(32) Soilless cultivation of outdoor horticultural crops in The Netherlands to reduce nitrogen emissions

de Haan Janjo, van Dijk Suzanne

Applied Plant Research - Wageningen UR
P.O. Box 430, 8200 AK, Lelystad, The Netherlands
janjo.dehaan@wur.nl

Abstract: *Many horticultural crops in open field production in The Netherlands do not meet the demands of the EU Water Framework Directive and EU Nitrates Directive mainly because of too high nutrient emissions. No solutions are available within the conventional cultivation systems to reduce nutrient emissions sufficiently while maintaining financial returns and crop quality. Addionally, growers have difficulties to manage their crops e.g. to comply with new market requirements, to have sufficient labour available or manage soil borne pest and diseases. Therefore, new soilless cultivation systems are being developed and tested for various horticultural crops (lettuce, leek, cabbage, strawberry, apple, blue berry, flower bulbs and tree nursery crops). A structured design method was used. First, an analysis was made of the conventional cultivation systems. Secondly, a brief of requirements was set up for all crops. Thirdly, various crop specific systems were designed, selected, engineered and tested on a small scale during several years. The sustainability and profitability of the selected systems are assessed in detail on all sustainability aspects (Planet, People, Profit). Almost all crops can be grown on a system without soil. Most promising systems are: deep flow systems for lettuce, leek and cabbage; NFT systems for strawberry and systems with substrate in pots, gutters or troughs for flower bulbs, tree nursery crops and fruit crops. The profitability and sustainability of the systems is currently under investigation, some first results are shown. Some leading growers have already installed prototypes of these new systems on their own farms.*

Keywords: *cultivation systems, recirculation, design, sustainability, profitability*

Introduction

Due to high nutrient emissions, many crops in open field production in the Netherlands do not meet the requirements of the EU Water Framework Directive (WFD) and EU Nitrates Directive (ND). Additionally, growers are facing difficulties complying with new market requirements, such as minimal pesticide residues, quality requirements and constant deliver. Moreover, growing crops is often labour intensive, working conditions are demanding and soil borne diseases are difficult to manage. Within conventional cultivation systems, only a few methods are available to reduce emissions without affecting crop productivity and quality (de Haan *et al*., 2010; de Haan *et al*., 2009).

At the end of 2009, the research program 'Soilless cultivation of outdoor crops' was started in a unique cooperation between government, research and trade and industry. This research and innovation program has the aim to develop soilless cultivation systems which comply with the EU WFD and ND for nine different (groups of) crops: leafy vegetables, leek, cauliflower, strawberry, blue berries, apple, tree nursery crops, flower bulbs and summer flowers. Essential are the prerequisites that the cultivation systems not only prevent emission, but also provide growers with other benefits (e.g. higher labour efficiency, better product quality or new market opportunities) and that the systems are profitable and accepted by society.

A structured method was used to design and develop new cultivation systems for each crop, followed by three years of experimental development. Adjacent to the technical design and development of the cultivation systems, relevant general subjects (e.g. water use and recirculation, food safety, acceptance by society) were studied.

Materials and Methods

A structured method was used to design and develop new cultivation systems derived from other methods used in the design of open field production systems (de Haan and Garcia Diaz, 2002; Vereijken, 1997), protected cultivation systems (van Henten et al., 2006) and animal husbandry systems (Groot Koerkamp and Bos, 2008). A system innovation approach was used; the essence of this approach is a balance between the use of well-funded theory, future oriented innovation and the involvement of different stakeholders as growers, suppliers, sales parties, government authorities and NGO's. For each of the crops, a working group was established, consisting of researchers, growers, advisors and sometimes other stakeholders. The working groups acted as steering committees for the research program, providing professional knowledge, advice and feedback.

