Mixing a Balanced Nutrient Solution[©]

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INTRODUCTION

Plant growers are dependant on the process of photosynthesis, driven in green leaves with energy from the sun, building carbohydrates with carbon dioxide (CO_2), and water (H_2O). Thirteen essential plant nutrients affect this process by ensuring that the leaves are green, filled with chlorophyll, and that the integrity of membranes and strength of cell walls are maintained. Plant roots absorb these nutrients from fertile soil. But, these nutrients can also be supplied by a well-balanced nutrient solution in soil-less culture. Arnon and Hoagland (1940) established some of the first well-balanced nutrient solutions, enabling soil-less crop production. Apart from the introduction of chelated iron, modern nutrient solutions do not differ much from the older ones. In this paper, an extract form "Nutrient Solution Management" (Combrink and Kempen, 2011), guidelines will be given to enable the reader to "build" his/her own nutrient solution. However, before this can be done, it is important to ensure that terms such as pH, salt concentration, and some basic chemical principles are understood.

ACIDITY AND ALKALINITY

pH

pH is a value taken to represent the acidity or alkalinity of an aqueous solution with values ranging from 1 to 14. At a reading of 7, the pH is considered to be neutral. At this point equal concentrations of hydrogen ions (H^+) and hydroxyl ions (OH^-) occur. Values lower than 7 indicate acidity and solutions with pH values higher than 7 are alkaline. The pH scale is logarithmic, thus the pH value of water will not decrease linearly when acids are added to it.

Total Alkalinity

Total alkalinity is the aggregate concentration of bases such as carbonates, bicarbonates, and hydroxides. The concentration of these ions (CO_3^{2-}, HCO_3^-, and OH^-) is determined with a titration, as measure of total alkalinity. It is usually expressed as HCO_3^-, but some laboratories may express total alkalinity as $CaCO_3$. The alkalinity can be neutralized by adding an equivalent amount of acid (H^+). Most soils are well-buffered, thus their pH values do not change easily. This is not the case for soil-less conditions where special precautions are needed to control the pH and the availability of nutrients in solution. Due to this pH-sensitive availability of some nutrients, soil-less crops are grown in solutions with pH values between 5.3 and 6.3. Compared to soil pH values, this pH range may seem to be relatively low, but a look at the dissociation pattern of phosphate (Table 1) shows why neutral to alkaline nutrient solutions should be avoided. In addition, micro-nutrients such as Fe and Zn precipitate, forming insoluble salts at pH values higher than 7.

Table 1. Phosphate dissociation pattern (Steiner, 1984).

pH	HPO_4^{2-} (Forming a soluble Ca salt) (%)	$H_2PO_4^-$ (Forming an insoluble Ca salt) (%)
pH = 5.0	100	0
pH = 6.0	90	10
pH = 6.5	78	22
pH = 7.0	50	50
pH = 8.0	15	85

Problems also arise with pH levels lower than 5, where the concentration of H^+ is too high, restricting the absorption of Ca^{2+}. This problem is aggravated in the presence of ammonium (NH_4^+). It is recommended that the pH limits for soil-less production systems be set at 5.3 to 6.3, with an optimum pH at about 5.8, where most crops should grow well.

ELECTRICAL CONDUCTIVITY
Electrical conductivity (EC) is a well-known term amongst soil-less growers. The EC of water is used as an indication of its salt content since higher concentrations of charged particles (ions) increase the electrical conductivity of water or nutrient solutions. When salts are added to water, the crystals dissolve or ionise. Using table salt or sodium chloride (NaCl) as an example, one sodium cation (Na^+) and one chloride anion (Cl^-) will be released per dissolved NaCl unit. These charged ions in the water enable the flow of an electrical current. The higher the concentration of ions (charge) per unit volume of water, the better the conductivity and the higher the EC will be. (But, one unit of $CaCl_2$ releases one Ca^{2+} cation and two Cl^- anions with a potential conductivity of about double that of NaCl, an aspect that will be dealt with later). At a very high EC, the water contains too much dissolved salts, restricting the osmotic movement of water from the root zone solution into the roots. Take note that non-polar molecules (sugar or urea) dissolve in water without the release of charged particles. Thus, these substances dissolve but do not increase the EC of a solution but do affect the osmolarity of the solution and may thus also restrict the uptake of water.

The use of different EC units may confuse growers. Siemens (S) is the SI unit for conductivity. With very low conductivity levels, a 1000 times' smaller unit such as milli Siemens (mS) can be used. The unit "mho" is equivalent to S and mmho to mS. Some laboratories use the electrical resistance of soil as indication of its salt content. Due to an inverse relationship between conductivity and resistance, higher resistance values (measured in ohm) are indicative of low salt contents. A lower resistance implies that more salts are in solution, the conductivity will thus be high. The direct relationship between conductivity and salt content is easy to understand and an important managerial tool for soil-less growers.

The distance between the two electrodes, while measuring the conductivity of a solution, also affects the reading. The reading in $mS \cdot m^{-1}$ will be 100 times bigger than a reading in $mS \cdot cm^{-1}$. Most growers use $mS \cdot cm^{-1}$ as unit to test the EC of standard nutrient solutions. Depending on the crop and the season, these values may vary between 0.8 and 3.0 $mS \cdot cm^{-1}$. The EC of good quality feeding water may be very low, explaining why most laboratories prefer to express the conductivity of irrigation water in $mS \cdot m^{-1}$.

Relation of $mS \cdot cm^{-1}$ to other EC units: $1 \ mS \cdot cm^{-1}$ $= 1 dS \cdot m^{-1}$
$= 1 \ mmho \cdot cm^{-1}$
$= 100 \ mS \cdot m^{-1}$
$= 1000 \ \mu S \cdot cm^{-1}$

Since temperatures affect EC readings, EC meters are calibrated at 25°C. Electrical conductivity meters such as those used by growers are not temperature compensating. These EC measurements can be corrected by subtracting 2% from the measured value per 1°C higher than 25°C solution temperature. With solutions colder than 25°C, 2% can be added per 1°C deviation.

Feeding Water Quality
The term "feeding water" is used to describe an untreated water source. Different factors can be used to define feeding water quality but it's chemical composition and the presence of potential dangerous micro-organisms are the most important. The risk to find toxic levels of micro nutrients in feeding water increases with increased EC levels. Micronutrients are usually present at very low concentrations, but can be phytotoxic at low levels; too low to even affect EC readings.

Feeding Water pH

Water pH cannot be used as sole parameter for pH adjustments. This must be done by adjusting total alkalinity, the aggregate concentration of bases such as carbonates, bicarbonates, and hydroxides. Laboratories measure the total concentration of these bases (CO_3^{2-}, HCO_3^- and OH^-) with a titration. Since fertilizers may be slightly acidic, the feeding water should be slightly alkaline to prevent the pH from dropping too low when mixing.

