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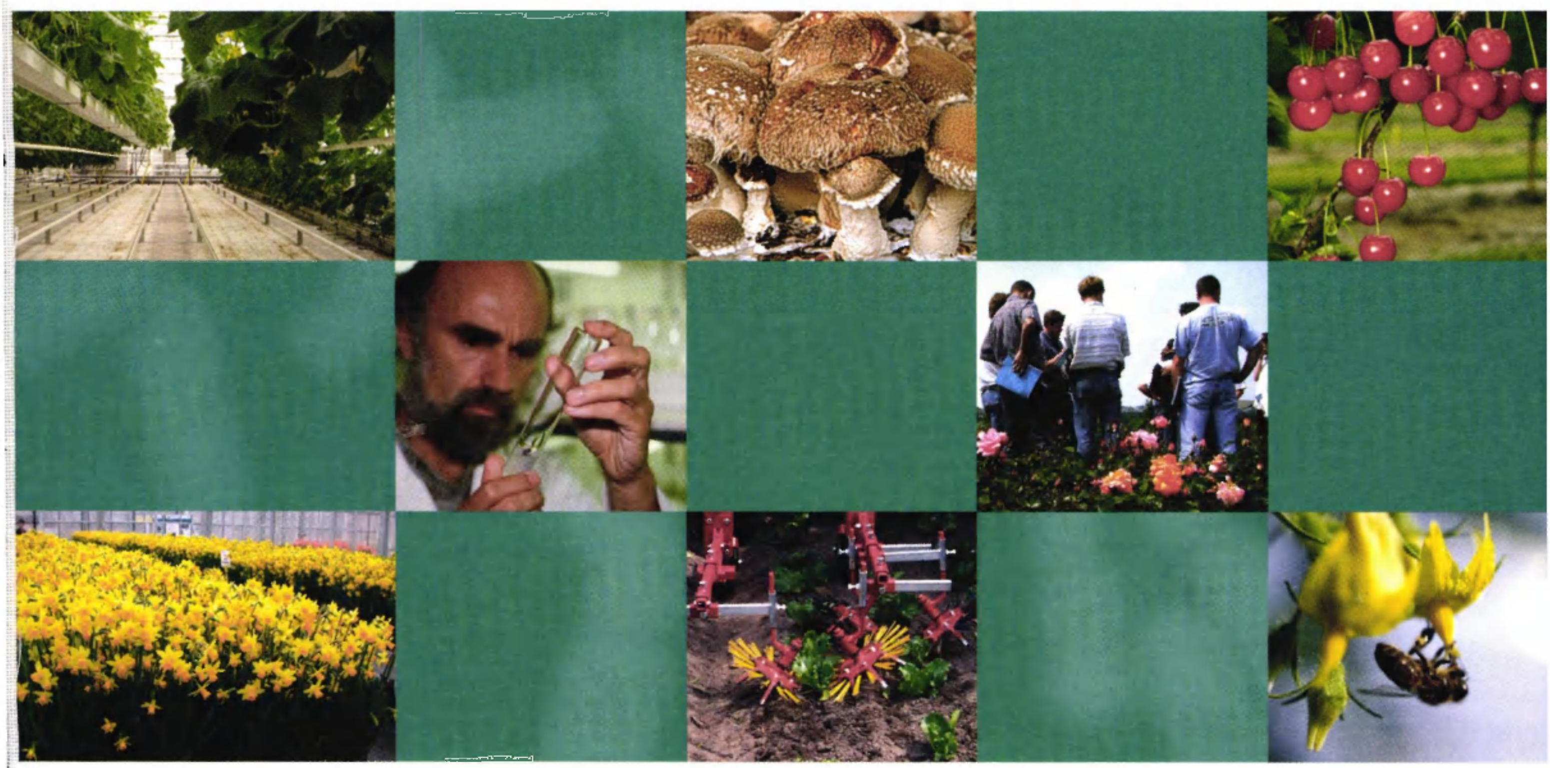
Nutrient Solutions and Water Quality for Soilless Cultures



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NUTRIENT SOLUTIONS AND WATER QUALITY FOR SOILLESS CULTURES

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Aster
Aubergine
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Carnation (see Dianthus)
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Dianthus
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Tomato

1. INTRODUCTION

The purpose of this brochure is to provide information on a method for calculating nutrient solutions for soilless cultures on the basis of standard nutrient solutions.
Using the standard nutrient solutions and the tables in this brochure it is possible to calculate nutrient solutions adjusted to different water qualities.

The compositions of standard nutrient solutions are expressed as mole. Therefore this unit will be used throughout this brochure. The internationally accepted definition of a mole is as follows. 'The mole is the amount of substance of a system which contains as many elementary entities as there are carbon atoms in 0.012 kilograms of carbon-12. The elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles or specified groups of such particles.
Atomic weights which are of interest for calculations are listed in table 1. The atomic weights are derived from the international atomic weights by rounding off to one decimal place. This is sufficiently accurate for our calculations.

Table 1 - Atomic weights (A_r) of a number of elements.

Element	A_r $g.mol^{-1}$	Element	A_r $g.mol^{-1}$
N	14.0	Fe	55.9
P	31.0	Mn	54.9
K	39.1	Zn	65.4
Ca	40.1	B	10.8
Mg	24.3	Cu	63.6
S	32.1	Mo	95.9
O	16.0	Si	28.1
H	1.0	Br	79.9
C	12.0	F	19.0
Na	23.0		
Cl	35.5		

2. WATER QUALITY

Sometimes ions found in water are plant nutrients, such as SO_4, Ca, Mg and B. Concentration of these plant nutrients should not exceed the concentration mentioned in the standard nutrient solutions of supplement 6. In a closed system concentrations in raw water should be lower than in an open system.

Ions in the water used by the plant as nutrients must be deducted from the standard nutrient solution. An exception to this is iron which is present in the water. This precipitates as $Fe(OH)_3$ and iron phosphate and hence is not available to plants.
Other ions present in water are absorbed by plants in small quantities, but will soon reach concentrations harmful to plants. Examples of this are Na and Cl.
Although HCO_3 is not a plant nutrient it has to be considered in the calculations. Accumulation of HCO_3 will increase the pH markedly. For this reason it must be neutralised with acids. With the addition of acids to water containing bicarbonate, the following reaction occurs:

$$HCO_3 + H_3O \rightarrow 2H_2O + CO_2$$

Usually nitric acid or phosphoric acid are used for this neutralisation. This is possible until a HCO_3 concentration of 6 $mmol.l^{-1}$.

