

# COMPUTER PROGRAM FOR THE CALCULATION OF NUTRIENT SOLUTIONS USED IN SOILLESS CULTURE

## Introduction

The program is intended to be used for the calculation of the weights of fertilizers used to prepare stock solutions in open and closed hydroponic systems in commercial practice. The current version is mainly used for the calculation of nutrient solutions used in open hydroponic systems in the sense that it does not take into consideration possible inputs derived from mixture of this solution with drainage solution. The program is based on an algorithm which has been presented in the following research paper:

**Savvas, D. and C. Adamidis, 1999. Automated management of nutrient solutions based on target electrical conductivity, pH, and nutrient concentration ratios. *Journal of Plant Nutrition* 22: 1415-1432.**

Please take into consideration also the following essential *Corrigendum* for the above paper:

**Savvas, D., and K. Adamidis, 2000. Automated management of nutrient solutions based on target electrical conductivity, pH, and nutrient concentration ratios. Erratum. *Journal of Plant Nutrition*, 23: 1371.**

The communication of the user with this computer program is performed via a single sheet, which includes a distinct area for input information, sites in which calculations take place, as well as a separate area for the output of the program. In the above sheet, **green** is used to mark input data (desired values or values imposed by the available facilities, such as type of fertilizer, composition of the fresh water used to prepare the nutrient solutions, etc.), while **blue** is used to mark the output of the program (kg of fertilizers to be added to the specified volume of each stock solution).

The symbols used in the program and the steps to be done to obtain the output of a nutrient solution are described below. Furthermore, some essential background knowledge is given in an Appendix.

## USE OF THE PROGRAM STEP BY STEP

The program enables formulation and calculation of nutrient solutions corresponding to any desired characteristics by taking into account the mineral composition of the water used to prepare the solutions.

First of all, the user is prompted to opt if he/she will introduce target ratios or concentrations to define the composition of the target nutrient solution with respect to K, Ca, Mg, NO<sub>3</sub>-N and NH<sub>4</sub>-N. All target ratios and concentrations introduced in the program should be on a molar basis. Specifically, the following alternative possibilities are available:

1. Metallic macrocations (K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>) The user can opt to introduce either a target K:Ca:Mg ratio (denoted by X:Y:Z), or a target concentrations for each of these ions, which is independent of the other target concentrations.

2. Nitrate nitrogen: The user can opt to introduce either a target total-N/K ratio, thereby indirectly connecting anions (NO<sub>3</sub><sup>-</sup>) with cations (K<sup>+</sup>), or a target NO<sub>3</sub><sup>-</sup> concentration. Total-N includes both inorganic-N forms (NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup>).

3. Ammonium nitrogen. The user can opt to introduce either a target NH<sub>4</sub>-N/total-N ratio, or a target NO<sub>3</sub><sup>-</sup> concentration. Again here, total-N includes both inorganic-N forms (NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup>).

The user can select a mixed option i.e. ratios for some of the above settings and concentrations for some others.

Subsequently, the user is asked to define the volume of each stock solution tank (in m<sup>3</sup>) and the concentration factor for each stock solution, i.e. the ratio at which the stock solution has to be diluted when fresh irrigation solution (diluted solution) has to be prepared and supplied to the plants.

Furthermore, the user has to select the fertilizer source for phosphorus (monopotassium phosphate or phosphoric acid), boron (boric acid, sodium tetraborate or sodium octaborate) and molybdenum (sodium molybdate or ammonium heptamolybdate).

Subsequently, the user has to introduce the target nutrient solution characteristics. In particular, the following target values have to be specified:

(i) E.C. of the target nutrient solution ( $E_t$ ), which is necessary only if a desired ratio is introduced for K, Ca and Mg (X:Y:Z). If the user has opted to introduce target concentrations for K, Ca and Mg, then the EC of the target nutrient solution will be automatically calculated by the program and given as output. In the latter case, introduction of a target  $E_t$  is meaningless, since fixed K, Ca and Mg concentrations correspond to a fixed EC.

(ii) pH of the target nutrient solution,

(iii) either a target K:Ca:Mg ratio (denoted by  $X:Y:Z$ ), or a target K, Ca and Mg concentrations,

(iv) either a target total-N/K ratio ( $R$ ) or a target total  $\text{NO}_3\text{-N}$  concentration,

(v) either a target  $\text{NH}_4\text{-N}/\text{total-N}$  ( $N_r$ ) ratio or a target  $\text{NH}_4\text{-N}$  concentration,

(vi) a target phosphorus ( $\text{H}_2\text{PO}_4$ ) concentration.