UNWANTED IONS IN FEEDING WATER

Iron and Manganese

High levels of soluble (ferrous) iron may be found in water from the mountainous areas of the Cape and along the Drakensberg. This iron is in a reduced state (Fe^{2+}) and when oxidized, ferric iron Fe^{3+} precipitate as an insoluble, red substance. Using this water to irrigate with sprinklers, the red pigment can be seen on leaves and on garden walls. Manganese is also soluble in its reduced state and precipitates as insoluble MnO_2 when oxidized. Should water with high Fe or Mn concentrations be used for drip irrigation, the ions are oxidized (micro-organisms may also be involved). Insoluble residues then block the drippers. Fe and Mn can be precipitated and removed by aeration of the feeding water, before using it. The higher the pH, the quicker it will precipitate.

Sodium and Chloride as well as Nutrients at Potential Phytotoxic Levels

Sodium and Cl ions can only be efficiently removed with expensive water purification systems such as reversed osmosis, currently used to purify sea water in Sedgefield. Should water purification companies claim that they can remove these ions from feeding water, samples should be obtained and the water should be chemically analysed to measure the Na and Cl levels before and after the process to determine whether the process lives up to its claim. The same expensive system of reversed osmosis is needed to remove nutrients such as Mg, Cu, Zn, and B, when these are present at phytotoxic levels.

Ions Associated With Alkalinity

The alkalinity level in saline feeding water is usually high, due to high levels of CO_3^{2-}, HCO_3^- and OH^-. These ions can easily be replaced by nitrate or phosphate, simply by using nitric- or phosphoric acid to lower the alkalinity.

BASIC HYDROPONIC CHEMISTRY

Mole

Mole is Avogadro's number with the value of 6.02×10^{23}. The atomic mass, expressed in grams, contains Avogadro's number of atoms. For example, 12 g of carbon (C) and 23 g of sodium (Na) contain the same number of atoms = 6.02×10^{23} = 1 mole. The atomic mass of some elements are shown in Table 2.

Molecular Mass

One mole of a substance is a mass in grams numerically equal to the molecular mass. With KCl as an example, 39.1 and 35.5 are added to reach 74.6, the molecular mass of this salt. Thus, 74.6 g of KCl contains Avogadro's number of KCl units: 1 mole (6×10^{23}) K and 1 mole Cl atoms.

Table 2. Chemical formula, ions of some elements and complex ions with their respective atomic and molecular masses.

Element	Symbol	Ion	Atomic mass	Complex ion	Chemical formula	Molecular mass
Hydrogen	H	H^+	1.0	Bicarbonate	HCO_3^-	61
Boron	B		10.8	Carbonate	CO_3^-	60
Carbon	C		12.0	Ammonium	NH_4^+	18
Nitrogen	N		14.0	Nitrate	NO_3^-	62
Oxygen	O		16.0	phosphate	$H_2PO_4^-$	97
Sodium	Na	Na^+	23.0	Sulphate	SO_4^{2-}	96
Magnesium	Mg	Mg^{2+}	24.3			
Silicon	Si		28.1			
Phosphorus	P		31.0			
Sulphur	S		32.1			
Chloride	Cl	Cl^-	35.5			
Potassium	K	K^+	39.1			
Calcium	Ca	Ca^{2+}	40.1			
Manganese	Mn		54.9			
Iron	Fe		55.8			
Copper	Cu		63.5			
Zinc	Zn		65.4			
Molybdenum	Mo		95.9			

Equivalent Mass (Mass per Charge)
The atomic mass of K is 39. When losing an electron it becomes a single charged cation K^+. Its mass (and equivalent mass) remains to be 39 (the mass of an electron is close to zero, it can be ignored). The atomic mass of Ca is 40, but when ionised, it loses 2 electrons, becoming a doubled charged cation (Ca^{2+}). Its atomic mass is 40, but its mass per single charge (equivalent mass) is 20. By dividing atomic mass by the charge of its ion, the equivalent mass is calculated. The molecular mass is calculated by adding the mass of all the atoms in a compound. Its equivalent mass is the molecular mass, divided by the charge of the ion (in the molecule) with the highest charge or valance. Thus, its equivalent mass is the mass of material with mole positive and mole negative charges. As an example: The mass of 1 mole $CaCl_2$ is 111 g (40+35.5+35.5) but 1 mole of positively (and negatively) charged units, or the equivalent mass is 111/2 or 55.5 g of $CaCl_2$. The equivalent mass of a salt is its molecular mass divided by the highest valence (charge) of the ions that will be released when it is dissolved in water. With mole charged particles per equivalent, the term mol_c is used, a unit 1000 times bigger than $mmol_c$. The concentration of macro-nutrients in nutrient solutions is expressed as $mmol_c \cdot L^{-1}$.

Transforming ppm or $mg \cdot L^{-1}$ to $mmol_c \cdot L^{-1}$
Chemical laboratories usually use $mg \cdot L^{-1}$ as unit for their water analyses reports. These can be transformed to $mmol_c \cdot L^{-1}$ by dividing it by the equivalent mass of the ion or the complex ion, as shown in Table 3.

Table 3. Concentrations expressed as mg·L^{-1} (or ppm) must be divided by the equivalent mass of the substance to transform it to mmol$_c$·L^{-1}.

Substance	Eqv. mass	Substance	Eqv. mass
Ammoinium-N	14	Nitrate-N	14
Ammonium (NH_4^+)	18	Nitrate (NO_3^-)	62
Bicarbonate (HCO_3^-)	61	Phosphate–P	31
Calcium ($Ca)^{2+}$	20	Phosphorus	31
Carbonate ($CO_3)^{2-}$	30	Potassium (K^+)	39
Chloride (Cl^-)	35.5	Sodium (Na^+)	23
Magnesium ($Mg)^{2+}$	12.1	Sulphate ($SO_4)^{2-}$	48

Molar (M)

By dissolving 1 mole KCl (74.6 g) into 1 litre of distilled water, the molarity of the solution will be 1 M KCl. In this case 6×10^{23} positively charged ions (K^+) and 6×10^{23} negatively charged ions (Cl^-) would be present in the water. Due to these charged particles, the solution will be able to conduct an electrical current, which is used as indication of the ion concentration. By dissolving only 2% of 74.6 = 1.49 g KCl per litre distilled water, the molarity of the solution will be 2% of 1 M = 0.02 M. This solution can be used as standard EC test solution to calibrate your EC-meter, because it's EC will be 2.77 mS·cm^{-1} at 25°C.

Normality (N)

By dissolving the equivalent mass of a substance into 1 litre of distilled water (1 mmol$_c$·L^{-1}) the solution's normality will be one (1 N). The normality of acids or liquid fertilizers can be calculated with the following formula:

N = (SG x C) / Eqv. mass
N = Normality
SG = Specific gravity of the solution
C = Concentration as g·kg^{-1} or (% × 10)
Eqv. mass = Equivalent mass of the dissolved chemical

ESSENTIAL NUTRIENTS

Micro-Nutrients

These are needed in extremely low concentrations. In European soil-less production environments, micronutrient concentrations are expressed as μmol·L^{-1}, a unit 1000 times smaller than mmol·L^{-1}. In South Africa, micronutrient concentrations are expressed as mg·L^{-1} (or ppm).

