

Best Practice Guidelines for Greenhouse Water Management

Green Agro Control
LABORATORY - RESEARCH & ADVICE 

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Passionate about Precision Growing

CREATING
A CLIMATE
FOR GROWTH
PRIVA



COLOFON

Commissioned by GRODAN & Priva

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Preface



Koen Boone

Managing Director-Europe of The Sustainability Consortium (TSC) and employed within LEI Wageningen UR, The Netherlands.

I am very pleased to have been invited to introduce these “Best Practice Guidelines for Greenhouse Water Management”.

At The Sustainability Consortium (TSC) we work with multiple stakeholders, using a science based approach, both to identify the sustainability “hotspots” within a supply chain and to define ways in which these “hotspots” can be addressed by implementing specific improvements. A sustainable food production sector is the only way we can provide a planet of nine billion people with adequate food and water. According to the United Nations, only 0.5% of the water on Earth is available fresh water and 70% of the fresh water which is consumed is used in the agriculture sector. Through its Food, Beverage, and Agriculture (FBA) working group, TSC aims to drive improvement in the environmental and social sustainability of global agricultural supply chains.

Increasingly, within the greenhouse industry, there is mounting pressure to reduce the environmental impacts associated with crop production. Retailers, producers, suppliers, governments, NGOs, researchers and consumers all hold a stake in the sustainability of global food production and consumption, including that coming from the greenhouse sector.

In this context, it is critical to identify the areas where the sustainability performance of the supply chain can be improved. The challenge before us, then, is to work collaboratively together, developing an approach that drives better understanding, standardization, and informed decision making.

The information provided within these “Best Practice Guidelines for Greenhouse Water Management” is an example of such a collaborative approach, where suppliers have come together to pool their knowledge and experience, offering advice to help facilitate improved environmental performance in the greenhouse sector via:

- More efficient use of water resources
- Reducing or eliminating pollution and the environmental problems caused by fertilizer run-off.

TSC’s own research has also highlighted these two issues, amongst others, as being environmental “hotspots” within the greenhouse sector. The guidance on water use and water management within this document should help to drive improvements in the horticultural supply chain. This, in turn, will allow producers to communicate clearly with other stakeholders about the tangible steps they are taking to make their contribution to improving the sustainability of the sector.

www.sustainabilityconsortium.org



Introduction

Sustainable food production

Consumers are increasingly looking for quality produce which is healthy, safe and at the same time cultivated sustainably. Greenhouse producers are therefore expected to take the necessary measures to reduce their environmental impact, not only with regard to their carbon footprint (i.e. energy management), but also use of raw materials (i.e. water and fertilizers) and their emission into the environment.

Greenhouse hydroponic cultivation already uses water more efficiently than field based production systems. However large amounts of water and fertilizers are lost in free draining hydroponic systems. Water use efficiency can be improved by collecting drain water and reapplying it to the crop. In this way, greenhouse growers can further improve their water use efficiency and consequently become more sustainable producers.

What will you find in this guide?

This guide has been written to provide greenhouse owners and managers with an overview of the current best practices for the application and recycling of water and nutrients in the greenhouse. The practices described in this guide will help you to grow an optimal crop and comply with existing (European Water Framework Directive, 2010) and future government legislation aimed at reducing nutrient emission to the environment.

Why would you recycle drain water?

Careful management of water and nutrients combined with recycling the drain water in your greenhouse will strengthen your business both in the short and long term because it will help you to:

- Reduce total fertilizer input
- Save costs
- Optimize the growth of your crop
- Secure the availability of sufficient and clean irrigation water
- Secure the availability of a sufficiently wide range of plant protection products
- Protect the environment
- Comply with legislation

Reduce total fertilizer input and save costs

Recycling drain water reduces the total quantity of fertilizer required to grow a crop. Are you aware of the annual cost of the water and fertilizer you are using and how much this can be reduced when operating with a closed hydroponic system? Table 1 provides an overview of the typical costs for a Dutch greenhouse. This example shows that recycling the water reduces the cost for fertilizers by approximately €4,000 per ha¹. The costs are attributed to expenses for water storage containers, cleaning and purification equipment and payments to the local Water Board. Moreover, prices for fertilizers have been steadily increasing over the past years. From a purely financial perspective it therefore makes sense to operate a closed hydroponic system within your greenhouse.

Table 1. Typical cost for water and fertilizer for hydroponic tomato grower in The Netherlands

Average EC	Cost of fertilizer per EC unit	Average water use GRODAN stone wool l/m ² / year	Total costs without recycling drain water	Total cost when drain water is recycled
3.0 m ^s / cm ²	€0.5	1.250	€1.88 / m ² or €18,000 / ha	€1.40 / m ² or €14,000 / ha

Optimize the growth of your crops

Better growth results can be obtained when the application of water and nutrients is carefully managed, especially in line with energy management practices, such as screening in winter. In these situations applying 'a little bit extra' does not lead to better growth results and can even be harmful to the plants. Every irrigation results in a 'vegetative' reaction from the plant. It is therefore important to know when and how much water you need to give to ensure optimal crop growth and fruit development.

Recent research has shown that for growers with a similar cultivation and greenhouse there can be tremendous differences in total water and fertilizer use. These differences arise from different attitudes towards root zone management and the time, in respect to the crop growth stage, that the drain water is first recycled.

Secure the availability of clean irrigation water

Recycling the drain water will ensure your business has an adequate supply of water of sufficient quality. Rain water is recommended for use, it is pure and therefore of good quality and is available for free (apart from storage costs, see Chapter 4). In some situations, where annual rainfall is inadequate a secondary water supply is required such as ground or well water. The quality of this water can vary considerably between regions and locations within regions. Therefore additional growing costs will be incurred if this water supply also needs treating for example via reverse osmosis (RO) prior to use.

Table 2. Comparison of the theoretical emission of N (kg/ha) from the greenhouse with an open and closed hydroponic system operating with different drain volumes. Figures presented assume application of 1250 l/m² with NO₃-N 18 mMol·l⁻¹ (252 ppm).

Theoretical N emission (kg/ha) for different irrigation strategies

Strategy	Open versus closed water cycle	Nitrogen emission (kg/ha)
1	100% run-to-waste 'open system' realizing 30% drain	945 kg/ha
2	85% re-use and realizing 30% drain	142 kg/ha
3	85% re-use and realizing 15% drain	71 kg/ha

Secure the availability of a sufficiently wide range of plant protection products

In many greenhouse areas plant protection products (PPPs) can be found in samples of surface water in concentrations that exceed the permitted legal limits. This endangers the already limited portfolio of PPPs which are available for use in greenhouse crops. If this situation continues products that are consistently found in concentrations which are too high are likely to be banned. With small and relatively simple changes in the daily management of your greenhouse water cycle, you will be able to reduce or eliminate PPPs from entering surface water.

Protect the environment

Closed hydroponic systems help protect the environment by minimizing fertilizer emission and conserving surface water quality. Table 2 provides an indication of the potential decrease in nitrogen emissions that can be obtained by using a closed hydroponic system and within this the impact of reducing the initial drain volume. See Chapter 3 on the emission of fertilizer at the start of the cultivation cycle and how with simple adaptations these can be avoided.

There are also planning implications to consider. When for instance you want to expand your greenhouse it could make a positive difference if your planning application outlines options for rain water collection, storage and drain water recycling and of course how you intend to deal with any unwanted emission in a responsible way.

Comply with legislation

Government requirements and the need for compliance will ultimately determine how your business develops in the future. The aim of the European Water Framework Directive is to establish chemically clean and ecologically healthy surface water. Dutch growers together with their government have set staged reductions for fertilizer emission targeted towards zero by 2027. This may seem a long time from now, but compliance to standards laid out in **table 3** will be a “license to produce” (Jean Aerts, LTO Glastracht, Wageningen UR Water Day 4th June, 2015).

Table 3. Overview of the emission norms for nitrogen in drain water from substrate crops in the Netherlands from 2013-2027.

Crop	Maximum allowed emissions of nitrogen (kg/ha/year) in the Netherlands		
	2013-2014	2015-2017	2018-2027
Tomato, herbs	125	83	67
Strawberry, eggplant, pepper	200	133	100
Orchid (Cymbidium)	75	50	38
Tulip, annual summer flowers	100	67	50
Rose, gerbera, propagation material vegetables	250	167	125
Phalaenopsis and other potted orchids	300	200	150
Anthurium	50	33	25
Other vegetables	25	25	25
Cucumber, potted plants, propagation material ornamental crops, other ornamental crops	150	100	75

How to use this guide?

We hope to have convinced you why you should apply water and nutrients accurately within a closed hydroponic system. The following chapters of this guide will inform you on how to achieve this. The checklists in this guide will help you to improve your practices and to inform your staff and importantly your customers on the steps you are taking to be a more sustainable grower. This guide is however only a short overview. For more specific and detailed information related to your own circumstances, please feel free to contact the relevant partner.

All our information and advice is compiled with the greatest possible care and in accordance with state of the art technology. However we are unable to assume any liability for the contents.

July 2016 – GRODAN, Priva and Groen Agro Control.



1

The Greenhouse water cycle

In this chapter we provide some background information and definitions concerning the greenhouse water cycle. A schematic overview of the water cycle in a typical closed hydroponic system is given in Figure 1.

Influx of irrigation water

The cycle begins with input of fresh irrigation water, this is often referred to as the primary water supply for the greenhouse. Preferably this should be rain water collected from the roof. When the amount of rain water is insufficient (and/or storage is too expensive), alternative primary water supplies can be used such as ground water (which is sometimes called "well" or "bore" water), surface water or tap water. However, this water must comply with quality requirements for use in a hydroponic system (Chapter 2).

Mixing with drain water

In a closed hydroponic system filtered and disinfected drain water can be mixed with the primary water supply. In order to maintain the correct balance of nutrient elements, a regular analysis of the drain water is recommended (Chapter 6).

Addition of nutrients

Nutrients are then applied to the irrigation water in the right concentration and ratios. (Chapter 4).

Distribution of the irrigation water through the greenhouse

A central pump then directs the irrigation water towards the plants via a system of pipes and drippers. Finally, the water trickles into the stone wool substrate. The irrigation start and stop time, frequency and session length are then adjusted to the needs of the plant (Chapter 3). The water leaving the substrate via the drain hole is defined as drain water.

Filtering and cleaning of the drain water

The drain water is collected, filtered and then stored in the 'dirty' drain water basin. As a precautionary measure the drain water is then disinfected by technologies such as heating, UV light, ozone or advanced oxidation (Chapter 5). The disinfected drain water is then stored in the 'clean' drain water basin ready for reuse.

