Comparison of Some Chemical and Non-Chemical Treatments to Disinfect a Recirculating Nutrient Solution

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Abstract

Closed hydroponic growing systems have a better water use efficiency (WUE) and a lower use of fertilizers, but a larger risk of spreading soil-borne pathogens all over the crop compared to open systems. In climates or regions where availability of water is limited closed systems should be preferred above open systems but the risk of spreading soil-borne pathogens should be minimized. Disinfection of the nutrient solution is a valuable method, but it often demands high investments. A desk study was made to compare the performance of some chemical and non-chemical treatments. For larger companies (>2 ha) heat treatment and UV radiation are still the best options. For smaller companies (<1 ha) slow sand filtration is a good option. Ozone and membrane filtration are good methods but expensive. Sodium hypochlorite (NaOCl) and hydrogen peroxide are cheap methods, but performance against pathogens is poor. They can be better used to sanitize pipe lines and equipment. Chlorine dioxide may be a promising method but little is known about dosage-effect relations against pathogens. Besides, safety measures and environmental restrictions may limit the use of this method. Investigations should be extended. Copper/silver ionisation and active carbon are not methods to be used for disinfecting the solution. Performance against pathogens is poor.

INTRODUCTION

Recirculating of the nutrient solution opens possibilities to save on water and fertilizers (Van Os, 1999). Increased application of technology shows a dramatic increase in the water use efficiency of a crop (Stanghellini et al., 2003). In case of open field production of tomato about 15 kg of fresh tomato can be produced per m^3 water, while in a Dutch climate controlled greenhouse with CO_2 enrichment 45 kg tomatoes can be produced per m^3 and in a closed hydroponic growing system even 65 kg per m^3 water. A similar increase in efficiency of the use of fertilizer can be achieved in a closed hydroponic growing system. The big disadvantage of the recirculation of the nutrient solution is the increasing risk of spreading root-borne pathogens all over the production system. To minimize such risks, the solution should be treated before re-use. The use of pesticides for such a treatment is limited: effective pesticides are not available for all such pathogens, and if available resistance may appear, and environmental legislation restricts release of water with pesticides into the environment. Disinfection of the nutrient solution may minimize the risks for outbreaks of root diseases if an appropriate method has been chosen.

In this paper several chemical and non-chemical disinfection methods will be discussed with a focus on performance and costs of application at relative small nurseries (1000-5000 m^2).

DESCRIPTION OF DISINFECTION METHODS

For a greenhouse of 1000 m^2, a disinfection capacity of about 1-3 m^3 per day is needed to disinfect an estimated needed surplus of 30% of the water supplied with drip irrigation to tomato plants during a 24h period in summer conditions. In a nutrient film system (NFT) about 10 m^3 per day should be disinfected daily. It is generally considered that such a capacity is uneconomical to disinfect (Ruijs, 1994). Because of the variable return rate of drain water, a sufficiently large catchment tank for drain water is needed in which the water is stored before it is pumped to the disinfection unit (Fig. 1). After disinfection another tank is required to store the clean water before adjusting EC and pH and blending with new water to supply to the plants.

Non-Chemical Methods

In general this type of methods does not alter the chemical composition of the solution and there will be no build up of residuals.

1. Heat Treatment. Heating the drainage water to lethal temperatures is the most reliable method for disinfection. Each type of organism has its own lethal temperature. Non-spore forming bacteria have lethal temperatures between 40 and 60°C, fungi between 40 and 70°C, with some exceptions to 85°C, nematodes between 45 and 55°C and viruses between 80 and 95°C (Runia et al., 1988) at an exposure time of 10 seconds. Generally the temperature setpoint (95°C) is high enough to kill most of the organisms that are likely to cause diseases during the period of time that the liquid is at these killing temperatures (minimal 10 seconds). While this may seem very energy intensive, it should be noted that the energy is recovered and reused with heat exchangers. Availability of a cheap energy source is of greater importance for practical application.

2. UV Radiation. UV radiation is electromagnetic radiation with a wavelength between 200 and 400 nm. Wavelengths between 200 and 280 nm (UV-C), with an optimum at 254 nm has a strong killing effect on micro-organisms, because it minimizes the multiplication of DNA chains. From experiments it is known that different levels of radiation are needed for different organisms so as to achieve the same level of efficacy. Runia (1995) recommends a dose which varies from 100 mJ/cm^2 for eliminating bacteria and fungi to 250 mJ/cm^2 for eliminating viruses. These relatively-high doses are needed to compensate for variations in water turbidity and variations in penetration of the energy into the solution due to low turbulence around the UV lamp or variations in output from the UV lamp.