Macro-Nutrients

These are known as N, P, K, Ca, Mg, and S. These are still seen as the only essential macronutrients, although Si and other minerals may positively affect the growth of some plants under specific conditions. Roots absorb macronutrients as ions: NH_4^+, K^+, Ca^{2+}, Mg^{2+} (cations) and NO_3^-, $H_2PO_4^-$, and SO_4^{2-} (anions). Only N can be absorbed as a positively charged cation (NH_4^+) as well as a negatively charged anion (NO_3^-). Several chemicals can be used to release these ions into feeding water.

Non-Essential Na and Cl

1. Sodium. Sodium is not essential for crop growth but most South African water sources contain some sodium. Most crop plants are salt excluders with limited uptake of Na^+ by roots. Some plants do not transport sodium ions from the roots to the shoots (Epstein and Bloom, 2004). The plant's ability to tolerate high Na^+ levels may improve in the presence of Ca^{2+}. This was demonstrated with saline-sensitive beans that could be grown in the presence of 50 mmol$_c$·L^{-1} NaCl, but only with addition of relatively high Ca levels (La-Haye and

Epstein, 1971).

2. Chloride. Chloride is considered to be an essential micronutrient, but it is usually present at macronutrient quantities. Please do not confuse the chloride ion (Cl^-) with chlorine gas (Cl_2), used by municipalities and growers as an oxidant to sterilize water. Some saline water sources contain high levels of chloride that may limit the uptake of nitrate (Kafkafi, Valoras and Letey, 1982). Fortunately the opposite is also true. Weigel et al. (1973) used feeding water with a high chloride level and by increasing the nitrate level in a nutrient solution from 1.25 to 7.0 $mmol_c \cdot L^{-1}$, found that chloride concentrations in soybean leaves dropped.

BASICS BEFORE STARTING WITH A NUTRIENT SOLUTION

Nutrient Recipes

By combining and evaluating the information available in the literature, Steiner (1968) made a huge contribution when he summarised basic nutritional principals for soil-less plant production. He proposed a well-balanced "universal nutrient solution" by dealing with cations- and anions separately and described safe areas for the K^+ : Ca^{2+} : Mg^{2+} and NO_3^- : $H_2PO_4^-$: SO_4^{2-} ratios. Using $mmol_c \cdot L^{-1}$ as unit, he expressed the ideal cation ratio as 35:45:20 % and chose 60:5:35 % as anion ratio. Some deviations from these ratios are allowed and he defined the outer limits beyond which deficiencies or toxicities may develop (Steiner, 1968). Before starting with nutrient solutions, the role of NH_4^+ should first be clarified.

Ammonium is Used as pH Regulator or N-Source for Acid-Tolerant Crops

Steiner did not include ammonium (NH_4^+) in his nutrient solution and used NO_3^- as the sole nitrogen source. As in Europe, all South African soil-less growers use ammonium. Ammonium is used in soil-less production systems to regulate the pH in the root zone. To understand this, it should be remembered that a neutral charge is maintained in the root. When a cation or anion is absorbed, the root secretes H^+ or OH^- respectively. Due to the fact that NH_4^+ is a very small ion and is easily absorbed, NH_4^+ is exchanged by H^+ at such a rate, that the root zone is acidified. During decomposition of organic substrates, bicarbonate is released, increasing the alkalinity and the substrate's pH. Some ammonium may then be useful to counteract this. Since too much NH_4^+ may acidify the rhizosphere to such an extent, that the uptake of Ca may be restricted, it should be carefully managed, especially on crops sensitive to blossom-end-rot, a Ca deficiency disorder (Combrink, 2005). Kafkaffi (2000) claims that the danger of damage by ammonium increases at high root zone temperatures. The difference in sensitivity of crops to ammonium toxicity is ascribed to differences in sugar concentrations in the roots where ammonium is metabolised. Ammonium-loving crops such as orchids and disas react positively to the presence of ammonium.

Compiling Your Own Nutrient Solution

Publications by Arnon and Hoagland (1940), Steiner (1984), and Dutch research workers (de Kreij et al., 1999; Straver et al., 1999) helped local fertilizer companies to develop "ready mix" nutrient solutions. The cation and anion ratios of these commercial mixes fall within the limits of Steiner's "universal nutrient solution." These products allow growers to avoid the tedious job of weighing and mixing fertilizers from several different bags, when compiling their own mixes. But, "ready mixes" can only be used where the feeding water contains almost no dissolved salts (EC <0.3 $mS \cdot cm^{-1}$). Most manufacturers of "ready mixes" make use of Cl-containing fertilizers. This is acceptable for growers with good quality feeding water but may be a risk for growers with saline sensitive crops and high levels of Cl^- in their feeding water. In addition, these saline water sources may also contain high levels of Mg and by simply adding the normal Mg level (using a "ready mix"), the optimum Mg level can easily be exceeded and Mg at this higher level may suppress the uptake of the other cations (Ca and K). This underlines the importance that nutrients, already present in feeding water, should be taken into account when preparing a nutrient

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mix.

Predicting the Electrical Conductivity of Solutions
Electrical conductivity is used as indication of the amount of dissolved salts in solution. The unit $mg \cdot L^{-1}$ is commonly used by laboratories where feeding water is chemically analysed. However, it is difficult to balance ion concentrations using this unit. This problem is solved by using $mmol_c \cdot L^{-1}$. In addition, the EC of the solution can then also be predicted with relative accuracy. By dividing the cation (or anion) concentration ($mmol_c \cdot L^{-1}$) by 10, a fairly accurate EC value is calculated ($mg \cdot L^{-1}$). As an example, if you add 20 $mmol_c \cdot L^{-1}$ cations (and anions) to distilled water, the EC will be about 2 $mS \cdot cm^{-1}$. By multiplying an EC value with 10, you can thus estimate its ion concentration in $mmol_c \cdot L^{-1}$. Using feeding water with an EC of 0.3 $mS \cdot cm^{-1}$, you know that dissolved salts are present at a concentration of about 3 $mmol_c \cdot L^{-1}$.