(vii) target micronutrient concentrations ( $[C_j]_t$ ,  $j = \text{Fe, Mn, Zn, Cu, B, Mo}$ ).

Further essential information needed by the program includes the percentages of pure  $\text{HNO}_3$  and pure  $\text{H}_3\text{PO}_4$  (if used) in the technical grade products used as sources of these chemicals. Furthermore, the percentage of pure Fe in the Fe-chelate used as iron source when preparing stock solutions has also to be specified.

The next step is the introduction of the ionic concentrations (mmol/L) in the irrigation water used to prepare the nutrient solution (settings to be introduced under “water composition”). These data originate from chemical analysis of the irrigation water in a reliable laboratory. Before introducing this data, the user has to check if the values are in compliance with the anion to cation balance constraint, which requires equal sum of cations with that of anions (both on equivalent basis, i.e. meq/L). Small differences (up to 0.5 meq/L) may be balanced by properly modifying the concentrations of Na, Cl, or nutrients occurring at large concentrations. If the difference between total anion and total cation concentrations is larger, then the irrigation water has to be analyzed again in another, more reliable laboratory.

Finally, the user may select how to allocate potassium nitrate in the two stock solution tanks by defining the percentage of  $\text{KNO}_3$  to be allocated to stock solution A. This option is useful if the user wishes to add roughly equal amounts of fertilizers (in terms of mass) in the two stock solution tanks, in order to minimize differences in the dilution ratio between the two stock solutions owing to different densities of the stock solutions.

After the introduction of these data, the user has to confirm this by clicking on . Immediately after that, the complete output will appear in the right-hand part of the sheet in form of a) target EC and pH values (to be introduced in the fertigation manager) and b) masses of fertilizers (in kg) to be added in each of the stock solution tanks. The selected volume of the nutrient solution tanks will also appear in the output area.

### **Abbreviations:**

C.A.S. and C.C.S. denote concentrations of anions and cations in the target nutrient solution, respectively (meq/L);

C.A.W. and C.C.W. denote concentrations of anions and cations in the tap water, respectively (meq/L);

A.A.F. and C.A.F. denote addition of anions and cations through fertilizers, respectively (dosages in meq/L).

## APPENDIX

### SOME BACKGROUND KNOWLEDGE ON EACH SUB-PROGRAM

1. A linear relationship is used to convert the electrical conductivity ( $E$  in  $\text{dS m}^{-1}$ ) of balanced nutrient solutions into total salt concentration  $C$  ( $\text{meq l}^{-1}$ ) and vice versa:

$$C = 9.819E - 1.462 \quad (1)$$

The electrical conductivity of the nutrient solutions used to obtain (1) ranged from 0.8 to 4.0  $\text{dS m}^{-1}$ . Consequently, (1) is valid only in this particular EC range. Using (1) and replacing  $E$  by  $E_t$ , it is possible to convert the electrical units ( $\text{dS m}^{-1}$ ) indicating the total salt concentration of the desired nutrient solution to chemical units ( $\text{meq l}^{-1}$ ).

2. The bicarbonate ( $\text{HCO}_3^-$ ) concentration  $C_b$  in  $\text{meq l}^{-1}$ , which is established in the irrigation solution after adjustment to the desired pH, is estimated by means of formula (2) in order to compute the bicarbonate fraction in aqueous solutions:

$$\frac{C_{\text{HCO}_3^-}}{C_{\text{CO}_3^{2-}} + C_{\text{HCO}_3^-} + C_{\text{H}_2\text{CO}_3}} = \frac{K_{a1}}{C_{\text{H}^+} B} \quad (2)$$

where  $K_{a1} = 10^{-6.3}$ ,  $K_{a2} = 10^{-10.3}$ , and

$$B = 1 + \frac{K_{a1}}{C_{\text{H}^+}} + \frac{K_{a1}K_{a2}}{(C_{\text{H}^+})^2}$$

