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THE ROAD TO SUSTAINABLE WATER AND NUTRIENT MANAGEMENT IN SOIL-LESS CULTURE IN DUTCH GREENHOUSE HORTICULTURE.

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Abstract: *Since the expansion of soil-less culture in the Netherlands in the mid-eighties of the previous century, emission of nutrients and plant protection products (PPP's) used in the root environment was considered as a huge problem. Eventually, the government and growers organisations reached an agreement which aimed at reducing the N, P and PPP emissions. For soil-less culture, reuse of drain water or closed growing systems became obligatory. Recently, the regulation changed by shifting the focus on reaching emission targets for N rather reaching 100 % closure of the systems. Yet, recirculation is still the key issue for reaching the goal of zero emission by 2027. These closed systems will potentially lead to substantial reduction of mineral leaching to the environment, however, they require adequate water quality and nutrient management. Moreover, satisfactory disinfection to control root diseases and removal of organic components is needed. In practice, substantial loss of water and minerals still occurs occasionally, when growers decide to flush the system and drainage water is partially discharged to the surface water or sewage system, causing emission of nutrients and PPP's. There are several reasons for growers to discharge e.g. accumulation of Na, mismanagement in EC or pH or nutrient supply, and serious problems with soil borne diseases or growth inhibition. This paper will give an overview of the state of the art of systems for nutrient solution recycling, and the requirements for water treatment, water quality and nutrient supply and strategies to obtain the highest efficiencies for nutrient and water use.*

Keywords: *Recirculation, Na accumulation, Discharge, Emission, Growth Inhibition*

Introduction

Protected cultivation in the Netherlands covers over 10 000 ha, mostly concentrated in the western part of the country with a high density of glasshouses. Almost 80 % of the area is soil-less culture. Glasshouse crops are intensively grown, with high inputs of capital and labour and high production levels. As the mineral uptake is proportional to the total yield, these high production levels involve high inputs of fertilisers. In comparison to open field vegetable crops, the annual fertiliser application is eight to ten times higher (Sonneveld, 1993). Apart from the high crop demand, the high fertiliser inputs are necessary to keep high osmotic pressure levels in the root environment to prevent lush growth and for enhancing product quality (Sonneveld, 2000). However, these high fertiliser applications and levels in the root environment increase the risk of leaching and emission of N and P into ground - and surface water. The problem of water pollution by minerals increased seriously with the introduction of soil-less culture from the early 1980's on. The fertiliser requirement increased as consequence of the higher yields in soil-less culture (Voogt, 2004). The main reason for the higher emission in substrate culture was, however, the practice of high irrigation frequency and quantity to compensate for the heterogeneity of the output of the irrigation system (Sonneveld and Voogt, 2009). It is therefore and as a consequence of the high density of greenhouses in most areas that the Dutch government decided, by the end of the 1980-ies, to start with comprehensive regulations and legislations to reduce the pollution of the aquatic environment in horticultural areas (Ministry, 1989). A complicating factor is that the costs of fertilisers and water in these intensive growing systems are low compared to the total costs (Ruijs, 1995). Savings on these items are therefore in general not an incentive to implement concepts and measures regarding sustainability.

This paper will give an overview of the state of the art of systems for nutrient solution recycling, and the requirements for water treatment, water quality and nutrient supply and strategies to obtain the highest efficiencies for nutrient and water use.

Legislation

In the late 1980s, the problem of high nutrient concentrations in surface waters in and near greenhouse areas were signalled. To diminish the problems of nutrient losses, closed growing systems were stimulated by governmental policy. Because of insufficient effect of the stimulation programme, the policy was adjusted and replaced by regulations (Roos-Schalij *et al*., 1995). From November 1996 reuse of drainage water was obligatory for soil-less crops. Enforcement of this regulation was assigned to the Polder boards. (A polder board is a semi-governmental, local body, set up to maintain the integrity of the water defences around polders and responsible for water quality) However, due to the large number of enterprises, local conditions as well as the impracticability of the control, the operation was unsuccessful. Therefore, the important stakeholders (central and local government, environmental groups and the growers' organization) organized themselves in the GLAMI committee, Dutch acronym for "Greenhouse Horticulture and Environment" (GLAMI, 1997). This resulted in an official agreement, covering the regulations and details concerning the obligation for recirculation (Infomil, 2002). The key issues in the regulation were:

- Obligation of reuse of drainage water
- Permission of temporarily discharge drainage water if Na concentrations exceed a certain crop specific level.
- Obligation of rainwater collection of at least 500 m^3/ha or sufficient water from sources with comparable quality as rainwater.

