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Zero liquid discharge in soilless greenhouse horticulture: solutions to save water and the environment while ensuring an optimal production

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Abstract

Zero liquid discharge (ZLD) should be the future for soilless production. In The Netherlands emission of nutrients and plant protection products to surface water is the main reason to investigate the potentials of cultivation methods without any discharge. In a few other countries water pollution issues is the main motive, but for a majority water shortage and the increasing competition for water of an acceptable quality is reason for the growing need for water efficient cultivation methods. During four years ZLD was investigated for cucumber (2014, 2017) and sweet pepper (2015, 2016). The primary goal was to reuse all drain water, while maintaining a similar yield and quality as in the traditional growing method with regular discharges. To achieve ZLD all practical reasons for growers to discharge the nutrient solution had to be anticipated before. In the ZLD trials technical and strategic solutions were jointly tested and further developed into an adapted growing strategy without any discharge. A number of factors could be mentioned as main reasons for discharge: sodium in the supply water, discharge of filter rinsing water, unbalances in the nutrient solution, no recirculation of the drainwater in the beginning of the cultivation, no disinfection equipment, too low drain storage capacity, appearance of calamities (technical failures) and the amount of remnant nutrient solution left in slabs and tanks at the end of the cultivation. The next step was demonstrating the technical and strategic solutions in a cultivation. In 2014 and 2015 we showed that ZLD-cultivation in stone wool substrate was possible without loss of yield and quality. In 2016 and 2017 the more challenging coir substrate was used to investigate the influence of buffering and sodium accumulation. It appeared that ZLD was possible without loss of production or quality. Appearing problems were more in the field of management of water flows than lack of technical equipment. Special care should come for technical failures of equipment, mostly not enough storage capacity is available.

Keywords: nitrate, nitrogen, plant protection product, pesticides, sweet pepper, cucumber, emission, circular economy

INTRODUCTION

The 2017 experiment with cucumber was the last in a row of four to demonstrate the options to grow a soilless crop without liquid discharge to the environment. The EU Water Framework Directive (EU, 2000) showed the way to go: ecological sound surface and groundwater by 2015 with the possibility to postpone to 2027 if the goals could not be achieved. For the Dutch government, employers organisations and the water boards reason to jointly structure the path for the individual greenhouse grower: an almost zero discharge of water with nutrients in 2027. For Plant Protection Products (PPPs) additional regulations (Ministry of Infrastructure and Environment, 2013; van Ruijven et al., 2014, 2019) were made to decrease concentrations of PPPs by 95% in 2018 as concentrations in surface water were too high (Teunissen, 2005). Beerling et al. (2014) investigated growers reasons to discharge: accumulation of sodium, refreshing the solution, root-borne diseases despite disinfection, discharge of filter rinsing water, remnant solutions at the end of the crop cycle and fear for accumulation of substances (softeners). Based on these enquiries a technical design was made how to realize a zero liquid discharge cultivation. The main goal was to demonstrate to growers and technicians that zero discharge can be achieved without loss of yield and quality, with currently available technology and with smart use of strategies.

MATERIAL AND METHODS

Sweet pepper (2015, 2016) and cucumber (2014, 2017) were pilot crops to grow in two nett 120 m^2 greenhouse compartments. Stone wool was used in 2014-2016, coir was used in 2016-2017 (van Os et al., 2019). All experiments in successive years were not statistically well block designed trials but similar practical comparisons of technical solutions and management strategies to achieve the zero emission. Each trial was used to learn and to demonstrate which was followed by improvements of design or strategy. During cultivation a group of growers and substrate suppliers followed and advised the way of growing to achieve the best result. The following parts were taken up in the design:

