Water quality and salinity aspects in hydroponic cultivation

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1 Water quality in hydroponics

Plants need water and nutrients to grow. In hydroponics, it is possible to achieve high yields and high qualities when water and nutrients are given at the required quantities. Nutrients and water required by the plants can be calculated. However, the water quality supplied is just as important but often the quality (the contents of salt and nutrients) is fixed. Therefore it is important to know what quality of water is being used, and, consequently, what corrections in fertilization are required. In this article basic principles of water quality will be explained.

1.1 Components of water

In table 1 an overview is given of the most frequent appearing elements in various water sources. The EC (see 1.1.1 Electric Conductivity) represents the total amount of ions in the water, the single elements show the individual components.
Components in the water may be useful, such as potassium, calcium or magnesium or harmful such as sodium and chloride but even a high value of bicarbonate is harmful. Sometimes it is directly toxic to plants, sometimes it influences the uptake of other elements.

Bicarbonate

The gas carbon dioxide dissolves in water partly as the gas CO_2, partly as the anion bicarbonate HCO_3^- and partly as the anion carbonate CO_3^{2-}.

$$CO_2 + H_2O \leftrightarrow HCO_3^- + H^+ \leftrightarrow CO_3^{2-} + H^+$$

This double reaction is dependent on the concentration (the pressure) of carbon dioxide and on the concentration H^+ (acidity). A higher carbon dioxide pressure pushes the reaction to the right resulting in more (bi)carbonate and a lower pH (more H^+). Adding acid will push the reaction to the left making carbon dioxide gas to leave the solution. Under normal pressure there is no (bi)carbonate in solution below a pH of 5.0. Between 5.0 and 8.0 the bicarbonate ion prevails, above pH 8.0 it is mainly carbonate.
Many wells and surface waters contain amounts of (bi)carbonates ranging from 3.0 -7.0 mmol/l. The higher bicarbonate levels go with higher pH levels (6.5-8.5). Even higher levels are possible in some wells (7.0-14.0) when water is over saturated (slightly bubbling).
At pH values over 6.0 plants find it increasingly difficult to take in phosphates and micro elements Fe, Mn, Cu, Zn, B. Therefore, water with bicarbonates is treated with acids to reduce the level of bicarbonates to about 0.5 mmol/l. This small buffer of bicarbonate left is useful in preventing the too rapid drop in pH possible in unbuffered water.

Sulphate

Sulphate levels in the supply water will result in (mild) precipitations when fertilisers are concentrated, for example in the A and B tanks. The problem can be avoided by preparing the A and B tanks with water without sulphates (rainwater or reverse osmosis water). Level should be <3 mmol/l in fresh water.

Other elements

- Sodium interferes with the uptake of calcium and magnesium which creates cell collapses and disorders particularly in tomato and pepper (Blossom End Rot (BER) and leaf edge necrosis).

Sodium can quickly become damaging in recirculation as the plant uptake is often low which results in rapid accumulation on the root surface.

- Ca, calcium often present; creates precipitates in stock solution preparation with sulphates. It is recommended to use high quality water for stock solution only (rainwater). 3-4 mmol/l in fresh water is often acceptable
- Mg, magnesium rarely precipitates in stock solution preparation. It is recommended to use high quality water for stock solution only. 1-2 mmol/l in fresh water is often acceptable.
- Cl, Chlorine is reducing the uptake of nitrate/phosphate. Damaging in recirculation but the level of uptake by the plant is higher than for sodium which makes accumulation slightly less of a problem.
- Fe, iron and Mn, manganese can be present in large quantities and clog irrigation systems (remove with oxidation before sending the water into the pipes).
- B boron will pass reverse osmosis membranes, it creates toxicity but only when recirculating (accumulation), not in free drainage or open systems. Level should be <25 µmol/l.

Table 1: Components of water and their limits in use for hydroponics

Parameter	Units	Degree of restriction on use		
		None	Slight to Moderate	Severe
EC	dS m^{-1}	0-0.75	0.75-2.25	>2.25
Bicarbonates	mol m^{-3} (ppm)	0-2 (0-120)	2-6 (120-360)	>6 (>360)
Nitrates	mol m^{-3}	<0.5	0.5-2	>2
Ammonium	mol m^{-3}	≈0	0.1-1	>1
Phosphorus	mol m^{-3}	<0.3	0.3-1	>1
Potassium	mol m^{-3}	<0.5	0.5-2.5	>2.5
Calcium	mol m^{-3}	<1.5	1.5-5	>5
Magnesium	mol m^{-3}	<0.7	0.75-2	>2
Sodium	mol m^{-3}	<3	3-10	>10
Chloride	mol m^{-3}	<3	3- 10	>10
Sulphates	mol m^{-3}	<2	2-4	>4
Iron	mmol m^{-3}			>90
Boron	mmol m^{-3}	30	30-100	>100
Cupper	mmol m^{-3}			>15
Zinc	mmol m^{-3}			>30
Manganese	mmol m^{-3}			>10

De Kreij, C; Voogt, W.; Baas, R., (1999). Nutrient solutions and water quality for soilless cultures. PBG, Naaldwijk, Holland, brochure 196.