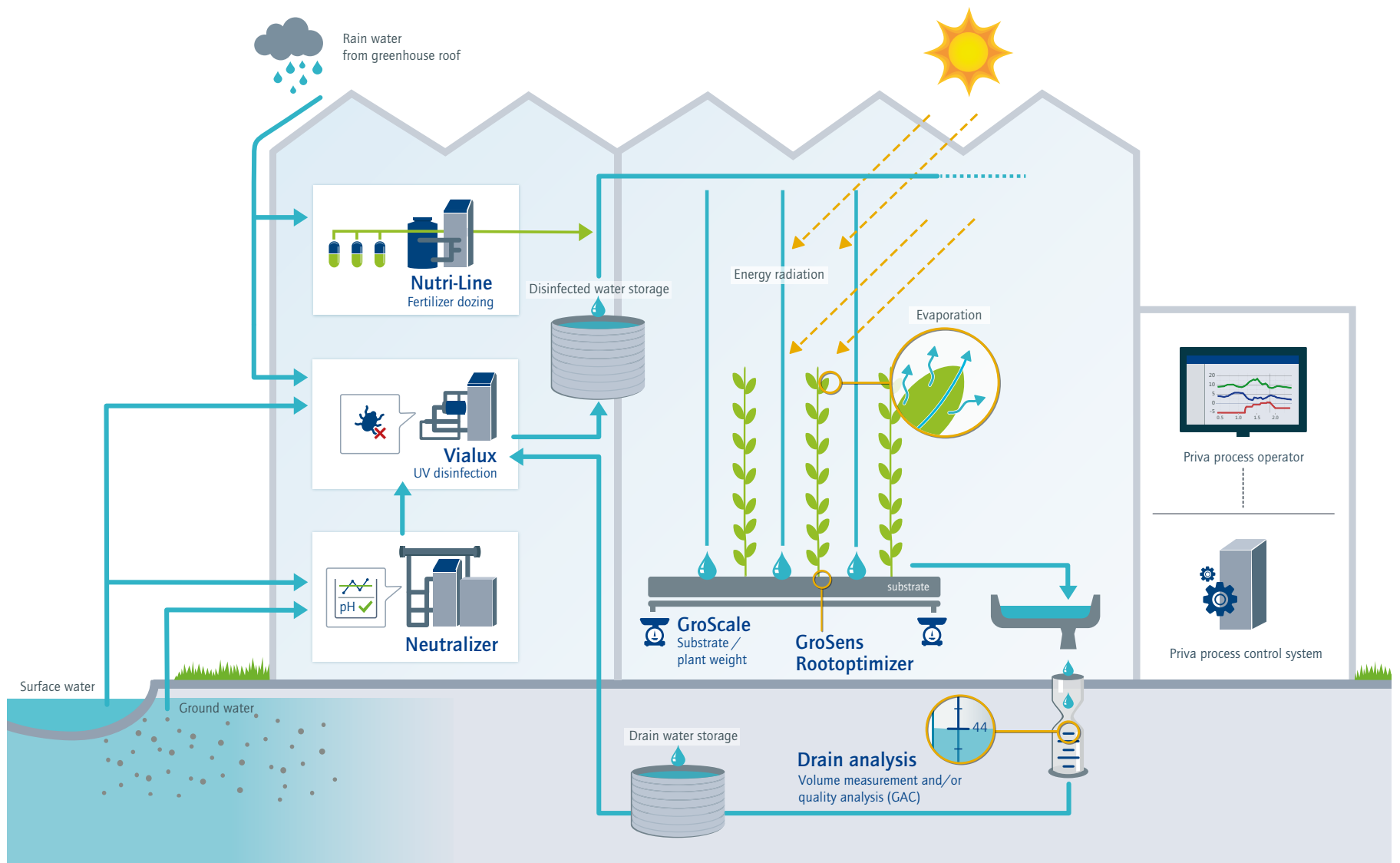


Figure 1 Schematic overview of the greenhouse water cycle

2

Primary water quality

The quality of the primary water supply is very important when operating within a closed hydroponic system. Rain water is pure and so is naturally the best primary water source for use in hydroponic cultivation. Rain water is usually collected from the roof of the greenhouse and stored on the property.

It is advisable to discard water collected from the first rain showers after a prolonged period of drought, since this may contain a lot of dirt and in coastal areas also sodium chloride. If discarding is not possible then this water can be added to the dirty drain water basin, so it will go through the cycle of purification and disinfection before being used as irrigation water. When rain water is scarce, other sources of water are required. However water quality does vary from region to region and within regions from location to location. **Table 4** provides an overview of minimal standards for “good quality” primary water. If water does not meet the criteria of at least class 3 (see **Table 4**) it is not suitable for use in greenhouse hydroponic

horticulture. If you are in any doubt or require further advice in respect to the quality of your primary water supply, we recommend that you contact Groen Agro Control or a reputable laboratory in your region.

Ground water

Apart from a high pH-value, ground water often contains minerals in concentrations which are too high such as iron. The water can be purified using a RO (Reverse Osmosis) machine. The law of osmosis says that water will move from a lower to a higher concentration until the concentrations of two solutions are equal. RO literally applies this law in “reverse” by applying a pressure to the ground water in order to force it through a membrane. The membrane traps the unwanted minerals, resulting in a clean supply of water on the other side of the membrane. RO water can serve as an insurance policy at times when rain water supply is limited. Rain water and RO water used together can provide the greenhouse with a large quantity

of high quality water. However it is important to note that RO water can be corrosive to metals, in particular galvanized zinc or copper pipes. It is therefore best practice to ensure pipes, tubing, drippers, misters and foggers are of the correct grade.

Table 4. Classification of water quality. Water of class 1 can be used for most applications. Water of class 2 is not suitable for cultures with limited root volume or when only limited amounts of water can be applied. Water of class 3 is not suitable for salt sensitive crops. Source: De Keij, C. et al. (1999). *Bemestings Adviesbasis Substraten. Proefstation voor Bloemisterij en Glasgroente.*

Quality class	EC (mS/cm)	Na (mMol/l)	Na (ppm)
1	< 0.5	0.0 - 0.5	0 - 11
2	0.5 - 1.0	1.5 - 3.0	34 - 69
3	1.0 - 1.5	3.0 - 4.5	69 - 103

DEFINITION BOX

pH: pH is a measure of how acidic or alkaline the nutrient solution is. Most nutrients are available at a pH range between 5.4-6.2 in stone wool substrates. The pH of the nutrient solution will therefore determine the availability of elements. Generally micro elements iron (Fe) and zinc (Zn) become less available as the pH is raised from 6.5 to 7.5 so it is always advisable to supply these in chelated form. At pH levels above 6.5 phosphate (H_2PO_4^-) will also precipitate as insoluble calcium phosphate, making H_2PO_4^- unavailable to the crop and blocking irrigation drippers.

Electrical Conductivity (EC): EC is a measure of the total salts concentration in the nutrient solution. EC is therefore a mixture of essential (e.g. NO_3^- , Fe_3^+) and non-essential (e.g. Na^+) elements required for plant growth. EC is usually expressed in milliSiemens per centimeter (mS/cm), or micro-Siemens per cm ($\mu\text{S}/\text{cm}$) where $1 \text{ mS} = 1000 \mu\text{S}$. Sometimes Siemens per meter is used ($1 \text{ S}/\text{m} = 10 \text{ mS}/\text{cm}$). The higher the total salts concentration the higher the EC. As non-essential elements such as Na^+ are not taken up by the plant they will accumulate in the root zone over time until at some point discharge from the greenhouse water cycle will be required. It is important to undertake a regular analysis of the nutrient solution used in closed systems to determine the composition of the EC so that essential elements are always present in correct ratios.

When no reverse osmosis water is used, special attention should also be paid to the concentration of iron in the ground water. High concentrations of iron are more common in deeper wells or bores where the ground water has been in contact with iron containing compounds for a longer time. When the iron reacts with oxygen, iron hydroxide is formed which can

precipitate and cause blockages in the water system. When the concentration of iron in the ground water exceeds $0.01 \text{ mMol}/\text{l}$ or 0.6 ppm it is recommended to take measures to remove it. A concentration between $0.01 \text{ mMol}/\text{l}$ or 0.6 ppm and $0.02 \text{ mMol}/\text{l}$ or 1.2 ppm can be easily removed by aeration, for instance by simply pumping the ground water from a closed well to an open storage basin. When the concentration is higher than $0.02 \text{ mMol}/\text{l}$ or 1.2 ppm the iron should be removed with an iron filter or RO installation.

Bore water can contain high concentrations of micro elements (Mn, Zn, B). Therefore you need to analyze the bore water before use, so you can calculate accurately the concentration of micro elements that you need to add to the irrigation water.

Tap water

Tap water is a relatively expensive option costing around $\text{€}1.0/\text{m}^3$ in The Netherlands. Therefore using tap water may only be appropriate if you require low volumes of an additional water supply. However tap water can, in certain locations, contain high concentrations of bicarbonate. Bicarbonate has a buffering effect on the pH value. High levels can influence your ability to stabilize and control pH of the resultant nutrient solution. In addition high bicarbonate levels can cause drippers to become blocked due to calcium deposition. In these situations it is necessary to install a Priva 'Neutralizer' in the water technical room (Chapter 4). The Neutralizer actively removes bicarbonate from the water supply via a combination of acidification and aeration.

Surface water

Surface water is not often used in hydroponic systems. The main drawbacks are that it contains elements

whose concentrations vary quite frequently. This makes it difficult to administer nutrients in the desired concentrations. Moreover, the level of sodium and chloride may be high, especially in dry periods. In addition, surface water may contain micro-organisms and plant protection products (as run off from field agricultural production systems) which is harmful to growth.

In short if a water supply is deemed unsuitable for use in a closed hydroponic system it can be treated. The only question is whether the benefits of treating the water outweigh the required cost of investment. The advisors of GRODAN, Groen Agro Control and Priva can help you to determine what measures would be most suitable to suit your specific situation.

TIPS FOR CLEAN WATER

- Know the quality of the primary water supply you are using by having it analyzed by a reputable laboratory. Groen Agro Control is wholly qualified to do this.
- Invest in sufficient rain water storage capacity, 500 m^3 per hectare is the minimum requirement in The Netherlands.
- Monitor the pH-value and the EC-value of your primary water source at least once per year.
- Be aware of the concentration of iron in ground water. If it is higher than $0.01 \text{ mMol}/\text{l}$ or 0.6 ppm action is required to remove it.
- Install a Priva Neutralizer if your water contains high concentrations of bicarbonate ($>1.0 \text{ mMol}/\text{l}$ or 61 ppm), especially if this occurs in combination with a high pH-value.

3

Root zone irrigation management

'Precision Growing' literally translates into growing more, with fewer inputs. In this context GRODAN focuses on root zone management solutions, yet understands the need for a holistic approach towards the cultivation. This chapter describes 'Precision Growing' with respect to root zone management. It focuses on substrate choice; design and use with respect to optimizing the water supply. This chapter consists of four parts. We first give some basic background information about root zone management in relation to substrates. Subsequently we provide detailed advice about irrigation during the first weeks of a new crop; during the main harvesting period and towards the end of the cultivation cycle.

Why root zone management?

A targeted water and nutrient supply will improve crop yield and fruit quality. This can be achieved by accurately steering substrate water content (WC) and the electrical conductivity (EC) in line with the incumbent climatic conditions and generative / vegetative plant balance.