At the start of the program, an analysis was made of the conventional cultivation systems, taking into account technical as well as environmental, societal and legal aspects. With this analysis, a list of system requirements was developed for each crop, containing a variety of requirements focusing on sustainability, profitability, product quality and plant growth. During the first year, using the system requirements, various cultivation systems were designed, engineered and tested on a small scale on experimental farms. Those cultivation systems that sufficiently met the system requirements were selected for further development and experimentation. This process was repeated once or twice until only the one or two most promising cultivation systems were selected. This final system was further optimized (e.g. on fertilization, use of growing media) and laid out on a larger scale, preferably at the farm of a commercial grower.

The selected cultivation systems are currently assessed in details on all sustainability aspects (Planet, Profit, People). A comparison is made on all sustainability aspects between soilless cultivation systems and conventional cultivation systems. For all sustainability aspects, themes are identified (e.g. greenhouse gas emissions, energy use, profitability, competitiveness, labour (conditions) and food quality). For each theme, indicators are used to determine the performance of both soilless cultivation systems and conventional cultivation systems. In this paper a quantitative comparison between both systems is made for some crops on yield (units per ha and number of cultivations) and cost price (€ per unit). Besides a generalized comparison is made on product quality, emission reduction, energy use and greenhouse gas emissions, adaptation to climate change, pesticide use, food safety, labour conditions and societal acceptance. A more detailed comparison of the sustainability of soilless and conventional cultivation systems is made in Breukers *et al*. (2013).

In addition to the development of soilless cultivation systems and the sustainability assessments, relevant general subjects were studied:

- Desk research on water flows and reduction of emission in outdoor soilless systems to understand emission risks and the need to control rainfall surplus (Van Os *et al*., 2013).
- HCCP analyses of the vegetable production systems to identify possible food safety risks (Van der Lans and Van der Voort, 2013).
- Focused interviews on societal acceptance of the soilless cultivation systems and the products with the aim to incorporate viewpoints of society in the design and development of the soilless cultivation systems.

Results and Discussion

Key elements of designed systems

The systems designed are specific for each crop dependent on the crop type and main challenges to tackle for the specific crop (Table 1). Three years of design, development and testing of new cultivation systems make clear that all crops can be grown on the chosen soilless cultivation systems. Selection of systems strongly depends on crop characteristics, crop value and type of product produced. For perennial crops, systems with substrate are selected. For crops with a short cultivation cycle and vegetable crops, mainly water systems are selected. Water systems are also selected for vegetables and strawberries because of the cleanliness of the system. Where bulbs or roots are the main product (flower bulbs, perennial plants) systems with substrate are selected.

The developed soilless cultivation systems can be considered relatively simple in comparison to greenhouse production. This is caused by the requirement of profitable systems in combination with lower crop values of outdoor crops compared to greenhouse crops.

Deep Flow (DF) systems are developed for crops with short growing cycles (2-4 cycles per year) as vegetables (lettuce, leek, cabbage, spinach) and summer flowers. DF systems consist of a water layer of 10-30 cm with floaters in which the plants are planted (Figure 1). This type of systems uses no or only small amounts of substrate and provides a clean production system. DF systems are robust as failure of the system does not directly lead to plant loss. Besides, DF systems offer possibilities for easy logistics by transport over water. Main disadvantage of the system is the large water volume, making disinfection of the water practically impossible and resulting in high emissions when discharge of water is needed. Another disadvantage of the system is the high energy use needed to pump the water.

Growing strawberry in troughs using peat substrate without recycling of water and nutrients is an existing cultivation system in The Netherlands used on about 150 hectares. Advantages of this system are better labour conditions (easy harvest) and product quality (dry fruits and less rotting). An NFT system was developed for strawberry (Figure 2), using water to reduce the use of peat substrate to a minimum. To make recirculation possible without the spread of diseases (e.g. *Phytophtora*)a slow sand filter in combination with chemicals (*dimethomorf,* Paraat) was successfully tested. Main bottlenecks of the NFT system are the use of a large water volume, resulting in costly disinfection of the water and a high energy use.

