GLASSHOUSE CROPS RESEARCH AND EXPERIMENT STATION
NAALDWIJK
THE NETHERLANDS

A METHOD FOR CALCULATING THE COMPOSITION OF NUTRIENT SOLUTIONS FOR SOILLESS CULTURES

Second translated edition

C. Sonneveld

May 1985

No. 57 Price ƒ 5,--
Informatiereeks

Introduction

The purpose of this brochure is to provide information about a method of calculating nutrient solutions for soilless cultures on the basis of standard nutrient solutions. Such nutrient solutions for several crops are given in a separate brochure (Sonneveld and Arnold Bik, 1984). Using the standard nutrient solutions and the tables in this brochure it is possible to calculate nutrient solutions adjusted to different water qualities.

The composition of standard nutrient solutions is expressed as mole. Therefore this unit will be used throughout this brochure.

Definition of mole

The internationally accepted definition for 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." (Aylward and Findley, 1974).

Atomic weights

Atomic weights which are of interest for calculations made in this brochure are listed in Table 1. The atomic weights are derived from the international atomic weights (Aylward and Findley, 1974) by rounding off to one decimal place. This is sufficiently accurate for our calculations.

Water quality

The demands for the quality of water for use in substrate systems has been described in a separate report (Sonneveld, 1983).

Sometimes the ions found in water are plant nutrients, such as SO_4^{--},

Ca^{++}, Mg^{++}. Other ions present in water are absorbed by plants in small quantities, but soon will reach concentrations harmful to plants. Examples of this are Na^{+} and Cl^{-}.

Table 1. Rounded atomic weights (Ar) of a number of elements.

Elements	Ar	Elements	Ar
N	14	Fe	55.9
P	31	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	Si	28.1
H	1		
C	12		
Na	23		
Cl	35.5		

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 water. This precipitates out as $Fe(OH)_3$ and then is not available to plants.

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 neutralized with acids. With the addition of acids to bicarbonate containing water, the following reaction occurs:

$$HCO_3^- + H_3O^+ \longrightarrow 2H_2O + CO_2\nearrow$$

Usually phosphoric acid or nitric acid are used for this neutralization.

Fertilizers

In Table 2 the fertilizers used for the composition of nutrient solutions are listed. In this table the chemical composition and the molecular weight are also given. Molecular weights of iron chelates and calcium nitrate

Table 2. Fertilizers used to compose nutrients solutions

Fertilizers	Chemical Composition	Percent Nutrients	Molecular Weights
Nitric acid 100%	$H\ NO_3$	22 N	63
Phosphoric acid 100%	H_3PO_4	32 P	98
Calcium nitrate	$Ca\ (NO_3)_2$	15.5N 19 Ca	(200)
Potassium Nitrate	$K\ NO_3$	13N, 38K	101.1
Ammonium nitrate	$NH_4\ NO_3$	35 N	80
Magnesium nitrate	$Mg(NO_3)_2.6H_2O$	11N,9Mg	256.3
Mono potassium phosphate	$K\ H_2\ PO_4$	23P, 28K	136.1
Mono ammonium phosphate	$NH_4H_2PO_4$	27P, 12N	115
Potassium sulphate	K_2SO_4	45K, 18S	174.3
Epsom salt	$MgSO_4.7H_2O$	10Mg, 13S	246.3
Manganese sulphate	$MnSO_4.H_2O$	32 Mn	169
Zinc sulphate	$ZnSO_4.7H_2O$	23 Zn	287.5
Borax	$Na_2B_4O_7.10H_2O$	11B	381.2
Copper sulphate	$CuSO_4.5H_2O$	25Cu	249.7
Sodium molybdate	$Na_2MoO_4.2H_2O$	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	$K\ H\ CO_3$	39K	100.1
Calcium hydroxide	$Ca\ (OH)_2$	54 Ca	74.1

have been estimated. Iron chelates often contain impurities, so molecular weights have been calculated on the basis of iron content. Calcium nitrate fertilizer contains crystallization water and ammonium nitrate. The exact molecular formula is $5\left[Ca\ (NO_3)_2.\ 2\ H_2O\right].\ NH_4NO_3$.

Then the molecular weight is 1080.5 and 1 mol calcium nitrate is chemically equivalent to 5 mol Ca^{++}, 11 mol NO_3^- and 1 mol NH^+_4.
To avoid complicated calculations it is indicated as Ca $(NO_3)_2$ and the molecular weight is rounded. Actually, a small proportion of the nitrogen is given as ammonium instead of nitrate and slightly extra nitrogen and less calcium is present. However, these deviations are slight and acceptable for practical purposes. Acids are given as pure chemicals. However, acids always contain water. The right quantities will be found by using the relative content (0.01*%) as dividend.