- Supply water: to avoid accumulation of sodium (Na) rainwater, collected from the greenhouse cover, was used as the preferred water source with a Na concentration less than 0.1 mmol L^{-1} (2.3 mg L^{-1}). Additionally reversed osmosis water was used with a similar low sodium concentration of less than 0.1 mmol L^{-1}. Sodium accumulation decreases the time that circulation is possible and, consequently, increases the amount of discharge. In 2014 and 2015 rainwater was disinfected to eliminate pathogens;
- Disinfection: to minimise the outbreak of soil-borne diseases spread by the circulating nutrient solution ozone (batch wise treatment up to 600 mV) was chosen to eliminate all spores of fungi and bacteria and viruses. No disinfection means a much higher risk on outbreaks of diseases and, consequently, a much higher water consumption and lower yields;
- Filtration: often a rapid sand filter is used before the disinfection technique to eliminate coarse particles (remnants of roots, leaves, algae, substrate) and additionally sometimes before the nutrient solution is pumped to the drip irrigation. Clogging of the filter automatically starts the rinsing or backwashing of the filter after which the rinsing water is being discharged. Filtration with a minimised amount of rinsing water or no rinsing water at all was preferred. A 35-µm flatbed filter was used at which no rinsing water was created and the solid waste could be composted including the filter tissue. Additionally the 5-um fibre filter was tried in 2016 and 2017;
- Drip irrigation: steering of irrigation to control growth is often used in soilless cultivation. A rapid system for quick changes in EC or composition of the solution or to supply plant protection products (PPPs) is required for optimal growth. However, drip irrigation systems are often slowly (using 4 or 8 L h^{-1} instead of 2 L h^{-1} drippers, large volume of the system). Three L h^{-1} pressure compensated drippers in combination with a 16 mm instead of a 25 mm pipe was chosen to optimize the frequency of irrigation. To make the system even more rapid a closed loop low pressure (<1.2 bar, no opening of drippers) network was used to bring fresh solution at the appropriate place before irrigating starts;
- Substrate choice: stone wool was used from 2014 to 2016, coir from 2016 to 2017. The first is an inert substrate where management of water flows was the important issue (recirculation of first drain). Coir faces the problem of potential high sodium concentrations at delivery and after which buffering with calcium nitrate is required. 2014 and 2015 were used to compare traditional discharge and growing methods with a zero liquid discharge (van Ruijven et al., 2019); 2016-2017 only zero liquid discharge variations were compared (2016 stonewool and coir; 2017 coir buffered and non-buffered);
- First drain: after filling the substrate with nutrient solution it has to be drained to create better growing conditions for the roots (oxygen). Often this first drain with a full nutrient solution was discharged to the environment due to a fear for softeners

which might be present in the substrates. As substrate manufacturers did not fear this softener problem recirculation by growers should be easily possible. The main challenge is to drain it in such a way that troughs and drain pit do not overflow. To avoid any overflow drain from slabs was created by making 1-2 small holes instead of making a cut of the width of the slab. In such a way the drainwater comes slowly and the troughs have more time to process this water. This was done in all successive crops;

- Composition of the nutrient solution: weekly analysis and usage of the Uptake Analysis of Groen Agro Control gives the grower more detailed information resulting in better growth and less need for discharge by adapting the composition at the right moment (2015, 2016). Now growers mostly analyse supply and drainwater once in a fortnight or less;
- Volumes of solution at crop change: an end of cultivation strategy (from about 6 weeks before the preset end date) was developed (2016, 2017) to avoid excessive discharge. Volumes of storage tanks and slabs should be minimised, while nutrient content (focus on nitrate) can be decreased by replacing it by chloride. An extensive overview of the results is given by Leyh et al. (2020).

In Figure 1 a schematic overview is given of the technical installation. In all the successive crops a group of growers and consultants guided the cultivations to achieve the best results.

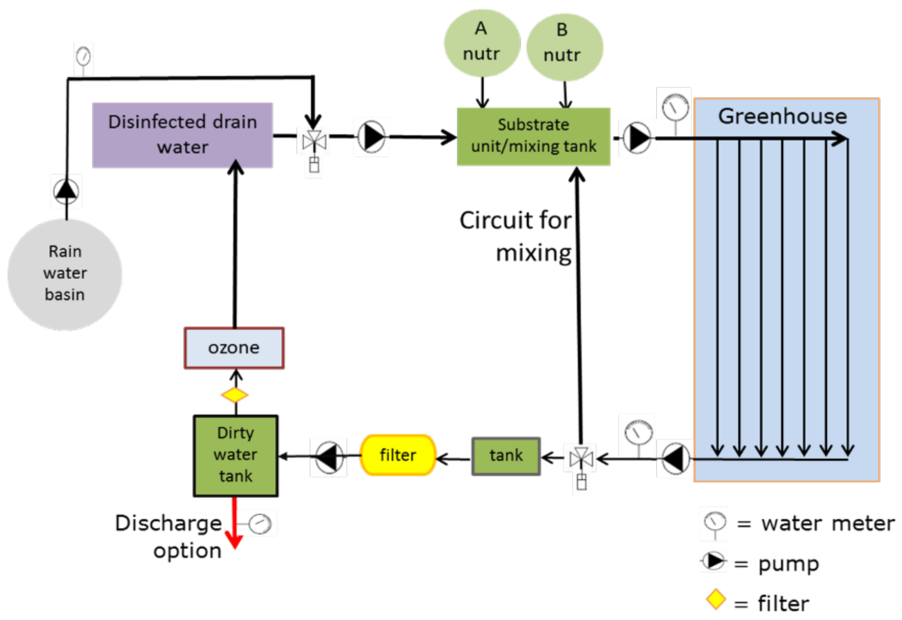

Figure 1. Schematic overview of ZLD technical design.

