Managing the Root Zone in Soilless Culture

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In solid growing media, there are five important parameters that should be monitored around the root zone to optimize plant growth and yields. EYAL RONEN offers some guidelines on how to manage these parameters to prevent major crop problems, and explains the importance of measuring fertiliser solution at both the dripper and drainage points.

General terminology
Soilless culture, commonly referred to as 'hydroponics', is a cultivation technique by which plants are grown detached from the soil. Plants are cultivated in containers filled with several possible growing media. If these media are solid, the method is called 'soilless culture'. If no medium is present and the plant roots are bathed in circulated nutrient solution, the method is called 'hydroponics. If no medium is present and plant roots get their nutrients by frequent spraying or misting, the method is called 'aeroponics'. The method we are concerned with in this article uses solid growing media.

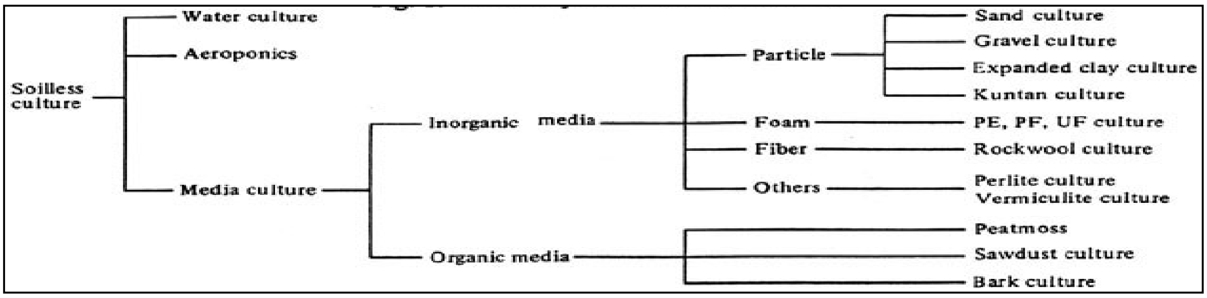


Figure 1. Different soilless cultivation methods.

Soilless culture characteristics
The limited volume of medium and water availability generally causes rapid changes in the status of water and nutrients. Changes in the medium solution, such as electrical conductivity (EC), pH and nutrients level, should be monitored for the efficient use of water and nutrients. Failures in the careful supervision of fertilisation and/or the accuracy of irrigation are likely to result in severe plant damage and reduced yields. Hydroponics, however, offers several major advantages in the management of both plant nutrition and plant protection, if the right tools are applied and careful management is carried out.

There are five important parameters that should be monitored by the grower, employing simple devices and methods. However, the common perception of some of these parameters is not always correct and this can result in some major problems.

There are two reference points of special importance used to determine the status of the medium. These are the 'drip-line point' (fertigation input) and the 'drainage' point (output), based on the understanding that the drainage point best reflects the condition in the active root zone. By monitoring these two points, it is possible to see what changes are occurring in the medium after fertigation.

Changes in the medium environment
Water functions as a source of some nutrients, and as a delivery vehicle to transport nutrients into the plant via the xylem vascular system. When plants are exposed to low relative humidity, they lose water by transpiration through their stomata. Water also evaporates from the medium. However, transpiration and evaporation can lead to a salt build-up in the medium if proper management practices are ignored. Although some salts are absorbed by the plant, there is a sharp increase in the concentration and a build-up of some undesirable salts.

When growing in soil, root volume and soil space are large enough that salt accumulation does not interfere with plant growth as quickly. But in soilless culture there is no space to buffer this salt build-up, and immediate action is needed to purge the medium and lower the concentration of these dangerous components by washing them away. To avoid this problem, the common practice is to supply extra water at every irrigation cycle to ensure sufficient drainage - irrigation water should pass through most of the medium volume and leach away high salt concentrations at the drainage point. Theoretically, a 10% increase in water volume during daily irrigation cycles should be sufficient, but practically, an extra 30-50% of water is used.

When plants are supplied with mineral fertilisers, although some are consumed and some are lost by leaching, the medium solution electrical conductivity is increasing compared to the drip-line point. The accumulation is mainly of nitrate and chloride.