Table 1. Overview of systems developed and crops in which they are applied. The main advantages next to direct yield and quality increase and the main remaining research questions per system are provided

Main system type	System type	Crops	Main advantages (next to production)	Main remaining research questions
Water systems	Deep flow system	Vegetables (e.g. lettuce, leek, cauliflower, spinach) Summer flowers	• Clean produce • Better planning of production • Possibilities for mechanization	• Energy use • Disease management (lettuce, leek) • Rainfall surplus management • Logistics of cropping system
	Nutrient Film Technique (NFT)	Strawberry	• Easy harvest • Minimum substrate use	• Disease management • Reduction of water volume
Substrate	Sand bed	Flower bulbs Apple trees Perennial ornamental plants	• Growth steering (apple) • Disease free substrate	• Substrate constitution and thickness • Disease management • Weed control • Water management
	Troughs, pots or crates above the soil	Blue berries Tree nursery crops Summer flowers	• Shortening start period (blue berries) • Extending growing season (blue berries and summer flowers) • Labour conditions	• Frost resistance of perennial crops

Figure 1 Deep flow system for lettuce

Figure 2 NFT system for strawberry

Figure 3 Substrate system for apple

Figure 4 Tree nursery crops in troughs

Sand beds in the soil were developed for apples, flower bulbs and perennial ornamental plants (Figure 3). Substrate systems provide isolation against frost, stability and robustness, with an excellent growth. In addition, growth regulation is possible for apple by steering water content and fertilization.

For tree nursery crops, substrate systems in troughs were developed (Figure 4). These systems provide better labour conditions, the possibility to harvest within one year, faster growth and better quality of the trees. For blue berries, a substrate system in pots above the soil was developed, resulting in faster growth. Crates with substrate were developed for summer flowers (multi annual), providing possibilities to relocate the flowers (inside and outside) and accelerate or delay production during the growing season, leading to a longer production period.

Sustainability of the developed systems

Yield and product quality

Yield increase using soilless cultivation systems is large for vegetables (Table 2). With the exception of cauliflower, product quality (% product class I) is better using soilless cultivation systems (data not shown). By unknown causes, the quality of cauliflower decreases in the end of the cultivation period. Less pesticides are used in the soilless cultivation system, resulting in lower risks for residues.

For the tree nursery crops grown on troughs it is estimated that growth is about twice as fast as compared to conventional cultivation. For blue berries, the time to establish a producing crop is halved from 4 to 2 years.

Table 2. Yield of vegetable crops in conventional and soilless cultivation systems

Crop	**Conventional cultivation system**		**Soilless cultivation system**	
	yield per ha per year	**Average number of cultivations per year**	**Yield per ha per year**	**Average number of cultivations per year**
Head lettuce	85.000 heads	2	684.000 heads	5.5
Leek	65 ton	1.5	285 ton	4
Cauliflower	21.000 heads	1	39.600 heads	3
Strawberry	20 ton	1	60 ton	1.5

Profitability

For all crops reviewed, cost price of conventional cultivation is lower than soilless cultivation (Table 3). The increase in costs is caused by high investment costs for the new cultivation system and high energy costs. Increase in production and reduction in land use and other costs is not sufficient to compensate for the cost increase. The cost estimations have large uncertainties as the soilless cultivation systems are still in development; the current scale of the system is small and mechanization not developed. When size of systems is increased and mechanization is developed, costs are expected to decrease. Besides, further optimization of the system will increase production and/or decrease costs. Energy reducing options are currently investigated. Therefore we expect that in the future for leek, lettuce and strawberry a profitable system is possible. For cauliflower, the production increase is too small to have a perspective on a profitable system. Higher product quality or (more) continuous delivery could result in better prices when using soilless cultivation systems. However we expect that the increase in product price will be small and will be available for a short period only.