However, during the late 1990s and early 2000s, some developments induced the central government to change policy again. This was driven on the one hand by the implementation of European Nitrate Directive (ND) and the Water framework Directive (WD) and on the other hand by the disappointing results of the water quality monitoring by the Polder boards in areas with many greenhouses and the evaluation of the nutrient emissions (Baltus and Volkers-Verboom, 2005). As a result, the GLAMI committee (now 'Platform Sustainable Greenhouse Horticulture') changed the agreement from 'prescription of means and requirements' towards 'prescription of targets' in the period 2005 – 2010. The new agreement defines specific goals for emissions, instead of a list of obligations. Obviously the main route for emission are the water flows, which is mainly the discharge of drainage. So all measures taken to reduce the amount of discharge also will reduce the emission of P – and other nutrients - as well as the emission of PPP's to surface waters and groundwater. Therefore the new agreement has chosen for defining N norms for emission, achieving a reduction of discharge and by that also for P and PPP's. The final target is zero emission from Greenhouse Horticulture to be achieved by the year 2027.

The agreement was translated into new regulations: "Activiteitenbesluit Glastuinbouw" (Infomil, 2012). From January 1st, 2013 growers are responsible for reaching the emission goals. However, the polder boards still have the legal means of enforcement as growers are obliged to officially register fertiliser use and the discharge quantity so that the quantity of N emission can be determined.

The main points of the regulations are:

- Crop specific norms for the emission of N (Table 1), which will be yearly decreased until 0 in 2027.
- Grower need to make a yearly report, with the registered water use, discharge and fertiliser use.
- Obligation for rainwater collection will be dismissed
- Discharged water may be used for other sectors like field vegetables.

For some crops, however, no economically feasible soil-less growing system was available (Ruijs, 1994). For soil grown greenhouse crops the solutions were directed towards improvement of the irrigation en fertilisation management, to avoid irrigation surpluses (Voogt, 2004)

Bottlenecks

Surplus irrigation in substrate cultures is necessary due to the unequal distribution of water and nutrients by the irrigation system and differences in transpiration of individual plants and spots in the greenhouse (Sonneveld and Voogt 2009). Closing the system can easily be done by the collection of runoff by a gutter system and reuse it in the system (Voogt and Sonneveld, 1996). The closed systems increase water- and nutrient use efficiency and reduce the risk of emission of nutrients and PPP's. However, there are some bottlenecks accompanying the recirculation of nutrient solution.

1) Recirculation can lead to rapid spread of spores of root pathogens, viruses, bacteria or nematodes from infected plants throughout the system. Sometimes serious problems and outbreaks of root diseases in closed growing systems are reported.
2) Salinity can be a problem, since residual salts present in the irrigation water or added by fertilisers accumulate in the system if the concentrations in the inputs are higher than the apparent uptake concentration. This is enhanced by the low buffer capacity of the system, due to the low volume and the inertness of the growing media.
3) As constrained by the salinity problem, only water of perfect quality is suitable (Table 2). This means that the major traditional water sources like surface water and well- water in the Netherlands are unsuitable, except for the well water in the east part of the country.
4) In some crops, mainly cut roses, the reuse of drainage water occasionally causes growth inhibition. It has been suggested that the accumulation of (organic-) compounds in the system or a build-up of microbiological activity causes infection and deterioration of the harvestable flowers.
5) Since the root environment is restricted all essential nutrients should be supplied, in the right quantity as well as in the required mutual ratios. A supply higher than needed by the crop will lead to rapid accumulation and a supply with lower concentrations than required will lead to rapid depletion.
6) Despite the high water and nutrient use efficiency potential of the closed system, discharge of the circulating nutrient solution is needed frequently due to the accumulation of Na^+, Cl^- or other elements. Growth inhibition is an obvious reason to refresh the recirculation water by discharge of drainage, but sometimes also done as precaution, even if growth inhibition is not yet observed. Some growers even discharge the drainage tank because of too high EC or pH. The discharge causes loss of nutrients and in some cases loss of PPP's. Since the discharge is applied in short time it causes serious environmental problems.

Sustainable management

Irrespective of the fact that reuse of drainage water is not anymore obligatory under the current legislation, the aim for emission reduction and the final goal of zero emission requires closed growing systems. Therefore, the reuse of the nutrient solution should be maximized by solving the problems with recirculation, to avoid discharge. As a certain discharge is unavoidable, the remaining nutrient solution to be discharged can be purified. The following measure can be taken to alleviate the above mentioned bottlenecks.