To prevent accumulation of elements the concentrations should be low enough. The accumulation depends largely on the amount of drain and the reuse of this drain water. For an open system with drain the EC, Na and Cl should be lower than 1.0 mS/cm, 3.0 and 3.0 $mmol.l^{-1}$. In a system with limited drain the EC, Na and Cl should be lower than 0.5 $mS.cm^{-1}$, 1.5 and 1.5 $mmol.l^{-1}$. In a closed system the element concentrations in the water should not exceed the maximum uptake of the crop. For Na and Cl this is at the maximum accepted level in the root environment in $mmol.l^{-1}$, respectively:
Cymbidium: 0.2 and 0.2
Rose: 0.2 and 0.3
Aubergine, pepper: 0.2 and 0.4
Bouvardia: 0.2 and 0.5
Aster, alstroemeria, anthurium, gypsophila, Hippeastrum, bean: 0.3 and 0.5
Gerbera: 0.4 and 0.6
Carnation, courgettte, cucumber, melon: 0.5 and 0.7
Tomato: 0.7 and 0.9

The micro element concentrations should not exceed the element concentrations in the standard nutrient solution.
To prevent blocking of drip irrigation the total Fe concentration should be lower than 5 $\mu mol.l^{-1}$ and the CH_4 less than 0.1 $mg.l^{-1}$. To prevent growth of algae when water is stored for a long time the Si concentration should be lower than 0.1 $mmol.l^{-1}$.

3. FERTILISERS

The fertilisers used for the composition of nutrient solutions are listed in table 2. In this table the chemical composition and the molecular weight are also given. The molecular weights of iron chelates and calcium nitrate have been estimated. Iron chelates molecular weights have been calculated on the basis of iron concentration. Calcium nitrate fertiliser contains water of crystallisation and ammonium nitrate. The molecular formula is $5\{Ca(NO_3)_2.2H_2O\}.NH_4NO_3$ and the molecular weight is 1080.5 $g.mol^{-1}$, so 1 mol calcium nitrate fertiliser is chemically equivalent to 5 mol Ca, 11 mol NO_3 and 1 mol NH_4. Acids are given as pure chemicals. However, acids always contain water. The right quantities will be found when dividing by the proportional nutrient concentration (percent nutrient * 0.01).

Table 2 - Fertilisers used to compose nutrient solutions.

Fertilisers	Chemical composition	Nutrients %	Molecular weight g/mol
Nitric acid 100%	HNO_3	22 N	63.0
Phosphoric acid 100%	H_3PO_4	32 P	98.0
Calcium nitrate	$5\{Ca(NO_3)_2.2H_2O)\}.$ $NH_4\ NO_3$	15.5 N,19 Ca	1080.5
Potassium nitrate	KNO_3	13 N, 38 K	101.1
Ammonium nitrate	$NH_4\ NO_3$	35 N	80.0
Magnesium nitrate	$Mg(NO_3)_2.6H_2O$	11 N, 9 Mg	256.3
Mono potassium phosphate	KH_2PO_4	23 P, 28 K	136.1
Mono ammonium phosphate	$NH_4H_2PO_4$	27 P, 12 N	115.0
Potassium sulphate	K_2SO_4	45 K, 18 S	174.3
Epsom salt	$MgSO_4.7H_20$	10 Mg, 13 S	246.3
Manganese sulphate	$MnSO_4.H_20$	32 Mn	169.0
Zinc sulphate	$ZnSO_4.7H_20$	23 Zn	287.5
Zinc sulphate	$ZnSO_4.6H_20$	24 Zn	269.5
Zinc sulphate	$ZnSO_4.H_20$	35.5 Zn	179.5
Borax	$Na_2B_4O_7.10H_2O$	11 B	381.2
Copper sulphate	$CuSO_4.5H_20$	25 Cu	249.7
Sodium molybdate	$Na_2MoO_4.2H_20$	40 Mo	241.9
Iron chelate EDTA 13%	Fe – EDTA	13 Fe	(430)
Iron chelate DTPA 6%	Fe – DTPA	6 Fe	(932)
Iron chelate EDDHA 5%	Fe – EDDHA	5 Fe	(1118)
Potassium bicarbonate	$KHCO_3$	39 K	100.1
Calcium hydroxide	$Ca(OH)_2$	54 Ca	74.1
Potassium silicate - liquid		9 K, 10 Si	(270)
Potassium silicate - liquid		25 K, 9 Si	(308)

4. CALCULATIONS OF THE AMOUNT OF FERTILISERS

Calculations of the amount of fertilisers can usually be divided into two parts. The first part involves calculating the major elements in the fertilisers used, which normally have two or more components to be considered. For example if KNO_3 is added to increase the potassium concentration, the nitrate has to be calculated too. The second part of the calculations concerns the minor nutrients. These are much easier to calculate because the other components of the fertilisers are negligible.

A practical example for calculating major elements of a nutrient solution is shown in table 3. In this table use is made of a hypothetical raw water which contains no nutrients.

Table 3 - Scheme for calculating a nutrient solution without correcting for ions in the raw water

Fertiliser	$mmol.l^{-1}$	NO_3	H_2PO_4	SO_4	NH_4	K	Ca	Mg
	Standard composition	11.75	1.25	1.0	1.0	5.5	3.25	1.0
		$mmol.l^{-1}$						
KH_2PO_4	1.25		1.25			1.25		
$Ca(NO_3)_2$	0.65*	7.15			0.65		3.25	
NH_4NO_3	0.35	0.35			0.35			
KNO_3	4.25	4.25				4.25		
$MgSO_4$	1.0			1.0				1.0

*fertiliser

The amounts of fertiliser calculated in table 3 can easily be converted to a ready solution or a 100 times concentrated stock solution. For example, calculating the amount of monopotassium phosphate required is: concentration * molecular weight = 1.25 * 136.1 = 170 $mg.l^{-1}$. The results are listed in table 4.

Table 4 - Major elements of ready and stock solution calculated from table 3

Fertiliser	Ready solution $mg.l^{-1}$	Stock solution $kg.m^{-3}$
Mono potassium phosphate	170	17.0
Calcium nitrate fertiliser	702	70.2
Ammonium nitrate	28	2.8
Potassium nitrate	430	43.0
Epsom salt	246	24.6

Calculation of the minor elements of the nutrient solution are given in table 5.

Table 5 - Calculations of minor nutrients for the nutrient solution

Addition $\mu mol.l^{-1}$	Fertilisers	Ready solution $mg.l^{-1}$	Stock solution $g.m^{-3}$
10 Fe	Iron chelate 6%	9.32	932
10 Mn	Manganese sulphate	1.69	169
4 Zn	Zinc sulphate (23%)	1.15	115
20 B	Borax	1.91	191
0.5 Cu	Copper sulphate	0.12	12
0.5 Mo	Sodium molybdate	0.12	12

Numbers in the third and fourth column are obtained as follows:
Fe 10 $\mu mol.l^{-1}$ = Fe-DTPA (6%) 10*932 $\mu g.l^{-1}$ = Fe-DTPA (6%) 9.32 $mg.l^{-1}$

The 100 times concentrated stock solution per m^3 contains: $9.32 * 10^6 * 10^2 * 10^{-6} = 932$ $g.m^{-3}$. A similar method can be applied to the other minor elements. Keep in mind that 1 mol Borax = 4 mol B. Therefore B 20 $\mu mol.l^{-1}$ = Borax ¼*20*381.2 $\mu g.l^{-1}$ = Borax 1.91 $mg.l^{-1}$. There are several other fertilisers which can be used; the choice can be fixed on technical merits. If this is not the case, the cheapest fertilisers can be used.