Choosing your substrate

The choice for substrate is made prior to the start of each cultivation cycle. Sometimes organic (coco) substrates are chosen as they are perceived by some growers as making their cultivation more sustainable. This is not true. A study commissioned by GRODAN and conducted by Blonk Milieu Advies revealed that

the environmental impact of both substrates was similar. The study concluded that the *'growing medium alone makes a negligible contribution to the total environmental impact of greenhouse production. However changes in production practices related to energy management and the use of fertilizers will have a massive effect on the overall environmental performance'*.

Of course in respect to fertilizer use this means recycling from day one of the cultivation, operating within a closed hydroponic system whilst working with a structured irrigation strategy and at all times an accurate fertilizer composition.

Substrate design

With the introduction of Next Generation 2.0 (NG 2.0) substrates GRODAN are focused on the relationship between WC and EC within the substrate and how these two parameters can be steered by the grower to ensure optimal growth and fruit quality (Picture 1). In this way we help the grower to address the major challenges facing greenhouse production, such as limiting energy input due to rising energy costs and conforming to legislation aimed at drain water discharge from the greenhouse.

GRODAN NG 2.0 substrates are made of inert hydrophilic fibres, they have high irrigation efficiency

and they are uniform which means structured irrigation strategies can be adopted by the grower.

Inert hydrophilic fibres

GRODAN slabs are made from basalt rock which is sourced from quarries in line with strict environmental regulations. In our factories in The Netherlands, Canada and Poland the basalt is melted and spun into fibres. During the process, the fibres are coated with a hydrophilic binder which helps to spread the water and nutrients evenly throughout the slab. The fibres are inert so they do not lock up any nutrients and the chemical stability of the slabs means drain water can be recycled from the beginning of the cultivation cycle.



Picture 1. Uniform high yielding tomato crop growing on GRODAN substrates

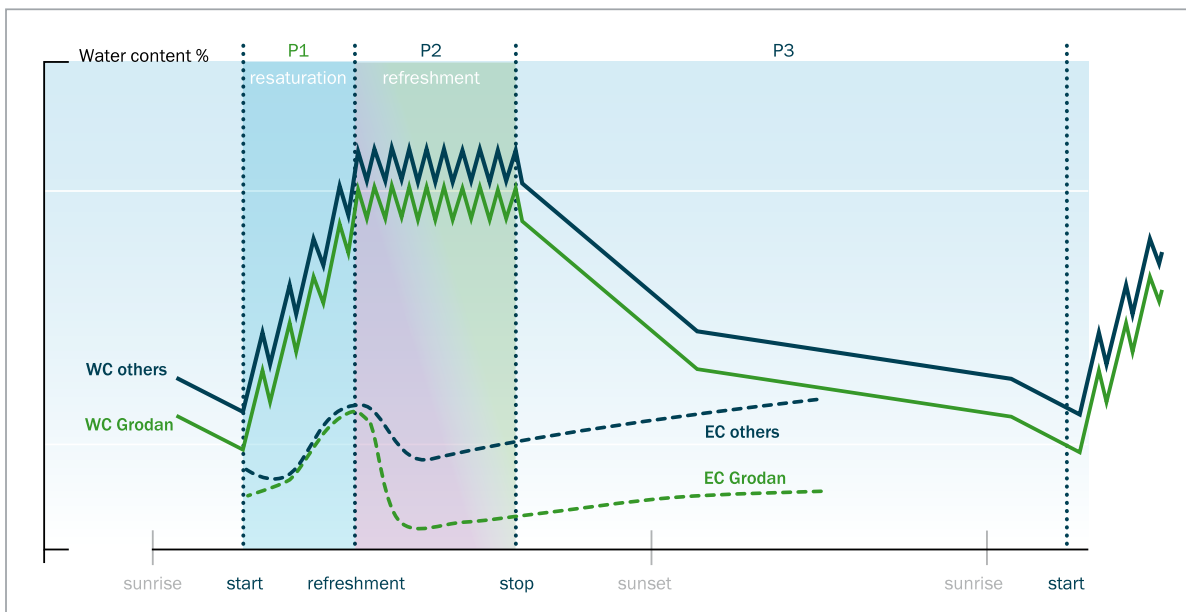


Figure 2. Irrigation efficiency means that with GRODAN stone wool substrate EC can be stabilized easily within the substrate during the irrigation period without the need to chase drain.

Irrigation efficiency

Irrigation efficiency is a term used to describe how the applied irrigation water is partitioned by the substrate between:

- re-saturation
 - ability to control WC
- refreshment
 - ability to control of EC

Irrigation efficiency is a feature which allows substrate EC to be managed without the need for a grower to 'chase drain' within the irrigation strategy (Figure 2).

Uniformity

The controlled manufacturing process of GRODAN results in uniform slabs. The uniformity of the substrate means that water and nutrients can be accurately targeted to the needs of the crop and do not need to be applied in excess to compensate for variation.

Control range WC

Control range WC is a function of the substrates irrigation efficiency and uniformity. Substrates with the widest control range are those with the highest

irrigation efficiency and greatest uniformity. Being able to steer substrate WC allows growers to adapt their irrigation strategy quickly and easily in respect to the season, stage of crop development and energy management practices such as screening strategies and outside growing conditions. This allows a targeted application of water and nutrients avoiding unnecessary drain volumes especially in periods of dark or changeable weather.

Irrigation advice for the start of the crop (first 6-10 weeks)

Drain hole positioning

The proportion of irrigation water partitioned into direct drainage is strongly influenced by the number of drain holes you make and their proximity to the drippers. Due to their irrigation efficiency GRODAN slabs require only 1 drain hole per linear 133 cm slab length (if they are positioned on a well profiled hanging gutter system). We recommend for maximum refreshment (and control of slab EC) that this is positioned at least 20 cm from the closest dripper (Figure 3).

Recycling from day one of the cultivation cycle

At the start of the cultivation cycle GRODAN slabs are saturated with a complete nutrient solution. A slab with dimensions 133 x 15 x 7.5 cm will absorb around 15 liters of nutrient solution. Assuming 6,000 slabs per ha this means that 90 m³ water (with nutrients) will be in the water system per ha.

When the drain hole is made, each slab will drain approximately 2 liters of nutrient solution (12 m³/ha). This nutrient solution is perfectly balanced. What you add in the irrigation water is measured in the slab and received back in the initial drain (Figure 4). This is in contrast to coco substrates which will contain high levels of Na⁺, Cl⁻ and K⁺ (Figure 5).

Moreover, no harmful substances are leached from GRODAN slabs. It is therefore perfectly safe to capture and recycle the drain water from the beginning of the cultivation cycle.

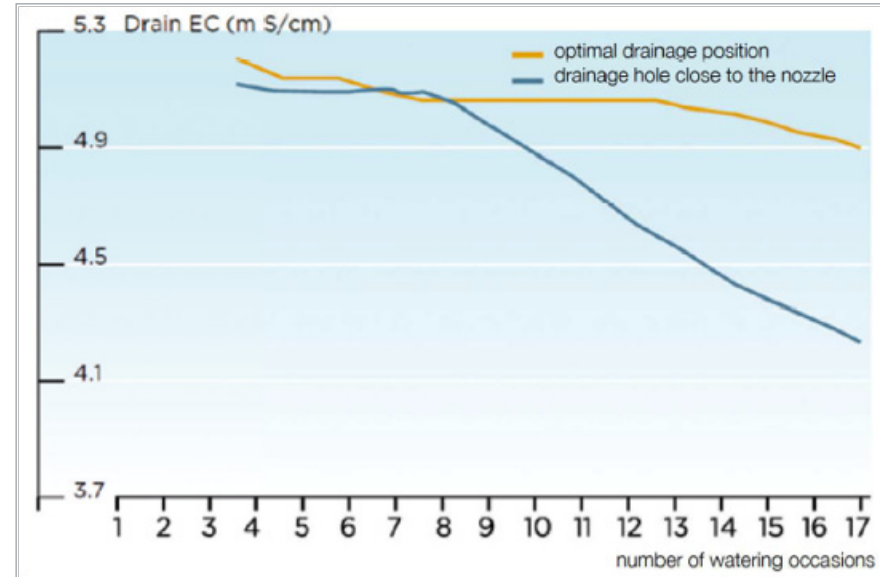


Figure 3. Illustration of the influence of the distance of the dripper towards the drain hole on the refreshment of the nutrient solution of the slab. The orange line represents a dripper at 20 cm from the drain hole. The blue line demonstrates a dripper at 10 cm from the drain hole. Drain EC is lower with the drain hole positioned at 10 cm because this drainage solution contains proportionally more fresh irrigation water than displaced substrate solution.

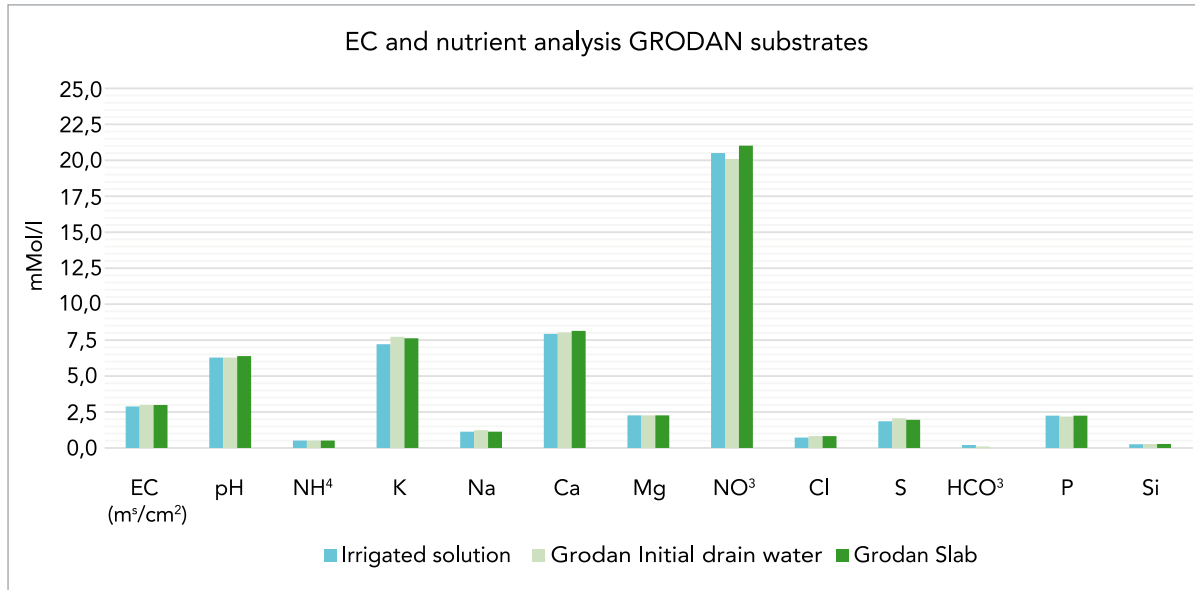


Figure 4. EC and nutrient analysis of irrigation water, substrate water and drain water from first flush recorded in GRODAN substrates. The figure illustrates that the substrate itself does not lock up nor release nutrients.