RESULTS AND DISCUSSION

Yield and quality

The 2014 cucumber stone wool crop (July-October 2014) was used to adjust all equipment, while water counters were not yet available. Yield measurements showed a similar yield (19.1 and 18.5 kg m^{-2} in respectively reference and ZLD greenhouse) in the reference as in the ZLD greenhouse. For the 2015-2017 crops an overview is given in Table 1. Differences between treatments were small. In 2016 coir was grown too vegetatively compared to stone wool, earlier fruit load could have been realised. There was no clear reason for the yield difference in the 2017 crop. Controlling growth appeared to give fluctuations as individual fruit weight was lower as expected because of lack of natural autumn light.

Table 1. Water balance and yield (kg m^{-2}) of crops grown in zero liquid discharge experiments.

		2015 sweet pepper (Dec-Nov)		2016 sweet pepper (Jan-Oct)		2017 cucumber (Jun-Oct)	
		Reference stone wool	ZLD stone wool	ZLD stone wool	ZLD coir	ZLD coir buffered	ZLD coir non-buffered
Water balance (%)							
In	Supplied to plants	100	100	100	100	100	100
	Rainwater	74	73	72	66	58	60
	Drain	26	27	28	34	42	40
Out	Plant uptake	70	73	68	65	57	60
	Drain	26	27	28	34	42	40
	Discharge	4	0	4	1	1	0
Yield (kg m^{-2})		26.3	27.4	28.1	26.5	43.9	48.2
Product use efficiency (L kg^{-1})		22.5	24.0	22.4	22.5	8.8	8.1

Water use and discharge

Table 1 gives an overview of the water use in the 2015-2017 crops. Discharge in Reference greenhouse in 2015 was 4% which is similar to 418 m^3 ha^{-1} $year^{-1}$ with 26 mmol L^{-1} NO_3, a little more as permitted according governmental regulations (Ministry of Infrastructure and Environment, 2013). It appeared that management of all water (discharge) flows should be directly linked to the accumulated amount of kg discharged. Otherwise it cannot be managed properly. In the 2016 crop a large quantity of nutrient solution had to be discharged in the stone wool crop (4%) in a few days due to a broken disinfection installation. Drainwater returns continuously and no storage capacity was available. Collected data about storage capacities it appeared that in case of calamities growers have limited space to store extra amounts of solution. There is no space for 1-2 days of drainwater storage without using it. The product use efficiency is used here instead of the water use efficiency as the water uptake by the crop is the only water use parameter, there is no evaporation of soil or substrate.

The use of water with such a low concentration of sodium (<0.1 mmol L^{-1}) does not give any accumulation, even not in sweet pepper. Disinfection of the rainwater was only done in 2014 and 2015 to avoid any risk of spreading pathogens. It was not done in the last two years, mainly because it is not done in commercial practice and there were no signs that it is really dangerous to take in non-disinfected rainwater. However, an analysis of the rainwater on pathogens should take place before such a decision is made. For example using surface water or dam water nematodes might be present to spread all over the substrate slabs.

At the beginning of the crop stone wool slabs are filled with nutrient solution to saturate the slab uniformly. Just before planting the slabs are drained. However, a large amount of water (about 3-4/slab) is drained away. When making large holes troughs overflow and large quantities flow into the ground. Similar to the drain pit, too much water in a short time gives an overflow. There appeared to be two good solutions: making a few holes with a 2-3 mm stick at first, followed by a larger drain cut at the bottom of the slab a few days later; draining of the slabs at half of the cultivation area and later at the other half.

In the successive experiments the nutrient solution was adapted on EC and pH before each irrigation by pumping it around under low pressure via the circle piping. It appeared that much energy is used while adaptation was not needed. It will be recommended to adapt only once a day before irrigation starts or at the moment the composition needs to be changed or PPPs need to be added.

Buffering of coir

Washing the coir with a calcium nitrate solution to replace the naturally present sodium (buffering of the coir) at which the latter is discharged can be done at the manufacturers site but also at the grower's. In most cases the grower has to do this by wetting the slabs with the solution mentioned. In 2016 coir was buffered and the amount of needed solution and discharge of nitrogen was measured. Filling with $CaNO_3$ solution and maintaining during a few hours was followed by rinsing the slabs, partly with clean water and partly with a complete nutrient solution. The drained rinsing water contained 2.6 mmol L^{-1} sodium and 12.9 mmol L^{-1} NO_3. The latter was about half of that of the nutrient solution (22-26 mmol L^{-1}). It was decided to discharge this amount, containing 8 kg N, which is part of the 133 kg N permitted to be legally discharged in 2017. If it was not discharged sodium concentration might accumulate causing a full concentrated solution (22-26 mmol L^{-1} NO_3) to be discharged. Reason to investigate in 2017 if discharge of buffer water could be avoided. As the nutrient solution has more sodium, the Ca concentration was increased with 2 mmol L^{-1}. The goal was to see if further accumulation of sodium would take place. However, the sodium concentration kept low, this can only be caused by the fact that the quality of the coir was very good (low sodium concentration). It is more often not the case.