The fertilisers should be divided into two different tanks, commonly named A and B. Tank A should not contain phosphates and sulphates, while in tank B no fertilisers which contain calcium should be added to prevent precipitation of calcium phosphate or calcium sulphate. The iron chelate fertiliser can be added to the A-tank. However, Fe-EDDHA precipitates at pH < 3 and Fe–DTPA at pH < 1. Which means that there is a restriction on the amount of acid added to the A-tank.

If a separate concentrated stock solution are made of the micro element fertilisers the pH should be taken into account. Borax increases the pH which causes precipitation of manganese hydroxide.

Tables are given in the supplement for the conversion of concentration or $mmol.l^{-1}$ or $\mu mol.l^{-1}$ in the standard nutrient solution to an amount in $g.m^{-3}$ or $kg.m^{-3}$ for a 100 times concentrated stock solution.

Frequently nutrient solutions have to be corrected for HCO_3, Ca and Mg because these ions are often constituents of many types of water. To neutralise the HCO_3 equivalent quantities of H_3O are added. Usually when the water contains HCO_3 equivalent amounts of Ca and Mg are present and subsequently similar amounts of these ions have to be subtracted from the standard solution. Table 6 gives an example of calculating a nutrient solution. In the calculation HCO_3 - 3 $mmol.l^{-1}$, Ca - 1 $mmol.l^{-1}$ and Mg - 0.5 $mmol.l^{-1}$ in raw water are taken into account.

Table 6 - Scheme for calculating a nutrient solution for water containing HCO_3 - 3 $mmol.l^{-1}$, Ca - 1 $mmol.l^{-1}$ and Mg - 0.5 $mmol.l^{-1}$

				Standard composition					
		NO_3	H_2PO_4	SO_4	H_3O	NH_4	K	Ca	Mg
		10.5	1.5	2.5		1.5	7.0	3.25	1.0
	Corrections				+3.0			-1.0	-0.5
Fertiliser				Composition to calculate					
Name	$mmol.l^{-1}$	10.5	1.5	2.5	3.0	1.5	7.0	2.25	0.5
				$mmol.l^{-1}$					
KH_2PO_4	1.5		1.5				1.5		
HNO_3	3.0	3.00			3.0				
$Ca(NO_3)_2$	0.45*	4.95				0.45		2.25	
NH_4NO_3	1.05	1.05				1.05			
KNO_3	1.5	1.50					1.5		
K_2SO_4	2.0			2.0			4.0		
$MgSO_4$	0.5			0.5					0.5

*fertiliser

The results calculated and listed in table 6 are converted to a ready solution or a 100 times concentrated stock solution. The amount of fertiliser calculated is shown in table 7. For nitric acid a solution of 65 % (mass/mass) is inserted, so a divisor of 0.65 is used.

Table 7 - Amount of fertiliser for a ready and a 100 times concentrated stock solution, calculated from table 6

Fertiliser	Ready solution $mg.l^{-1}$	Stock solution $kg.m^{-3}$
Mono potassium phosphate	204	20.4

Nitric acid 65%	291	29.1
Calcium nitrate	486	48.6
Ammonium nitrate	84	8.4
Potassium nitrate	152	15.2
Potassium sulphate	349	34.9
Epsom salt	123	12.3

5. OPEN SYSTEM

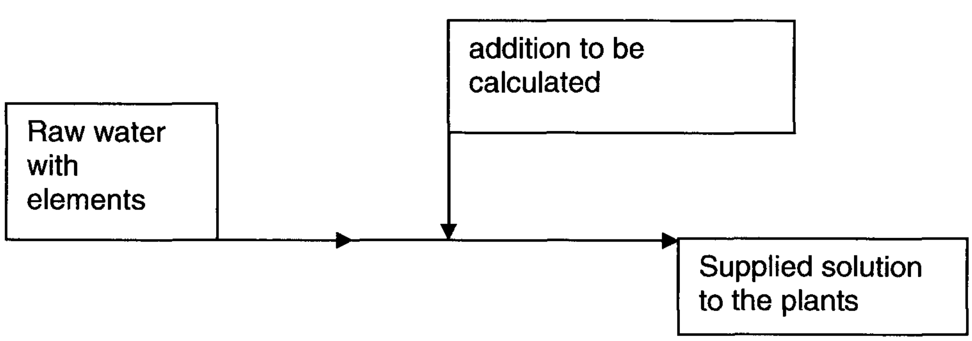
The standard nutrient solution for an open system and the target values for the root environment are used. In an open system the standard nutrient solution gives the target values in the root environment assuming a leaching fraction of 30 % of the volume of the water. These target values has been found to give the optimal production and quality in standard situation. For a range of different crops the composition of the standard nutrient solution for an open system and the target values in the root environment has been given in Appendix 2.
The target values in the root environment are given for a certain EC-comparison (=EC_c). This EC_c is calculated on the macro elements without Na and Cl.
The analysis of the root environment has to be corrected to compare the actual EC with the EC_c and also the individual element concentrations have to be corrected for the actual EC. Therefore the EC from the nutrients (=EC_n) has been calculated from the actual EC (=EC_a) and the concentrations of Na and Cl.

EC_c = comparison EC in the root environment without the Na and Cl, in $mS.cm^{-1}$

EC_a = EC analysed from the root environment, in $mS.cm^{-1}$

EC_n = EC from the nutrients in the root environment, this has been calculated as:
$EC_a - (0.1 * Na\#Cl)$, where Na#Cl = Na or Cl concentration in the root environment. If Na > Cl it is the Na concentration. If Cl > Na it is the Cl concentration, in $mmol.l^{-1}$.

In certain physiological stages of crop growth the standard solution has been changed. This is valuable because it is known that the uptake in that stage is different from standard.
In many cases the EC of the desired nutrient solution is different from the standard nutrient solution. Therefore the solution to be made has to be recalculated from the standard to the desired EC.
After the adaptations of the standard solution the cation and anion sum may not be equal. In that case the cations and anions are changed so that the sum becomes equal. In these calculations NH_4 and H_2PO_4 are not taken into account and the ratios of the cations and anions are not changed.



