COMPUTATION & PREPARATION OF NUTRIENT SOLUTIONS

Principles, properties &

preparation of nutrient solutions

Nutrient solutions

- **Nutrient solutions are diluted water solutions containing one or more inorganic solutes, which are used to supply the necessary nutrient elements to plants.**

- **The supply of water soluble fertilizers via the irrigation water in form of a nutrient solution is termed fertigation.**

Nutrient Solution and Soilless Culture

The composition and management of nutrient solution are the main tools to optimize plant nutrition and thus to maximize yield

Nutrient solution characteristics

- Electrical conductivity (EC)
- pH
- Macronutrient ratios or concentrations
- Micronutrient concentrations

Nutrient forms in nutrient solutions

Macronutrient	Chemical form	Micronutrient	Chemical form
nitrogen (N)	NO_3^-, NH_4^+	Iron (Fe)	Fe^{2+}
Phosphorus (P)	$H_2PO_4^-$	Manganese (Mn)	Mn^{2+}
Sulphur (S)	SO_4^{2-}	Zinc (Zn)	Zn^{2+}
Potassium (K)	K^+	Copper (Cu)	Cu^{2+}
Calcium (Ca)	Ca^{2+}	Boron (B)	H_3BO_3
Magnesium (Mg)	Mg^{2+}	Molybdenum (Mo)	MoO_4^{2-}

Typical compositions of nutrient solutions for soilless culture

Macro-nutrient	mmol L^{-1}			Micro-nutrient	µmol L^{-1}		
	Hoagland & Arnon	Sonneveld &Straver, cucumber	Sonneveld &Straver, roses		Hoagland & Arnon	Sonneveld &Straver, cucumber	Sonneveld &Straver, roses
NO_3^-	14.0	16.00	11.00	Fe	25.00	15.00	25.00
$H_2PO_4^-$	1.0	1.25	1.25	Mn	9.10	10.00	5.00
SO_4^{2-}	2.0	1.375	1.25	Zn	0.75	5.00	3.50
K^+	6.0	8.00	4.50	Cu	0.30	0.75	0.75
NH_4^+	1.0	1.25	1.50	B	46.30	25.00	20.00
Ca^{2+}	4.0	4.00	3.25	Mo	0.10	0.50	0.50
Mg^{2+}	2.0	1.375	1.125				

Stock solutions

- To reduce the frequency of nutrient solution preparation, the required fertilizers are mixed with irrigation water to form concentrated stock solutions.

- The concentration factor of the stock solutions with respect to the final solution supplied to the plants is commonly 100 but may range between 100-200.

Stock solutions

The fertilizers used to prepare stock solutions should be distributed over at least two different tanks to separate Ca^{2+} from $H_2PO_4^-$ and SO_4^{2-}.

The mixture of Ca^{2+} with $H_2PO_4^-$ & SO_4^{2-} results in precipitation of $CaSO_4$ & $Ca(H_2PO_4)_2$ because the solubility of these two salts in water is low.

Preparation and supply of nutrient solution to the crop

- To prepare and supply to the crop fresh nutrient solution, the stock solutions are diluted with irrigation water at a ratio corresponding to their concentration factor using suitable equipment.

- An acid is also used in form of a separate stock solution (commonly HNO_3) to adjust the nutrient solution pH.

An installation for automated nutrient solution preparation comprising two stock solutions of fertilizers and one stock solution of an acid.

A fully automated installation for nutrient solution preparation and supply with a separated stock solution tank for each fertilizer.

Constraints governing the establishment of a nutrient solution composition:

I. Association between anions and cations

The addition of a macronutrient ion imposes addition of another ion of different charge at an 1 : 1 equivalent ratio

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The input of a macronutrient cannot be considered independently of the other macronutrients

An example: Addition of potassium

$KCl \rightarrow K^+ + Cl^-$

$KNO_3 \rightarrow K^+ + NO_3^-$

$KH_2PO_4 \rightarrow K^+ + H_2PO_4^-$

$K_2SO_4 \rightarrow K^+ + SO_4^{2-}$

Constraints governing the establishment of a nutrient solution composition:

II. Mineral composition of water

- **In most cases, the irrigation water contains considerable amounts of some:**
  - **macronutrients (Ca, Mg, S-SO_4^{2-}),**
  - **micronutrients (Mn^{2+}, Zn^{2+}, Cu^{2+}, B και Cl^-)**
  - **other macroelements (HCO_3^-, Na^+).**

In some cases the concentrations of the above elements in the irrigation water may approach or even exceed their target concentrations in the nutrient solution.