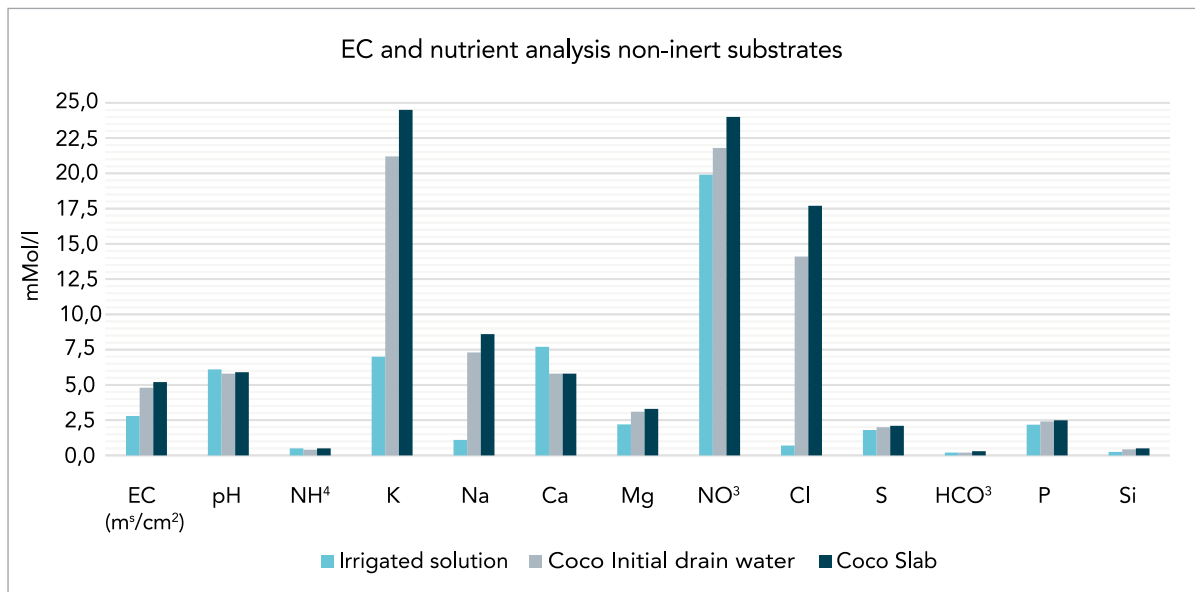


Figure 5. EC and nutrient analysis of irrigation water, substrate water and drain water from first flush recorded on a non-inert substrate. Slab and drain water in these substrates contain high levels of Na, Cl and K.

As shown in Figure 5, the nutrient solution which enters the drain basin from coco slabs is nutritionally unbalanced. Additionally, fine particles of organic matter and tannins are also washed out with the drain water, which makes it appear the color of tea (Fig. 6). In contrast to GRODAN stone wool, coco substrates need to be flushed in order to balance the nutrient

ratios within the slab and remove the tannins from the drain water. Flushing usually means applying 70 liters of water (and fertilizer) per slab to reach an acceptable T10 value (see Chapter 5). If discharged this volume of water, although minor compared to that used during the cultivation, has a huge impact on the emission of fertilizer (Table 5).

emission source	Total N emission (kg/ha/year)	
	GRODAN	coco substrate
from first drain	0	7.9
from flushing in	0	59.2
TOTAL EMISSION	0	67.1

Table 5. Difference in N emission as a result of extra flushing of coco substrates.

In this respect, it is important to note that the N emission targets for 2018-2020 in the EU Water Framework Directive in the Netherlands are 100 kg N/ha for sweet pepper, 67 kg N/ha in the case of tomato and 75 kg N/ha for cucumber (see Table 3).



Figure 6. First flush drain water from GRODAN substrate (left) compared to coco (right).

Structured irrigation advice during cultivation

The GRODAN 6-phase model offers a template for structured user advice with respect to irrigation management for each distinct growing phase of the crop. The advice is tailored so you can attain the best possible results with the GRODAN slab type of your choice. Users of the 6-phase model receive an e-mail with the relevant cultivation recommendations before the beginning of each cultivation phase.

Irrigation management during a 24 hour period

Irrigation is all about managing the conditions in the root zone. During a 24 hour period in the greenhouse three phases can be distinguished in the root zone as a response to irrigation.

Figure 7 gives an overview of how the WC and EC behave. Phase 1 begins with the first irrigation in the morning and the WC is increased in a step wise manner until the point at which drain is reached.

Phase 2 begins with first drainage; it is characterized by stable WC and a decreasing EC.

Phase 3 starts with the last irrigation of the day and overnight the WC decreases, allowing the roots to grow, and the EC value increases.

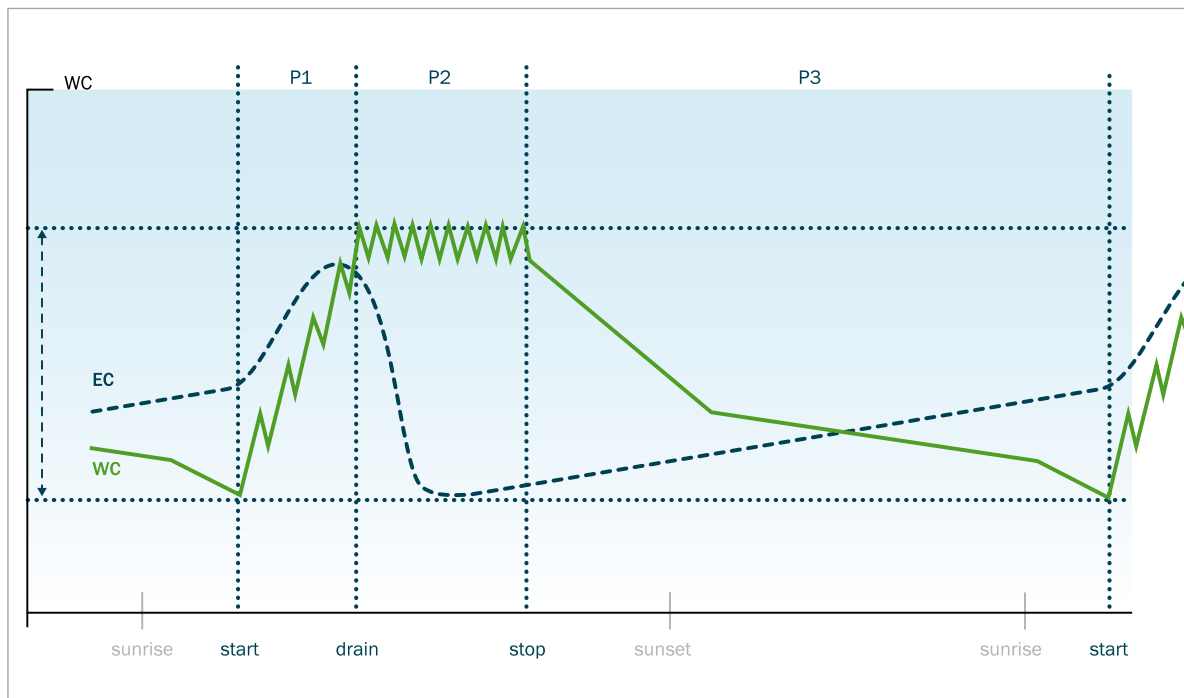


Figure 7. Schematic representation of WC and EC behaviour in the substrate over a 24 hour period.

GroSens sensors positioned in the substrate enable growers to measure WC and EC (Picture 2).

The actual graphics produced (Figure 8) enable growers to make informed decisions and to visualize how WC and EC develops over a day and between days and if needed, to make informed choices on how the irrigation strategy should be adjusted.

This data can be supported by adding light data (light sum J/cm^2) and light intensity (W/m^2) to the graphic. It is then easy to answer the following questions:

Start time

- What is the level of outside radiation?
- What was decrease in WC% from sunrise?

Time of first drain

- What is the level of outside radiation?
- Is EC lowest when radiation is highest?

Stop time

- What is the level of outside radiation?
- What was the decrease in WC% 3 hrs from last irrigation?
- What was the decrease in WC% overnight?

These questions when answered can then be cross referenced to the information contained in the GRODAN 6-phase advice for a particular crop growth stage. Changes, if required, to the irrigation strategy can be made quickly and easily.

Start & stop times

The timing of the first irrigation in the morning is most important. As a rule-of-thumb for a fully grown crop you should start irrigation 1-2 hours after sunrise and stop the irrigation 1-2 hours before sunset. These rules-of-thumb obviously do not apply when the weather conditions are changing quickly from day to day. However modern greenhouse control computers such as Priva Connex can account for changing climatic conditions and keep the root zone WC and EC stable.



Picture 2. GroSens helps growers make informed root zone management decisions

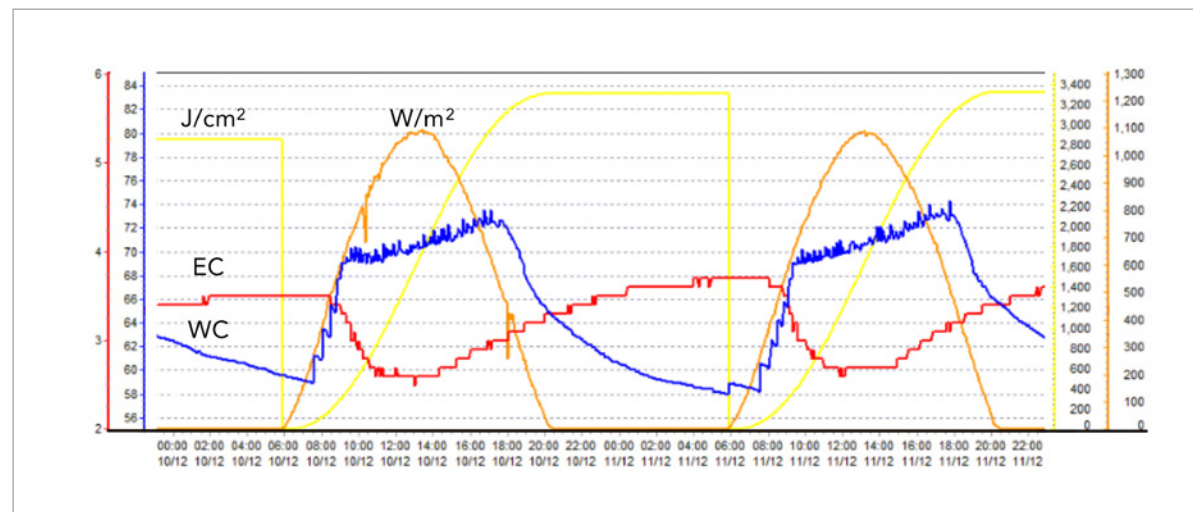


Figure 8. GroSens graphic as seen in Priva Office showing measured WC and EC values in the substrate along with radiation (W/m^2) and light sum (J/cm^2).