Soil-borne diseases

Prevention is obviously the first priority, taking strict hygiene measures for the preparation of the greenhouse and the growing system at the start of the crop. Next, disinfection of drainage water is highly recommended and has been practiced for many years. There are many ways for disinfection (Van Os, 2010). UV radiation is the most popular water treatment, chemical treatments with peroxide and chlorine becoming more commonly used. Despite the high effectiveness of the UV treatment, serious problems and outbreaks of root diseases in closed growing systems are still reported such as the 'Thick Root Syndrome' with cucumber (Gaag *et al*. 2002) and more recently with 'Crazy roots' caused by *Agrobacterium* (Ludeking, 2009).

Water quality and salinity

To prevent the accumulation and salinity problems, water sources low in Na and Cl should be selected for closed systems (Voogt and Sonneveld, 1996). For closed growing systems, the input concentrations for Na and Cl will be determined by the maximum uptake concentration which is reached at the maximum acceptable Na or Cl concentration in the root environment. For all crops so far known, Na is always the limiting factor, since Na and Cl is usually present in waters in more or less the same molar ratio, the suitability of water sources will be determined by Na (Voogt and van Os, 2012). Next to Na and Cl, virtually all nutrient-ions could be the limiting factor for suitability of water sources, if the concentrations present are higher than the average uptake rate of plants. In practice, this is mainly the case with Ca, Mg and SO_4. In some (well-)water sources also some micro-nutrients like Mn or B could be a problem. The ions in this category are nutrients and have to be taken into account when preparing the nutrient solution. The concentration present in the source water should be deducted from the required concentration in the nutrient solution. General guidelines for water quality have been developed (Table 2) however, since the tolerance for salinity and also the uptake differ substantially among crops, the guidelines must be interpreted for specific situations (Sonneveld and Voogt, 1994). Despite all measures, Na accumulation will be a remaining problem, since for some crops the capacity for Na uptake is very low. Therefore some discharge is hardly avoidable, to keep Na within an acceptable level. The lowest volume of necessary discharge will then be achieved if the Na uptake by the specific crop is maximized. This can be reached if the Na concentration in the root environment is kept at the highest acceptable Na concentration in the root environment. This level coincides with the minimum required concentration for nutrients (Voogt and van Os, 2012).

Substrate and fertilisers

Although the main input of residual salts is by the irrigation water, to some extend also other inputs like substrates and fertilisers contribute to the Na accumulation. Sometimes the growing medium can have high Na levels, like coir if this is not properly pre-treated (Verhagen, 1999) or composts used in peat mixtures for potted plants. Some fertilisers have relatively high Na levels, for instance some of the Fe chelates and some K sources like in KNO3, K2SO4 and KH2PO4, or even liquid alkaline K sources like KOH or K2CO3. However, the total contribution of Na from either substrate or fertilisers are rather negligible if compared to the potential for Na input by the irrigation water (Voogt, unpublished data).

Growth inhibition

The sometimes observed growth inhibition is not straightforward identified but yet a major problem. So far, no relation with salinity, nutrition, pathogens or any known micro-organism has been observed. It is assumed that the growth inhibition in rose is connected with the prolonged recirculation of drain water and might be caused by accumulation of growth inhibiting substances in the water (Ehret *et al*. 2005). Both the accumulation of (organic-) compounds in the system and a build-up of microbiological activity, causing infection and deterioration of the vegetation, have been suggested as possible causes. Obviously, growth inhibition should be prevented as it is a driving force for discharge. Recently Van der Maas *et al*. (2013) showed that growth inhibition has a micro-biological cause, most likely of bacterial origin. Disinfection of recirculating water with existing techniques such as UV, ozone or heat treatment inactivated the growth inhibition. Parameters as the O_2 concentration in the root environment or oxidative stress might be useful as early warning for growth inhibition.