Constraints governing the establishment of a nutrient solution composition:

III. Adjustment of pH

- Due to the presence of HCO_3^-, the pH of the irrigation water is in most cases higher than the optimal range for plant growth (commonly >7).

- To lower the pH of the irrigation water to the optimal range (5.5 – 5.8) it is necessary to add an acid (H^+).

- However, the supply of H^+ via an acid is essentially accompanied by the addition of an anion, which should be taken into consideration in the calculations.

Principles of nutrient solution calculation

To define the composition of a nutrient solution, target values for the following characteristics are needed:

1. Total ionic concentration (EC in dS m^{-1})

2. pH

3. Macronutrient ratios (mM):
- **3.1. K:Ca:Mg**
- **3.2. N:K**
- **3.3. $NH_4^+/(NH_4^+ + NO_3^-)$**

or:

3. Macronutrient concentrations (mM):
- **3.1. K, Ca, Mg**
- **3.2. NO_3^-,**
- **3.3. NH_4^+.**

4. $H_2PO_4^-$ concentration (mM)

5. Micronutrient concentrations (mM)

The pH of nutrient solution

- Desired values in the root environment: 5.5-6.5

- Acceptable range in the root environment: 5-7.

- To maintain the pH in the root zone in the desired range, the pH of the nutrient solution delivered to the crop should range between 5.5-5.8.

- This is attained by adding an acid (H^+), which reacts with the HCO_3^- contained in the irrigation water.

INPUT DATA

Stock solutions	V, m^3	A
Stock solution A	0,5	100
Stock solution B	0,5	100
Stock solution C (Acid)	0,2	200
Selection of phosphorus fertilizer: Select 1 for monopotassium phosphate, or 2 for phosphoric acid	1	
Selection of boron fertilizer: Select 1 for boric acid, 2 for sodium tetraborate (borax), or 3 for sodium octaborate (solubor)	1	
Selection of molybdenum fertilizer: Select 1 for ammonium heptamolybdate, or 2 for sodium molybdate	2	
Target values for K, Ca, Mg: Select 1 for a target K:Ca:Mg ratio (mmol/mmol), or 2 for target concentrations (mmol/L)	1	
Select 1 to introduce a total-N/K ratio (mmol/mmol) or 2 to introduce a target nitrate concentration (mmol/L)	1	
Select 1 to introduce a target ammonium to total-nitrogen ratio, or 2 for a target ammonium concentration	1	

Target characteristics of N.S.			Water composition		
E_t*	2,80	dS/m	E.C.	0,32	dS/m
pH opt.	5,6		pH	7,3	
X: (K)	6,000		Ca^{2+}	0,90	mmol/l
Y: (Ca)	5,000		Mg^{2+}	0,30	mmol/l
Z: (Mg)	2,500		K^+	0,00	mmol/l
R (tot.-N/K)	2,500		NH_4^+	0,00	mmol/l
Nr (NH4/tot.-N)	0,100		Na^+	0,40	mmol/l
$[H_2PO_4]$	1,250	mmol/l	SO_4^{2-}	0,20	mmol/l
$[Fe]_t$	12,00	μmol/l	NO_3^-	0,00	mmol/l
$[Mn]_t$	10,00	μmol/l	$H_2PO_4^-$	0,00	mmol/l
$[Zn]_t$	4,00	μmol/l	HCO_3^-	2,00	mmol/l
$[Cu]_t$	0,75	μmol/l	Cl^-	0,40	mmol/l
$[B]_t$	20,00	μmol/l	Fe	0,00	μmol/l
$[Mo]_t$	0,50	μmol/l	Mn^{++}	0,00	μmol/l
[Si]	0,00	mmol/l	Zn^{++}	2,15	μmol/l
% pure fertilizer			Cu^{++}	0,00	μmol/l
pure HNO_3 %	68	(% w/w)	B	0,00	μmol/l
pure H_3PO_4 %	85	(% w/w)	Mo	0,00	μmol/l
Fe in Fe-chelate	6	(% w/w)	Si	0,00	mmol/l
$[NH_4]_t$ (C17=2, C23=1, C20=1 ή 2)	1,50		Σcat_w	2,80	meq/l
Fertilizers (kg/tank)	60,75		Σan_w	2,80	meq/l