It is important to identify the reason for any EC elevation to avoid taking wrong corrective action. For example, chloride is a micronutrient and is required by plants in very small amounts. However, excess chloride will not be absorbed and will easily accumulate in the medium. Because chloride is highly soluble, it will almost always be present in the solution and affect the EC.

Nutrient consumption can be roughly estimated by checking the changes in the nitrate (NO_3^-) content of the nutrient solution. Compared to the drip-line point, it will go up and down, generally reflecting changes in plant consumption. Another form of nitrogen that can tell us about the status of the growing medium is nitrite (NO_2^-) concentration. In case of over-irrigation, water accumulation in the medium leads to waterlogging, and to decreased availability of oxygen in the medium. This change uncouples the chemical transformation of ammonium to nitrate causing nitrite to appear and accumulate in the medium. The nitrite anion is toxic to plant roots and will eventually lead to plant death.

Another important parameter is the pH of the solution flowing through the medium, which can affect the availability of microelements and phosphate to plants. One of the advantages of soilless culture is the ability to control pH in the medium solution. This is achieved by adding acid to the irrigation water to change the ratio between NH_4^+ and NO_3^-, which are the only two forms of nitrogen allowed in this cultivation method. It is a common phenomenon that while passing through the root system, the pH will drop slightly due to root respiration and lack of buffer capacity in the soilless medium.

It is possible to check these other parameters in the growing medium as well, but this requires relatively sophisticated lab equipment. It should be stressed that EC and pH should be monitored over time, where the trends are more important than the absolute values which are not always accurate. Although the day-to-day measurements of EC and pH are not the most accurate for predicting changes in the crop, relatively inexpensive meters are adequate for quick field evaluations.

Table 1. Most important parameters, and how to manage them.

Parameter	Factors affected	Units	Recommended relationship between value at drainage point and at the dripper	Action to be taken if undesirable values show at the drainage point
pH	Availability of phosphorus and of micronutrients	pH units	Lower by one unit, and at the range of 5.5 – 6.0	Add more acid to the irrigation water and/or increase ammonium share out of total nitrogen.
E.C	Salinity and water availability	Deci-siemens/meter or Millisiemens/cm	Up to 20% higher.	Rinse the medium with a lot of water (2-3 fold of the regular volume), enriched with a small amount of 50 ppm nitrogen, if the drainage EC is 20% above the optimum.
Cl^-	Irrigation volume	ppm	Up to 50 ppm higher.	Same action as the above if value at drainage is 50 ppm or more higher than at dripper.
NO_3^-	Fertilization status	ppm	Can be higher or lower	Increase or decrease fertilization concentration according to change.
NO_2^-	Irrigation intervals or rate	ppm	Should not be present, and max of 10 ppm.	Rinse the medium if >10 ppm is detected. Increase intervals between irrigations and increase acid application rate.

Table 1 is a compilation of common management guidelines used in soilless cultivation. Crop management is generally achieved by comparing EC and pH values between the drip-line point and drainage point; but is the latter the optimal point to compare?

In many cases, the values obtained at the drainage point do not reflect the real situation in the active root zone and may mislead the grower about the status of the growing medium. To obtain a more accurate picture, we need to be sure that the irrigation water is passing through all possible pore spaces in the growing medium.

Although irrigation water passes horizontally and vertically through the growing medium, several factors can influence which way it moves. A low density of emitters and a high flow capacity, and a growing medium with large aggregate particles and square 'packing', will dictate a more vertical movement of the irrigation water. Conversely, a high density of emitters (two lines) and low flow capacity (0.2 l/h), and a medium with small aggregates and triangular shape, will dictate a more horizontal flow of water, thus ensuring a better flush of the medium and a drainage that will be more representative of the status of the growing medium (see *Fig. 2*).

Big aggregates
Low emitters density
Low flow capacity

Small aggregates
High emitters density
High flow capacity

Figure 2. Water movement through the medium in different conditions.