Nutrient management

Closed growing systems entail that the inputs of nutrients should match the output or uptake by the crop (Voogt and Sonneveld, 1997). The relevance of this constraint is enhanced by the restricted rooting volume and the inertness of the growing media, making the water- and nutrient buffer limited. The supply of nutrients should therefore be tuned adequately to the crop requirements, to prevent rapid accumulation or depletion of nutrients. In line with the development of closed growing systems in the 1990's, nutrient solutions for specific crops in closed systems have been developed (Sonneveld and Voogt 2009). These are designed to keep to the nutrient status in the root environment optimal for soil-less cultures with recirculation under the current growing conditions. Factors to be considered are: the specific uptake ratios of the crops, substrate characteristics, crop growth stage and climatic conditions. According to water quality, analytical results of the root environment or other parameters adjustments to the nutrient composition can be made easily. It is not sufficient to derive the nutrient requirements from crop uptake data only. Some crops will deplete the nutrient solution almost completely for specific nutrients, not necessarily meaning a great demand, which is demonstrated for rose and strawberry (De Kreij *et al*., 1985; van Bastelaere, 1993). Opposite effects were found with sweet pepper, since for this crop relatively high B levels in the root environment are needed, to achieve sufficient uptake (Voogt and Bloemhard, 2013). To characterize the differences in nutrient uptake and demands, the accumulation factor is a useful parameter which has been elaborated in Voogt and Sonneveld (1996). The uptake during the growing period changes, as crop stages require different nutrient ratios. A clear example of crop stage depending shift in uptake ratios is shown in Fig 1. The change in K:Ca ratio of the uptake of a tomato crop is rapid and substantial and if no adjustments are made in time, rapid depletion occurs resulting in K deficiency (Voogt, 2002).

To avoid mismatch of nutrient supply and uptake, a tuned supply is necessary in the first place and secondly, proper control by taking regularly samples for nutrient analysis from the root environment in the second place. These analysis are the basis for adjustments to the fertiliser recipes and have been proven to work quite well in common practice in the last twenty years. As part of the trend of having more control over all growth processes, there is also need for more direct measurement of nutrients in the root environment. Recently hand-held analytical devices for nutrients became available (Blok et al. 2012). New developments in micro- electronica, like capillary electrophoresis (Van der Lugt, 2013) open the way for the long desired wish of on-line nutrient measurements (Gieling, 2001).

Purification of discharge water

Taking the measures as discussed above will help to reduce discharge as much as possible. Nevertheless discharge will be unavoidable occasionally. For instance, when sodium levels exceed the crop-specific threshold values, nutrients are out-of-balance, technical failures appear, or growth inhibition is observed or feared. The pollution with nutrients and ppp's can be reduced substantially by purification before discharge. Recently, van Ruijven *et al*. (2013) evaluated purification techniques for drainage water. Four technologies were tested. It proved that ozone as well as UV with H_2O_2 combination proved to be able to remove the PPPs with an effectiveness of approximately 80%. Activated carbon filter after ozone treatment improved effectiveness up to 100%.

Discussion and conclusion

Although soil-less culture with closed systems are common practice in the Netherlands, reaching complete closure still faces serious bottlenecks. An important issue is the Na accumulation. Due to the high quality requirements (Table 2) many water sources are unsuitable. In practice, only rainwater and in the eastern part of the country, deep well-water is suitable. Sufficient rainwater storage capacity that makes it possible to bridge the gaps of dry periods should be available.

However, the space for sufficient rainwater collection buffers is lacking or very expensive. Moreover, even with extreme large buffers the availability of rainwater is uncertain due to the unpredictable climate (Fig 2) (Voogt *et al*. 2012). Therefore growers need installations for desalination by reverse osmosis (RO) as back-up. In addition, due to coastal influence the Na concentration in the collected rainwater is sometimes too high (Voogt and Sonneveld, 1996). Also in case of ill-tuned RO installations the residual salt concentration can be too high. This makes Na accumulation and consequently occasional discharge a remaining problem.

With the state of the art automation and monitoring, an uncontrolled EC or pH of the drainage should be no excuse for discharge, as being avoidable. This would be also true for mismatch of nutrients, if the right recommendations and frequent analysis are accomplished. This will be facilitated by hand-held analytical devices already in the market. With the development of continuous on-line nutrient determination, any mismatch of nutrients are no longer a problem. Moreover, it opens new perspectives for managing the crop nutrient uptake.

In the prevailing regulations for soil-less greenhouse crops in the Netherlands, the focus for reaching the WFD and ND targets was shifted from obligatory recirculation to emission targets going down to zero by 2027. So growers should make their own assessments how they will meet these targets today and in the coming years. Reduction the discharge of drainage water is inevitable. Some growers have to invest in alternative water sources to assure sufficient water of good quality, whilst others have to focus on disinfection with advanced techniques or elimination of growth inhibition factors. Nevertheless, there will always be a remaining quantity to be discharged. With advanced purification technologies all PPP's and even nutrients can be removed. However, it is questionable if these steps are economically feasible for individual growers. Clustering of greenhouse holdings and cooperation for the purification of water is probably more obvious. Implementation of a yearly gradual reduction of the N-emission norm urges the greenhouse industry and individual growers to develop innovations to maximise reuse of the drainage by solving problems that lead to discharge, and to purify the inevitable remaining discharged water.