CALCULATIONS

Cation/Anion	C.C.S	C.C.W.	C.A.F.	SO_4^{2-}	NO_3^-	$H_2PO_4^-$	HCO_3^-	Cl^-	Si
C.A.S.	26,03			8,64	15,38	1,25	0,37	0,40	0,00
C.A.W.		2,80		0,40	0,00	0,00	2,00	0,40	0,00
A.A.F.			24,86	8,24	15,38	1,25	0,00	0,00	0,00
Ca^{2+}	11,39	1,80	9,59	0,00	9,59	0,00	0,00	0,00	0,00
Mg^{2+}	5,70	0,60	5,10	5,10	0,00	0,00	0,00	0,00	0,00
K^+	6,83	0,00	6,83	3,14	2,44	1,25	0,00	0,00	0,00
NH_4^+	1,71	0,00	1,71	0,00	1,71	0,00	0,00	0,00	0,00
Na^+	0,40	0,40	0,00	0,00	0,00	0,00	0,00	0,00	0,00
H^+	0,00	0,00	1,63	0,00	1,63	0,00	0,00	0,00	0,00

Grower:	
Crop species:	
Type of recipe:	
Date:	

NUTRIENT SOLUTION RECIPE

E.C.	2,80	dS/m
pH	5,60	
Stock solution A	**500**	**LITRES**
1 Calcium nitrate	51,819	Kg
2 Potassium nitrate	5,368	Kg
3 Ammonium nitrate	3,000	Kg
4 Fe-chelate	0,559	Kg
Stock solution B	**500**	**LITRES**
1 Potassium nitrate	6,990	Kg
2 Magnesium sulphate	31,378	Kg
3 Magnesium nitrate	0,000	Kg
4 Monopotassium phosphate	8,506	Kg
5 Potassium sulphate	13,684	Kg
6 Phosphoric acid	0,000	Litres
7 Manganese sulphate	84,50	g
8 Zinc sulphate	26,59	g
9 Copper sulphate	9,36	g
10 Boric acid	61,80	g
11 Borax	0,00	g
12 Solubor	0,00	g
13 Ammonium heptamolybdate	0,00	g
14 Sodium molybdate	6,05	g
Stock solution C (Acid)	**200**	**LITRES**
1 Nitric acid	4,264	Litres

Calculations (C_b) related to acid addition

$[H_3O^+]_w$	5,011872336	C_t (C17=1)
B_w	11,01	26,03
$[CO_3^{2-}]+[HCO_3^-]+[H_2CO_3]$	0,002202	$[K]_t$ (C17=1,
$[H_3O^+]_{(n.s.)}$	0,000002511	C20=1, C23=1)