1.2 Electric conductivity

The electric conductivity is one of the most important parameters in hydroponic cultivation. It represents the total amount of ions in the solution and is mostly expressed in the unit mS/cm or dS/m. All ions in the solution contribute to the EC, regardless whether the ions are useful of harmful to the plants. If substances are not split in ions they have no influence on the EC. In soil cultivation urea is very much used as fertilizer, it makes soils more acid which is often useful. In hydroponics there is no need to add much acidifying fertilizers. Apart from the acidifying effect, urea does not split into ions, it is a molecule

without any charge. The EC meter measures ions, so if a molecule does not split in ions it cannot be measured. But the unmeasured urea still influences the nitrogen contents and pH. It is therefore recommended to avoid the use of urea fertilisers.
The latter is of importance when urea is used as fertiliser.

Figure 1. Hand EC meter (left) and measurement of a sample in practice (right).

Almost all nutrients –urea is an exception- are salts which in water split in positively charged cations and negatively charged anions. The number of positive and negative charges is always equal. The more charges water carries, the better it conducts electricity, the higher the EC is. That is why an electro conductivity meter reading is a measure of the amount of salts present. Some rules of thumb:

1 dS m^{-1} ≅ 10 mmol L^{-1} positive + 10 mmol L^{-1} negative charges

Or: EC = 0.1* sum of positive ions in milliequivalence (me)

1 dS m^{-1} ≅ 650 mg salts in natural waters (if the relatively light sodium chloride sets the EC)

1 dS m^{-1} ≅ 850 mg salts in nutrient solution water

All charged particles (cations and anions) contribute to osmotic value of the water. The osmotic value is a measure of the force a plant need to exert if it takes water in. Rules of thumb state:

1 dS m^{-1} ≅ 35 kPa ≅ 350 cm water column ≅ 350 g cm^{-2}

This means that saline water requires plants to pull harder to get water in the cells. The result is that cells of plants growing in saline solution are smaller and darker green (as the green chlorophyll stays closer together) but with a higher percentage dry matter.
More difficult is the calculation of the EC per specific fertiliser:

- 1 g/l $Ca(NO_3)_2$ = 1.24 mS/cm
- 1 g/l K_2SO_4 = 1.54 mS/cm
- and so further for all fertilizers in the solution

1.3 Water sources

Depending on the country and region the water quality may vary very much. Therefore, it is important to know the individual components of the water to be used in hydroponics. A chemical analysis (pH, EC, NH_4, K, Ca, Mg, NO_3, SO_4, H_2PO_4, HCO_3, Fe, Mn, Zn, B and Cu) in a laboratory is demanded before starting hydroponics. The following water sources can be distinguished:

- rainwater
- surface water, including dam water
- ground water, including bore hole water, and well water

- municipal tap water
- other sources

Rainwater

In general rainwater is of an excellent quality for hydroponic cultivation. Only close to the sea, there might be more sodium in the water. Harvesting of rainwater takes place by collecting the rainfall from the greenhouse cover. Depending on the rainfall pattern, the type of greenhouse and the storage capacity 20-90% of the water need of a tomato crop might be covered by rainwater. If the rainfall pattern is evenly divided over the year, such as in the Netherlands, 80-90% of the rainfall can be used. Recommended storage capacity is 1500 m^3/ha. Metal tanks are used for sizes smaller than 2000 m^3. For larger volumes basins (ponds) are used.
In Jordan rain falls in mainly 4-6 months which means that during the rainy season in the Highlands the rain should be collected. Rough estimations tells that about 50% of the water need can be covered. Storage should be more than 1500 m^3/ha to reach highest usage. It should be investigated if the first rain which cleans the greenhouse cover contains much salts from dust or sand.

Figure 2. Storage of rainwater in tanks (left), basin in the Netherlands (middle) and a basin in Jordan (right).

Collecting rainwater from the roofs of greenhouses is for multispan houses not a big issue. It is more complicated when using single tunnels. There is not yet a standard solution to be used. However, it is quite well possible to dig a trench at both sides of the tunnel, cover it with a plastic liner of 0.5 mm, put a drain pipe at the bottom and fill it with a coarse gravel up to ground level. The drain pipe will be connected at the top end of the tunnels to a lateral pipe to deliver it to a storage basin (figure 3).