In the next example more details are given (table 8)

Table 8 - Calculation of the nutrient solution in an open system

Elemen	Standard	Target	Root env.	Root env. Corr.	Correct-ions	Correc-ted	Desired EC	Raw water	Corr. Raw water	Eq. Sum
1	2	3	4	5	6	7	8	9	10	11
EC	2.8	3.7	5.2			2.8	2.6		2.6	2.6
pH		5.5	7							
NH_4	1.2	0.1	0.1		+0.6	1.8	1.8		1.80	1.8
K	9.5	8	6.2	5.46	+2	11.5	10.68		10.68	10.6
Na			4.9							
Ca	5.4	10	12.1	10.65	-0.125	5.275	4.90	1.00	3.90	3.9
Mg	2.4	4.5	7.5	6.60	-0.625	1.775	1.65	0.25	1.4	1.4
NO_3	16	23	17.1	15.05	+1.5	17.5	16.26		16.26	17.0
Cl			9.7							
SO_4	4.4	6.8	11	9.68	-1	3.4	3.16	0.75	2.41	2.7
HCO_3			0.5					1.00		
H_2PO_4	1.5	1	0.75	0.66	+0.25	1.75	1.63		1.63	1.6
H_3O								-1.00	1.00	1.0
Fe	15	15	26.3	26.3	-25%	11	11		11.0	11.0
Mn	10	7	9.3	9.3		10	10		10.0	10.0
Zn	5	7	9.9	9.9		5	5		5.0	5.0
B	30	50	5	5	+50%	45	45	5.0	40.0	40.0
Cu	0.75	0.7	1.2	1.2		0.75	0.75		0.75	0.8
Mo	0.5	0.5	1.1	1.1		0.5	0.5		0.50	0.5

Explanation of the columns in table 8:

1. The elements. EC in $mS.cm^{-1}$, macro elements in $mmol.l^{-1}$ and micro elements in $\mu mol.l^{-1}$.
2. Standard nutrient solution for an open system for this crop, tomato
3. Target values in the root environment for this crop at the EC_c
4. Analysis of the root environment from sampling of the root environment
5. Corrections of the analysis of the root environment for the EC and the Na and Cl. The correction is 3.7 / ((5.2 – (0.1 * 9.7)) = 0.88. Micro elements and NH_4 are not corrected. (5) = (4) * 0.88.
6. Correction of the standard nutrient solution for the analysis in the root environment and for the physiological stage of the crop. In this example the two corrections are done in one step. For the physiological stage the corrections are K+0.5; Ca–0.125 and Mg-0.125. The physiological stage has to be known together with the corresponding corrections. The rest of the corrections in this column are due to the analysis of the root environment. There is also a correction for NH_4 based on pH, HCO_3 and NH_4 in the root environment. Here the pH is too high and NH_4 is increased by 0.6.
7. (7) = (2) + (6)
8. Correction for the desired EC which has to be known. (8) = (7) * 2.6/2.8. NH_4 and micro elements are not corrected
9. Raw water element concentrations; H_3O = - HCO_3
10. (10) = (8) – (9)
11. Corrected for the equilibrium of the sum of the cations and anions. Both cations and anions can be changed. The ratios between cations and anions should stay the same. The NH_4 and H_2PO_4 are never changed. This is the final calculated make-up solutions to be added

6. CLOSED SYSTEM

6.1 Principle 'drip solution minus drain water'

In this system the standard nutrient solution for the open system has been used. The solution to be calculated is corrected for the extra input of drain water. The solution to be calculated is added to the total stream of water, i.e. the raw water mixed with the drain water.

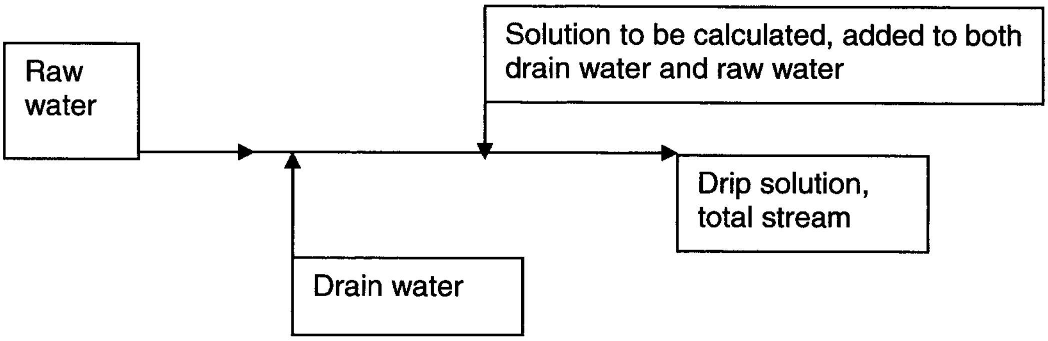


Table 9 - Example of the calculations of the nutrient solution to be added to both the drain water and the raw water. Raw water composition from table 8.

Elem.	Drip	Target	Root env.	Drain	Root env. Correct.	Correctio ns	Correct ed.	Drip EC	Drain supply	Raw water	Drain & Raw	Eq. sum
1	2	3	4	5	6	7	8	9	10	11	12	13
EC	2.8	3.7	5.2	3.9			2.8	2.6	1.2		1.4	1.4
pH		5.5	7	5.2								
NH_4	1.2	0.1	0.1	0.1		+0.6	1.8	1.8			1.8	1.8
K	9.5	8	6.2	12	5.46	+1.5	11	10.2	3.69		6.5	6.5
Na			4.9	6								
Ca	5.4	10	12.1	8.8	10.65		5.4	5.01	2.71	0.69	1.61	1.5
Mg	2.4	4.5	7.5	4.1	6.60	-0.25	1.9	1.99	1.26	0.17	0.56	0.5
NO_3	16	23	17.1	19.4	15.05	+1.5	17.5	16.25	5.97		10.28	10.3
Cl			9.7	5.8								
SO_4	4.4	6.8	11	6.1	9.68	-1	3.4	3.16	1.88	0.52	0.76	0.75
HCO_3			0.5	0						0.69		
H_2PO_4	1.5	1	0.75	1.36	0.66	+0.25	1.75	1.62	0.42		1.20	1.2
H_3O										-0.69	0.69	0.7
Fe	15	15	26.3	12.3	26.3	-25%	11	11	3.78		7.2	7.2
Mn	10	7	9.3	11.2	9.3		10	10	3.45		6.5	6.5
Zn	5	7	9.9	8.4	9.9		5	5	2.58		2.4	2.4
B	30	50	5	40	5	50%	45	45	12.30	3.5	29.2	29.2
Cu	0.75	0.7	1.2	0.9	1.2		0.75	0.75	0.28		0.5	0.5
Mo	0.5	0.5	1.1	1	1.1		0.5	0.5	0.31		0.19	0.19

Explanation of the columns in table 9:

1. The elements. EC in $mS.cm^{-1}$, macro elements in $mmol.l^{-1}$ and micro elements in $\mu mol.l^{-1}$.
2. Standard nutrient solution for an open system for this crop, i.e. the standard drip solution
3. Target values in the root environment for this crop at the EC-target
4. Analysis of the root environment from sampling of the root environment
5. Analysis of the drain from sampling of the drain water
6. Corrections of the analysis of the root environment for the EC and the Na and Cl. The correction is 3.7 / ((5.2 – (0.1 * 9.7)) = 0.88. Micro elements and NH_4 are not corrected. (6) = (4) * 0.88
7. Corrections for the analysis of the root environment and for the physiological stage. In this example no corrections for the physiological stage are necessary. Also NH_4 has been corrected based on pH and HCO_3 and NH_4
8. (8) = (2) – (7)
9. Correction for the desired EC of the drip irrigation's. This EC has to be known. (9) = (8) * 2.6/2.8
10. The input of the nutrients from the drain solution. In this example the drain is supplied to the raw water until the concentration of the stream gets an EC of 1.2 $mS.cm^{-1}$. That means that the total stream contains 31 % drain water and 69 % raw water. This can be seen from 31 % of 3.9 = 1.2 $mS.cm^{-1}$ assuming that the raw water has an EC = 0.
11. Correction for the raw water. In this case the total stream contains 69 % raw water and the element concentrations in the raw water have to be corrected for 69 %. H_3O = - HCO_3
12. (12) = (9) – (10) – (11). Mixing of drain water and raw water gives an EC of 1.2 $mS.cm^{-1}$; the desired drip solution has an EC of 2.6 $mS.cm^{-1}$. That means that the EC to be added to the total stream is 1.4 $mS.cm^{-1}$.
13. Corrected for the equilibrium of the sum of the cations and anions sum.
    This is the final calculated make-up solution to be added to both drain water and raw water.