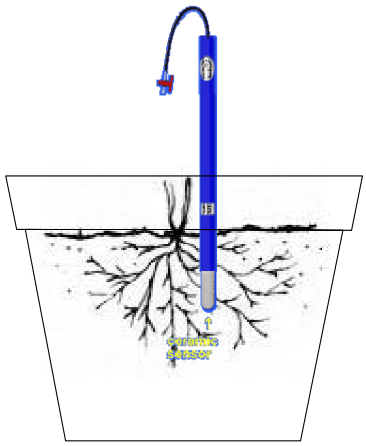
Generally, the water found in the drainage does not characterise the real situation near the active root zone. Most of the water in the drainage is collected beneath the dripper from a narrow, sausage-like basin; where water movement is faster than in its periphery. Undesirable salts like chloride show in this water at a lower concentration than can be found in the active root zone, which has a much lower 'hydraulic conductance'. While drainage chloride may show an acceptable situation, a careful inspection of the medium around the active root zone (which is difficult to perform), may show an undesirable concentration of salts, expressed by a high EC.

One of the functions of water supplied to soilless culture, other than fulfilling the need of transporting nutrients in plants, is to maintain a low level of salts in the medium and to prevent a possible build-up of salts. Commonsense tells us material cannot disappear from the system. Therefore, although water evaporates from the system, salts do not; hence they will always remain behind. Every anion and cation not consumed by the plant will accumulate in the medium. If the salt is not outside in the drainage it is inside the medium!

Growers should aim to allow for an EC value at the drainage point as high as possible and not just higher by 20% more of the irrigation water at the drip-line point. Also, as high as possible chloride and not only 50 ppm at the drainage, as compared to the irrigation water at the dripper. If the values are only higher by 20% in E.C and 50 ppm in chloride the grower should be worried, since it means the drainage was not effective enough and in this equation the salt is still hiding in the medium. The drainage is ineffective in removing excessive salts with most left in the medium.

Growers should check the status of the growing medium at the active root zone. There are two ways to do this. One can dig into some of the medium, squeeze it by hand over a filter paper, and analyse the solution for the relevant parameters. A better method uses a fixed soil-solution extractor that can extract the medium solution from any location selected by the grower as being a characteristic point to determine the real environment that the plant roots are surrounded by (see *Fig. 3*).

Figure 3. Soil solution extrector inside a pot.



Above all, the grower should bear in mind that both methods described for checking the drainage solution and the medium itself are only an approximation. However, because the grower needs some indication of what is going on in the medium, this method of medium evaluation will suffice as long as the EC is not higher than 20% compared to the drip-line EC, and chloride does not exceeds 50ppm over the drip line point, referring to the drainage analysis over there parameters should be higher as possible in comparison to the drip line point.

One must also remember that these guidelines are not crop-specific. A better way is to balance the EC specifically for each crop according to its threshold level, above which plant productivity will decrease (see *Table 2*). The idea is to always keep the EC below this threshold, and when it does exceed this level to take some corrective action and flush the medium with extra water. It's always better to make frequent small adjustments to the irrigation and fertiliser regime, than to make extreme changes when it is already too late. As a cautionary note, the action of flushing the medium should only be taken when EC levels exceed the threshold and not as a routine, because it will upset the sensitive balance the plants live in.

Table 2. Crop salinity sensitivity, threshold and yield decrease (Maas and Hoffman, 1993).

Crop	**Salinity threshold expressed in *ds/m***	**Percentage of yield decrease above the salinity threshold *% per every ds/m***
Lettuce	1.3	13
Pepper	1.5	14
Cucumber	2.5	13
Tomato	2.5	9.9

Some growers might consider this procedure as labour intensive and rather than checking the EC at the drainage point, they wash the medium heavily from time to time instead. Although this may work, it is the wrong management practice. The methods described in this article will ensure plants are grown in the right zone, beneath the threshold of reduced dry-matter production (see *Fig. 4* and *Fig 5*).