Surface water

Surface water from rivers, lakes or canals might have a variable chemical quality. It can differ from excellent to very poor depending on the source, but it is also possible that the quality differs over the year. As in Jordan Valley the canal water is getting more saline when it is more to the south, and also more saline later in the year, this water source should be analysed more frequently. After a first full chemical analysis, weekly control with an EC meter is often sufficient. If quality drops, an additional analysis should be made. If the surface water source flows through urban or horticultural areas one should also be aware of the risk of introducing human and plant pathogens in the greenhouse and perhaps also remnants of pesticides. An initial analysis on pathogens and pesticides then is required.

Ground water

The quality of ground water very much depends on the local situation. It might be of excellent chemical quality, but it may also contain such large amounts of salts that it should be desalinated with for example reverse osmosis before use. At the moment groundwater is withdrawn in large quantities, there might be political and environmental concern about the effect of a decreasing ground water table. Ground water from deep aquifers is pathogen free.

Municipal tap water

Tap water contains salts to improve the taste of water. It is often too saline to use for hydroponics and contains chloride. Besides tap water is often expensive and quantities per hour too low. Therefore, it is mostly not a first choice. Tap water is pathogen free at start.

Treated waste water
It is not yet in use on many locations, but more and more waste water from sewage systems is investigated for use in horticulture. In Almeria (Spain) waste water is being used (pathogen free, but EC = 1.5-2.5 mS/cm). The Almerian waste water is therefore too saline and unsuitable for hydroponics with recirculation. Again, it very much depends on the quality of the water. Before use and before leaving the installation pathogens must be eliminated (UV, Ozone and others). The risk is spreading of human pathogens, but plant pathogens have also to be removed. In Jordan Valley the main source of irrigation water is treated waste water (100 million m^3/year). Further quality should be uniform over the year. A fluctuating composition is difficult to handle.

In general, hydroponics requires a much higher quality water to feed the plants compared to traditional soil grown crops. Before starting it has to be investigated which sources are available in sufficient quantities. Laboratory analysis are required here.

2 Salinity effects on plants

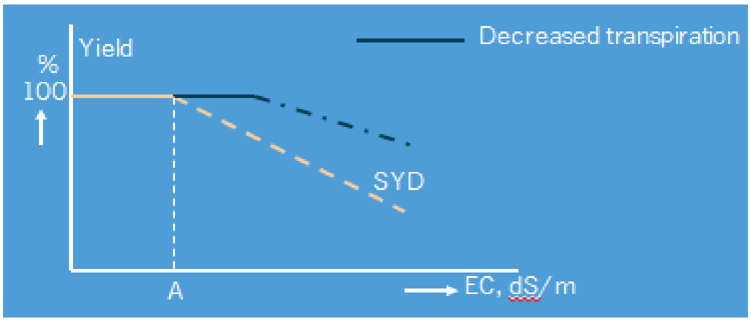
High salt (sodium and chloride, NaCl) concentrations will harm plant growth. There are two main causes:

- water stress; water stress appears in hours because there is a reduction in water uptake and the plant needs more energy to take up water. Final result is wilting of the leaves.
- Salinity stress; salinity stress is a more long term effect at which the single elements become toxic for the plants resulting in growth reduction. Besides there is the antagonism between Na, Ca, Mg and K. If there is more sodium in the solution, the uptake of Ca might be reduced, which results in tomato and sweet pepper in blossom end rot or leaf edge necrosis.

For most hydroponically grown crops the fresh weight growth reduction caused by excess salinity is known (figure 3). It can be calculated as:

SYD ≅ (EC - A) * B in which:

- SYD is salinity yield decrease in % of fresh weight loss
- EC is electro conductivity in dS m^{-1}
- A is a crop specific threshold (around 2.5 dS m^{-1})
- B is a crop specific factor in % fresh weight decrease per unit EC



Crops:

- Bean 14.7%
- Celery 7.7
- Cucumber 8.8
- Lettuce 4.6
- Pepper 12.6
- Spinach 1.2
- Tomato 6.5

Figure 3. Salinity yield decrease for specific hydroponically grown crops

The differences in SYD per crop are caused by differences in the uptake of sodium, but also on the crop specific threshold value. Figure 4 gives an overview per crop.