3. Membrane Filtration. Filtration can be used to remove any undissolved material out of the nutrient solution. Various types of filters are available relative to the range of particle sizes. Rapid sand filters are often used to remove large particles from the drain water before adding, measuring and control of EC, pH and application of new fertilizers. After passing the fertiliser unit often a fine synthetic filter (50-80 µm) is built in the water flow to remove undissolved fertilizer salts or precipitates to avoid clogging of the drippers. These synthetic filters are also used as pre-treatment for disinfection methods as heat treatment, ozone treatment or UV radiation. With declining pore size, the flow is inhibited, so that removal of very small particles requires a combination of adequate filters and high pressure followed by frequent cleaning of the filter(s). Removal of pathogens requires relatively small pore size (<10 µm; so-called micro-, ultra- or nanofiltration).

Various membrane filtration technologies are available where water under high pressure is pressed through a membrane. The water is divided in the required clean water (filtrate) and the remaining water with concentrated salts (the so-called brine. The investment in a generally reliable filter system is still high; therefore it is only additionally used as method for the removal of pathogens. All over the world there is far more use of reverse osmosis (removal of ions, <0.001 µm) to desalinate seawater or other “grey” (waste) water to be used as supply water for the plants.

4. Slow Sand Filtration. Slow sand filtration (SSF) is considered to be a reliable, low-cost solution to eliminate soil-borne pathogens (Wohanka, 1995; Van Os et al., 1997b; Runia et al., 1997; Ehret et al., 2001) in greenhouse horticulture. *Phytophthora* spp. and *Pythium* spp. can be eliminated completely by this method, but *Fusarium* spp., viruses and nematodes are only partly (90-99.9%) removed by this method. The principle (Fig. 1) is based upon a supernatant water layer, which trickles slowly through a sand layer. Experiments proved that a flow rate of 100 L/m^2/h increases the performance compared to higher flow rates and so does the selection of finer sand (grain size 0.15-0.35 mm; D_{10}<0.4 mm) compared to coarser sand (Van Os et al., 1997a, b). Satisfactory performances can also be obtained when either the grain size increases to 1 or 2 mm or the filtration rate increases to 300 L/m^2/h (Wohanka et al., 1999). The mechanism of elimination is not only filtering (mechanical) as the size of the pores is generally larger than the pathogens eliminated. The forming of a biological active filter skin upon top of the sand appeared to be of great importance (Wohanka et al., 1999).

Chemical Methods

1. Ozone (O_3). Ozone is produced from dry air and electricity using an ozone-generator (converting $3O_2 \rightarrow 2O_3$). The ozone-enriched air is injected into the water that is being sanitized and stored for a period of one hour. Runia (1995) concluded that an ozone supply of 10 g per hour per m^3 drain water with an exposure time of one hour is sufficient to eliminate all pathogens, including viruses. Human exposure to the ozone that vents from the system or the storage tanks should be avoided since even a short exposure time of a concentration of 0.1 mg/L of ozone may cause irritation of mucous membranes. Therefore, ozone treatment is not very popular (expensive, strict rules) although it works technically well. A disadvantage is the inability to process large quantities of water at the same time. Another drawback of the use of ozone is that it reacts with iron chelate. Consequently, higher dosages of iron are needed and measures need to be taken to deal with iron deposits in the system.

2. Hydrogen Peroxide (H_2O_2). Hydrogen peroxide is a strong, unstable oxidizing agent that reacts to form H_2O and an $O^\bullet$-radical. Commercially so-called activators are added to the solution to stabilize the original solution and to increase the efficacy. Activators are mostly formic acid or acetic acid, which decrease pH in the nutrient solution. Different dosages are recommended (Runia, 1995) against *Pythium* spp. (0.005%), other fungi (0.01%) as *Fusarium* spp. and against viruses (0.05%). The 0.05% concentration is also harmful for plant roots. Hydrogen peroxide is especially helpful for cleaning the watering system, while the use for disinfection has been taken over by other methods. The method is inexpensive, but not efficient.