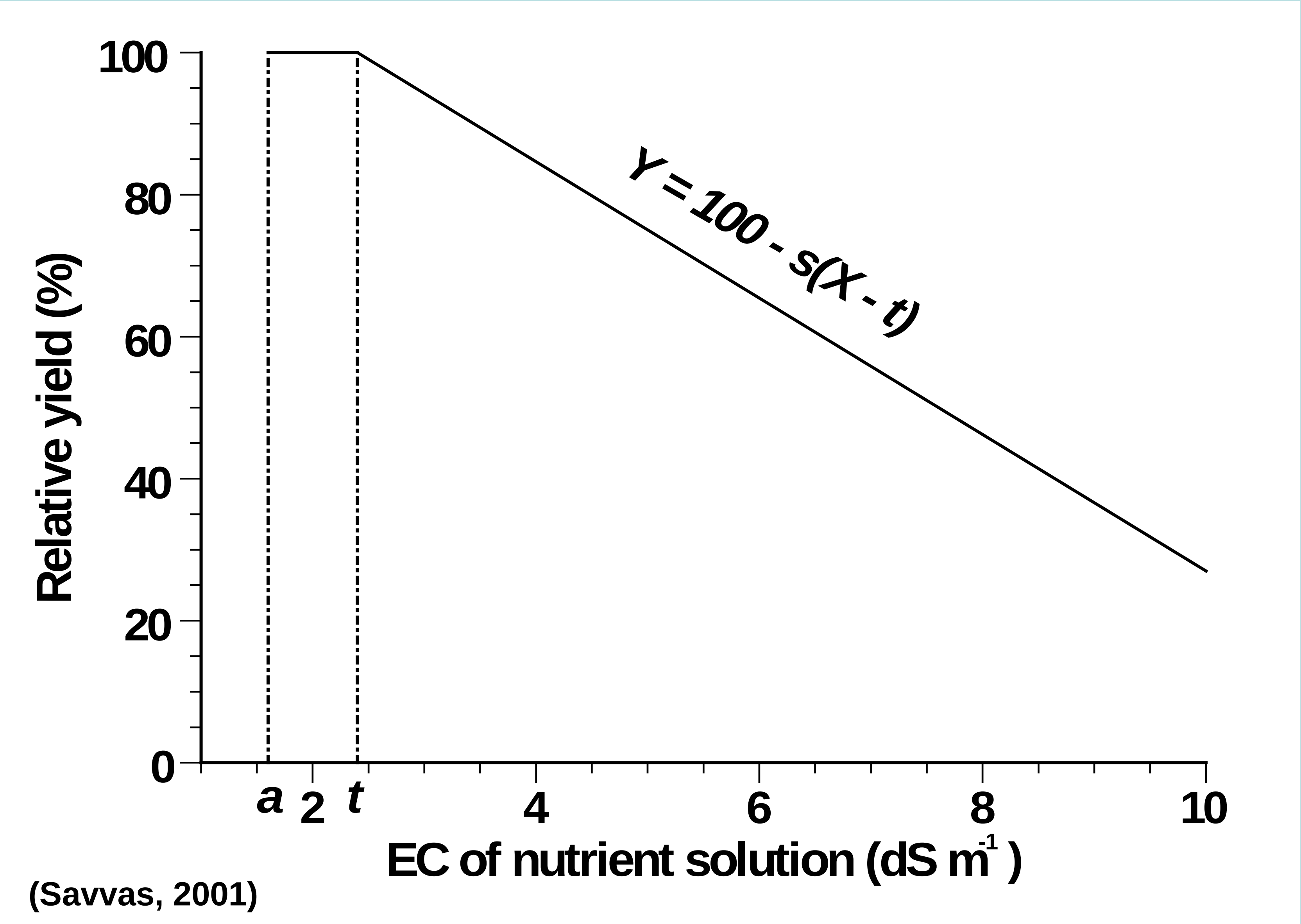
Accession of the computer program used to calculate nutrient solutions for soilless culture

www.ekk.aua.gr/excel/index_en.htm

Savvas and Adamidis, 1999. J. Plant Nutr. 22.