Minimum & maximum rest times

Irrigation volume will vary substantially between bright days and dark days. On bright days a good rule-of-thumb for a healthy fully grown crop is that the total applied volume should equal 3ml/J. i.e. a 2000 J/cm² day = 6 l/m² of irrigation water.

It must be remembered that the minimum rest time, or irrigation capacity (l/m²/hr) will govern the total irrigation supply on bright days and the maximum rest time will normally govern the total irrigation supply on dark days. For more information see Chapter 4. An indication as to the frequency of irrigation per hour is provided in Table 6.

Radiation (w/m ²)	Desired number of irrigations per hour
200	0–1
400	1–2
600	2–3
800	3–4
1000	4–5

Table 6. *The preferred number of irrigations per hour for a tomato crop in relation to outside light intensity*

Obviously applied irrigation volumes (l/m²) need to be in line with frequency. Table 7 provides some indicative values which may be used on GRODAN substrates.

(w/m ²)	J/cm ² /hour	Amount (3x radiation)	Frequency/hour	Volume/irrigation	Joules/irrigation
200	72	216 ml/m ²	0.5	400 ml	135
400	144	432 ml/m ²	1.1	380 ml	128
600	216	648 ml/m ²	1.9	340 ml	113
800	288	864 ml/m ²	3.0	290 ml	98
1000	360	1080 ml/m ²	4.1	260 ml	84

Table 7. Indicative irrigation volumes (ml/m²) and their frequency (joules per irrigation moment in relation to light intensity).

Managing drain

Drain should not be a goal but a result of a structured irrigation strategy. In line with Precision Growing i.e. with a structured irrigation strategy, drain volumes can be significantly reduced (Table 8).

Managing EC toward the end of the cultivation

To optimize your total input of nutrients you need to make sure the drain basins are empty at the end of the cultivation. The way to achieve this is twofold. First, in line with the 6 phase model reduce the total

Max exp day radiation in Watt	Radiation sum in joules	Drain% traditional	Drain % precision growing
200	500	20-30%	5%
400	1000		10%
600	1500	30-60%	15%
800	2000		20%
1000	2500		25%

Table 8. Example of how total drain volumes can be adjusted with a structured irrigation strategy in relation to outside growing conditions in line with Precision Growing.

volume of drain created in the final stages of harvesting. This will reduce the volume of drain entering the drain basin. Secondly, increase the EC supply (ECs) setting on the Priva Connex. This means proportionally more disinfected drain solution from the clean drain basin is mixed with fresh primary water. Figure 9 shows an example for Priva Connex.

The EC which will be delivered to the greenhouse is the desired EC (in the example in Figure 9 this is 2.4mS). ECs controls two valves, one from the clean drain water basin, and the other from the primary water supply. The nutrient dosing channels will dose EC – ECs so the nutrient recipe must take account of how much EC will come from the recycled drain water (ECs). In this example this is 0.8 mS/cm². Increasing the ECs setting to 1.5-1.8 mS/cm² as the cultivation cycle draws to an end will result in proportionally more recycled drain water being used to irrigate the crop. The combined effect of lowering the volume of solution entering the drain basins and using proportionally more recycled water to irrigate the crop will ultimately reduce the volume of fertilizer held in the drain basins.

This results in several benefits for you:

- you will use all the fertilizer you paid for;
- as the basins are now empty they can be easily cleaned;
- the basins are ready to collect first drain from the next cultivation.

Recipe settings

1	Recipe for water system/rinse group	1	1
2	Selection fertilizer dosage		SELECT.1

3		Temp	ECs	EC	pH
1	Too high alarm	0,0	0,0	0,0	0,0
2	Nutrient recipe		0,8	2,4	---
3	Desired	---		2,4	---
4	Too low alarm	0,0	0,0	0,0	0,0

-DOSING CHANNEL-						
4	DC	Channel	Calc quant	Quantity	Unit	Function
1		---	0,0	0,0	l/m3	DOSING
2		---	0,0	0,0	l/m3	DOSING
3		---	0,0	0,0	l/m3	DOSING

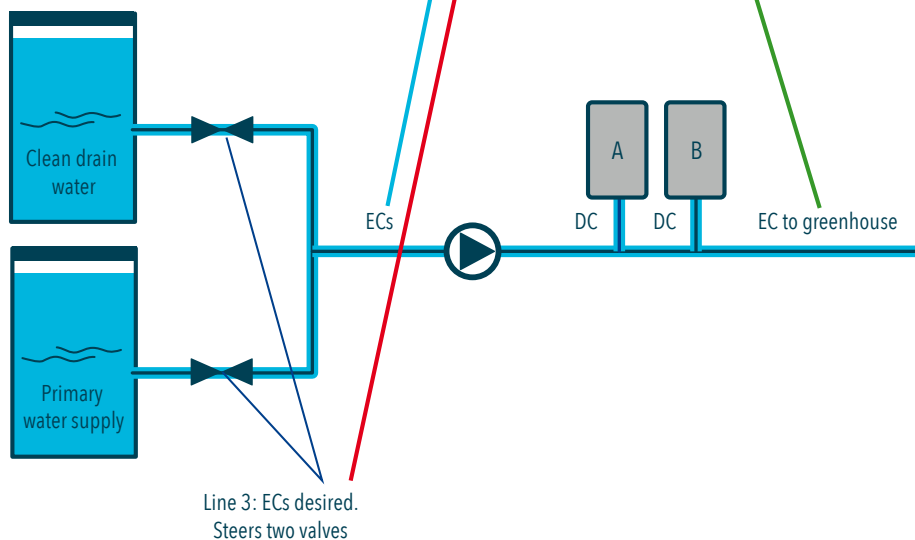


Figure 9. Screen I403 of the Priva Connex will allow you to adjust the ECs.

TIPS

- Substrate design and how you use it can help reduce discharge of fertilizer to the environment.
- The number of drain holes you make and their proximity to individual drippers will influence the total drain volume created.
- Recycling drain water from the start of the cultivation contributes to lower discharge of fertilizer.
- Monitoring WC and EC in the substrate will allow you to make informed management decisions in respect to fine tuning the irrigation strategy.
- Using proportionally more recycled water (ECs) towards the end of the cultivation cycle will mean you use all of the fertilizer you paid for. It will also allow the drain basins to be cleaned and empty for the start of the next cultivation.

CUTTING THE DRAIN HOLE

- Saturate the stone wool substrate with complete nutrient solution before the drain hole is made
- Ideally make one hole per 133 cm slab (assuming slabs are on a good gutter profile)
- Cut the hole at the lowest point in the slab in the direction of the slope.
- Ideally the drain hole should be at least 20 cm away from the nearest dripper.
- Never make the drainage holes directly below a propagation block or dripper.

4

Technical design of the irrigation system

STANDARD FOR WATER TECHNICAL INSTALLATIONS

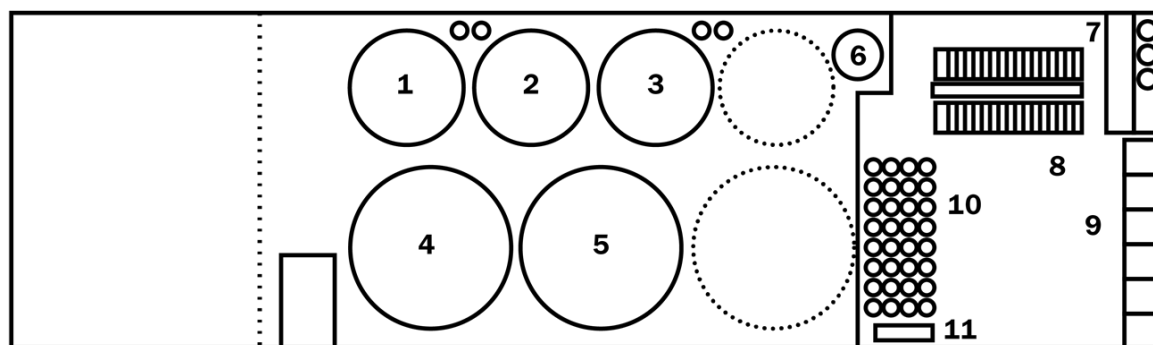
In the Netherlands, a private standard exists for the water technical installations in greenhouses. This guideline, called 'Kwaliteitseisen voor watertechnische installaties in tuinbouwkassen' (ISBN: 978-90-5044-148-3) can be ordered from www.issso.nl. The guideline is bilingual and contains Dutch and English texts in parallel.

The water system is central to the efficient functioning of your greenhouse. In line with emission reduction and best practice it is extremely important that you know what is going on within the water system. It is therefore essential that all water flows inside and outside the greenhouse are mapped and correctly monitored. This will help you to immediately identify those areas which will have the largest (and smallest) impact in relation to drain water recycling and managing discharge.

The water technical room

In the water technical room, all water flows come together at a central point in the greenhouse. Figure 10 gives an overview of the water technical room. However as every greenhouse is tailor made, depending on the crop being grown and the size of the operation, no standard template can be given for the setup within the room and the equipment it should contain.

There are however key generic points to consider whatever your situation. The size of the water technical room depends very much on the size of your operation. But whatever the size there should be sufficient space to allow you to work safely, to perform regular maintenance and to store the fertilizers. It is also worthwhile to leave space for new equipment in anticipation for future greenhouse expansion. In the example provided in figure 10 you can see that space has been left for two additional basins and for storage of additional liquid fertilizer, most likely due to a planned expansion of glass in the future.



Legend:

- 1+ 3 Dirty drain water basin
- 2 Clean drain water basin
- 4 + 5 Day water storage basins
- 6 Waste water basin
- 7 Liquid fertilizer stock tanks
- 8 Fertilizer dosing unit
- 9 A & B stock tanks (in this example 3 sets which will allow for different feed recipes)
- 10 Solid fertilizer storage area
- 11 Reverse osmosis unit

Figure 10. Schematic representation of the water room and the equipment that it might contain.

Figure 11 illustrates how the technical equipment can be installed in the water technical room. The different units such as the dosing unit, irrigation unit, drain unit and disinfection unit are all aligned, allowing the operator to see quickly if all processes are working correctly. The equipment panels are all located on the same side so that any malfunction can be seen immediately. In addition modern systems such as these are able to alert the operator of problems by text messaging to mobile phone applications. You will also notice the space and clear floor area ensuring that the operator can also work safely.



Figure 11. Picture of the technical installations in the water technical room. The setup shown here allows the grower to quickly check the proper functioning of all systems.

Key elements of the water system

Taking figure 10 as a reference we will look at the key individual elements in the water technical room.

Water dosing unit

Rain water and well (bore) water, which in this case requires treatment with RO (number 11 in Figure 10), and clean drain water come together into the dosing

unit (number 8 in Figure 10). In the dosing unit the right mixture of rain water, drain water and RO water is made and additional nutrients are added. As the pH-value of the water in the silos can increase from 5.2 to 6.0, this needs to be corrected by adding acidity (usually nitric acid) or alkali (usually Potassium hydroxide or (bi)-carbonate) compounds. Different systems are available to add nutrients to the water. Two modern systems are described below.