Electrical Conductivity and Nutrient Uptake
The size of a root system as well as ion concentration in root zones affect the rate of ion uptake. It is obvious that a well-developed root system is needed for optimum uptake and that a specific root system is likely to absorb more nutrients at higher nutrient concentrations (higher EC levels). The increase in ion uptake is linear with increased nutrient concentrations, but only up to a certain level. As soon as the EC rises above a certain level, the rate of ion uptake decreases (Bar-Yosef, 1995). Uptake of the massive double-charged Ca ion declines first. This may induce a Ca-deficiency (Combrink, 2005). This illustrates that the rate of ion uptake can be increased by an increased ion concentration – but only up to a certain point. Even saline tolerant crops grow slower, should the EC of the root zone solution be increased beyond the crop's optimum need (Ribeiro and Combrink, 2006). Benoit (2003) compared a salt sensitive to a salt tolerant crop and showed that the yield potential of the sensitive crop declined at a rate of at least 10% for each 1 $mS \cdot cm^{-1}$ rise beyond its optimum EC of 2 $mS \cdot cm^{-1}$. The yield of the salt tolerant crop only declined at EC levels higher than 4 $mS \cdot cm^{-1}$ at a rate of approximately 5% for each 1 $mS \cdot cm^{-1}$ higher than EC 4 $mS \cdot cm^{-1}$.

In an effort to improve the sugar content of 'Daniela', one of the first "long shelf life" tomato cultivars grown in South Africa, the nutrient solution's EC of 2 $mS \cdot cm^{-1}$ was increased to 4 $mS \cdot cm^{-1}$ with addition of 2 mmol NaCl per litre. The fruit's total soluble solids (°Brix) did increase but the associated higher sugar percentage was due to the fact that less water was absorbed and not due to a better sugar production. This was reflected by an associated 30% reduction in yield and fruit size (Combrink, 1998).

PLANNING A MACRONUTRIENT SOLUTION
Steiner was a prominent figure on the soil-less culture scene for many years and it may be useful to do our first exercise with his "universal nutrient solution." At this stage we ignore the composition of the feeding water, assuming that it is of good quality, not needing pH adjustment.

The macronutrient percentages for cations in Steiner's 'Universal nutrient solution' are: 35% K^+, 45% Ca^{2+}, and 20% Mg^{2+} (on a $mmol_c \cdot L^{-1}$ basis). The recommended anion ratio is 60% NO_3^-, 5% $H_2PO_4^-$, and 35% SO_4^{2-}. Say that the aim is to have a nutrient solution at an EC of 2 $mS \cdot cm^{-1}$, then the cation as well as anion totals need to be 20 $mmol_c \cdot L^{-1}$. The K^+ level will thus be 35% of 20 or 7 $mmol_c \cdot L^{-1}$, Ca^{2+} at 45% of 20 at 9 $mmol_c \cdot L^{-1}$, and Mg^{2+} at 20% of 20 $mmol_c \cdot L^{-1}$ at 4 $mmol_c \cdot L^{-1}$. The same procedure will indicate that 12 $mmol_c \cdot L^{-1}$ NO_3^-, 1 $mmol_c \cdot L^{-1}$ $H_2PO_4^-$, and 7 $mmol_c \cdot L^{-1}$ SO_4^{2-} are needed. Pure hydroponic-quality salts are used as sources of these ions.

Procedure to Select Chemicals
1) Look for the smallest nutrient need; 1 $mmol_c \cdot L^{-1}$ $H_2PO_4^-$ and choose a P source. Since no ammonium is prescribed for this mix, this eliminates ammonium phosphate. Thus, choose mono potassium phosphate and add 1 $mmol_c \cdot L^{-1}$ potassium (K), as well as the

associated 1 $mmol_c \cdot L^{-1}$ phosphate at the anion side (Table 4).

2) Look for the next smallest need, 4 $mmol_c \cdot L^{-1}$ Mg. Choose a Mg source. Mg-nitrate and Mg-sulphate options are available. Choose the Mg salt with the anion with the smallest need in your planned solution (nitrate vs. sulphate). The choice is $MgSO_4$. Add 4 $mmol_c \cdot L^{-1}$ Mg^{2+} at the cation side and 4 $mmol_c \cdot L^{-1}$ SO_4^{2-} at the anion side.

3) The next smallest need is 3 $mmol_c \cdot L^{-1}$ SO_4^{2-}. Since the Mg need is already satisfied, K-sulphate is chosen as SO_4^{2-} source. Apply the balance of 3 $mmol_c \cdot L^{-1}$ SO_4^{2-} and remember also to add 3 $mmol_c \cdot L^{-1}$ of K^+ at the cation side.

4) The next smallest need is 3 $mmol_c \cdot L^{-1}$ potassium (7 needed, but 1 K-phosphate and 3 K-sulphate were given). With only nitrate still needed at the anion side, the only option is to use KNO_3 at 3 $mmol_c \cdot L^{-1}$.

5) The last action is to apply the Ca need as well as the balance of nitrate still needed with 9 $mmol_c \cdot L^{-1}$ of ammonium-free Ca-nitrate (This procedure changes when using NH_4^+-containing Ca-nitrate, Table 5).

Table 4. Mixing Steiner's ammonium-free macro-nutrient solution (Steiner, 1984).

EXERCISE: Steiner's solution

Nutrients to be added (mmol$_c$ L^{-1}):					7	9	4	12	1	7
Fertilizer		mol. mass	eqv. mass	Application (See y)	K^+	Ca^{2+}	Mg^{2+}	NO_3^-	$H_2PO_4^-$	SO_4^{2-}
KNO_3	(4th step)	101	101	3 x 101 = **303**	3			3		
K_2SO_4	(3rd step)	174	87	3 x 87 = **261**	3					3
$K H_2PO_4$	(1st step)	136	136	1 x 136 = **136**	1				1	
$Ca(NO_3)_2.4H_2O^z$	(Last)	236	118	9 x 118 = **1062**		9		9		
$Mg SO_4.7H_2O$	(2nd step)	246	123	4 x 123 = **492**			4			4
					7	9	4	12	1	7

z Ammonium-free Ca-nitrate is used for this exercise.

y Nutrient concentration (mmol$_c$ L^{-1}) x equivalent mass of fertilizer = Application (mg L^{-1} or g 1000 L^{-1})

Adjust Alkalinity and Add Nutrients

The aim of this exercise is to set your feeding water's total alkalinity between a minimum of 0.2, up to a maximum of 1.0 $mmol_c \cdot L^{-1}$. Some fertilizers such as potassium sulphate (K_2SO_4) and mono potassium phosphate (MKP) may contain acid residues. On average, the H^+ released from fertilizers used for a normal macronutrient mix varies from 0.2 to 0.4 $mmol_c \cdot L^{-1}$. With only this limited acidity in fertilizers to neutralize, an alkalinity buffer of 0.4 should be sufficient. The alkalinity of feeding water for organic substrates (releasing HCO_3^- during decomposition) should be lowered to 0.2 to 0.4. Using inert substrates, the input alkalinity may be set at 0.5 to 1.0 $mmol_c \cdot L^{-1}$.

Add Alkalinity

Distilled water is an example of water with a neutral pH and alkalinity of zero, as would also be found in pure rain water. Water from high rainfall areas may have no alkalinity, it may even be slightly acidic. Due to the low solubility of $CaCO_3$ (Table 16) calcitic lime can be used to increase the total alkalinity of these water sources without the danger of an over-dosage.

