DESIGN OF SUSTAINABLE HYDROPONIC SYSTEMS IN RELATION TO ENVIRONMENT-FRIENDLY DISINFECTION METHODS

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Abstract

The last few years Dutch horticulture has changed from a classical production-oriented market to a customer-oriented market. It is no longer the grower who decides about amount and quality of the product. Now, the consumer, and for vegetables more specifically the supermarket prescribes. One of the results is a change from large amounts of a single quality and bulk products to a very segmented presentation of products with different qualities and with added values. In this situation it is important for the grower how the consumer looks at the sustainability of cultivation methods. The enormous boom in system development in the Netherlands has come to a standstill. This enables us to look back to see if there are differences between the former basic assumptions of a "safe, sustainable and competitive" horticultural sector and the commercial application of hydroponic systems. It became clear that many growers choose a certain system for economic reasons. Factors such as low investment, clean restart, labour input are more important than the environment, low annual costs, reuse of materials and substrate. In former years it was said that all circulating nutrient solution had to be disinfected and sterilised to avoid the risk of rapid dispersal of soil-borne pathogens. Now, it is said that the microflora present in the circulating nutrient solution plays an important role in suppressing of root diseases. In that case it becomes more important to eliminate pathogens in such a way that the microflora keeps alive. It has to be determined whether active methods (heat treatment, ozone, UV) can play this role or whether a passive method such as slow sand filtration, which eliminates pathogens group specific, has better prospects. In this paper the commercial application of hydroponic systems will be discussed in relation to the role the natural microflora may have, to suppress soil-borne diseases in the nutrient solution.

1. Introduction

In the Netherlands the development of hydroponic systems was originally only based on cultivation demands of the crops and on technical limitations of materials such as substrates, plastics and control equipment. Amongst others the following developments can be seen, not only in the Netherlands, but also elsewhere:

- the horticultural market is changing from a production-oriented push market towards a customer-oriented pull market;
- supermarkets are going to prescribe cultivation techniques;
- contamination of the environment with fertilisers and pesticides have to be avoided;
- the use of methyl bromide as soil fumigant will be banned all over the world;
- organic production is seen as a sustainable growing method.

The above mentioned developments force growers to look in a different way to future soilless growing systems. Designs of soilless growing systems require other basic assumptions. The integrated growing system should be judged as a whole, preferably on

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the basis of a Life-Cycle-Analysis (LCA), and not on its separate parts such as open or closed, disinfection system, substrate and materials.

In this paper the present state of commercial systems and its relationship to the sustainability needed in the future will be discussed. Besides, a connection will be made with the elimination of soil-borne pathogens from the nutrient solution in a more sustainable way and with the role that the present microflora and metabolites can play in this process.

2. Developments in the market

Technical and cultivation factors would prescribe the development of soilless growing systems in the past. Those factors were translated to one or more economically feasible growing systems per crop. The change from open to closed hydroponic systems was a sign that others were looking to the horticultural sector and its techniques used to produce vegetables and flowers. The crisis in the greenhouse sector in the early nineties with very low market prices for especially tomato was a turning point. The result was that the complete greenhouse sector changed from a production-oriented approach to a market-oriented approach (Meulenberg, 1998). It is no longer the grower who prescribes the amounts and quality of the product, but the consumer. In the horticultural sector the consumer is often represented by a few supermarkets who buy most of the vegetable produce. First, the supermarkets only prescribed the amounts and quality of the produce, but more and more they are prescribing the cultivation method. Hitherto, the following factors can be mentioned: the way of grading and packing, the use of pesticides or biological control, the reuse of the nutrient solution, the type of substrate used, the type of energy.

Now an increasing trend can be seen to produce in an organic way. Although organic growing is still very small: about 8% of the total Dutch horticultural sector and less than 3% for greenhouse production (Willems, 1996), the signs cannot be ignored. The number of nurseries with organic growing increase by 20% annually (Goewie, 1998). Supermarkets are very interested to sell more organic produce. The message of one of the biggest Dutch supermarkets to have the goal to sell only organically produced food from 2005 onwards demands to think more about sustainable soilless growing systems for the grower, which are accepted by the consumer. Points of discussion will include the use of soil or substrate, pesticides or biological control, organic or inorganic fertilisers and the input of energy and technical means.