Calculations of nutrient solutions

Calculations of nutrient solutions can usually be divided into two parts. The first part involves calculating the major elements with which as a rule in the fertilizers used two or more components have to be considered. For example if KNO_3 is added to increase the potassium content, 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 fertilizers 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 the standard nutrient solution for cucumbers in case that no nutrients are available in the raw water.

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

		Standard composition $mmol.l^{-1}$						
Fertilizer	$mmol.l^{-1}$	NO_3^-	$H_2PO_4^-$	SO_4^{--}	NH_4^+	K^+	Ca^{++}	Mg^{++}
		11.75	1.25	1.0	0.5	5.5	3.5	1.0
NH_4NO_3	0.5	0.5			0.5			
KH_2PO_4	1.25		1.25			1.25		
$Ca(NO_3)_2$	3.5	7.0					3.5	
$K NO_3$	4.25	4.25				4.25		
$Mg SO_4$	1.0			1.0				1.0

The amounts of fertilizer calculated in table 3 expressed in $mmol.l^{-1}$ can be easily be converted to $mg. l^{-1}$ for a ready solution or $kg. m^{-3}$ for a 100 times concentrated stock solution. The results are listed in table 4.

Table 4. Major elements of ready and stock solution for cucumbers calculated from table 3.

Fertilizer	Ready solution $mg.l^{-1}$	Stock solution $kg. m^{-3}$
Ammounium nitrate	40	4.0
Mono potassium phosphate	170	17.0
Calcium nitrate	700	70.0
Potassium nitrate	430	43.0
Epsom salt	246	24.6

Calculations for the minor elements of the cucumber solutions are given in Table 5.

Numbers in the third and fourth column are obtained as follows:
10 umol Fe = 10*932 ug Fe-DTPA (6%) = 9.32 mg Fe-DTPA (6%).
The 100 times concentrated stock solution per m^3 contains
10 $umol*10^3*m^{-3}*932*10^{-6}g*umol^{-1}*10^2=932\ g.m^{-3}$. A similar method can be applied to the other minor elements. Keep in mind that 1 mol borax ≡ 4 mol B. So 20 umol $B.l^{-1} = \frac{1}{4}*20*381.2\ ug.l^{-1} = 1,91\ mg.\ l^{-1}$.

Table 5 Calculations of minor nutrients for the cucumber solutions

Addition $umol.l^{-1}$	Fertilizers	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	1.15	115
20 B	Borax	1.91	191
0.5 Cu	Cupper sulphate	0.12	12
0.5 Mo	Sodium molybdate	0.12	12

There are several other fertilizers which can be used; the choice can be fixed on technical merits. If this is not the case, the cheapest fertilizers will be used. The fertilizers 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 fertilizers which contain calcium should be added, to prevent precipitation of calcium phosphate or calcium sulphate. Tables are given in the supplement for the conversion of $mol.l^{-1}$ in the standard nutrient solution to g 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 neutralize 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 8 gives an example for calculating a nutrient solution for growing tomatoes in rockwool. In the calculation 3 mmol HCO_3^-, 1 mmol Ca^{++}, and 0.5 mmol Mg^{++}. l^{-1} in the raw water are taken into account.

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

Fertilizer	mmol.l^{-1}	NO_3^-	$H_2PO_4^-$	SO_4^{--}	H_3O^+	NH_4^+	K^+	Ca^{++}	Mg^{++}
		Standard composition							
		10.5	1.5	2.5		0.5	7.0	3.75	1.0
		Corrections							
					+3.0			-1.0	-0.5
		Composition to calculate							
		10.5	1.5	2.5	3.0	0.5	7.0	2.75	0.5
H_3PO_4	1.5		1.5		1.5				
HNO_3	1.5	1.5			1.5				
NH_4NO_3	0.5	0.5				0.5			
$Ca(NO_3)_2$	2.75	5.5						2.75	
$K\ NO_3$	3.0	3.0					3.0		
K_2SO_4	2.0			2.0			4.0		
$Mg\ SO_4$	0.5			0.5					0.5

The results calculated and listed in table 6 are converted to mg.l^{-1} for a ready solution or kg.m^{-3} for a 100 times concentrated stock solution. The amounts of fertilizer calculated are shown in table 7. For phosphoric acid and nitric acid solutions of 75% and 65% respectively are inserted. So dividends of 0.75 and 0.65 are used.

Table 7 Amounts of fertilizer for a ready and a 100 times concentrated stock solution, calculated from table 6

Fertilizer	Ready solution $mg.l^{-1}$	Stock solution $kg.\ m^{-3}$
Phosphoric acid 75%	126	12.6
Nitric acid 65%	145	14.5
Ammonium nitrate	40	4.0
Calcium nitrate	550	55.0
Potassium nitrate	303	30.3
Potassium sulphate	349	34.9
Epsom salt	123	12.3

For tomatoes, cucumbers, sweet peppers and eggplants 100 times concentrated stock solutions with adjustments for HCO_3^-, Ca^{++} and Mg^{++} are published (Sonneveld en Van der Wees, 1984, 1982, 1984a and Voogt, 1982). By using these nutrient solutions it is not necessary in most cases to calculate a different stock solution for each type of water.