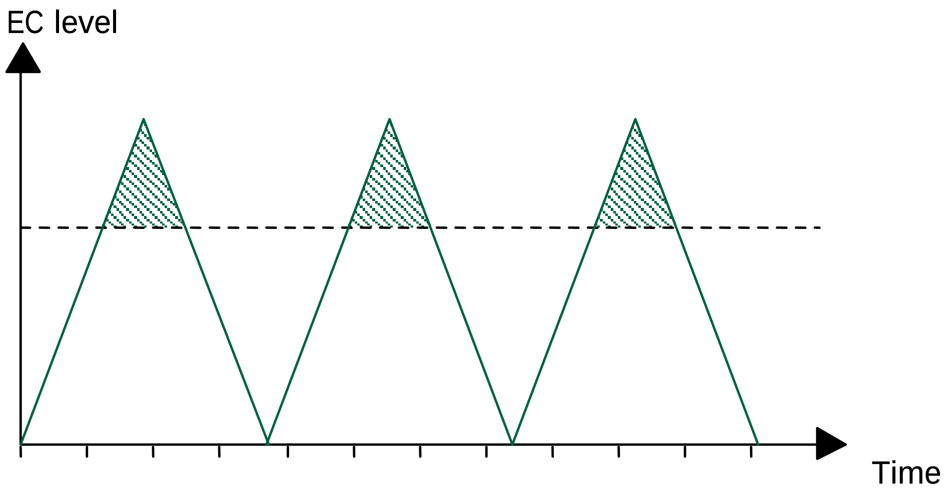


Figure 4. Characteristic EC pattern in non-controlled soilless cultivation, with rinsing once in a while. The grey part of the triangle is over the threshold, where productivity decreases.

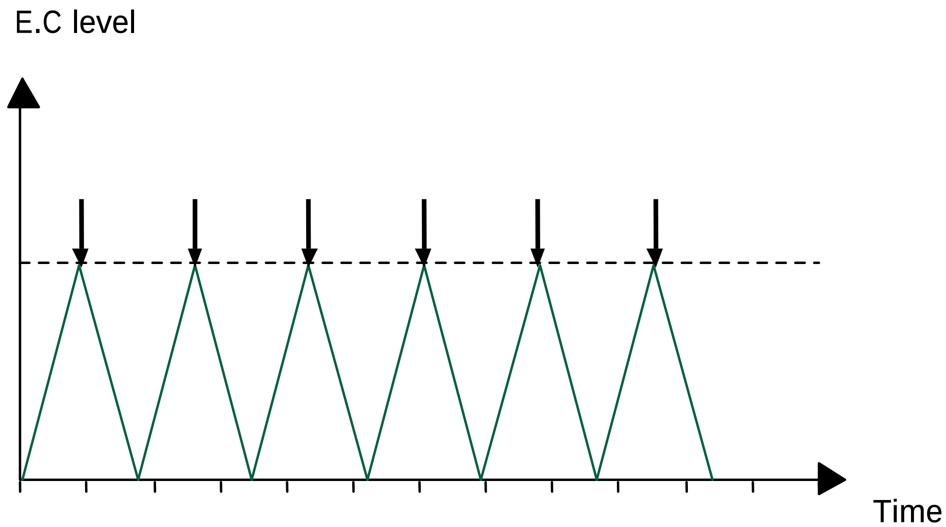


Figure 5. Characteristic EC pattern in a controlled soilless cultivation, with rinsing that maintains optimum level with no production losses.

Further investigation of EC
When checking EC of the medium, it is also important to breakdown this general term into its major components. Checking the EC itself will reflect that the concentration of electrolytes is high. At the working range in soilless cultivation, it is important to know whether this EC is due to nitrate nitrogen or chloride. If the majority is from nitrate, it means that the grower has over-fertilised and fertiliser concentration should be lowered. If the majority is from chloride, it means that the grower is not irrigating with a proper volume of water; water consumption is exceeding supply and since chloride only comes from water, it is accumulating very fast. In this case, the appropriate action is to increase the irrigation volume. In both cases, the high EC can be diminished by extra washing, if needed.

To sum up, one needs to understand that soilless cultivation is a flexible growing method that lets the grower have full control over the growing environment, including the active root zone. However, plants and yields will suffer if the grower doesn't have a good understanding of EC and the specific limitations of the crop, the growing medium, and irrigation water. "

About the author

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