Water from the Cederberg area (low EC and pH) flows into the Clanwilliam dam. Water is then fed to growers via cement canals. The exposure of the water to the cement ads alkalinity to the water. It is possible that the alkalinity may increase as it moves to growers further downstream. In winter with a low need for irrigation water, the flow will be slow, thus allowing more time for the water to interact with the cement that may

further increase the alkalinity of the water. The effect is about the same as where municipalities treat corrosive water by letting it flow through a lime pebble tank.

Where lime-pebble pre-treatment operations are impractical and the alkalinity of the feeding water is too low, a soluble alkaline such as KOH can be added, at a levels between 0.2 to 0.8 $mmol_c \cdot L^{-1}$.

Decrease the Alkalinity
With addition of acid to alkaline feeding water, carbon dioxide gas as well as water is released. The HCO_3^- is replaced with NO_3^-, $H_2PO_4^-$ or SO_4^{2-} by using either nitric acid (HNO_3), phosphoric acid (H_3PO_4), or sulphuric acid (H_2SO_4) as source of H^+.

Table 5. A mild lowering of the alkalinity of a low-EC feeding water (suitable for the use of a "ready mix"), before adding nutrients.

	mol mass	Eqv mass	Application — Dry products $mmol_c\,L^{-1}$ x eqv mass (g 1000 L^{-1})	Application — Liquids $mmol_c\,L^{-1}/N$ (L 1000 L^{-1})	Na$^+$	NH$_4^+$	K$^+$	Ca^{2+}	Mg^{2+}	H$^+$	NO$_3^-$	H$_2$PO$_4^-$	SO$_4^{2-}$	Cl$^-$	HCO$_3^-$
Water composition:					0.8			0.3	0.2					0.4	0.9
HNO$_3$ (N = 12.7)				0.039 L						0.5	0.5				
KOH	56	56													
pH corrected water:					0.8			0.3	0.2	0	0.5			0.4	**0.4**
To be added: (Demonstrated in the table below)*							7	9	4		12	1	7		
Final nutrient solution: EC ± 2.13 mS cm^{-1}:					**0.8**		**7**	**9.3**	**4.2**		**12.5**	**1**	**7**	**0.4**	**0.4**

Table* only for calculation of added nutrients	mol mass	Eqv	Dry products		Na$^+$	NH$_4^+$	K$^+$	Ca^{2+}	Mg^{2+}		NO$_3^-$	H$_2$PO$_4^-$	SO$_4^{2-}$	Cl$^-$	HCO$_3^-$
KNO$_3$	101	101	3 x 101 = 303				3				3				
K$_2$SO$_4$	174	87	3 x 87 = 261				3						3		
K H$_2$PO$_4$	136	136	1 x 136 = 136				1					1			
NH$_4$ H$_2$PO$_4$	115	115													
NH$_4$NO$_3$	80	80													
Ca (NO$_3$)$_2$. 4H$_2$O^z	236	118	9 x 118 = 1062					9			9				
Mg SO$_4$.7H$_2$O	246	123	4 x 123 = 492						4				4		
Mg(NO$_3$)$_2$.6H$_2$O	256	128													
Totals added *							7	9	4		12	1	7		

z = Pure Ca (NO$_3$)$_2$.4H$_2$O is used for this exercise.   Most Ca-nitrate sources in S-Africa contain some ammonium.

Although the alkalinity is not very high in the example (Table 5), it is lowered from 0.9 to 0.4 because the plants will be grown in an organic substrate (adding alkalinity) and Steiner's solution contains no acidifying ammonium. The grower can thus expect a rise in alkalinity and pH as the nutrient solution passes through the root zone. A higher alkalinity would be needed for a nutrient solution containing a high ammonium level, especially using an inert substrate. The EC of the feeding water, containing 1.3 $mmol_c \cdot L^{-1}$ ions, can be calculated as 1.3/10 = 0.13 $mS \cdot cm^{-1}$. This EC value remains unchanged after the acid treatment. After addition of 20 $mmol_c \cdot L^{-1}$ salts for Steiner's solution, the EC should be 0.13 + 2.0 = 2.13 $mS \cdot cm^{-1}$. Due to relatively low levels of nutrients in the feeding water and the fact that only a small increase in nitrate level results due to the addition of 0.5 $mmol_c \cdot L^{-1}$ nitric acid, the end result does not differ much from Steiner's recipe. This feeding water is pure enough to allow the use of a "ready mix," obtainable from most fertilizer companies.

High EC-Feeding Water Requires Major Adjustments
In Table 6 the EC of the feeding water is 0.7 $mS \cdot cm^{-1}$, a level often found in South African production areas. Should 20 $mmol_c \cdot L^{-1}$ be added to this water, using a "ready mix," the expected EC of the nutrient solution will be about 2.7 $mS \cdot cm^{-1}$, a level where the uptake of water may be slightly restricted. In addition, the levels of Ca, Mg and

sulphate (usually present in saline water) will probably be unnecessarily high. The following example (Table 6) shows that only 17 mmol$_c$·L^{-1} need to be added to equal Steiner's nutrient solution, ending with a final EC of 2.4 mS·cm^{-1} and a lower fertilizer bill and better ion ratios in the root zone.

Table 6. Lowering of the alkalinity of a high EC feeding water before adding nutrients, aiming to satisfy ratios as suggested by Steiner.

		Application		Salinity, pH correction and adapted Steiner										
		Dry products	Liquids											
mol	Eqv	mmol$_c$ L^{-1} x eqv mass	mmol$_c$ L^{-1}/ N	mmol$_c$ L^{-1}						mmol$_c$ L^{-1}				
mass	mass	(g 1000 L^{-1})	(L 1000 L^{-1})	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}	Mg^{++}	H$^+$	NO$_3^-$	H$_2$PO$_4^-$	SO$_4^=$	Cl$^-$	HCO$_3^-$
Water composition:		EC of feeding water ± 0.7 mS cm-1		4			2	1				2	3	2
HNO$_3$ (*N* = 12.7)			0.126 L						1.6	1.6				
KOH	56	56												
pH corrected water: (EC unaffected, still at ± 0.7 mS cm^{-1})				4			2	1	0	1.6		2	3	0.4
To be added: (Do it in the table below)			*			7	7	3		10.4	1	5.6		
Final nutrient solution: EC ± 2.4 mS cm^{-1}				4	7	9	4			12	1	7.6	3	0.4

Table* only for calculation of added nutrients				Na$^+$	NH$_4^+$	K$^+$	Ca^{++}	Mg^{++}	NO$_3^-$	H$_2$PO$_4^-$	SO$_4^=$	Cl$^-$	HCO$_3^-$
KNO$_3$	101	101	3.4 x 101 = **343**			3.4			3.4				
K$_2$SO$_4$	174	87	2.6 x 87 = **226**			2.6					2.6		
K H$_2$PO$_4$	136	136	1 x 136 = **136**			1				1			
NH$_4$ H$_2$PO$_4$	115	115											
NH$_4$NO$_3$	80	80											
Ca (NO$_3$)$_2$. 4H$_2$O^z	236	118	7 x 118 = **826**				7		7				
Mg SO$_4$.7H$_2$O	246	123	3 x 123 = **369**					3			3		
Mg(NO$_3$)$_2$.6H$_2$O	256	128											
Totals added *						7	7	3	10.4	1	5.6		

z = Ammonium-free Ca-nitrate is used for this exercise.