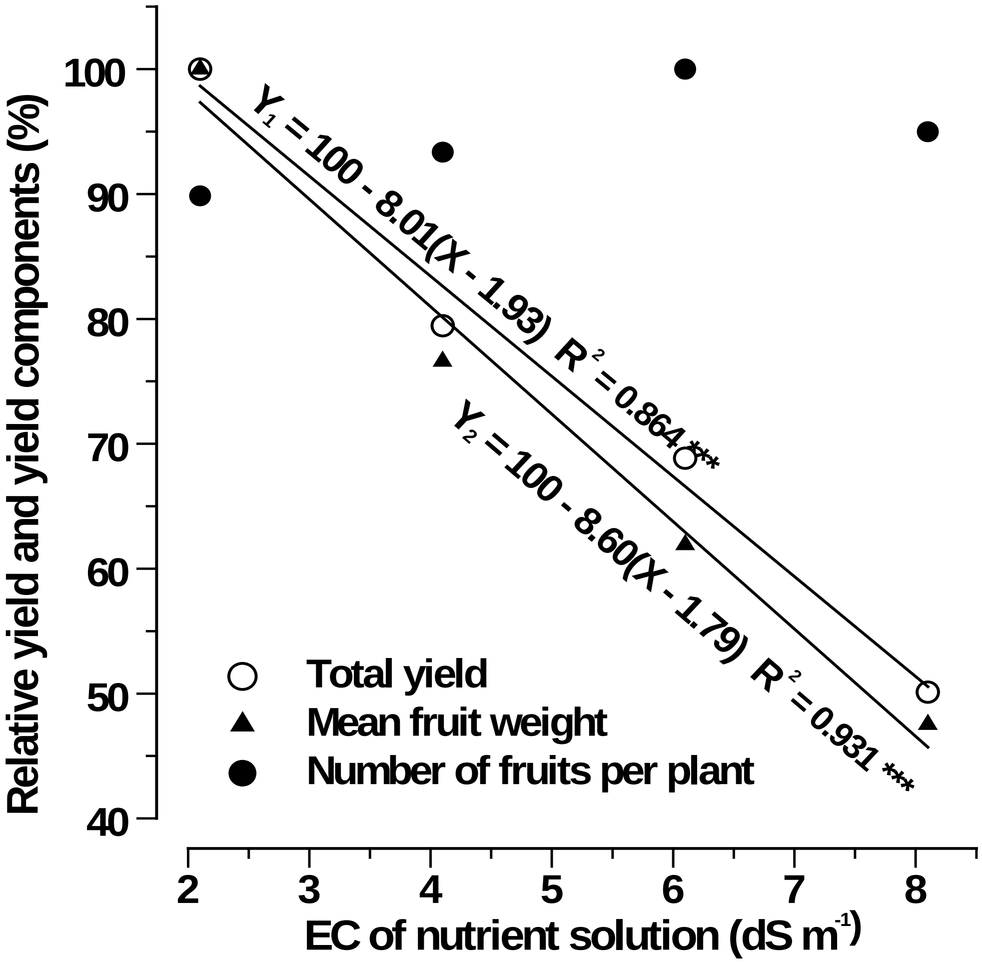
CONTROL OF THE TOTAL SALT CONCENTRATION IN THE ROOT ZONE

Relationship between yield and total salt concentration in the root zone of soilless grown crops



Relationship between yield and total salt concentration in the root zone of an eggplant crop

(Savvas, Διδ. Διατρ. 1992)



Mean EC values from a tomato crop grown in rockwool (Sonneveld 1981, Acta Hort. 126)

EC in the solution supplied to the crop dS m^{-1}	EC in the root environment (dS m^{-1})
1,4	1,6
1,8	2,2
2,1	3,1
2,6	4,0

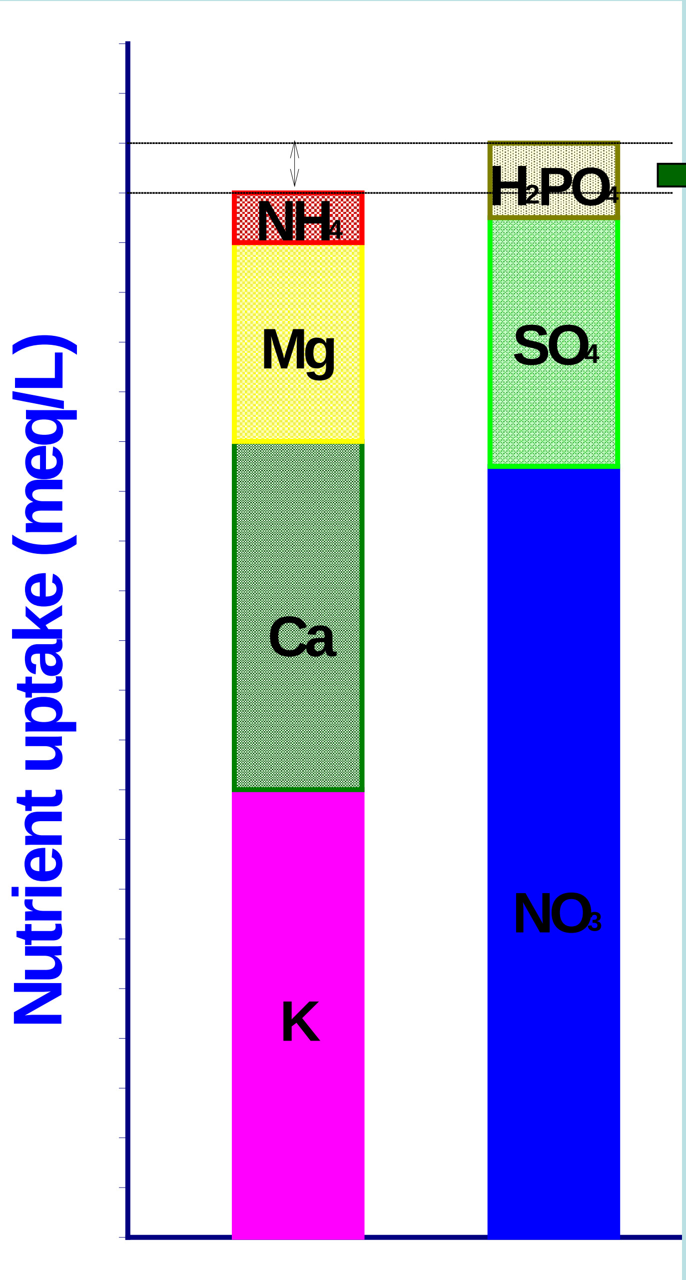
Control of EC in the root zone

- **Water of good quality (low NaCl, Ca, Mg, SO_4-S)**
- **Balanced composition of the supplied nutrient solution (EC, nutrient ratios)**
- **Proper irrigation scheduling (irrigation frequency in accordance with the energy input, i.e. solar radiation and heating)**
- **Irrigation water should not be used to wash out salts from substrates, unless it is rainwater.**