3. Sodium Hypochlorite (NaOCl). Sodium hypochlorite is a compound having different commercial names (household bleach) with different concentrations but with the same chemical structure (NaOCl). It is widely used for water treatment, especially in swimming pools. The product is relatively inexpensive due to this widespread use. When added to water, sodium hypochlorite decomposes to HOCl and $NaOH^-$ and depending on the pH to OCl^-, the latter decomposes to Cl^- and $O^\bullet$ for strong oxidation. It reacts directly with any organic substance and if there is enough hypochlorite it also reacts with pathogens. Le Quillec et al. (2003) showed that the tenability of hypochlorite depends on the climatic conditions and the related decomposing reactions. High temperatures and contact with air causes rapid decomposition, at which $NaClO_3$ is formed with phytotoxic properties. Runia (1995) showed that hypochlorite is not effective for eliminating viruses. Chlorination with a concentration of 1-5 mg Cl/L and an exposure time of 2 hours achieved a reduction of 90-99.9% of *Fusarium oxysporum* , but some spores survived at all concentrations. Safety measures have to be taken for safe storage and handling. Hypochlorite might work against a number of pathogens, not all, but at the same time Na^+ and Cl^- concentration is increased in a closed growing system which will also lead to levels which decrease productivity of the crop and at which the nutrient solution has to be leached. Despite the above-mentioned the product is used and recommended as a cheap and useful method.

4. Chlorine Dioxide (ClO_2). A yellowish gas can be formed on-site by combining hydrochloric acid and sodium chlorite, but this will be explosive and instable. It has to be solved into water to stabilize it and where it is highly soluble. Even solved in water chlorine dioxide easily decomposes in sunlight. The efficacy is optimal in a wide pH between 4 and 10 (Lenntech, 2008). It is even very active at a high organic load of the water. Strict safety measures have to be taken for the workers. The forming of trihalomethanes (carcinogenous) is much less compared to other chlorine products because the working is mainly based on oxidation in stead of substitution. It is mostly used as a disinfectant where it is able to eliminate biofilms completely. Little is known about disinfection of recirculating solutions. Mebalds et al. (1996) reports about its efficacy against a number of soil-borne pathogens (*Phytophthora cinnamomi*, *Pythium ultimum*, *Fusarium oxysporum*) in dosages varying between 1 and 5 ppm at an exposure time of 10 minutes. Much more information is available on its efficacy against *Legionella*, *E. coli* and *Bacillus* spp. (Zhang, 2007), whereas it is in use to disinfect drinking water and waste water or for cleaning equipment (Ritenour, 2001).

5. Copper Silver Ionization. Electrolysis of water by silver and copper electrodes releases positive charged free Cu^+ ions in the water, which react with membranes of micro-organisms. Runia (1995) did not see a log 3 (99.9%) reduction for tomato mosaic virus and for *Fusarium oxysporum* after a treatment of 2h, 1 or 4 days. Recently released commercial equipment (Anon., 2005) claims disinfection of the nutrient solution with an adjustable input of Cu ions. It is a disadvantage that the Cu input in the nutrient solution is much higher than the plant needs, which will lead to toxic levels in closed systems. However, pot plant growers claim a better growth and less loss of plants when using the apparatus. Another negative aspect is the release of heavy metals (silver, copper) into the environment, which is restricted by law in many countries.

6. Active Carbon Adsorption. Active carbon is specially produced to achieve a big internal surface area (500-1500 m^2/g) for adsorption of mainly organic, non-polar substances. Also halogenated substances, odours and tastes can be adsorbed (Lenntech, 2008). Water flows constantly through the carbon realizing an accumulation of substances in the filter. Regeneration of the filter has to take place when it looses 5-10% of its efficacy. The method is used for drinking water treatment but not very much used for the removal of pathogens. The method is too expensive, while performance is insufficient. An additional disadvantage it that a big part of the fertilizing elements may be removed from the solution, which makes fertilization much more expensive.