1: A and B stock tanks

A and B stock tanks (number 9 in Figure 10) are commonly used to apply nutrients to the primary water supply. The stock tanks vary in size depending on the situation and will contain a balanced but concentrated nutrient solution which is usually diluted 100 or 200 times before going to the crop. The two stock tanks allow concentrated calcium fertilizer to be separated from the phosphate and sulphate fertilizer. These minerals need separating in order to avoid precipitation of calcium phosphate and calcium sulphate. Calcium is placed into the A-tank and phosphate and sulphate into the B-tank.

As filling of the A and B stock tanks is a manual task, the possibility of a human error is always present. One should ensure that solid fertilizers are properly dissolved. Taking a sample of the final irrigation solution as it exits the drippers in the greenhouse is one way of checking that the fertilizer has been prepared correctly.

2: Automatic filling of the A-B-C-D stock tanks

Placing the nutrients into A and B stock tanks is time consuming and can be prone to human error. With greenhouses growing in size and complexity and labour costs increasing, new solutions are becoming

TIPS

- Make sure proper (safety) instructions are available for the mixing of nutrients. Especially when handling acid or alkali substances. Groen Agro Control as part of their fertilizer recommendation will tell you exactly how much (kg or g) to add to each of the tanks.
- However as mixing is a manual operation make sure the person responsible is following a methodical procedure and recording accurately what has been added.

available to improve how the nutrients are mixed. When concentrated liquid fertilizer³ is used the stock tanks can be filled automatically. This can be carried out by Priva process control.

Irrigation unit

Drip irrigation is standard practice for crops grown on substrate. These units allow irrigation to be applied accurately and directly to the root zone (Figure 12).



Figure 12. Standard dosing unit for drip irrigation (right) and UV disinfection unit (left).

³ Liquid nutrients (number 7 in Figure 9) need to be stored at a minimum temperature of 7°C in order to prevent the crystallization of certain nutrients.

TIPS

Check the variation between individual drippers within a valve section during crop turn around.

- A variation of 0 and 5% is good
- A variation of 5 and 7% is acceptable
- A variation of > 7 to 10% usually indicates that the drippers need cleaning or replacing.

Pumps push water with dissolved nutrients into the greenhouse via the main water pipe. The main water pipe usually divides the greenhouse into two equal parts. Those two parts are usually subdivided into separate irrigation zones or valve sections before distribution into the substrate via the individual dripper hoses. However keep in mind that the correct irrigation capacity is maintained.

Irrigation capacity

It is important that the system is designed with total "irrigation capacity" in mind. The irrigation capacity (l/m²/hr) determines how much water can be applied per hour within a particular "irrigation zone" or within a particular valve compartment. As a general rule the distribution system should be designed to deliver 1.2 - 1.5 l/m²/hr. The advantages of having the correct irrigation capacity are better control over substrate WC and EC, especially in summer and consequently better plant steering. Factors which determine the irrigation capacity are the number of drippers per m², the capacity of individual drippers and the number of irrigation zones within one valve/pump compartment.

Drippers

For accurate control in the root zone it is important that each individual dripper delivers the right amount of water and nutrients into the substrate. An accurate and equal amount of water and nutrients through all drippers with the right capacity enables the grower to manage substrate WC and EC and reduce total drain volumes whilst at the same time securing uniform growth and fruit quality.

Preferably pressure compensated drippers should be used in order to apply the exact amount of irrigation water and nutrients to the plants. Various types of drippers are on the market, differing in capacity and suitability to the crop. Tomato and cucumber would be suited to drippers with a capacity of 3.0 litre per hour (55 ml/minute). As peppers are usually planted at a higher density 2.0 litre per hour drippers (33 ml/minute) would be suitable.

Drain collection and reuse

Drain water collected by the hanging gutter system is pumped back into the water technical room and stored firstly in the "dirty" drain basin (number 1 in Figure 10). After passing through the UV disinfection unit (Chapter 5) it is then stored in a "clean" drain basin (number 2 in Figure 9). If required day water basins can be installed (number 4 and 5 in Figure 9). These allow the grower to store enough water with added nutrients to supply the crop for a full day. Ideally all basins should be located in the water technical room and not outside, as the temperature inside is constant and the installation strictly controlled. It is also important that the basins are correctly sized to cope with a maximum expected volume of water.

Disinfecting unit

The disinfecting unit contains the different systems to disinfect the water. We recommend high pressure UV or a combination of UV-light and hydrogen peroxide. The systems have to remove viruses, bacteria and fungi. Advanced oxidation can also remove certain plant protection products. Read more about the cleaning of drain water in Chapter 6.

Rain water storage

In the Netherlands, greenhouse growers are obliged by law to have a rain water storage capacity of at least 500 m³ water per ha. For most greenhouses the storage capacity ranges from 500-1000 m³ per ha. When water is stored above the ground, the basins should be covered (Figure 13).

Drain water storage capacity

As a general rule the storage capacity for dirty drain water and clean drain water should be at least equal to the total amount of drain realized on a summer's day. The amount of drain depends strongly on the substrate and irrigation strategy. When constructing a new greenhouse, the water storage capacity should be adapted to the needs of the crop. Moreover, future climate scenarios indicate that rainfall will become more irregular with periods of drought alternating with periods of heavy showers. The changing weather patterns will demand a robust water system and storage capacity. Trying to save money on storage capacity will often be 'penny wise, pound foolish'.

Waste water basin

Water that is of no value to the production ultimately needs to be discharged in a responsible manner.

Figure 13. A tent construction film to cover the water basin.



This waste water can be stored in a special basin prior to discharging responsibly into the sewage system (number 6 in Figure 9). Depending on the regulations in your country, costs may be involved in discharging into the sewage system. Whether the water may be discharged into the surface water will also depend on the concentration of nutrients and plant protection products.

With current knowledge and technology discharge of waste water is unavoidable. However by carefully choosing the period in which you discharge waste water, you can make substantial contributions to minimizing nutrient emissions from your greenhouse. For example if you need to discharge drain water because of a high sodium concentration in your recirculation water you can plan the best time to

apply a plant protection product to the root zone. Firstly discharge the water based on the sodium concentration and secondly apply the plant protection product. In this way you prevent discharge of waste water contaminated with plant protection products and the product will also have greater efficacy as it stays in the system for longer.

TIPS FOR A PROPER SYSTEM DESIGN

- Know and map all water flows on your property
- Ask for or make a technical map of all pipes and gutters.
- Do not economize on water storage capacity
- Check all your systems and machinery on a regular basis.
- Check whether the water meters are working correctly and are measuring the right things
- Let a technician calibrate your system on a regular basis.

TIPS FOR A WISE APPLICATION OF PLANT PROTECTION PRODUCTS

It is important that the application of the crop protection agents via the irrigation system is done accurately and uniformly. The following tips will help you do so.

- Make sure you've identified the pest or disease correctly.
- Apply the plant protection agents accurately at the right time.
- Calibrate and maintain your equipment to make sure you are using the amount recommended on the label.
- Carefully time the application in relation to discharging waste water.

5

Cleaning drain water

By far the easiest way to reduce the discharge of drain water to is to work with a high quality primary water supply and low drain volumes (Table 2). Substrate design and knowledge has improved over the years. Drain should no longer be the “goal” but a result of a structured, managed approach towards irrigation (Chapter 3). This chapter describes how this drain can be collected, cleaned and recycled in order to reduce the input of fertilizer and contribute to a sustainable cultivation.

Of greatest concern to many growers when recycling drain water is the risk of spreading diseases. Therefore care should be taken that any pathogens and growth inhibitors are removed. It is also recommended to regularly monitor the total concentrations of individual nutrients and their ratios in the drain water so the input of new nutrients can be optimized (Chapter 6).

Reasons to clean the drain water

There are several root-infecting pathogens such as *Pythium* and *Phytophthora* which are distributed through the greenhouse via recirculation water. To avoid the dispersal of pathogens via drain water, the water needs to be disinfected before being re-used. Also growth inhibition is perceived as a barrier for recirculation. Growth inhibition is often reported in flower cultures lasting longer than a year. Exactly what is causing the growth inhibition is still

unclear. Sometimes certain bacteria seem to be involved. At other times, proper steering and control measures are enough to prevent growth inhibition.

Also in the event drain water needs to be discharged into the sewage system or environment, it is recommended to first treat the drain water via advanced oxidation. In this way residues of plant protection products which were not absorbed by the crop or not yet broken down chemically are removed. Please note by January 1st 2018 this will be mandatory for Dutch growers.

Methods to clean the drain water

Drain water is collected firstly into the ‘dirty’ drain water basin. Cleaning consists of two phases: (1) removing the large particles, and (2) purifying the water of pathogens, growth inhibiting factors and plant protection products.

The first step traditionally involved sand filters to remove fine particles. More recently mechanical screen filters have been introduced. The advantage of these filtration techniques is that they require only a fraction of rinsing water compared to sand filters. The second step in the process involves techniques such as heating, UV-radiation or advanced oxidation.

Heating

Heating is a simple technique to break down micro-organisms. Heating however requires a lot of energy; moreover the temperature of the drain water increases, which is an undesired side-effect as you want the temperature of the drain water to be as constant as possible. High temperatures also reduce the concentration of dissolved oxygen in water. Therefore heating is not considered the current best practice.

UV-C light

UV-C light has the advantage that neither the temperature nor the pH of the water is affected during treatment. The wavelength of UV-C light is approximately 200-280 nm, which, when applied at the right dose damages the DNA of micro-organisms including viruses such that reproduction is impossible. Optimal destruction is at 265 nm. The clarity of the drain water has an impact on the effectiveness of the treatment. This clarity is measured as the T10 value, which is the percentage of UV light transmitted through 10 mm of (polluted) water. A minimum of 5 mW/cm² UV-C is required everywhere in the UV chamber⁴.

Three types of UV-C systems exist in the market, working with high, mid and low pressure lamps. The high-pressure system produces UV-C light

between 200-300 nm, whereas the mid and low pressure system produces UV-C light at 254 nm. Mid and low pressure UV require less energy and are best used at low water flow rates. High or mid pressure UV is able to eliminate pathogens in a more controlled way. Vialux systems, calculate and operate at the optimum UV dose by continuously monitoring the water being treated. Powerful turbulence in the water flow through the light chamber ensures that all the water is exposed to the UV light for a certain amount of time and at a critical intensity (UV dose in mJ/cm²). For each plant pathogen a specific UV dose is required to obtain a minimum of 99.9% reduction of pathogens; usually in the level 80-250 mJ/cm². When the water is not sufficiently clean, the system

will not allow the water to go through to the greenhouse. Instead the system design should redirect the untreated drain water into the dirty drain water basin (Figure 14).