6.2 Principle of the uptake of the plant

In this method the average uptake of the plant is known. This is called the standard nutrient solution of a closed system or the recirculation solution. The recirculation solution is corrected for the element concentrations in the root environment, physiological stage of the crop and for the element concentrations in the raw water. The solution is calculated as the amount added to the stream of raw water only. This means that the EC of the nutrient solution to be calculated is higher than in the case of 'drip solution minus drain water and raw water', since in the latter case the solution is supplied to the whole stream of solution, i.e. both to the raw water plus the drain water. In the system where the uptake of the plant is followed the supply is calculated to the raw water fraction only. The method can be used when the composition and the volume of the recirculating drain water are not known, e.g. in NFT systems.

In general the following relationships holds:

EC-drip = $(EC_d * f) + (EC_m * (1-f))$, where

f= fraction drain water (in litres water per total amount of water, i.e. l/l or m^3/m^3);
EC_m = EC of fertiliser supplied to the raw water plus the EC of the raw water itself
EC_d = EC of the drain water.

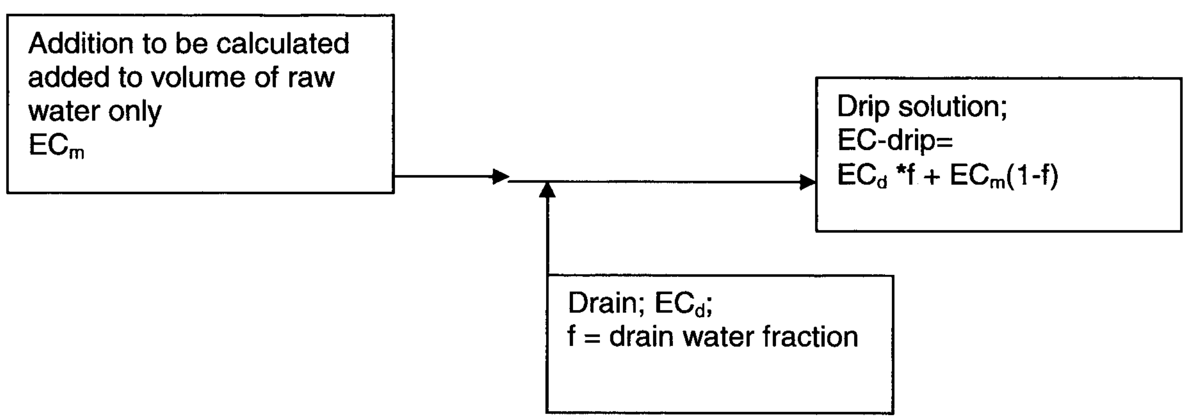


Table 10 - Example of the calculation of the nutrient solution based on uptake of the plant

Element	Recirc.	Target	Root env.	Root env. corr.	Corrections	Corrected	EC supply	Raw water	Corr. raw water	Eq. Sum
1	2	3	4	5	6	7	8	9	10	11
EC	1.5	3.7	5.2			1.5	2.0		2.0	2.0
pH		5.5	7							
NH_4	1	0.1	0.1			1.6	1.6		1.6	1.6
K	6.5	8	6.2	5.46	2	8.5	11.33		11.33	10.8
Na			4.9							
Ca	2.75	10	12.1	10.65		2.75	3.67	1.0	2.67	2.5
Mg	1	4.5	7.5	6.60	-0.5	0.5	0.67	0.25	0.42	0.3
NO_3	10.75	23	17.1	15.05	2	12.75	17.00		17	17.0
Cl			9.7							
SO_4	1.5	6.8	11	9.68	-1.25	0.25	0.33	0.75	-0.42	0.0
HCO_3			0.5					1.0		
H_2PO_4	1.25	1	0.75	0.66	0.25	1.5	2.00		2	2.0
H_3O								-1.0	1.0	1.0
Fe	15	25	26.3	26.3		15			15.0	15.0
Mn	10	5	9.3	9.3		10			10.0	10.0
Zn	4	7	9.9	9.9		4			4.0	4.0
B	20	50	5	5	50%	30		5	25.0	25.0
Cu	0.75	0.7	1.2	1.2		0.75			0.75	0.75
Mo	0.5	0.5	1.1	1.1		0.5			0.5	0.5

Explanation of the columns in table 10:
1. Elements
2. Standard recirculation solution
3. Target values in the root environment $EC_c = 3.7\ mS.cm^{-1}$
4. Analysis of the root environment
5. Corrections of the analysis of the root environment for the EC and Na and Cl.
6. Corrections for the analysis of the root environment and for the physiological stage.
7. (7) = (2) + (6)
8. Calculation for the EC of the supplied solution. This has to be calculated from the EC-drip solution, the amount of drain water and the EC of the drain water. In this example the EC has to be 2.0 $mS.cm^{-1}$, because (0.69 * 2.0) + (0.31 * 3.9) = 2.6
9. The element concentration in the raw water. This is corrected completely because the calculation of the supply is to the stream of the raw water only.
10. (10) = (8) – (9)
11. Correction for the equilibrium of the cations and the anions.

SUPPLEMENT 1. Conversion of element concentrations to fertilisers

Conversion of acids and salts from concentration in $mmol.l^{-1}$ in ready nutrient solution to amount in $kg.m^{-3}$ in a 100 times concentrated stock solution

Concentration	HNO_3*	H_3PO_4*	KNO_3	NH_4NO_3	KH_2PO_4
$mmol.l^{-1}$	$kg.m^{-3}$	$kg.m^{-3}$	$kg.m^{-3}$	$kg.m^{-3}$	$kg.m^{-3}$
0.5	3.2	4.9	5.1	4.0	6.8
1.0	6.3	9.8	10.1	8.0	13.6
1.5	9.4	14.7	15.2	12.0	20.4
2.0	12.6	19.6	20.2	16.0	27.2
2.5	15.8	24.5	25.3	20.0	34.0
3.0	18.9	29.4	30.3	24.0	40.8
3.5	22.0	34.3	35.4	28.0	47.6
4.0	25.2	39.2	40.4	32.0	54.4
4.5	28.4	44.1	45.5	36.0	61.2
5.0	31.5	49.0	50.6	40.0	68.0
5.5	34.6	53.9	55.6	44.0	74.9
6.0	37.8	58.8	60.7	48.0	81.7
6.5	41.0	63.7	65.7	52.0	88.5
7.0	44.1	68.6	70.8	56.0	95.3
7.5	47.2	73.5	75.8	60.0	102.1
8.0	50.4	78.4	80.9	64.0	108.9
8.5	53.6	83.3	85.9	68.0	115.7
9.0	56.7	88.2	91.0	72.0	122.5
9.5	59.8	93.1	96.0	76.0	129.3
10.0	63.0	98.0	101.1	80.0	136.1

* Calculated as pure acid. The concentration available must be taken into account.