The alkalinity in the example shown in Table 6 is 2 mmol$_c$·L^{-1}. Growers with high alkalinity levels, as in this case, may choose to add phosphoric acid at the same level as needed for H$_2$PO$_4^-$. Since phosphoric acid will be used to supply 1 mmol$_c$·L^{-1} H$_2$PO$_4^-$, Nitric acid (always added first) should only be applied at 0.6 mmol$_c$·L^{-1} to lower the alkalinity to 1.4 and then with phosphoric acid down to 0.4 mmol$_c$·L^{-1}. By adding phosphoric acid directly to water with high alkalinity and Ca levels, Ca-phosphate may precipitate. In the following example, nitric acid is used as sole acid to lower the alkalinity from 2.0 to 0.4 by adding H$^+$ and NO$_3^-$ at 1.6 mmol$_c$·L^{-1}. In this case the added nitrate cannot be ignored and will be taken into account when deciding how much nitrate to add.

The planned added cations and anions must be equal. Start with the cations, adding levels of K, Ca, and Mg to reach Steiner's preset values (mmol$_c$·L^{-1}). With no K in the water the K application will be 7 mmol$_c$·L^{-1}. However, the water contains some Ca and Mg, thus top it up with 7 and 3 mmol$_c$·L^{-1} respectively. At this stage, take note that the total added cations will be 17 mmol$_c$·L^{-1}. Now plan to add exactly 17 mmol$_c$·L^{-1} anions. Top nitrate up by adding 10.4 mmol$_c$·L^{-1} and add the total phosphate need of 1.0 mmol$_c$·L^{-1}. Of all the macro nutrients, plants can adapt to sulphate at a very wide range. As long as the sulphate level ends up at a level ±50% higher or lower than the target value, the plants will still be happy. In this example the phosphate target is exceeded by about 10% in order to balance the cations and anions.

Only now you can start using the lower table to add the ions, starting with the smallest need first, usually phosphate. Select the ammonium-free MKP and by adding K and P at 1 mmol$_c$·L^{-1}, satisfying the P-need and lowering the K-need from 7 to 6 mmol$_c$·L^{-1}. With the Mg-need at only 3 mmol$_c$·L^{-1}, this ion is added next. Now choose between the two Mg-salts. Since Mg-sulphate will also supply sulphate, and the fact that the sulphate-need is smaller than the nitrate need, this salt is chosen. By adding Mg-sulphate at 3 mmol$_c$·L^{-1},

the sulphate-need is the smallest, thus the only other sulphate-containing salt is used. After adding K- sulphate at 2.6 $mmol_c \cdot L^{-1}$, the next smallest need is K at 3.4 $mmol_c \cdot L^{-1}$. The only anion still needing a top-up is nitrate. After adding K-nitrate at 3.4 $mmol_c \cdot L^{-1}$, ammonium-free Ca-nitrate can be used to top up both Ca and nitrate, using 7 $mmol_c \cdot L^{-1}$.

Ammonium Affecting Root Zone pH

Organic substrates decompose with time, releasing HCO_3^- (Benoit, 2003). Coco peat decomposes slower than pine sawdust and therefore its associated rise in alkalinity and pH is also slower. The expected increase in root zone alkalinity (especially during the first 6-8 weeks after starting with a fresh organic substrate) can be counteracted with addition of more ammonium to the nutrient solution. With inert substrates (rockwool, sand, or gravel) or with NFT systems, lower ammonium levels may be used. Apart from its effect on pH, orchid need relatively high ammonium levels (Pienaar, 2005).

Steiner's ammonium-free solution was used as an example, but in practice, growers have to use ammonium. Mono potassium phosphate (MKP) was used as K- and P-source in our previous examples, but mono ammonium phosphate (MAP) is a popular ammonium- and P-source. The ammonium-free Ca-nitrate [$Ca(NO_3).4H_2O$] that was also used in previous examples, was only recently introduced to the Republic of South Africa on commercial scale. Most South African growers buy Ca-nitrate, an ammonium-containing product, from big fertilizer companies. Looking at its chemical composition, $Ca(NO_3)_2.0.2(NH_4NO_3.10H_2O)$, one can see that 11/12 of the applied N is given as nitrate-N and 1/12 as ammonium-N. By ignoring the ammonium content of Ca-nitrate and by using MAP ($NH_4H_2PO_4$) as P-source (Table 7), ammonium can reach an extremely high level.

Table 7. Ammonium phosphate as P-source in combination with ammonium containing Ca-nitrate, using Mg-sulphate, or Mg-nitrate as alternative Mg sources.

Fertilizer	Concentration tank	Eqv mass	Application g 1000 L^{-1}	$mmol_c L^{-1}$	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	NO_3^-	$H_2PO_4^-$	SO_4^{-2}
KNO_3	A and/or B	101	404	4		4.0			4.0		
K_2SO_4	A	87	174	2		2.0					2.0
$NH_4H_2PO_4$	C	115	115	1	1.0					1.0	
$5Ca(NO_3)_2.NH_4NO_3.10H_2O$	B	108	891	9	0.75		8.3		9.0		
$MgSO_4.7H_2O$	A	123	492	4				4.0			4.00
Three stock solution tanks needed					**1.75**	**6.0**	**8.25**	**4.0**	**13.0**	**1.0**	**6.0**

NH_4^+ as % of N-Total: 1.75/(1.75+13.0)*100 = **11.9%**

Fertilizer	Concentration tank	Eqv mass	Application g 1000 L^{-1}	$mmol_c L^{-1}$	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	NO_3^-	$H_2PO_4^-$	SO_4^{-2}
K_2SO_4	A	87	522	6		6.0					6.0
$NH_4H_2PO_4$	A	115	115	1	1.0					1.0	
$5Ca(NO_3)_2.NH_4NO_3.10H_2O$	B	108	891	9	0.75		8.25		9.0		
$Mg(NO_3)_2.6H_2O$	B	128	512	4				4.0	4.0		
Two stock solution tanks needed					**1.75**	**6.0**	**8.25**	**4.0**	**13.0**	**1.0**	**6.0**

The second option, shown in Table 7, shows that Mg-nitrate can be used as Mg source to replace Mg-sulphate. This is only possible where the K-need is equal to, or higher than the sulphate-need.

MIXING PROCEDURE, USING AMMONIUM-CONTAINING CA-NITRATE

The tomato nutrient solution is used in the following example, containing ammonium at 1 $mmol_c \cdot L^{-1}$. The mixing procedure, as was previously demonstrated, was done with ammonium-free Ca-nitrate. Using ammonium-containing Ca-nitrate, this procedure needs adjustment, as discussed below and illustrated in Table 8.