3. Soilless growing systems

During the late eighties and early nineties many growing systems were developed, because of the approaching legislation: “the horticultural sector should become safe, sustainable and competitive, all crops should be grown in closed soilless systems before the year 2000 (Agricultural, 1989). At a certain moment more than 100 systems could be distinguished (Lataster *et al.*, 1993). An inventory had to be made: which system is really sustainable, for which crop or group of crops and is it economical to invest in such a system. Studies investigating the economic, technical and environmental aspects of many (closed) soilless growing systems, proved that specific groups of crops can be distinguished, that these groups need a specific system and that materials and substrates to be used are more or less sustainable (Ruijs & van Os, 1991; Van Os *et al.*, 1991; Ruijs, 1994). In a sustainable growing system, materials and substrates should have low costs, have a life span of at least 3-4 years, have constant physical properties during use (water capacity, steam resistance), be safe (no damaging volatilisation of damps) and be recycled by the supplier (Van Os *et al.*, 1991). Based on the mentioned assumptions, crops can be divided as to the way they are placed in the greenhouse (Van Os, 1995):

- growing in rows
  crops with 2-6 plants per m^2 such as fruit vegetables (tomato, pepper) should be

grown in multi-year-usable substrates (rockwool, polyurethane foam) which are enveloped by plastic foil or by a long-shaped polypropene container. The enveloped slabs lie in a flat or profiled polypropene or coated steel trough.

- growing in beds
  crops such as carnation, freesia and alstroemeria should be grown in 3-4 beds with aisles per 6.40 m span. Upon a perfectly horizontal soil 1.00-1.50 m wide beds are created, made from 1.5-2.0 mm thick polyethene foil, aluminium or concrete. The beds are filled with a loose substrate such as sand, perlite or volcanic sands.
- growing span-wide
  crops with many plants per m^2 such as lettuce and radish should be grown span-wide. They need a system of dig-in polyethene foil on which a loose substrate such as sand, volcanic sand or perlite is placed.

4. Present commercial application

Depending on the demands of the crop, the grower can select from about 6 materials and 10 substrates, all in many different variations. Each supplier offers many systems. Choosing is very difficult. Investment is mostly the decisive factor, but a low investment does not always result in low annual costs or a sustainable system. Consequently, there are still many systems that are not completely sustainable, although they comply with legislation. These systems are cheaper or easier to handle. For fruit vegetables (tomato, cucumber, sweet pepper), commercial firms mostly use single-year rockwool that is made in several qualities (water content, density) and by several brands. The main reasons for that are the need for a quick change of crops in winter, the low investments and the clean restart: the old crop and slabs are taken out of the greenhouse, the greenhouse is cleaned and new materials are brought in. Disinfection of used slabs costs extra labour and energy and has to be done in an already busy period. After the cultivation period, all rockwool is collected and recycled by the manufacturer. For the Dutch situation this is an enormous environmental advantage which is economically feasible. The area with polyurethane foam is decreasing, growers find the water content too low for easy working. Coir is coming up, but experiences are variable. First, the initial quality was too variable (too much salt), but now these problems are solved. It is also in use for its environment-friendly image: it is a natural product, it is a waste product of another industry, it can be composted after use and sold again.

Growers also try to find the cheapest way to collect the drain water too. Not only sustainable troughs are used but also “drain profiles” (Fig. 1B). Drain profiles are not self-supporting and are laid down partly into the soil, because they do not have flat bottoms. They are placed below one single row or between two rows without an aisle. Mostly PVC (polyvinyl chloride) is used, because of the easy handling and, to a lesser degree polypropene. Upon the profile, mostly single-year slabs enveloped in polyethene foil are laid down. Another measure to make the system cheaper is the change from the traditional 4-row per 3.2 m system into a 2-row system at which the plants are trained in a V-shape. Half of the materials are necessary then, but the substrate slab used is slightly bigger.

For cut flowers to be harvested more than once, e.g. roses and carnations, similar systems and substrates are recommended. Some rose growers use rolling benches to increase the utilisation of space, but most growers use a slab system laying on the soil with wide beds. Gerbera is grown on stages at which only self-supporting troughs can be used. A coated steel trough is sometimes used, but the grower mostly use cheaper systems with PVC troughs or long-shaped containers. Crops growing span-wide with many plants per m^2, such as chrysanthemums, lettuce and radish are not grown in hydroponic systems. Investments for those crops are too high. In Belgium there is an NFT system for lettuce and herbs, at which the troughs can be spaced automatically. Technically a wonderful system, but there are doubts about its economical feasibility. The system is also in use in the Scandinavian countries, but there, market prices of lettuce and herbs are much higher.