Choice of substrate

Stone wool appeared to be a substrate at which with good management ZLD was possible. The overflow of troughs and drain pit could be easily overcome by an adapted working method; first small holes, there after a wide cutting at bottom level of the slab. The growers fear for softeners or other substances released by the slabs appeared to be groundless. Unfortunately, not all cultivations were ZLD, but not caused by the substrate. Coir was the most challenging substrate to choose. Well-known about the sodium accumulation and buffering requirements we showed that ZLD was possible. In the 2016 crop only the buffering solution was discharged, in the 2017 crop there was even no buffering but also no accumulation of sodium. As there are many suppliers on the market, growers have to be careful. It is recommended to buffer the coir in the first year and if it proved to have no accumulation of sodium an next step could be to start without buffering while using a nutrient solution with extra calcium. Other substrates might have other challenges, but it is not expected that they will give other or more problems in one or another way.

Nutrient analysis

The weekly analysis of supply and drainwater in combination with data about radiation, temperature and CO_2 concentration gives growers detailed information about crop uptake and concentration of elements in the nutrient solution. Accumulation of i.e., potassium or decrease of calcium can be seen in advance with time to react without a need to discharge. A and B solution storage tanks should be adapted in the same week as analysis results return. Growers often say (Beerling et al., 2014) that an unbalanced nutrient solution is reason for discharge. van Os et al. (2019) showed that a more stable solution can be achieved with less need to discharge.

Filtration and disinfection

Normally growers use a sand filter to eliminate coarse materials (remnants of roots, leaves, algae, substrate), consequently the filter clogs and have to be rinsed. For a long time the rinsing water was discharged while nobody knew about the volumes. As discharge water (just drainwater) contained nitrogen it was placed under the regulations to minimise these emission (Ministry of I and M, 2013). Solutions were investigated: recirculation of rinsing water and other filters with a minimized amount of rinsing water and flatbed filters without any rinsing water. The flat bed filter used filtered up to 35 µm, however, other values are also possible. It worked without any problems and is on the market now for sale. The quality of the cloth (tearing when pulling forward) is an important point to watch. The 3-µm fibre filter, used in 2016 and 2017 worked also well, it needs some rinsing which is recirculated.

For all successive crops ozone was chosen to disinfect the nutrient solution. The batch wise method was used in the 1990s (Runia, 1994), but slowly disappeared: too complicated, too expensive. The present design is safe and works well. An improvement is the variable dosing of ozone in relation to the quality of the solution. The disinfection process continuous till a level of an adjustable 500 or 600 mV (redox value) instead of a fixed dose m^{-3} solution. Consequently ozone disinfection can be used in stone wool with rather clean water as in coir with brownish water in the beginning.

Technical failure of all equipment is a point of concern. Growers have not enough storage capacity to store unexpected water flows, it was usage to discharge. In the 2016 stone wool crop we had to face such a failure which led to about 3-4% discharge (Table 1) just because storage tanks run over.

End of cultivation strategy

The 2016 and 2017 experiences with finishing the entire nutrient solution stock by the end of the cropping period appeared to be difficult but possible. It is very weather depending, if transpiration is still high during the last weeks decrease in irrigation is hardly possible without decrease in fruit quality. During visits of growers it also appeared to be very difficult to explain, convincing them on the use looks difficult as it is complicated and there is hardly any profit.

CONCLUSIONS

In a four-year programme (2014-2017) the potentials of zero liquid discharge (ZLD) were extensively investigated and demonstrated to growers. Production and quality were not negatively influenced by full recirculation and with the use of currently available equipment. It is much more management of water flows than technical issues to achieve ZLD. Starting point is almost sodium free supply water, using an adequate disinfection technique and filters which produce less or no rinsing water. Any substrate can be used in a ZLD cultivation, but each with its own specific measures (first-drain management in stone wool, buffering in coir). During cultivation frequent analysing of the composition of the solution enables to minimise discharge because changes in composition are made visible sooner. At the end of the cultivation a strategy has to be followed to minimise the amounts of nutrient solution in the slabs and the volumes in the storage tanks.

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