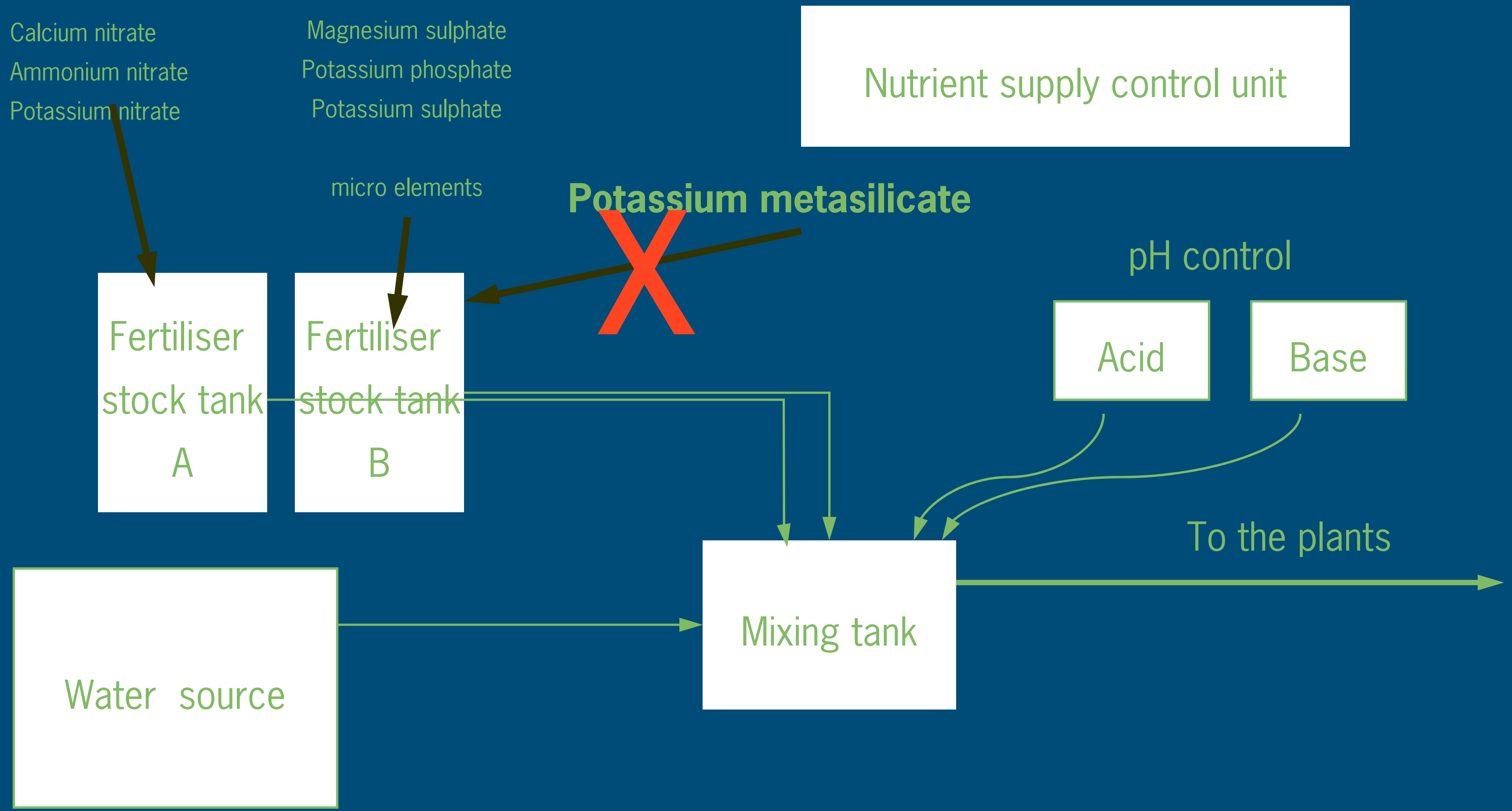
replacement KNO_3 by equal quantities of HNO_3