Step 1

Deal with the nutrient at the lowest need first (ammonium). Using ammonium-containing Ca-nitrate, this salt is dealt with first. Calculate the Ca-nitrate application (needed to satisfy the Ca need) and then see how much ammonium was applied concurrently. Calcium is needed at 8.5 $mmol_c \cdot L^{-1}$. Multiply this Ca-need with $1.1 = 9.35$ $mmol_c \cdot L^{-1}$. This is the level of nitrate in this application. With Ca^{2+} at 8.5 $mmol_c \cdot L^{-1}$ the difference (9.35-8.5) is ammonium (0.85 $mmol_c \cdot L^{-1}$). Peppers need a low ammonium level, forcing growers to use the ammonium-free Ca-nitrate product.

Table 8. Mixing procedure, using ammonium-containing Ca-nitrate.

Nutriënt mix for tomatoes (mmol_c L^-1), ignoring feeding water :					1	7	8.5	3.5	12.5	1.5	6
FERTILIZER Adding		mol mass	eqv. mass	**Application** (See y)	NH_4^+	K^+	Ca^{++}	Mg^{++}	NO_3^-	$H_2PO_4^-$	$SO_4^=$
K NO₃	Step 4	101	101	3.15 x 101 = 318		3.15			3.15		
K₂ SO₄	Step 5	174	87	2.5 x 87 = 218		2.50					2.50
K H₂PO₄	Step 3	136	136	1.35 x 136 = 184		1.35				1.35	
NH₄ H₂PO₄	Step 2	115	115	0.15 x 115 = 17.3	0.15					0.15	
X 5Ca(NO₃)₂.(NH₄NO₃.10H₂O)	Step 1	216	108	9.35 x 108 = 1010	0.85		8.50		9.35		
Mg SO₄.7H₂O	Step 6	246	123	3.5 x 123 = 431				3.5			3.5
					1	7	8.5	3.5	12.5	1.5	6

X = *Ammonium-containing Ca-nitrate*
y = **Nutrient concentration (mmolc L⁻¹) x equivalent mass of fertilizer = Application (g 1000 L⁻¹)**

Step 2

The next step is to add the smallest need, in this case ammonium. By adding 0.15 $mmol_c$ MAP, the NH_4^+-level is lifted from 0.85 to 1.0 $mmol_c$.

Step 3

In the previous step, phosphate was lifted to 0.15, still needing 1.35 to reach a level of 1.5 $mmol_c$. This can be done by using potassium phosphate as third step.

Step 4

The next smallest need is nitrate: Add K-nitrate at 3.15 $mmol_c$.

Step 5

The need for K was lowered in the previous step. We already have nitrate and phosphate at their required levels, thus 2.5 $mmol_c$ K-sulphate must be used.

Step 6

Both Mg and sulphate need 3.5 $mmol_c$. This is applied using Mg-sulphate.

PLANNING A MICRONUTRIENT SOLUTION

Since high levels of Fe and Mn may block drippers, Fe and Mn should be removed from the feeding water in advance. It is seldom possible to remove all the Fe and Mn but with these nutrients at safer lower levels, Mn may be topped up to its required level. Due to its quick oxidation and loss in irrigation pipes, the remaining Fe in the feeding water must be ignored and the total Fe-need applied as chelated Fe (Deckers, 2002). As with

macronutrients, the other micronutrient levels in feeding water should also be topped up to optimum levels. The procedure that should be followed when preparing nutrient solutions (macro- and micronutrients) will be discussed after a closer look at the solubility of salts.

SOLUBILITY OF SALTS

Some growers use partly shaded porta-pool reservoirs to mix their nutrient solutions. After filling these reservoirs with water, fertilizers are dissolved into it, using pumps to circulate the water. The problem is that algae grow in nutrient-rich water when it is exposed to light. Even though the solution may not appear green, low concentrations of algae may still block filters and drippers. The modern trend is to switch to smaller fertilizer tanks, containing 100x concentrated stock solutions to be released into passing feeding water. However, some ion combinations may form relatively insoluble salts that may precipitate in concentrated solutions.

Why not Concentrate the Entire Nutrient Solution into One Tank? By concentrating a standard nutrient solution with an EC of 2.2 mS·cm^{-1}, you do not find a linear increase in EC, as expected (Fig. 1).
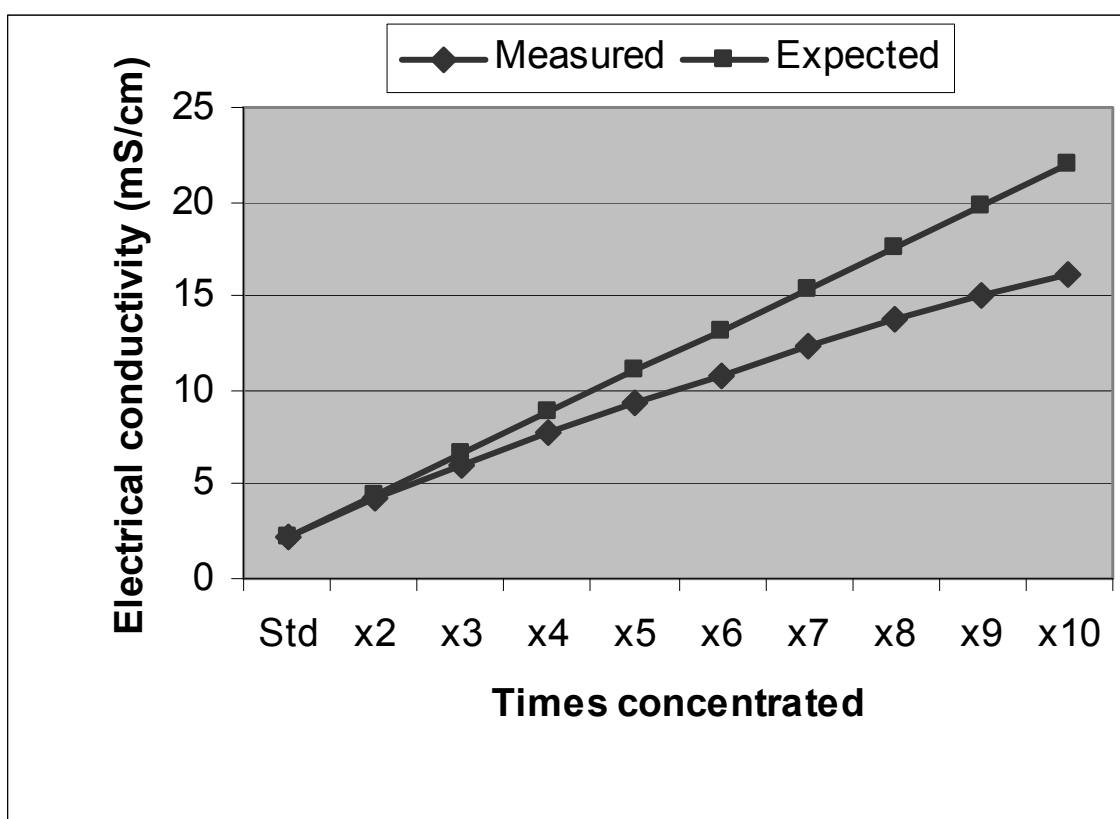

Fig. 1. Expected and measured electrical conductivity (EC) values of a standard nutrient
solution at increasing concentrations (up to 10x).