Conversion of salts from concentration in $mmol.l^{-1}$ in ready nutrient solution to amount in $kg.m^{-3}$ in a 100 times concentrated stock solution

Concentration	$Mg(NO_3)_2.6H_20$	K_2SO_4	$MgSO_4.7H_20$
$mmol.l^{-1}$	$kg.m^{-3}$	$kg.m^{-3}$	$kg.m^{-3}$
0.25	6.4	4.4	6.2
0.50	12.8	8.7	12.3
0.75	19.2	13.1	18.5
1.00	25.6	17.4	24.6
1.25	32.0	21.8	30.8
1.50	38.4	26.1	37.0
1.75	44.9	30.5	43.1
2.00	51.3	34.9	49.3
2.25	57.7	39.2	55.4
2.50	64.1	43.6	61.6
2.75	70.5	47.9	67.8
3.00	76.9	52.3	73.9
3.25	83.3	56.6	80.1
3.50	89.7	61.0	86.2
3.75	96.1	65.4	92.4
4.00	102.5	69.7	98.6
4.25	108.9	74.1	104.7
4.50	115.3	78.4	110.9
4.75	121.7	82.8	117.0
5.00	128.2	87.2	123.2

Conversion of calcium nitrate fertiliser based on calcium application from concentration in $mmol.l^{-1}$ in the ready solution to amount in $kg.m^{-3}$ in a 100 times concentrated stock solution

Concentration	$Ca(NO_3)_2$*	NO_3 added	NH_4 added
Ca, $mmol.l^{-1}$	$kg.m^{-3}$	$mmol.l^{-1}$	$mmol.l^{-1}$
0.25	5.4	0.55	0.05
0.50	10.8	1.10	0.10
0.75	16.2	1.65	0.15
1.00	21.6	2.20	0.20
1.25	27.0	2.75	0.25
1.50	32.4	3.30	0.30
1.75	37.8	3.85	0.35
2.00	43.2	4.40	0.40
2.25	48.6	4.95	0.45
2.50	54.0	5.50	0.50
2.75	59.4	6.05	0.55
3.00	64.8	6.60	0.60
3.25	70.2	7.15	0.65
3.50	75.6	7.70	0.70
3.75	81.0	8.25	0.75
4.00	86.4	8.80	0.80
4.25	91.8	9.35	0.85
4.50	97.2	9.90	0.90
4.75	102.6	10.45	0.95
5.00	108.0	11.00	1.00

- $5(Ca(NO_3)_2.2H_2O).NH_4NO_3$

Conversion of iron chelates from concentration in µmol.l^{-1} in ready nutrient solution to an amount in g.m^{-3} in a 100 times concentrated stock solution

	% iron in the fertiliser		
Concentration of Fe	13%	6%	5%
µmol.l^{-1}	g.m^{-3}	g.m^{-3}	g.m^{-3}
5	215	466	559
10	430	932	1118
15	645	1398	1677
20	860	1864	2236
25	1075	2330	2795
30	1290	2796	3354
35	1505	3262	3913
40	1720	3728	4472
45	1935	4194	5031
50	2150	4660	5590
55	2365	5126	6149
60	2580	5592	6708
65	2795	6058	7267
70	3010	6524	7826
75	3225	6990	8385
80	3440	7456	8944
85	3655	7922	9503
90	3870	8388	10062
95	4085	8854	10621
100	4300	9320	11180

Conversion of minor nutrient fertilisers from concentration in μmol.l^{-1} in ready nutrient solution to an amount in g.m^{-3} in a 100 times concentrated stock solution

	$MnSO_4.H_20$		$ZnSO_4.7H_20$	$Na_2B_4O_7.10H_20$*		$CuSO_4.5H_20$	$Na_2MoO_4.2H_20$
μmol.l^{-1}	g.m^{-3}	μmol.l^{-1}	g.m^{-3}	g.m^{-3}	μmol.l^{-1}	g.m^{-3}	g.m^{-3}
2	34	1	29	38	0.1	2.5	2.4
4	68	2	58	76	0.2	5.0	4.8
6	101	3	86	114	0.3	7.5	7.3
8	135	4	115	152	0.4	10.0	9.7
10	169	5	144	191	0.5	12.5	12.1
12	203	6	172	229	0.6	15.0	14.5
14	237	7	201	267	0.7	17.5	16.9
16	270	8	230	305	0.8	20.0	19.4
18	304	9	259	343	0.9	22.5	21.8
20	338	10	288	381	1.0	25.0	24.2
22	372	11	316	419	1.1	27.5	26.6
24	406	12	345	457	1.2	30.0	29.0
26	439	13	374	496	1.3	32.5	31.4
28	473	14	402	534	1.4	35.0	33.9
30	507	15	431	572	1.5	37.5	36.3

* Keep in mind that 1 mol $Na_2B_4O_7.10H_2O$ = 4 mol B.

SUPPLEMENT 2. Standard nutrient solution for closed and open system and target values in the root environment

The valencies of the ions are not added in this brochure.

The electrical conductivity (EC) is given at 25°C.

Alstroemeria

Element	Standard nutrient solution		Target value in root environment
	Closed system	Open system	
EC, $mS.cm^{-1}$	1.2	1.6	2.0
pH			5.5
NH_4, $mmol.l^{-1}$	0.7	0.7	0.1
K	4.3	5.8	5.0
Na			<5
Ca	2.0	3.5	5.0
Mg	0.7	1.3	2.0
NO_3	7.3	11.2	13.0
Cl			<5
SO_4	1.2	1.95	2.5
HCO_3			<1.0
H_2PO_4	0.7	1.0	1.0
Fe, $\mu mol.l^{-1}$	25	25	30
Mn	5	5	5
Zn	4	4	5
B	20	30	40
Cu	0.75	0.75	1.0
Mo	0.5	0.5	0.5