Practical consequences

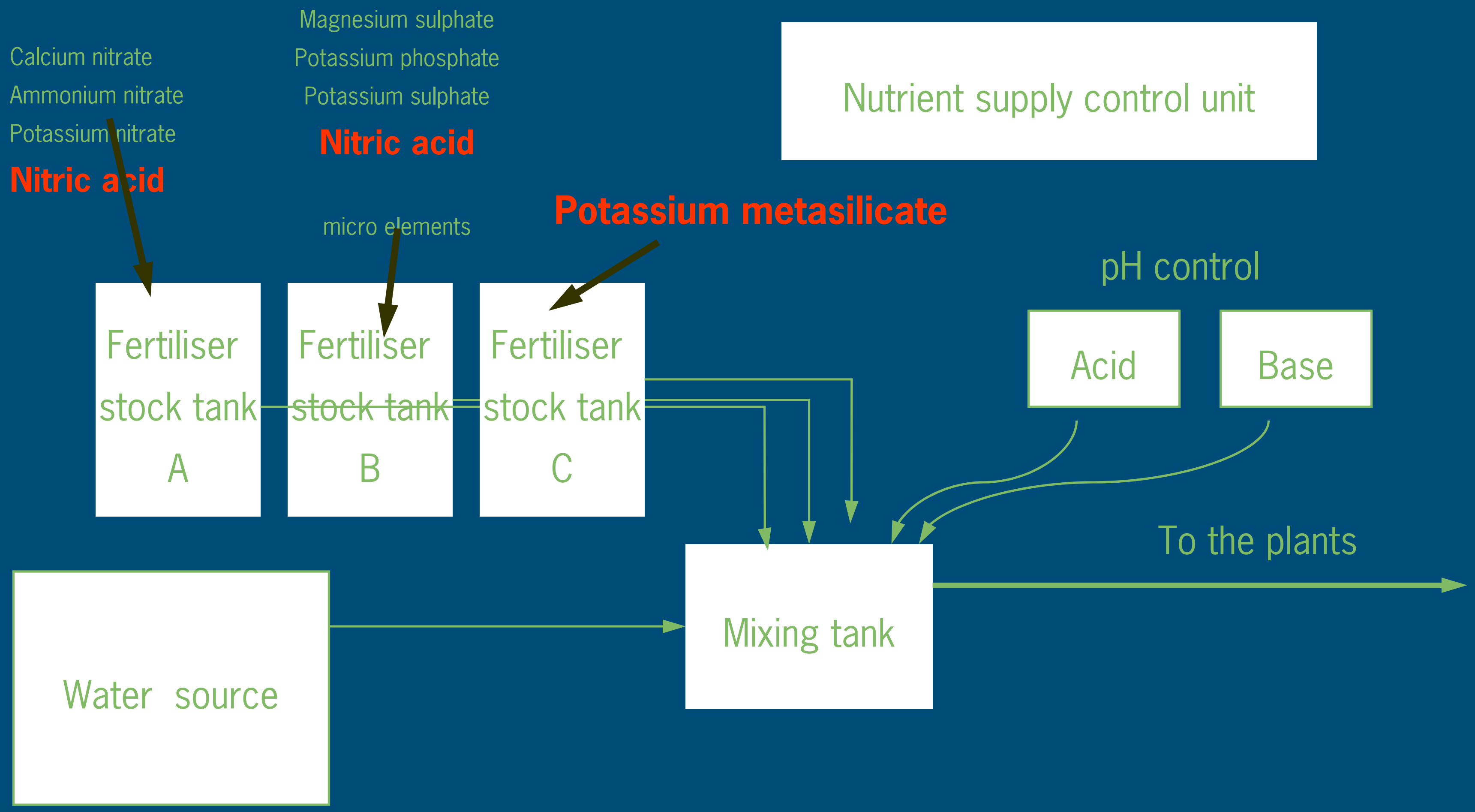
Usual nutrient supply



Usual nutrient supply



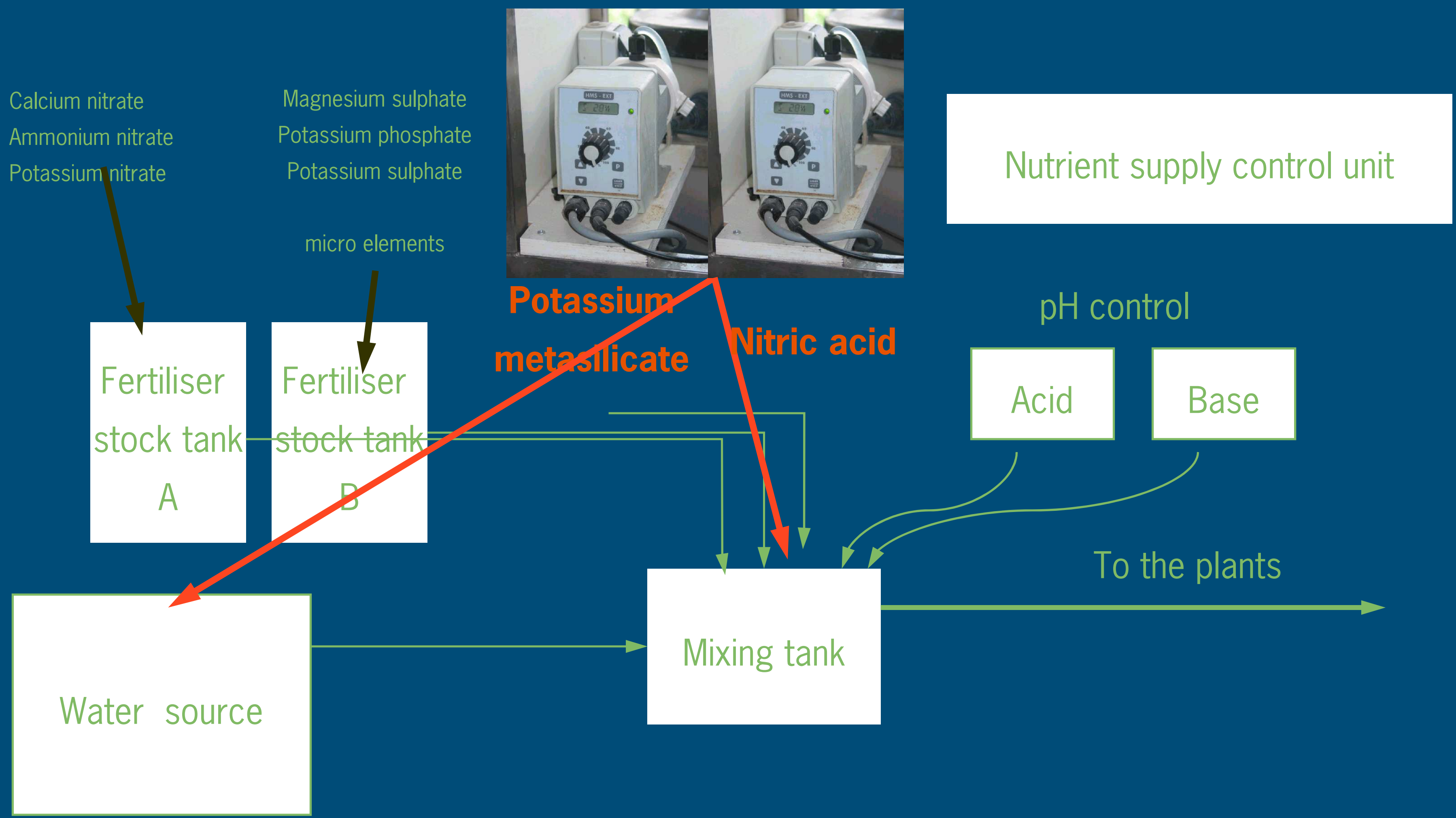
Practical solution 1: introduction C tank



Complication

- Fertiliser supply (stock solutions) is tuned to EC setpoint
  - EC setpoint fluctuate (crop stage, climate)
  - Acid for metasilicate in fixed rate in stock tanks

Practical solution 2: Injection pump



Complication 2

- Relative high acid input in stock tank
  - disturb regular pH control
- move final pH control

Optimising Si supply

- Benefits
  - Yield increase
  - Mildew reduction
    - less chemical
    - labour

- Costs
  - fertiliser
  - supply system
  - production costs
  - reduction fruit quality

Costs and benefits

- Yield increase
  - € 0.53 kg^{-1} f
- Plant protecti
  - treatments 1
  - saving € 0.30

costs

kg^{-1}

ystem

0

on costs

kg^{-1}

- Fruit quality (bloom)
  - - 15 %

Costs and benefits: Cucumber crop

In conclusion

- Si in growing media
  - insufficient, uncontrolled
    - exc. Rice hull in mixtures
- Si in nutrient solution
  - Potassium metasilicate (KOH + $Si(OH)_4$)
  - complicated
    - irrigation system clogging
    - pH control
    - expensive
- Break even point:
  - cucumber 0.75 mmol l^{-1}
  - rose 1 mmol l^{-1}

Obrigado !





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