Advanced oxidation

A hydrogen peroxide (H₂O₂) oxidation module can be added to the Vialux installation. Hydrogen peroxide is added to the traditional mid and high pressure UV-system. The hydrogen peroxide is split into hydroxyl radicals by the UV light. These radicals eliminate organic chemical materials like growth inhibiting factors and crop protection agents. The mid and high pressure UV eliminates viruses, pathogens, bacteria and nematodes. Hydrogen peroxide and

UV complement each other, leading to even better results. The benefits of using advanced oxidation are diverse. First there is the possibility to recirculate longer and to discharge less water, thereby reducing the emission of nutrients and crop protection agents and improving plant health.

The same installation can, with some slight modifications in the amount of hydrogen peroxide and the radiation strength, also be used to clean waste water before it is discharged.

TIPS FOR CLEANING DRAIN WATER

- Operate and maintain machinery according to the instructions of the supplier.
- If you are using a UV-disinfector, make sure the (sand) filter is properly filtering out all the dirt particles.
- Clean your filters frequently, preferably with clean water.
- Make sure the capacity to store drain water is sufficient.
- Be aware of the emission limits for chlorine when using chlorine to disinfect and clean your water system.

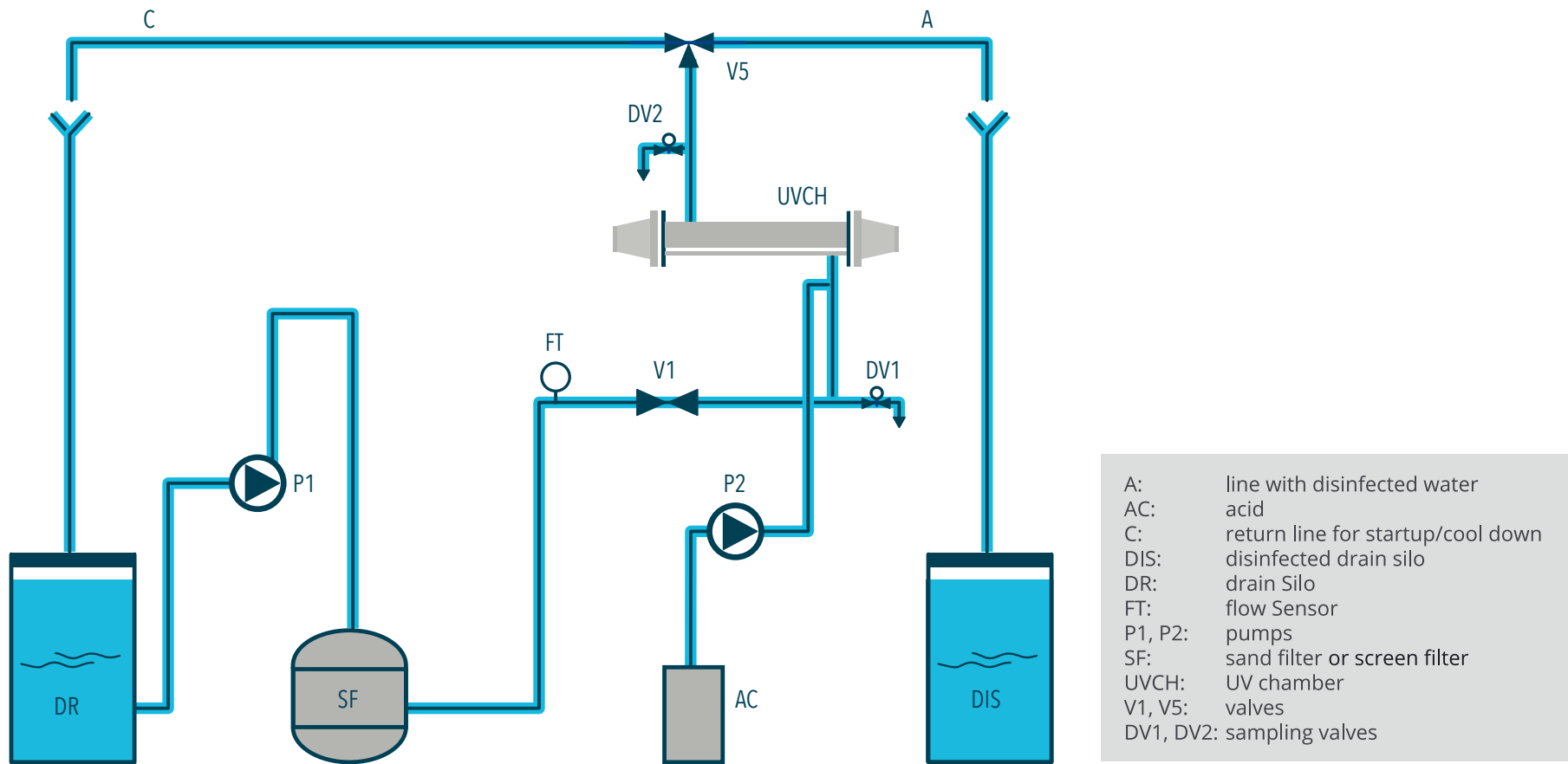


Figure 14. A schematic overview of the disinfection process. Water is pumped from the drain silo through the sand filter, from where the water is disinfected with UV light.



Figure 15. An example of the Priva Vialux M-Line UV disinfection system. The modular system is based on a new technology called mid pressure UV. Depending on the scale of operation, two, four, six or eight UV disinfection chambers can be installed. The Priva Vialux M-Line destroys all existing organisms such as fungi, bacteria and viruses within the irrigation water. UV disinfection systems can be applied for both new entry water and recycled drain water. UV disinfection allows continuous recirculation of the irrigation water in a safe way. As a result, expensive fertilisers are not flushed down the drain and do not contaminate the environment.

6

Nutrient management

Nutrient recovery makes sense economically and environmentally (Tables 1 and 2). Why would you discharge valuable nutrients when they can be used again? Furthermore by accurately managing nutrient levels growth disorders can be avoided, crop growth and yield optimized. This chapter outlines the importance of individual nutrient elements and details how they need to be management in the irrigation system.

Essential nutrients for crop growth

Sixteen elements

Plants require 16 elements to be able to grow. Those elements are carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), iron (Fe), manganese (Mn), boron (B), zinc (Zn), copper (Cu), molybdenum (Mo) and chlorine (Cl). The plant is able to take up carbon and oxygen from the surrounding air and hydrogen from the irrigation water. The other thirteen elements have to be added to the irrigation water. You can add them via a hydroponic nutrient solution in which the different elements are present in the right ratios. It is important to know what the role of each element has in plant development in order to adapt the nutrient mixture to the needs of the plant.

Macro and micro nutrients

The nutrients mentioned above are divided into macro and micro nutrients. The division is somewhat arbitrary but in general macro nutrients are required in larger quantities than micro nutrients. Nitrogen, phosphorus, potassium, calcium, magnesium and sulphur are macro nutrients. Iron, manganese, boron, chlorine, zinc, copper and molybdenum are micro nutrients. The functions of the nutrients vary. Nitrogen is an important element for plant growth. It is the nutrient that is responsible for the development of leaf area. Phosphorus is responsible for cell division and energy transfer reactions during photosynthesis. Potassium is important for the quality and quantity of fruits. Calcium is used in the development of new cell walls. Magnesium is the central element in the chlorophyll molecule: without this nutrient, photosynthesis would not be possible. Sulphur plays a major role in synthesis of amino acids. Chlorine is the nutrient involved in the evolution of oxygen during the photosynthetic process and is essential for cell division in roots and leaves. It also helps in the uptake of other elements, especially calcium. Iron is another element needed for chlorophyll synthesis and manganese is also required for photosynthesis. Boron is an element of the plant cell wall and is needed for sugar metabolism and transport, flowering, fruit set and seed development. Zinc is an element

important in the early growth phase and development, while copper activates enzymes and has an influence on nitrogen metabolism. Finally, molybdenum is a component of nitrate reducing enzymes.

Uptake of nutrients by the plant

Frequent analysis necessary

The uptake of nutrients depends on plant growth, plant development and the balance in the nutrient mixture. For example, in the phase from vegetative growth to fruit set, the uptake of potassium increases and the uptake of calcium and magnesium decrease. An overdose of one nutrient can reduce the uptake of other nutrients. To ensure that plants have an adequate and balanced supply of each element, the nutrient composition in the irrigation water should be adjusted on a regular basis. In order to do so, frequent sampling ideally every 7 days (at least every two weeks) of both the slab and drain water is necessary. Analysis of the samples will give you an overview of the concentrations of the nutrients that are present in the slab and drain water. The laboratory of Groen Agro Control will also compare these values with target values and will provide advice based on the crop species and growth phase. Groen Agro Control can also measure the nutrient element in the leaves as an additional analysis. This will give you more insight in the nutrient status of your crop.

The effects of nutrient deficiencies and excess are often not noted until it is too late. It is therefore vital to monitor the nutrient status of the slab and the drain water on a regular basis.

EC-value

The electric conductivity (EC) is a measure of the total amount of nutrients present in a solution: the more nutrients present in a solution, the higher the conductivity of electricity. When the EC-value is too high, the osmotic pressure around the roots becomes too high, preventing the uptake of water by the roots. The optimal EC value depends on the type of crop, the growth stage of the plant, and the climatic circumstances. It is recommended to first regulate the EC-value and then the pH-value.

pH-value

A too low or a too high pH value can be fatal to the crop. This is due to the fact that the pH-value of the root zone affects the availability of nutrients, especially micronutrients such as iron. If the pH deviates too much from ± 5.5 it can inhibit the uptake of nutrients by the plant. Most nutrients are available at a pH range of 5.4-6.2 in the root environment. However, the optimal pH varies for each crop species. When you have your slab and drain water analyzed, the pH value is also measured. You can however also

measure the pH yourself using a pH meter. When the pH value is too high, the nutrient solution (drip water) can be made slightly more acidic. When the pH-value is too low, the nutrient solution (drip water) can be made slightly more alkaline. However it is more effective to correct pH in the slab by adapting the ammonium concentration in the drip water. If the pH in the root zone is too high, more ammonium should be added. If the pH in the slab is too low the ammonium concentration should be decreased.

Water quality

As mentioned in Chapter 2 the quality of the primary water is very important. As long as the elements in the primary water supply do not exceed the concentrations in the fertilizer scheme it is possible to correct them. Although not required for plant nutrition, it is also important to know the bicarbonate (HCO_3) concentration in the primary water supply. As this determines the amount of acid (usually nitric) that is required to neutralize the bicarbonate without affecting its buffering capacity. Bicarbonate buffers the pH, so a little bicarbonate (0.25mMol/l or 15ppm-0.50mMol/l or 30ppm) is good as it stabilizes the pH of the drip water. High levels of bicarbonate (>1mMol/l or 61ppm) will result in an upward drift in pH. The excess can be removed with a Priva Neutralizer prior to its use in the fertilizer dosing unit.