Adjustment of pH in the root zone

- **Desired pH range in the root zone: 5.5 - 6.5**
- **Acceptable pH in the root zone: 5 - 7.**
- **In most cases the pH tends to increase in the root zone**

Increase of pH due to cation to anion imbalance

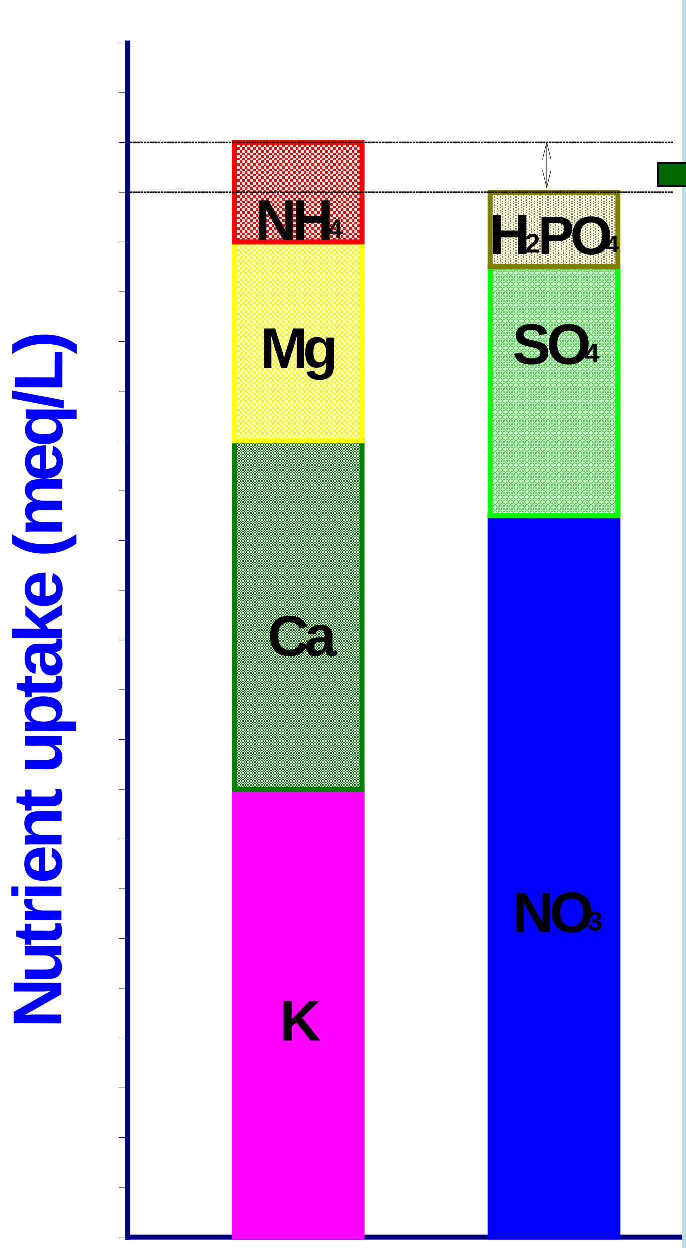


Anion uptake exceeds cation uptake

The charge difference in cytosol is electrochemically compensated for by excretion of HCO_3^- and / or OH^-

The pH in the external solution increases

Decrease of pH due to cation to anion imbalance



Cation uptake exceeds anion uptake

The charge difference in cytosol is electrochemically compensated for by excretion of H^+

The pH in the external solution decreases

Changes of pH in the root zone
Impact of nitrification

Nitrification of ammonium

***Nitrosomonas* sp.:**

$$2NH_3 + 3O_2 \rightarrow 2NO_2^- + 2H^+ + 2H_2O$$

***Nitrobacter* sp.:**

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

Maintenance of pH within the desired range in the root zone

- **Supply of irrigation solution with a pH ranging between 5.5 and 5.7.**

- **Part of nitrogen should be supplied in form of ammonium (N_r = 0.06 - 0.15)**