Anthurium andreanum

Element	Standard nutrient solution		Target value in root environment
	Closed system	Open system	
EC, $mS.cm^{-1}$	0.8	1.1	1.0
pH			5.5
NH_4, $mmol.l^{-1}$	0.3	0.3	0.1
K	3.5	3.9	3.0
Na			<3
Ca	0.9	1.3	2
Mg	0.7	1.0	1.2
NO_3	4.7	6.4	5.0
Cl			<3
SO_4	0.8	0.8	1.5
HCO_3			<1
H_2PO_4	0.7	0.8	0.75
Fe, $\mu mol.l^{-1}$	15	15	15
Mn	0	0	2
Zn	3	3	4
B	20	30	40
Cu	0.5	0.75	1
Mo	0.5	0.5	0.5

Aster

Element	Standard nutrient solution		Target value in root environment
	Closed system	Open system	
EC, $mS.cm^{-1}$	1.1	1.8	2.2
pH			5.8
NH_4, $mmol.l^{-1}$	0.75	1.0	0.1
K	4.4	7.5	7.0
Na			<4.0
Ca	1.5	3.5	5.0
Mg	0.6	1.0	2.2
NO_3	7.25	13.0	14.0
Cl			<4.0
SO_4	0.7	1.25	3
HCO_3			<1.0
H_2PO_4	0.7	1.25	0.9
Fe, $\mu mol.l^{-1}$	20	25	20
Mn	5	10	3
Zn	3	4	5
B	15	25	50
Cu	0.5	0.75	1
Mo	0.5	0.5	0.5

Aubergine

Element	Standard nutrient solution		Target value in root environment
	Closed system	Open system	
EC, $mS.cm^{-1}$	1.7	2.1	2.7
pH			5.5
NH_4, $mmol.l^{-1}$	1.0	1.5	0.1
K	6.5	6.75	6.2
Na			<6
Ca	2.25	3.25	6.2
Mg	1.5	2.5	4.5
NO_3	11.75	15.5	20
Cl			<6
SO_4	1.125	1.5	3.0
HCO_3			<1
H_2PO_4	1.0	1.25	0.9
Fe, $\mu mol.l^{-1}$	15	15	25
Mn	10	10	7
Zn	5	5	7
B	25	35	80
Cu	0.75	0.75	0.7
Mo	0.5	0.5	0.5

Bean

Element	Standard nutrient solution		Target value in root environment
	Closed system	Open system	
EC, $mS.cm^{-1}$	1.3	1.8	2.8
pH			5.5
NH_4, $mmol.l^{-1}$	1.0	1.0	0.1
K	5.25	6.25	7
Na			<6
Ca	2.0	3.25	7
Mg	0.75	1.25	2.5
NO_3	9.45	12.0	15
Cl			<8
SO_4	0.7	1.5	4.5
HCO_3			<1
H_2P0_4	0.9	1.25	1.0
Fe, $\mu mol.l^{-1}$	10	15	15
Mn	5	5	5
Zn	3	4	7
B	20	20	40
Cu	0.5	0.5	1
Mo	0.5	0.5	0.5

Bouvardia

Element	Standard nutrient solution		Target value in root environment
	Closed system	Open system	
EC, $mS.cm^{-1}$	1.5	1.7	2.2
pH			5.5
NH_4, $mmol.l^{-1}$	1.0	1.0	0.1
K	5.5	6.0	6.0
Na			<3
Ca	2.5	3.5	5.0
Mg	0.7	1.3	2.0
NO_3^-	10.5	12.15	12.5
Cl			<6
SO_4	0.7	1.6	3.0
HCO_3			<1
H_2PO_4	1.0	1.25	1.5
Fe, $\mu mol.l^{-1}$	25	25	25
Mn	5	10	3
Zn	3.5	4	3.5
B	20	25	20
Cu	0.75	0.75	1.0
Mo	0.5	0.5	0.5

Courgette

Element	Standard nutrient solution		Target value in root environment
	Closed system	Open system	
EC, $mS.cm^{-1}$	1.4	2.2	2.7
pH			5.5
NH_4, $mmol.l^{-1}$	1.0	1.25	0.1
K	5.25	7.25	8.0
Na			<8
Ca	1.75	3.625	6.5
Mg	1.275	2.0	3
NO_3	9.6	16.0	18
Cl			<10
SO_4	0.9	1.25	3.5
HCO_3			<1
H_2PO_4	0.9	1.25	0.9
Fe, $\mu mol.l^{-1}$	10	15	15
Mn	10	10	7
Zn	5	5	7
B	30	35	60
Cu	1.0	1.0	1
Mo	0.5	0.5	0.5

Cucumber

Element	Standard nutrient solution		Target value in root environment
	Closed system	Open system	
EC, $mS.cm^{-1}$	1.7	2.2	2.7
pH			5.2
NH_4, $mmol.l^{-1}$	1.0	1.25	0.1
K	6.5	8.0	8
Na			<8
Ca	2.75	4.0	6.5
Mg	1.0	1.375	3.0
NO_3	11.75	16.0	18.0
Cl			<1.0
SO_4	1.0	1.375	3.5
HCO_3			<1.0
H_2PO_4	1.25	1.25	0.9
Si*	0.75	0.75	0.6
Fe, $\mu mol.l^{-1}$	15	15	25
Mn	10	10.0	7
Zn	5	5	7
B	25	25	50
Cu	0.75	0.75	1.5
Mo	0.5	0.5	0.5

* Optional

Dianthus

Element	Standard nutrient solution		Target value in root environment
	Closed system	Open system	
EC, $mS.cm^{-1}$	1.1	1.8	2.2
pH			5.8
NH_4, $mmol.l^{-1}$	0.75	1.0	0.1
K	4.4	6.75	7
Na			<4
Ca	1.5	3.5	5
Mg	0.6	1.0	2.2
NO_3	7.25	13.0	14
Cl			<4
SO_4	0.7	1.25	3
HCO_3			<1.0
H_2PO_4	0.7	1.25	0.9
Fe, $\mu mol.l^{-1}$	20	25	20
Mn	5	10	3
Zn	3	4	5
B	20	30	60
Cu	0.5	0.75	1.0
Mo	0.5	0.5	0.5

Gerbera

Element	Standard nutrient solution		Target value in root environment
	Closed system	Open system	
EC, $mS.cm^{-1}$	1.1	1.6	2.0
pH			5.2
NH_4, $mmol.l^{-1}$	0.75	1.5	0.1
K	4.50	5.5	6.0
Na			<6
Ca	1.60	3.0	5
Mg	0.40	1.0	2
NO_3	7.25	11.25	13
Cl			<6
SO_4	0.7	1.25	2.5
HCO_3			<1.0
H_2PO_4	0.6	1.25	1.0
Fe, $\mu mol.l^{-1}$	25	35	40
Mn	5	5	3
Zn	3	4	5
B	20	30	40
Cu	0.5	0.75	1
Mo	0.5	0.50	0.5