References

Aylward, G.H. and T.J.V. Findlay, 1974. SI Chemical data. Second edition. John Wiley and Sons.

Sonneveld, C., en R. Arnold Bik, 1984. Voedingsoplossingen voor groenten en bloemen geteeld in water of substraten. Nutrient solutions for vegetables and flowers grown in water or substrates (Fourth edition) Proefstation voor Tuinbouw onder Glas, Naaldwijk. Informatiereeks No. 69.

Sonneveld, C., 1983. Adviesbasis voor waterkwaliteit voor de glas tuinbouw. (Derde druk). Proefstation voor Tuinbouw onder Glas, Naaldwijk. Informatiereeks No. 75.

Sonneveld, C. en A. van der Wees, 1982. Voedingsoplossingen voor de teelt van komkommers in steenwol (Vierde druk). Proefstation voor Tuinbouw onder Glas, Naaldwijk, Informatiereeks No. 44.

Sonneveld, C. en A. van der Wees, 1984. Voedingsoplossingen voor de teelt van tomaten in steenwol (Vijfde druk). Proefstation voor Tuinbouw onder Glas, Naaldwijk. Informatiereeks No. 63.

Sonneveld, C. en A. van der Wees, 1984. Voedingsoplossingen voor de teelt van paprika in steenwol (Tweede druk). Proefstation voor Tuinbouw onder Glas, Naaldwijk. Informatiereeks No. 76.

Voogt, W., 1982. Voedingsoplossingen voor de teelt van aubergines in steenwol. Proefstation voor Tuinbouw onder Glas, Naaldwijk. Informatiereeks No. 77.

Supplement 1

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

Aantal mmol	HNO_3* kg	H_3PO_4* kg	KNO_3 kg	NH_4NO_3 kg	KH_2PO_4 kg
½	3.2	4.9	5.1	4.0	6.8
1	6.3	9.8	10.1	8.0	13.6
1½	9.4	14.7	15.2	12.0	20.4
2	12.6	19.6	20.2	16.0	27.2
2½	15.8	24.5	25.3	20.0	34.0
3	18.9	29.4	30.3	24.0	40.8
3½	22.0	34.3	35.4	28.0	47.6
4	25.2	39.2	40.4	32.0	54.4
4½	28.4	44.1	45.5	36.0	61.2
5	31.5	49.0	50.6	40.0	68.0
5½	34.6	53.9	55.6	44.0	74.9
6	37.8	58.8	60.7	48.0	81.7
6½	41.0	63.7	65.7	52.0	88.5
7	44.1	68.6	70.8	56.0	95.3
7½	47.2	73.5	75.8	60.0	102.1
8	50.4	78.4	80.9	64.0	108.9
8½	53.6	83.3	85.9	68.0	115.7
9	56.7	88.2	91.0	72.0	122.5
9½	59.8	93.1	96.0	76.0	129.3
10	63.0	98.0	101.1	80.0	136.1

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

Supplement 2

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

Aantal mmol	$Ca(NO_3)_2$ (15.5%N) kg	$Mg(NO_3)_2$ 6 H_2O^3 kg	K_2SO_4 kg	$MgSO_4$ $7H_2O$ kg
0.25	5	6.4	4.4	6.2
0.50	10	12.8	8.7	12.3
0.75	15	19.2	13.1	18.5
1.00	20	25.6	17.4	24.6
1.25	25	32.0	21.8	30.8
1.50	30	38.4	26.1	37.0
1.75	35	44.9	30.5	43.1
2.00	40	51.3	34.9	49.3
2.25	45	57.7	39.2	55.4
2.50	50	64.1	43.6	61.6
2.75	55	70.5	47.9	67.8
3.00	60	76.9	52.3	73.9
3.25	65	83.3	56.6	80.1
3.50	70	89.7	61.0	86.2
3.75	75	96.1	65.4	92.4
4.00	80	102.5	69.7	98.6
4.25	85	108.9	74.1	104.7
4.50	90	115.3	78.4	110.9
4.75	95	121.7	82.8	117.0
5.00	100	128.2	87.2	123.2

Supplement 3

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

	% iron in the chelate		
	13	6	5
µmol Fe	g	g	g
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

Supplement 4

Conversion of minor nutrient fertilizers from umol.l^{-1} in the ready nutrient solution to g.m^{-3} in a 100 times concentrated stock solution.

µmol	$MnSO_4$ H_2O g	µmol	$ZnSO_4$ 7 H_2O g	$Na_2B_4O_7$* 10 H_2O g	µmol	$CuSO_4$ 5 H_2O g	Na_2MoO_4 2 H_2O g
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 $Na_2B_4O_7$. 10 H_2O = 4 mol B.