3. The target macroelement concentrations in the irrigation nutrient solution  $C_{it}$  in  $\text{meq l}^{-1}$  are estimated using the Eqns in Table 1, as functions of the target K:Ca:Mg ratio ( $X:Y:Z$ ), the desired N:K ratio ( $R$ ), the target ratio of phosphorus to total macronutrient anions ( $P$ ), and the ratio of ammonium to total nitrogen ( $N$ ). The above ratios are expressed on equivalent basis. These ratios and the concentrations of all micronutrients as well as those of the ballast ions  $\text{Na}^+$  and  $\text{HCO}_3^-$  in the raw water ( $C_{iw}$ ) are input data. The Eqns of Table 1 are based on the assumptions that no  $\text{Na}^+$  and  $\text{Cl}^-$  are added via fertilisers and any  $\text{Na}^+$  and  $\text{Cl}^-$  input originating from fertiliser impurities is neglected. The target concentration of  $\text{H}^+$  ( $\text{H}_3\text{O}^+$ ) in the irrigation solution is less than  $10^{-2}$   $\text{meq/l}$ , since the desired pH in nutrient solutions is commonly higher than five, and is, therefore, neglected.
4. The input of macroelements (except  $\text{H}^+$  and  $\text{HCO}_3^-$ ) to the irrigation water via fertilisers  $I_{if}$  (in  $\text{meq l}^{-1}$ ), when preparing fresh nutrient solution, is calculated using Eqn

$$I_{if} = C_{it} - C_{iw} \quad (3)$$

where  $C_{it}$  indicates the target concentration of the  $i$  macroelement in the nutrient solution as calculated via the Eqns of Table 1 and  $C_{iw}$  are the macroelement concentrations in the raw water. The input of  $H^+$  (acid) is aimed at reducing the  $HCO_3^-$  concentration up to  $C_b$ , which corresponds to the target pH. Thus:

$$I_{H^+f} = C_{HCO_3^-w} - C_b$$

since  $HCO_3^-$  is neutralized by  $H^+$  at an 1:1 molar ratio.

5. The input dosages of fertilisers,  $I_{pn}$  in meq/l, ( $p = Ca, Mg, K, NH_4, H$ , and  $n = SO_4, NO_3, H_2PO_4$ ) are calculated using the Eqns given in Table 2.
6. Based on the previously calculated input dosages of fertilisers ( $I_{pn}$ ), the amounts of fertilizers ( $W_{pn}$  in kg) needed to prepare certain quantities ( $V_{pn}$  in  $m^3$ ) of stock solutions are calculated using the following formula:

$$W_{pn} = \frac{I_{pn} Q_{pn} V_{pn} A_{pn}}{1000} \quad (4)$$

where  $Q_{pn}$  is the equivalent weight of the  $pn^{th}$  fertilizer and  $A_{pn}$  denotes the dilution ratio of the stock solution containing the  $pn^{th}$  fertilizer. The chemical formula of the commercially used calcium nitrate is  $5[Ca(NO_3)_2 \cdot 2H_2O]NH_4NO_3$ . Therefore, when using (4) to calculate the weight of calcium nitrate ( $W_{Ca(NO_3)_2}$ ) the equivalent weight corresponding to Ca (108.05) should be introduced as  $E_{Ca(NO_3)_2}$ . Moreover, to take into account the amount of  $NH_4NO_3$  that is included in the commercially used calcium nitrate,  $[NH_4NO_3]$  should be replaced by  $[NH_4NO_3] - 0.1[Ca(NO_3)_2]$  when using (4) to calculate the weight of ammonium nitrate ( $W_{NH_4NO_3}$ ).

7. The amounts of micronutrient fertilizers which are required to achieve the target trace element concentrations are calculated using the formula

$$W_j = \frac{I_j M_j V_j A_j}{1000 n_j} \quad (5)$$

where  $W_j$  is the amount (g) of the fertilizer containing the  $j$  micronutrient ( $j = Fe, Mn, Zn, Cu, B$  and  $Mo$ ), that is needed to prepare a certain volume ( $V_j$  in  $m^3$ ) of stock solution containing the  $j$  micronutrient;  $n_j$  is the number of gr-atoms of the  $j$  micronutrient in one mol of the related fertiliser;  $I_j$  is the input dosage of the  $j$  micronutrient, which is calculated by deducting the target concentration ( $\mu mol l^{-1}$ ) of the  $j$  micronutrient in the nutrient solution from that found in the raw water ( $I_j = C_{jt} - C_{jw}$ );  $M_j$  is the molecular

weight of the fertilizer containing the  $j$  micronutrient; and  $A_j$  is the dilution ratio (concentration factor) of the stock solution containing the fertilizer of the  $j$  micronutrient. However, the concentration of Fe in the tap water is not taken into account when applying (5) to calculate the weight of iron fertilizer because after addition of the stock solutions most of this iron precipitates, mainly in form of iron phosphate<sup>38</sup>.