Another reason for the hesitation among growers to change to sustainable closed systems is the legislative approval of a typically Dutch system: recirculation via the subsoil (Van Os, 1998). In Dutch polders the groundwater level is at an artificially constant level of about 80 cm below ground level. Just above the ground water level there are drain pipes. Nearly all superfluous nutrient solution can be collected via the drain pipes and being reused. This system cannot be applied by all growers. There are two major limitations: there may be downward seepage (less drain water is available and nutrients pollute the environment) and there may be infiltration (bad-quality water with salts and/or pathogens may enter the watering system). The big advantage of the system is the price: low investments.

5. Disinfection of the nutrient solution

The change from soil to soilless growing systems has not resulted in the disappearance of soil-borne pathogens. The introduction of closed systems increased the risks of dispersal of pathogens all over the nursery. To avoid root diseases chemicals can be added to the solution. In the Netherlands the use of chemicals added to the nutrient solution has always been minimal, because of the risks for humans when eating the yielded vegetables. Therefore, elimination of root pathogens should be realised in a different, non-chemical, way. Most growers choose for a disinfection system to minimise the risks (Anonymous, 1996; Runia, 1995; Van Os, 1999). But also in other countries this kind of equipment has come into use (Deniel *et al.*,1999; McPherson *et al.*, 1995; Nederhoff, 1998). A number of methods proved themselves through the last ten years. The proof is a combination of performance and price. Consequently, several methods disappeared after having been on the market for several years. Below, the most commonly used disinfection methods are discussed.

5.1. Heat treatment

Heat treatment is the most frequently used method in the Netherlands. The method itself is rather old and is widely used for the pasteurisation of milk. IMAG-DLO made the method technically suitable for the treatment of recirculating nutrient solutions (Runia *et al.*, 1988; Van Os *et al.*, 1988). The excess nutrient solution is pumped into a heat exchanger, where it is preheated to a temperature of about 80^o C by heat recoveed from disinfected water. In a second heat exchanger the solution is heated to the disinfection temperature, using an external heat source. The disinfected solution flows back to the first heat exchanger to be cooled down and subsequently to be stored in a “clean water tank”. Currently, it is recommended to heat the solution to 95^o C and to maintain this temperature for 30 s. In that case, all organisms are killed: bacteria, fungi, viruses and nematodes. Recent research (Runia, 1999, this proceedings) proved that similar results could be obtained by decreasing the disinfection temperature and increasing the exposure time. The big advantage of the latter disinfection temperatures is that no extra external heater is needed, which makes the unit cheaper. The disadvantage is that the exposure time must be extended. The amount of gas to heat the water (1 m^3 gas per m^3 water) is also a disadvantage.

5.2. Ozone treatment

Ozone (O_3) is a very powerful oxidiser and reacts with all living organic matter, but also for example with the used fertiliser iron-chelate. It can kill all organisms in the water, depending on exposure time and concentration (Runia, 1995). Ozone has to be made at the place where it is needed. Ozone is generated by passing dry air through a high-energy electric field between an active electrode and a dielectric insulator. It is important that the air is prepared (sometimes oxygen bottles are used), the water is prefiltered to reduce the organic load and the pH is lowered to increase the stability of the ozone. In all installations the drain water is treated in batches (1 or 2 m^3) in a closed tank where the pH is lowered and ozone is injected at the same time. From several trials Runia (1995) concluded that an ozone supply of 10 g per hour per m^3 water with an exposure time of one hour is sufficient to kill all pathogens.

5.3. Ultra-violet radiation (UV)

Since a few years UV has been becoming popular. In the eighties organic material in the water caused unreliable results and the investment was high. Now, the elimination rates are comparable with heat treatment and equipment is much cheaper than ozone (KWIN, 1998). UV is an electromagnetic radiation, and especially the wavelength between 200 and 280 nm (UV-C) with an optimum at 254 nm has a strong killing effect on micro-organisms. At the moment mainly two types of lamps are used: there is a high or a low pressure of the gas inside the bulbs. Their performance in eliminating pathogens may be the same, but in general the high-pressure lamp is less energy efficient. The recommended dose varies from 100 mJ/cm^2 to eliminate bacteria and fungi to 250 mJ/cm^2 to eliminate viruses (Runia, 1995). These values are only valid when the transmission of the water is sufficient and there is no precipitation of salts on the quartz tube, which inhibits radiation to come through. High transmission values could be realised by placing an extra, rapid, sand filter before the UV lamp or by mixing the drain water with supply water.