Gypsophila

Element	Standard nutrient solution		Target value in root environment
	Closed system	Open system	
EC, $mS.cm^{-1}$	1.3	1.6	2.3
pH			5.8
NH_4, $mmol.l^{-1}$	0.75	0.75	0.1
K	3.5	4.25	5
Na			<8
Ca	2.5	3.5	6
Mg	1.0	1.5	2.5
NO_3	9.0	12	19
Cl			<8
SO_4	0.75	1.0	1.2
HCO_3			<1
H_2PO_4	0.75	1.0	1.0
Fe, $\mu mol.l^{-1}$	15	15	25
Mn	5	10	5
Zn	4	4	5
B	20	30	60
Cu	0.75	0.75	1.2
Mo	0.50	0.5	0.5

Hippeastrum

Element	Standard nutrient solution		Target value in root environment
	Closed system	Open system	
EC, $mS.cm^{-1}$	1.0	1.8	2.2
pH			5.5
NH_4, $mmol.l^{-1}$	0.5	1.25	0.1
K	4.0	7.0	6.5
Na			<6.0
Ca	1.2	3.0	5.0
Mg	0.6	1.0	2.0
NO_3	6.3	12.6	16.0
Cl			<6.0
SO_4	0.6	1.2	2.0
HCO_3			<1.0
H_2PO_4	0.6	1.25	1.0
Fe, $\mu mol.l^{-1}$	10	10	15
Mn	7	10	7
Zn	5	5	7
B	20	30	45
Cu	0.5	0.7	1.0
Mo	0.5	0.5	0.5

Lettuce in recirculating water

Element	Standard nutrient solution		Target value in root environment
	Closed system	Open system	
EC, $mS.cm^{-1}$	2.6		2.5
pH			5.5
NH_4, $mmol.l^{-1}$	1.25		0.1
K	11.0		6
Na			<8
Ca	4.5		7
Mg	1.0		1.5
NO_3	19.0		19
Cl			<10
SO_4	1.125		2.0
HCO_3			<1.0
H_2PO_4	2.0		1.0
Si	0.5		0.5
Fe, $\mu mol.l^{-1}$	40		40
Mn	0 *)		1
Zn	4		5
B	30		50
Cu	0.75		1
Mo	0.50		0.5

*) If peat cubes are used, no Mn should be added, otherwise 5 $\mu mol.l^{-1}$ is advisable.

Melon

Element	Standard nutrient solution		Target value in root environment
	Closed system	Open system	
EC, $mS.cm^{-1}$	1.5	2.2	2.2
pH			5.5
NH_4, $mmol.l^{-1}$	1.0	1.25	0.1
K	6.5	8	7
Na			<8
Ca	2.75	4	7
Mg	1.0	1.375	2.5
NO_3	11.75	16.0	20
Cl			<10
SO_4	1.0	1.375	3.5
HCO_3			<1.0
H_2PO_4	1.25	1.25	0.8
Fe, $\mu mol.l^{-1}$	15	15	25
Mn	8	10	5
Zn	4	5	7
B	25	25	50
Cu	0.75	0.75	1
Mo	0.50	0.50	0.5

Pepper

Element	Standard nutrient solution		Target value in root environment
	Closed system	Open system	
EC, $mS.cm^{-1}$	1.6	2.1	2.7
pH			6.2
NH_4, $mmol.l^{-1}$	0.5	0.5	0.1
K	5.75	6.75	5
Na			<8
Ca	3.5	5.0	8.5
Mg	1.125	1.5	3
NO_3	12.5	15.5	17
Cl			<12
SO_4	1.0	1.75	3
HCO_3			<1
H_2PO_4	1.0	1.25	1.2
Fe, $\mu mol.l^{-1}$	15	15	15
Mn	10	10	5
Zn	4	5	7
B	25	30	80
Cu	0.75	0.75	0.7
Mo	0.5	0.5	0.5

Pot plants in expanded clay

Element	Standard nutrient solution		Target value in root environment
	Closed system	Open system	
EC, $mS.cm^{-1}$	1.6		1.7
pH			5.5
NH_4, $mmol.l^{-1}$	1.1		0.1
K	5.5		4.5
Na			<4
Ca	3.0		4.0
Mg	0.75		1.0
NO_3	10.6		9.5
Cl			<5
SO_4	1.0		2
HCO_3			<1
H_2PO_4	1.5		1.0
Fe, $\mu mol.l^{-1}$	20		15
Mn	10		5
Zn	3		4
B	20		40
Cu	0.5		0.7
Mo	0.5		0.5

Propagation of vegetables in rockwool

Element	Standard nutrient solution		Target value in root environment
	Closed system	Open system	
EC, $mS.cm^{-1}$	2.4		2.5
pH			5.5
NH_4, $mmol.l^{-1}$	1.25		0.1
K	6.75		6.5
Na			<5
Ca	4.5		6.0
Mg	3.0		3.0
NO_3	16.75		18.0
Cl			<5
SO_4	2.5		2.5
HCO_3			<1
H_2PO_4	1.25		1.5
Fe, $\mu mol.l^{-1}$	25		35
Mn	10		5
Zn	5		7
B	35		50
Cu	1.0		0.7
Mo	0.5		0.5

Rose

Element	Standard nutrient solution		Target value in root environment
	Closed system	Open system	
EC, $mS.cm^{-1}$	0.7	1.6	2.0
pH			5.5
NH_4, $mmol.l^{-1}$	0.8	1.0	0.1
K	2.2	4.5	5
Na			<6
Ca	0.8	3.25	5
Mg	0.6	1.5	2.5
NO_3	4.3	11.25	12.5
Cl			<8
SO_4	0.5	1.25	2.5
HCO_3			<1
H_2PO_4	0.5	1.25	0.9
Fe, $\mu mol.l^{-1}$	15	25	25
Mn	5	5	3.0
Zn	3	3.5	3.5
B	20	20	20
Cu	0.5	0.75	1.0
Mo	0.5	0.5	0.5

Strawberry in recirculating water

Element	Standard nutrient solution	Target value in root environment
	Closed system	
EC, $mS/.m^{-1}$	1.5	2.0
pH		
NH_4, $mmol.l^{-1}$	0.5	0.1
K	5.25	5
Na		<4
Ca	2.75	4.5
Mg	1.125	2.0
NO_3	10.0	12.0
Cl		<4
SO_4	1.125	2.5
HCO_3		<1
H_2PO_4	1.25	0.7
Fe, $\mu mol.l^{-1}$	20	35
Mn	10	7
Zn	4	7
B	20	20
Cu	0.75	0.7
Mo	0.5	0.5

Tomato

Element	Standard nutrient solution		Target value in root environment
	Closed system	Open system	
EC, $mS.cm^{-1}$	1.6	2.6	3.7
pH			5.5
NH_4, $mmol.l^{-1}$	1.0	1.2	0.1
K	6.5	9.5	8
Na			<8
Ca	2.75	5.4	10
Mg	1.0	2.4	4.5
NO_3	10.75	16.0	23
Cl			<12
SO_4	1.5	4.4	6.8
HCO_3			<1
H_2PO_4	1.25	1.5	1.0
Fe, $\mu mol.l^{-1}$	15	15	25
Mn	10	10	7
Zn	4	5	7
B	20	30	50
Cu	0.75	0.75	0.7
Mo	0.5	0.5	0.5