The lower than expected EC with the increase in concentration can be ascribed to ion losses due to the precipitation of Ca-sulphate, Ca-phosphate, and other relatively insoluble ion combinations.

Exactly the same problem exists for calcium and phosphate, especially at a relatively high pH. Thus, Ca and phosphate should also be kept apart when solutions are concentrated.

Another relatively insoluble ion combination is ammonium-magnesium-phosphate-hexahydrate at pH = 7. This implies that not all three of these ions (NH_4, Mg, and H_2PO_4) may be together at high concentrations, should the pH of the concentration tank be higher than 5.5.

When preparing stock solutions, ammonium-containing solutions should never be exposed to high pH levels, where ammonium losses occur due to the formation of NH_3 gas. The stock solution pH should always be below 6.5. Most growers with modern greenhouses use concentrated stock solutions. They use special electronic or volumetric equipment to control the release from the stock solution tanks into the feeding water, to reach the greenhouse at the correct EC and pH.

Table 9. Nutrient solutions for different crops, grown with drain-to-waste production systems. The EC values represent listed nutrients alone (Subscript x).

	Macronutrients ($mmol_c.L^{-1}$)							EC^x ($mS.cm^{-1}$)		Micronutrients ($mg.L^{-1}$)					
	NH_4	K	Ca	Mg	NO_3	H_2PO_4	SO_4			Fe	Mn	Zn	B	Cu	Mo
Disa	1.7	1.9	1.4	1.0	3.3	0.7	2.0		**0.60**	0.45	0.55	0.25	0.20	0.03	0.04
Cymbidiium	1.0	2.8	2.0	1.5	4.0	0.8	2.5		**0.73**	0.45	0.55	0.25	0.20	0.03	0.04
Anthurium	0.3	3.8	2.5	1.9	6.1	0.8	1.6		**0.85**	0.85	0.15	0.25	0.30	0.04	0.05
Lettuce	0.7	5.5	5.8	1.0	10.0	1.0	2.0		**1.30**	1.00	0.55	0.25	0.30	0.05	0.05
Rose	0.7	4.3	6.5	2.5	10.4	1.1	2.5	z	**1.40**	0.85	0.30	0.25	0.20	0.03	0.05
Gerbera	1.5	5.5	6.0	2.0	11.0	1.2	2.8		**1.50**	2.00	0.30	0.25	0.30	0.05	0.05
Gypsphila	0.7	4.0	7.3	3.0	12.0	1.0	2.0		**1.50**	0.85	0.55	0.25	0.30	0.05	0.05
Strawberry	1.0	5.0	6.5	2.5	10.0	1.0	3.0		**1.50**	1.15	0.75	0.45	0.10	0.05	0.05
Alstromeria	0.7	5.0	7.0	2.5	10.5	1.0	3.7		**1.52**	1.40	0.30	0.25	0.30	0.05	0.05
Amaryllis	1.2	6.3	6.0	2.0	12.0	1.0	2.5		**1.55**	0.55	0.55	0.30	0.30	0.04	0.05
Beans	1.0	5.5	7.0	2.5	12.0	1.0	3.0		**1.60**	0.85	0.30	0.25	0.20	0.03	0.05
Carnation	1.0	6.0	7.0	2.0	12.3	1.2	2.5		**1.60**	1.40	0.55	0.26	0.33	0.05	0.05
Crysanth	1.0	6.0	7.0	2.0	12.3	1.2	2.5		**1.60**	1.40	0.55	0.26	0.25	0.05	0.05
Brinjal	1.0	4.5	7.0	4.0	12.5	1.0	3.0		**1.65**	0.85	0.55	0.30	0.38	0.05	0.05
Courgette	1.0	5.5	7.0	3.0	13.0	1.0	2.5	z	**1.65**	0.85	0.55	0.30	0.38	0.07	0.05
Cucumber	1.0	5.5	7.5	2.5	13.0	1.0	2.5	z	**1.65**	0.85	0.55	0.30	0.30	0.05	0.05
Pepper	0.3	5.2	9.0	3.5	12.8	1.2	4.0		**1.80**	0.85	0.55	0.30	0.30	0.05	0.05
Tomato	1.0	7.0	8.5	3.5	12.5	1.5	6.0	y	**2.00**	0.85	0.55	0.30	0.30	0.05	0.05
Melon	1.2	7.0	9.8	4.0	13.0	1.5	7.5	y	**2.20**	0.85	0.55	0.25	0.35	0.05	0.05
Cherry toms	1.5	8.0	9.5	4.0	13.0	1.5	8.5	y	**2.30**	0.85	0.55	0.30	0.30	0.05	0.05
Swiss chard	1.0	7.0	10.8	4.2	13.0	1.5	8.5	y	**2.30**	0.85	0.55	0.25	0.35	0.05	0.05
Amaranthus	1.0	7.0	10.8	4.2	13.0	1.5	8.5	y	**2.30**	0.85	0.55	0.25	0.35	0.05	0.05

[X] The crop recipes should produce these EC values with zero Na and Cl in the feeding water. These values may be increased with 10% to 20% by concentrating the nutrient solutions during cold and low radiation conditions. During sunny, hot and low humidity conditions (with poor climate control structures) the EC values can be reduced by lowering the nutrient concentrations with 15 to 25%.

[Y] The relatively high sulphate levels may be reduced with 2 up to 3 $mmol_c·L^{-1}$ and replaced with equivalent levels of Cl, only with a drain-to-waste system and with the water Cl levels < 2 $mmol_c·L^{-1}$.

[Z] Addition of silicon (Si) to these nutrient solutions may reduce the incidence of powdery mildew.

RECIPES FOR SPECIFIC CROPS
Standard (input) nutrient solutions should be changed when root zone solutions indicate that imbalances develop. Recipes for drain-to-waste systems (Table 9) differ from those used in closed systems but the root zone norms (not discussed in this paper) are exactly the same.

It is dangerous to use nutrient recipes from foreign countries, without understanding their conditions. As an example, relatively high Mg levels occur in Israel's feeding water. Thus, hardly any Mg is used by Israeli growers. Dutch growers use inert media such as rock wool, whereas most South African growers use organic substrates, such as pine sawdust. Side-

effects of decomposing organic material, such as lowered root zone N levels during the first 6 to 8 weeks after transplanting, associated with an increased root zone pH or alkalinity, should be taken into account (Benoit, 2003).

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