5.4. Slow sand filtration

Since five years it is possible to buy a slow sand filtration installation (Wohanka, 1995; Van Os *et al.*, 1997). *Phytophthora* and *pythium* can be eliminated completely by this method, but *Fusarium oxysporum,* Tomato mosaic virus, nematodes and bacteria only partly (90-99.0 %) (Wohanka, 1995, Wohanka *et al.*, 1999; Van Os *et al.*, 1997, 1998; Runia *et al.*, 1997; Deniel *et al.*,1999). Furthermore, the solution is not sterilised, (part of) the natural microflora keeps alive (Van Os *et al.*, 1997; Postma *et al.*, 1999). Instead of sand, other filter media can be used such as rockwool or foam (Wohanka *et al.*,1999). The principle of slow filtration is based upon a supernatant water layer which slowly trickles through a (sand) layer. A flow rate of 100 $l \cdot m^{-2} \cdot h^{-1}$ improved the performance compared with 300 $l \cdot m^{-2} \cdot h^{-1}$, and so does the selection of finer sand (0.15-0.35 mm; D_{10}= 0.2 mm) compared with middle (0.2-0.8 mm; D_{10}= 0.5 mm) and coarse sand (0.5-1.6 mm; D_{10}= 0.7 mm) (Van Os *et al.*, 1997). The D_{10} variable represents 10% of the weight to be smaller than a certain value in mm. Installations were already in use before much was known of the limiting conditions and the working mechanism. Another factor effecting the elimination rate may be the pH. Two pH values (5 and 7) were tested in lab-scale filters for the elimination of *Erwinia carotovora* and *Fusarium oxysporum* from the nutrient solution. *F. oxysporum* proved to be eliminated to a higher extent at pH 7 than at pH 5, while *E. carotovora* was eliminated better at pH 5 than at pH 7 (Postma *et al.*, 1999).

5.5. Other disinfection methods

Several other disinfection methods have been tried out and are sometimes still in use on a small scale, but all those methods have certain disadvantages. The following methods can be mentioned:

- activated hydrogen peroxide: a weak oxidator in combination with a weak acid to stabilise the chemical. High dosages are needed to give a reasonable result, but it initiates the danger of burning the roots;
- lava bed filtration: the nutrient solution is pumped through a lava bed in combination with added air. Elimination rates are comparable with slow sand filtration and so is the investment.
- membrane filtration: depending on the size of the filter particles of different sizes (pathogens, nutrients) can be eliminated. It is still very expensive;

- iodine treatment: the method disappeared because the performance was too poor in relation to the price;
- silver/copper electrodes: the method disappeared because of poor performance and high investment. Besides the dispersal of heavy metals was a major disadvantage for environmental reasons.

6. Microbial optimisation of the nutrient solution

A change in the way of thinking about the elimination of pathogens from nutrient solutions can be noticed. First, all methods were based on eliminating all the pathogens and sterilising the nutrient solution (heat treatment, ozone, UV). Now, another trend can be noticed. Perhaps it is not right to kill all life in the solution, there is a certain microflora present playing a role in the suppression of diseases (Postma, 1996; Postma *et al.*, 1999; Waechter-Kristensen *et al.*, 1994; Garibaldi *et al.*, 1993; Tu *et al.*, 1999). For example pythium can disperse very rapidly in a sterilised surrounding, while its growth in a non-sterilised environment is much slower (Postma, 1996). Similar phenomena can be seen with phytophthora (McPherson *et al.*, 1995). From those experiments it was concluded that certain micro-organisms were able to suppress diseases, there was a microbial buffering. If those micro-organisms are killed, the nutrient solution looses its suppressiveness and a fast outbreak of a disease may be a consequence.

Besides, in those systems there is a role for metabolites released by plant roots and/or micro-organisms (Waechter-Kristensen *et al.*, 1994, 1997). An accumulation of certain metabolites may occur giving favourable or inhibitory effects on root growth and/or disease suppression.

Research, funded by the European Union, just started to sustain the claim of the importance of the role of the natural microflora. The essence of the research will be trials in which the natural suppressiveness of a nutrient solution will be tested against the root diseases *Pythium aphanidermatum* and *Phytophthora cryptogea.* For this, the nutrient solution will be treated by UV (sterilisation), slow filtration (partly elimination) and a control without any disinfection treatment. First, the detection techniques of microflora, metabolites and plant disease have to be optimised. It is the goal to determine the dynamics of the microflora and the metabolites in the three (disinfection) systems mentioned, growing tomato, cucumber or gerbera. The knowledge achieved from this research enables us to understand, hopefully, a part of the role of micro-organisms in suppressing root diseases. The final outcome should be a sustainable soilless growing system with a biological control of root diseases and, if needed, with the help of a disinfection system.