DISCUSSION

Chemical versus Non-Chemical Methods

Disinfection methods were often divided in groups (sustainability (Van Os, 1999); active/passive methods (Postma et al., 2001)) to give a better understanding of its working principle. Those divisions focus on a certain aspect of the elimination process and do not give overall information about the performance of the method. Growers do prefer a method with an excellent performance in combination with low costs. A good performance can be described by eliminating pathogens with a reduction of 99.9% (or a log 3 reduction) and a clear, understandable and controllable process. Low costs are preferably combined with low investments, low maintenance costs and no need for the grower to change into a laboratory specialist. Heat treatment, UV radiation, ozone treatment and membrane filtration show a good performance. However investments in ozone treatment and membrane filtration are very high, resulting in high annual costs. Heat treatment and UV radiation show also high annual costs, but investments are lower, while the eliminating process is easily controllable. The latter two methods are most popular among growers, especially at nurseries larger than 1 or 2 ha. Slow sand filtration shows a slightly lesser performance but considerably lower annual costs. This method could be recommended for nurseries smaller than 1 ha. Sodium hypochlorite and hydrogen peroxide are also cheap methods, but performance is insufficient. Chlorine dioxide, copper/silver ionization and active carbon adsorption combine a poor performance with high costs. Probably the performance of chorine dioxide can be improved after appropriate investigations (dosage-effect relation), but safety measures may still lead to high costs.

Bio Fouling and Pretreatment

Disinfection methods are not very selective between pathogens and other organic material in the solution. Therefore pretreatment (rapid sand filter, 50-80 µm mechanical filter) of the solution before disinfection is recommended at heat treatment and UV radiation. Sometimes pH adaptation is needed too (heat treatment, several oxidizing methods). If after disinfection residuals of chemical methods keep in the water they may react with bio-films which have been formed in the pipe lines of the watering systems. If the bio-film is released from the walls they will be transported to the drippers and cause clogging there. Several oxidizing methods (sodium hypochlorite, hydrogen peroxide with activators, chlorine dioxide) are mainly in use to clean pipe lines and equipment. They give a special risk for clogging of drippers if used in equipment already in use for a certain time.

CONCLUSIONS

Various chemical and non-chemical disinfection methods are available for disinfecting the recirculating nutrient solution. Growers prefer a good performance with low annual costs. Heat treatment and UV radiation are good methods for larger companies (>2 ha), while slow sand filtration is a good option for smaller companies (<1 ha). Membrane filtration and ozone treatment show a good performance in eliminating pathogens, but the methods are generally too expensive. Sodium hypochlorite and hydrogen peroxide with activators are methods to clean pipe lines and equipment, but they are less suitable to eliminate pathogens completely. Chlorine dioxide has the potential to be used as a disinfection method, but too little information is available. For the use as disinfectant for pipe lines and equipment investments may be too high. Copper silver ionisation cannot be recommended now for use as disinfection method, disadvantages are too big. Active carbon adsorption is not a disinfecting method, it can be used to eliminate certain substances to purify the solution.

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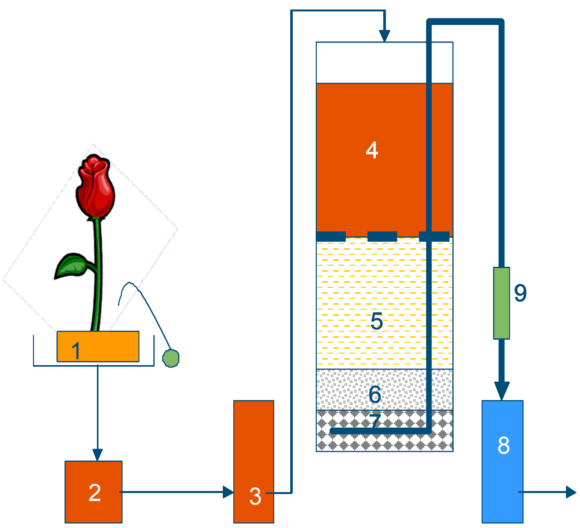
Figures



Legend:
Nutrient solution drains from substrate (1) to recatchment tank (2). From there it is pumped to the day storage tank (3) and into the top of a large container or metal silo (4), from which it drips into a sand layer of 1 m thickness (5). The layer between 4 and 5 is called the Schmutz-decke or filter skin. 6 and 7 are a 10 cm fine and a 15 cm coarse gravel layer, respectively. The filtrate is pumped out of the gravel layer to container 8. In a metal silo it is done via the top, in a synthetic filter it is possible to drain via the bottom of the filter. For initial filling of the filter water is pumped from 8 into the gravel layers 7 and 6 and to above the sand layer. Flow meter 9 controls the filtration rate. From container 8 the filtrate will be mixed with fresh water to a new nutrient solution for the plants.

Fig.1. Scheme of principle of slow sand filtration (no 1, 2, 3 and 8 are also part of other disinfection methods).