Sample Slab tomato crop
Date day-Month-year
Crop Tomato (TOI)
Customer 1234
Sample nr. 123456
 Tomato Grower
 Distributieweg 1
 2645 EG Delfgauw
 Netherlands

Element	pH	EC	mM											µM						
			NH4	K	Na	Ca	Mg	Si	NO3	Cl	SO4	HCO3	H2PO4	Fe	Mn	Zn	B	Cu	Mo	
Analysis	6.7	4.0		2.2	4.7	11.3	9.6	0.4	10.3	11.1	10.5	1.2	0.6	91.6	5.2	78.0	318.0	2.4	2.6	
Analysis (EC(c))		3.7		2.8	4.7	14.5	12.3	0.4	13.2	11.1	13.4	1.2	0.8	117.3	5.2	99.9	407.1	3.1	3.3	
Target	5.5	3.7	0.5	8.0		10.0	4.5		23.0		6.8		1.0	25.0	7.0	7.0	50.0	0.7		
Standard feed		2.6	1.2	9.5		5.4	2.4		16.0		4.4		1.5	15.0	10.0	5.0	30.0	0.8	0.5	
Corrections				3.0		-0.8	-0.3		3.0		-1.0			-7.5		-2.5	-15.0	-0.4		
Drip water		2.6	2.0	11.5		4.3	2.0		18.2		3.1		1.5	7.5	10.0	2.5	15.0	0.4	0.5	
Tap/well	%from:																			
Surface water	%from:																			
Recirculation	30 %from:	2.5	0.1	3.1	2.1	5.7	4.4	0.2	7.4	5.2	4.7	0.5	0.6	44.2	4.1	26.0	144.0	1.1	1.2	
Injection concentrations			2.0	10.6		2.6	0.7		16.0		1.7		1.3	4.5	8.8	1.5	9.0	0.2	0.2	

		Solid Fertiliser					Remarks:
		A-Tank			B-Tank		
Water							
Tap/well	%			55.4	kg	Nitric acid	0.0 liter
Scheme code				11.7	liter	Potassium nitrate	43.1 kg
Rain	70 %			0.0	kg	MonoPotPhos	18.1 kg
Surface	%			28.8	kg	Magnesium sulphate	16.2 kg
Recirculation	30 %					Potassium sulphate	18.6 kg
System							
EC drip water	2.6 mS/cm						
Tank A volume	1000 liter	Fe-chelate 3.0 %		837	g	Mn sulphate 32.0 %	148 g
Tank B volume	1000 liter			675	ml	Zn sulphate 23.0 %	42.7 g
Concentration factor	100 x					Borax 11.0 %	85.8 g
						Cu sulphate 25.0 %	5.6 g
						Na-Molybdate 40.0 %	3.6 g

Disclaimer: This recipe is made under the condition that no liability is claimed by the user

Figure 16. An example of an analysis of slab and drain water and the fertilizer advice. In this advice the nutrients in the recirculation water are taken into account.

DEFINITION BOX

Calculations for the EC(c)-values

The EC is the electrical conductivity of all the ions in the solution. The unit that is used in horticulture is mS/cm (milliSiemens/centimeter). A higher EC generally means there are more plant nutrients in the solution. To be able to compare the nutrient concentrations in the samples with the target values (and other samples) we use the corrected EC, EC(c). To calculate the 'corrected' concentration of the elements, the concentrations of the elements in the sample are multiplied by the factor EC(c)/EC(v). EC(v) is the reduced value of the EC. To obtain the EC(v) the EC is reduced with one tenth of the maximum concentration of either chlorine (Cl) or sodium (Na).

In a formula it would be $EC(v) = EC - (0.1 \times (\max([Na], [Cl])))$. In this example the $EC(v) = 4.0 - (0.1 \times 11.1) = 4.0 - 1.11 = 2.9$.

For all the elements, except NH_4 , Na, Cl and HCO_3 the concentrations are recalculated to the EC(c), as you can see in Figure 16.

Mixing drain water and the nutrient solution

The easiest way to get an accurate feed recipe and therefore optimize the input of fertilizer is to send a sample of the water from the slab and from the drain to Groen Agro Control for analysis. Sample bottles, labels and sampling procedure will be provided.

Figure 16 provides an example of an analysis. If you choose another analytical laboratory, Groen Agro Control can still put the results of the analyses into their Netfeed program. This online program was developed in co-operation with GRODAN and you can calculate the recipe for the fertilizer mixture yourself.

Whichever method is used, the example shown in Figure 16 illustrates the process involved. The results of the analysis are noted on the row "Analysis" (but you will also receive reports for the analysis). These numbers are recalculated to the corrected EC (EC(c)), see the second row, "Analysis (EC(c))" of the table. For an explanation of the corrected EC, see the definition box "Calculations of the EC(c) values" opposite. The EC(c) value is arbitrary and we recommend it to be the EC value of the root environment that you prefer. The EC(c) values are compared to the target values which are crop specific. Based on this comparison the necessary adjustments are made. See the row "Corrections Analysis". This row is calculated by Netfeed. Further adjustments for e.g. pH, crop phase, or any other individual preferences can be made in the row "Corrections Extra". These corrections are added by hand, to keep the system flexible. The concentrations of the elements in the drip water are calculated with the above mentioned values.

In this example we recirculate the drain water and use 30% drain water in the irrigation water. In order for the system of analysis and recipes to work well, the percentage drain water (relative to the amount of drip water, in the greenhouse) should not exceed 30%. The drain water has also been analyzed and the results are on the row "Recirculation". These elements are taken into account in the calculation of the amount of fertilizers. As you can see this example uses solid fertilizers, but this can be changed to liquid fertilizer when applicable (Chapter 4).

TIPS FOR NUTRIENT MANAGEMENT

- Take frequent analyses of slab and drain water (once a week). This way you can monitor the nutrient uptake by the crops carefully.
- Save money in the right way. Cheap nutrients often contain sodium, which is detrimental to your crop. Avoid accumulation of sodium. Sodium accumulation forces you to discharge your water, throwing away valuable nutrients.
- Monitor the condition of the crop closely for any signs of deficiencies.
- Deficiency and toxicity are most often caused by:
 - pH problem in slab or drip water
 - Precipitation in A or B tank as a result of a mistake when filling the tanks
 - Root problems: diseases or cold
 - Excessive corrections
- First adjust the EC, then the pH when making the drip water.
- Adjust your given nutrient solution to the target figures per crop phase. E.g. fill, start, setting and fruit growth for tomato and vegetative or generative for pot plants. And in case of special demands for your cultivar, make sure you know these.



8

Conclusion

In this best practices guide we have argued that diligent water and nutrient management is a fundamental part of greenhouse crop production. We have provided you with some attention points and tips in order to help you comply with environmental legislation with respect to emission reduction. In doing so as suppliers we are working together to create a more sustainable greenhouse sector. We are acutely aware that each greenhouse operation is different and circumstances do vary per country. Please do not hesitate to contact us to see which tailor made solutions we can offer you.

OVERALL CHECKLIST

Primary water quality

- Know the quality of the primary water supply you are using by having it analyzed by a reputable laboratory.
- Invest in sufficient rain water storage capacity, 500m³ per hectare is minimum recommended in The Netherlands.
- Be aware of the possible presence of iron in bore hole water supply. In this case you need to adjust the nutrient recipe or use an iron filter.
- Use a Neutralizer if your water contains high concentrations of bicarbonate, especially if this occurs in combination with a high pH-value.

Irrigation management

- Create a system of frequent monitoring and registration of water use.
- Measure substrate WC & EC.
- Adapt your irrigation strategy to the growth phase of your crop and to the weather.

Technical design of the irrigation system

- Know and map all water flows on your property.
- Ask for or make a technical map of all pipes and gutters.
- Check all your systems and machinery on a regular basis.
- Check whether the water meters are working correctly and are measuring the right things.

Managing waste water discharge

- Carefully time the application of plant protection products in relation to discharging drain water.
- Let a technician check your water system at the end of each growing season.

Cleaning drain water

- Monitor your disinfectant regularly. Is it doing what it should do?
- If you are using a UV-C disinfection unit, make sure the (sand) filter is properly filtering out all the dirt particles.
- Clean your filters frequently, preferably with clean water.
- Make sure the capacity to store drain water is sufficient.
- Be aware of the emission limits for chlorine when using chlorine to disinfect and clean your water system.
- Always disinfect your drain water before using it as irrigation water, by e.g. advanced oxidation.

Nutrient management

- Do not economize on a frequent analysis of slab and drain water (once a week).
- Take a close look at the prices of nutrients. You will be able to save money when you buy and store a large quantity when the price is right.
- Avoid accumulation of sodium. Sodium accumulation forces you to discharge your water, throwing away valuable nutrients.
- Monitor the nutrient uptake by your crops carefully.
- Monitor the condition of the crop closely.
- Nutrient deficiencies and toxicities are often related to the use of poor quality irrigation water.
- Take into account the growth stage of your crop i.e. a young crop consumes more calcium and magnesium and less potassium than an old crop with a heavy fruit load.

GRODAN

Since 1969 GRODAN has been the global market leader in the supply of a wide range of integrated substrate solutions to professional growers endeavoring to achieve the optimum cultivation of high-quality vegetables and plants. GRODAN represents reliable and sustainable substrate solutions for the cultivation of vegetables and plants. GRODAN provides its customers innovative, certified and environmentally-friendly products, advice and services to enable them to increase the quality and quantity of their production.

For more information:

www.grodan.com



Priva

Priva provides sustainable solutions for the more efficient control of energy and water within greenhouse environments, as a means to conserve scarce resources and reduce our impact on the planet. Priva is a world leader in developing and supplying sustainable technologies for the control of greenhouse environments within horticulture. Together with local partners we offer our customers across the world access to high-quality hardware, software and services.

For more information:

www.priva-international.com/water



Groen Agro Control

Groen Agro Control is a laboratory specifically set up to service the horticultural sector. Our team of horticultural experts can quickly and efficiently provide fast, accurate results. We pride ourselves on the close personal contact we maintain with our clients. We also realize that problems can occur at inconvenient times. Even then, we are on-call to answer your needs. We offer advice on nutrients, the root zone environment as well as crop protection treatments which take into consideration your specific growing conditions.

For more information:

www.agrocontrol.nl/en



Annex 1:

Good quality primary water supply

Characteristic	Unit	Group		
		1	2	3
EC	dS m ⁻¹	< 0.5	< 1	< 1.5
pH		see text		
Na	mmol l ⁻¹	< 0.5	< 3	< 5
Cl	mmol l ⁻¹	< 0.5	< 3	< 5
Ca	mmol l ⁻¹	< 1.5	< 2.5	< 3.5
Mg	mmol l ⁻¹	< 0.7	< 1.25	< 2
SO ₄	mmol l ⁻¹	< 0.7	< 1.25	< 2
HCO ₃	mmol l ⁻¹	< 5	< 7.5	< 10
Fe	µmol l ⁻¹	< 10	see text	
Mn	µmol l ⁻¹	< 10	see text	
B	µmol l ⁻¹	< 10	< 25	< 50
Zn	µmol l ⁻¹	< 3	< 5	< 10
Cu	µmol l ⁻¹	< 1	< 1.5	< 3

Guide values for water quality

The water of group 1 is required if no or nearly no leaching (< 5%) is accepted; the values of group 2 are required for moderate leaching conditions (5-20%) and for group 3 high leaching requirements are necessary (>20%).