8. If each macronutrient fertiliser is contained in a separate stock solution tank, it can be independently injected to the raw water, when fresh nutrient solution is prepared, by means of a dosing pump having a constant injection rate  $J_{pn}$  in  $l\ s^{-1}$ . Thus, the amount of each stock solution that is required to achieve the target concentrations in the irrigation solution can be precisely dispensed by automatically controlling the injection time  $T_{pn}$  in s of the corresponding dosing pump, which can be calculated using Eqn

$$T_{pn} = \frac{I_{pn} Q_{pn} V_{pn} V_t}{J_{pn} W_{pn}}, \quad (6)$$

where  $I_{pn}$  denotes the required input dosages of fertilisers in  $meq\ l^{-1}$ ,  $Q_{pn}$  the equivalent weight in  $g\ eq^{-1}$  of the  $pn$  fertiliser,  $V_t$  the volume in  $m^3$  of the nutrient solution to be prepared, and  $W_{pn}$  the weight in kg of the  $pn$  fertiliser contained in  $V_{pn}\ m^3$  of stock solution. However, the injection of nitric acid should preferably be controlled by means of on-line monitoring of pH and not by calculation of  $T_{HNO_3}$  via (6).

Table 1. Equations used to estimate the target macroelement concentrations in the nutrient solution ( $C_{it}$  in  $\text{meq l}^{-1}$ ), based on given target electrical conductivity, pH, and macronutrient ratios.

<i>Cations</i>	<i>Anions</i>
$C_{K^+t} = X(C_t - C_{Na^+w})(1 + NRX)^{-1}$	$C_{NO_3^-t} = RC_{K^+t} - C_{NH_4^+t}$
$C_{Ca^{2+}t} = C_{K^+t} YX^{-1}$	$C_{HCO_3^-t} = C_b$
$C_{Mg^{2+}t} = C_{K^+t} ZX^{-1}$	$C_{H_2PO_4^-t} = P(C_t - C_b - C_{Cl^-w})$
$C_{NH_4^+t} = NRC_{K^+t}$	$C_{SO_4^{2-}t} = C_t - C_{NO_3^-t} - C_{H_2PO_4^-t} - C_b - C_{Cl^-w}$
$C_{Na^+t} = C_{Na^+w}$	$C_{Cl^-t} = C_{Cl^-w}$
$C_{H^+t} = 0$ (less than $10^{-2}$ meq/l)	

Table 2. Equations used to estimate the input of each individual fertilizer ( $I_{pn}$  in  $\text{meq l}^{-1}$ ), required to achieve the target EC, pH and macronutrient ratios in the nutrient solution.

$I_{Ca(NO_3)_2} = I_{Ca^{2+}f}$
$I_{MgSO_4} = I_{Mg^{2+}f}$ if $I_{SO_4^{2+}f} > I_{Mg^{2+}f}$ ; $I_{MgSO_4} = I_{SO_4^{2-}f}$ if $I_{SO_4^{2+}f} < I_{Mg^{2+}f}$
$I_{Mg(NO_3)_2} = 0$ if $I_{SO_4^{2+}f} > I_{Mg^{2+}f}$ ; $I_{Mg(NO_3)_2} = I_{Mg^{2+}f} - I_{MgSO_4}$ if $I_{SO_4^{2+}f} < I_{Mg^{2+}f}$
$I_{K_2SO_4} = I_{SO_4^{2-}f} - I_{Mg^{2+}f}$ if $I_{SO_4^{2+}f} > I_{Mg^{2+}f}$ ; $I_{K_2SO_4} = 0$ if $I_{SO_4^{2+}f} < I_{Mg^{2+}f}$
$I_{KH_2PO_4} = I_{H_2PO_4^-f}$ if P is added as $KH_2PO_4$ ; $I_{KH_2PO_4} = 0$ if P is added as $H_3PO_4$
$I_{H_3PO_4} = 0$ if P is added as $KH_2PO_4$ ; $I_{H_3PO_4} = I_{H_2PO_4^-f}$ if P is added as $H_3PO_4$
$I_{KNO_3} = I_{K^+f} - I_{K_2SO_4} - I_{KH_2PO_4}$
$I_{NH_4NO_3} = I_{NH_4^+f}$
$I_{HNO_3} = I_{H^+f} - I_{H_3PO_4}$