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Tables and Figures

Table 1. Maximum acceptable yearly emission of N in discharged drainagewater in kg ha^{-1} yr^{-1} *(Infomil , 2012)*

	2013 & 2014	2015- 2017	>2018
Other vegetables	25	25	25
Anthurium, Container crops, Bedding plants	50	33	25
Orchid (Cymbidium)	75	50	38
Tulip, Annual	100	67	50
Tomato, Herbs	125	83	67
Cucumber, Potted plants, Propagation ornamentals	150	100	75
Strawberry, Eggplant, Sweet pepper	200	133	100
Rose, Gerbera, Propagation vegetables	250	167	125
Pot orchids (Phalaenopsis)	300	200	150

Table 2. Guide values for water quality for closed growing systems *(Sonneveld and Voogt, 2009).*

Class	EC mS cm^{-1}	Na mmol l^{-1}	Cl mmol l^{-1}	
1.1	<0.5	<0.2	<0.2	Suitable for all crops
1.2	<0.5	0.2 – 0.5	0.2 – 0.5	Suitable for salt sensitive crops
1.3	<0.5	0.5 – 1.0	0.5 - 1.0	Suitable for salt tolerant crops or crops with high Na uptake

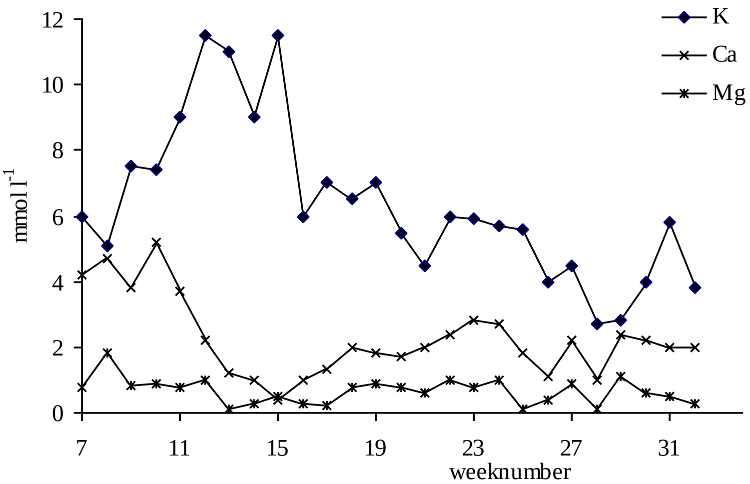

Figure 1. Uptake of K, Ca and Mg of a year round crop of tomato in a closed growing system, planted in week 1, first yield in week14, expressed in mmol l^{-1} *(from Voogt (1997).*

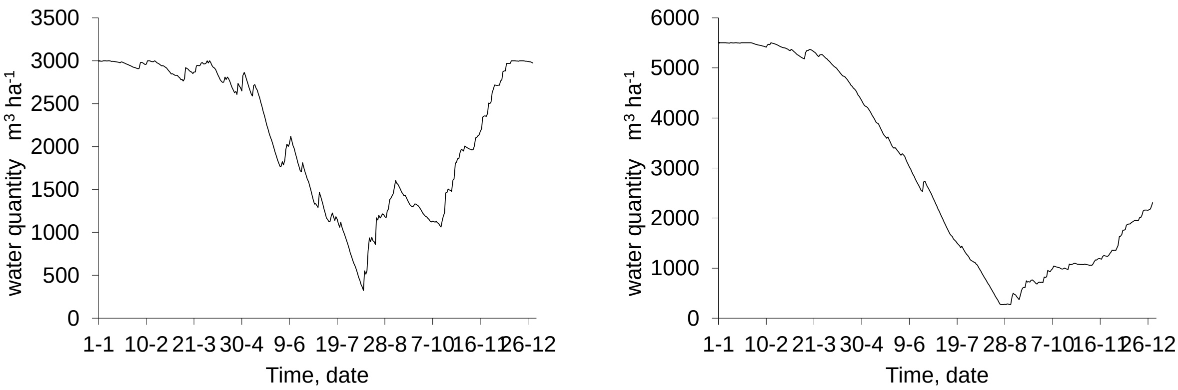

Figure 2 Required basin capacity (m^3 ha^{-1}) and available water (m^3 ha^{-1} day^{-1}) in a rainwater basin during a normal year (left) and an extreme dry year. Results of simulation for a year round tomato crop in closed system, with the model Watersteams *(Voogt et al, 2012).*