Crop		Limit		Uptake	
		Na	Cl	Na	Cl
tomato		10	15	1	1.2
cucumber		8	10	1.2	2
sw. Pepper	vegetative	8	12	0.8	1
	generative	8	12	0.3	0.9
lettuce		8	15	1.5	2
chrysant		6	8	0.3	0.9
rose		6	8	0.3	1
gerbera		10	10	0.4	1.5

Figure 4. Overview of uptake and threshold value of sodium and chloride for various crops

3 EC in supply, drain and root environment

As EC is the total amount of ions in the water it will be a mixture of salt (NaCl) and nutrients (figure 5). In an experiment, different values of EC were given to a tomato and cucumber crop. Either only nutrients were added to achieve the setpoint EC of 2.5, 3.7 and 5.2 dS/m or up to an EC of 2.3 nutrients were given, above 2.3 only NaCl was added to achieve the setpoint EC. Figure 5 shows that for tomato it is quite well possible to supply NaCl, but for cucumber you see a strong decrease in yield with increasing EC.

	Tomato yield (%)		Cucumber yield (%)	
EC (dS/m)	Nutrients	NaCl	Nutrients	NaCl
2.5	100	100	100	100
3.7	94	95	92	91
5.2	83	84	78	74

Voogt, W., 1995.

Figure 5. Influence of salt on yield at rising EC levels

Characteristics	EC 2.5	EC 3.5
Number of fruits, m^{-2}	224	222
Fruit yield, kg m^{-2}	12.7	11.9
Average fruit weight, g	56	54
Colouring in days	4.4	4.1
Shelf life in days	17.5	19.2
EC fruit sap, dS m^{-1}	5.8	6.2
Acids in fruit sap, mmol l^{-1}	75	84
Refraction in fruit sap, % Brix	4.8	5.0

Effects of EC in the root environment on yield and quality of tomato fruits. After Sonneveld and Welles, 1988

Figure 6. effect of EC on yield and quality

Another experiment shows the EC effect on yield and quality (figure 6). Grown at different EC levels the yield at the lower EC of 2.5 is slightly higher compared to an EC of 3.5. However, quality parameters (shelf life, EC and acidity of fruit sap, Brix) are in favour of the higher EC of 3.5 dS/m.

Both experiments show that EC influences yield and quality. It is not only about getting the highest yield, but also about a good quality tomato with a pleasant taste. Partly nutrients are needed, but it is also possible to get a higher EC with a certain amount of salt, which may be in the supply water and does not need to be removed. For other crops, such as pepper and cucumber or even lettuce, the above is not or just marginally valid.

4 EC recommendation per crop

The optimum EC differs per crop and should be achieved around the roots, because there water and nutrients are taken up. In hydroponics always a surplus of water and nutrients is given to the plants, to overcome differences in growth speed, place in the greenhouse and release of the drippers, while water is easier taken up by the plant compared to nutrients. Consequently, the EC of the supply or irrigation water may differ from EC in the root environment or in the drain. Figure 7 gives an overview of the recommended EC per crop.

Crop	EC root environment	EC drain	EC Irrigation
Tomato	3.8	4	3.2
Cucumber	3.5	3.8	2.8
Lettuce (DFT)	2.5	2.5	2.3
Sweet pepper	3.5	3.8	2.8
Eggplant	3.5	4.0	3.0
Strawberry	2.0	2.5	1.5
Bean	2.8	3.3	1.8
Rose	2.5	3.0	2.0
Gerbera	2.5	3.0	2.0

Figure 7. Recommended EC in the root environment and required EC of irrigation water and drain for various crops in an open soilless substrate system.

It is important to realise that the EC in the root environment can only be checked by frequent measurements of EC and simultaneously pH, three times a week first, later 1-2x per week. After frequent checking the EC in the slab you know the relations between the EC in the drain and in the irrigation water.

5 Conclusions

Hydroponic cultivation requires an excellent water quality. If the supply water contains certain elements there are restrictions in use. It is always recommended to analyse the supply water before starting a cultivation. In particularly high sodium and bicarbonate levels may disturb a smooth growth of plants. Crop specific threshold values indicate the salinity yield decrease. The EC (electric conductivity) is an easy to measure parameter and is leading on steering the growth. Therefore, it is important to know, to measure, the EC of the root environment, which is the steering EC. To realise the appropriate EC along the roots a lower EC has to be supplied, while a higher EC is measured in the drain.
It is not just the quality, but also the quantity of irrigation water which is important. Various sources might be available: rainwater, surface water treated waste water, ground water. Rainwater is one of the best sources (quality). However the quantity in Jordan is limited due to little precipitation in a short period. Even then it is worthwhile to collect and to use it. Higher yields may be expected. Another water source should be available, an overview is given. Depending local quality and price one or the other source is more favourable.