*Table 1. Recommended EC (dS m<sup>-1</sup>), pH and nutrient concentrations (mmol L<sup>-1</sup>) in nutrient solutions (NS) for soilless tomato crops grown under Mediterranean climatic conditions. The initially applied NS is that used to moisten the substrate or introduced to water culture systems before planting.*

Desired characteristics	Initially applied NS	Vegetative stage			Reproductive stage		
		SSOS <sup>1</sup>	SSCS <sup>2</sup>	RE <sup>3</sup>	SSOS	SSCS	RE
EC	2.80	2.50	2.00	3.20	2.40	1.85	3.40
pH	5.60	5.60	-	5.80 – 6.70	5.60	-	5.80 – 6.70
[K <sup>+</sup> ]	6.80	7.00	6.40	7.50	8.00	7.50	8.20
[Ca <sup>2+</sup> ]	6.40	5.10	3.10	7.80	4.50	2.30	8.00
[Mg <sup>2+</sup> ]	3.00	2.40	1.50	3.40	2.10	1.10	3.40
[NH <sub>4</sub> <sup>+</sup> ]	0.80	1.50	1.60	<0.60	1.20	1.40	<0.40
[SO <sub>4</sub> <sup>2-</sup> ]	4.50	3.60	1.50	5.00	4.00	1.50	6.00
[NO <sub>3</sub> <sup>-</sup> ]	15.50	14.30	12.40	18.00	12.40	11.00	17.20
[H <sub>2</sub> PO <sub>4</sub> <sup>-</sup> ]	1.40	1.50	1.30	1.00	1.50	1.20	1.00
[Fe]	20.0	15.00	15.00	25.00	15.00	15.00	25.00
[Mn]	12.00	10.00	10.00	8.00	10.00	10.00	8.00
[Zn]	6.00	5.00	4.00	7.00	5.00	4.00	7.00
[Cu]	0.80	0.80	0.80	0.80	0.70	0.70	0.80
[B]	40.00	35.00	20.00	50.00	30.00	20.00	50.00
[Mo]	0.50	0.50	0.50	-	0.50	0.50	-

<sup>1</sup>SSOS: solution supplied to open systems; <sup>2</sup>SSCS solution supplied to closed systems; <sup>3</sup>RE target concentrations in the root environment.

*Table 2. Recommended EC ( $dS\ m^{-1}$ ), pH and nutrient concentrations ( $mmol\ L^{-1}$ ) in nutrient solutions (NS) for soilless cucumber grown under Mediterranean climatic conditions. The initially applied NS is that used to moisten the substrate or introduced to water culture systems before planting.*

Desired characteristics	Initially applied NS	Vegetative stage			Reproductive stage		
		SSOS	SSCS	RE	SSOS	SSCS	RE
EC	2.40	2.20	1.90	2.50	2.10	1.80	2.70
pH	5.60	5.60	-	5.30- 6.40	5.60	-	5.20 – 6.40
[K <sup>+</sup> ]	6.30	6.20	6.00	6.40	7.20	6.50	8.00
[Ca <sup>2+</sup> ]	5.00	4.15	3.20	6.00	3.40	2.65	5.50
[Mg <sup>2+</sup> ]	2.00	1.60	1.10	2.30	1.40	1.00	2.50
[NH <sub>4</sub> <sup>+</sup> ]	0.80	1.40	1.60	<0.50	1.40	1.40	<0.50
[SO <sub>4</sub> <sup>2-</sup> ]	1.90	1.30	1.00	2.20	1.40	1.00	2.60
[NO <sub>3</sub> ]	15.60	14.75	12.50	17.00	13.75	11.60	17.20
[H <sub>2</sub> PO <sub>4</sub> ]	1.20	1.25	1.20	1.00	1.15	1.10	1.00
[Fe]	20.00	15.00	15.00	25.00	15.00	15.00	25.00
[Mn]	12.00	10.00	10.00	8.00	10.00	10.00	7.00
[Zn]	6.00	5.00	5.00	7.00	5.00	5.00	8.00
[Cu]	0.80	0.80	0.80	1.30	0.80	0.70	1.50
[B]	40.00	25.00	30.00	50.00	25.00	25.00	50.00
[Mo]	0.50	0.50	0,50	-	0.50	0.50	-

<sup>1</sup>SSOS: solution supplied to open systems; <sup>2</sup>SSCS solution supplied to closed systems; <sup>3</sup>RE target concentrations in the root environment.