7. Concluding remarks

The Dutch grower had to face many changes in his surrounding influencing his production method. A customer-oriented pull market replaced the well-known and traditional production-oriented push market. Governmental legislation forced him to apply a more sustainable production method at which contamination of the environment had to be minimised. To the grower, the most important aspect appeared the need to invest in environment-friendly systems, while he still had to produce in an economical way. Not all the growers have yet made all the legislative steps, while new steps have to be expected.

The present commercial closed soilless growing systems are a mixture of sustainability and economical feasibility. For fruit vegetables (tomato, sweet pepper, cucumber) it is no problem to grow them economically in a closed soilless growing system, but for once harvestable leaf vegetables there is hardly a soilless future. In floriculture most profits can be obtained if the utilisation of space can be increased in combination with a small number of plants per m^2 (rose, gerbera, orchid, anthurium). If it is not economical to grow in a soilless system, growers do not change their systems.

Consequently, in half of the total greenhouse area production still takes place in soil, which will not change very rapidly.

Closed systems increase, per definition, the risk of a rapid dispersal of pathogens. Disinfection equipment has always been recommended to avoid large problems with soil-borne diseases. Heat treatment and UV lamps have best prospects for a high-tech, expensive sterilisation treatment. Slow filtration, with sand or another porous material as filter medium, opens prospects for a more low-tech and cheaper solution. The latter is also of great importance as method at which the present microflora in the nutrient solution keeps (partly) alive. More and more results come available about the role of the microflora to suppress root diseases, especially for *pythium* and *phytophthora* species.

Recently started research has the goal to detect those (groups) of micro-organisms and metabolites which can promote or inhibit root diseases. In this case it is important to know the influence of a disinfection system on the dispersal of a root disease, on the present microflora and metabolites and on recolonisation. It is a question whether the suppressiveness-promoting organisms are still present after sterilisation or whether a treatment with slow filtration will encourage the growth of those organisms or, at least, keep them alive. Now the idea is that slow filtration keeps part of the natural and useful microflora alive by which the natural suppressiveness against certain pathogens is maintained.

Future hydroponic growing systems have to be designed in such a way that the above-mentioned factors are incorporated. An integrated approach is needed to get sustainable hydroponic growing systems.

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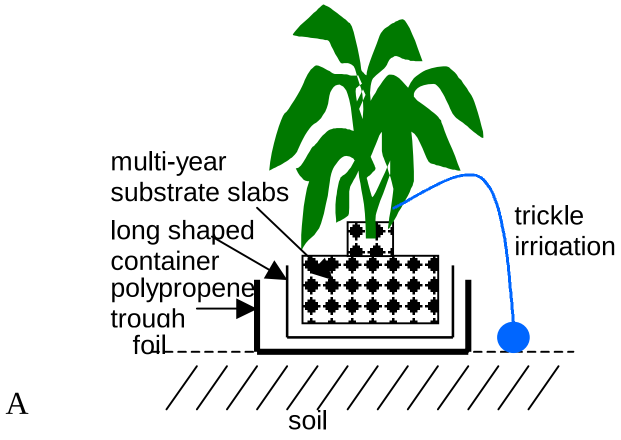
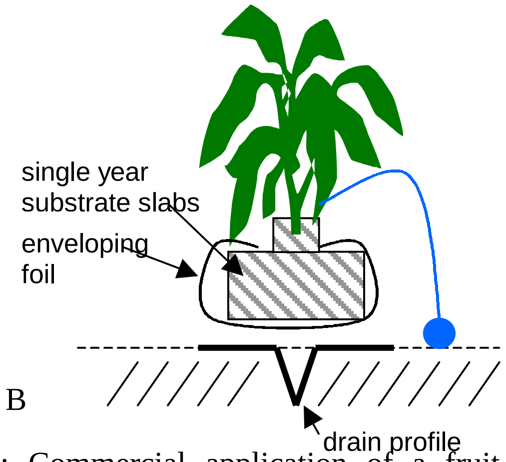
<u>Figures</u>



1A: Sustainable solution for fruit vegetables



1B: Commercial application of a fruit vegetable closed system