Table 3. Producing costs in conventional and soilless cultivation systems in € per head or kg product

		Conventional cultivation system	**Soilless cultivation system**
Head lettuce	€ per head	0.17	0.30
Leek	€ per kg	0.49	0.56
Cauliflower	€ per head	0.52	1.73
Strawberry	€ per kg	2.20	3.10

Emission reduction

The soilless cultivation systems were mainly developed to drastically reduce emissions of nutrients and pesticides. Systems for blueberries and tree nursery crops were developed to minimize drainage without recirculation. It appears that nutrient emissions can be reduced with more than 50% in these systems.

In the other systems water is recirculated. Large reductions in emission are expected. However, it is still difficult to give an accurate estimation of the emission reduction of these systems as the need for discharge of water in the developed systems is still unknown. The need for discharge is firstly depending on the rainfall surplus of the system. If the rainfall surplus is entering the system, discharge is needed on a yearly basis. Therefore it is important to a) adapt the systems avoiding that rainwater is able to enter the systems, b) cover the system when no crop is present or c) use purification of the discharge via reversed osmosis. This is especially necessary in the deep flow systems (vegetables) and the sand beds (flower bulbs, perennial plants). In systems with smaller sand beds, troughs or pots, the rainfall surplus is more limited (van Os *et al.*, 2013).

Besides, the occurrence of pests, diseases and harmful root exudates in the recirculation water make it necessary to discharge the water leading to emissions. Disinfection and purification of water can reduce the need for discharge and reduce emissions but will increase the costs.

Finally there are emission risks because of leakage of the ponds and subsequent leakage of the solution to surface - and ground water bodies. These kind of accidents have to be prevented by a well-designed system and good maintenance.

Other sustainability aspects

In Deep Flow and NFT systems, the energy use and greenhouse gas (GHG) emissions are much higher compared to conventional cultivation due to the need to pump the water and due to the material use for the system. In tree nursery crops, the energy use and greenhouse gas emissions are lower compared to conventional cultivation due to more efficient use of inputs and machinery.

Reductions in pesticide use per crop unit is very large, varying from 75 to 100%. For vegetable crops, reductions in pesticide use per area vary between 75% and 100% as well. For three nursery crops however, the reduction is absent calculated on an area basis. Reduction is caused by higher planting densities, absence in use of herbicides and pesticides for soil borne diseases and lower amount of infections observed. Based on this, it is assumed that in soilless cultivation systems, disturbances in growth are less, leading to less stress and less infections.

The identified food safety risk for vegetables were small. The main food safety risks consist of the possibility of crop protection equipment to leak on the crop and into the pond water, risks on microbiological infections, parasites, viruses and heavy metals or pesticides in the water. Based on these food safety risks periodic testing of water in each growing system is a minimum requirement. Besides, regular refreshment/ disinfection of the pond water and cleaning the plates of algae is needed (van der Lans & van der Voort, 2013).

Labour conditions are better in soilless production systems compared to conventional systems. Examples are better working heights in the systems for strawberry and tree nursery crops. Harvesting of strawberries can be done standing instead of on the knees and harvesting of the trees nursery crops can be mechanized. In the Deep Flow systems it is possible to take the harvest to a central processing place instead of harvesting in the field.

Citizens (in their roles as citizens, neighbours and consumers) evaluate cultivation systems and products produced by these systems mainly on the basis of taste, health, freshness and quality. These criteria consider citizens as the most important buying criteria. Possible degradation of the landscape is considered to be the most important disadvantage of soilless cultivation systems. To incorporate viewpoints of society and increase social acceptance of soilless cultivation systems, natural materials (e.g. wood) and colours should be used, the systems need to blend in with their (natural) environment and they need to be neat and tidy. Citizens are inquisitive to the origins of soilless cultivation systems, therefore communication on and around farms with soilless cultivation systems is advised.

Remaining questions and challenges

Almost all soilless production systems are still in development: the troughs system for tree nursery crops is the only system that is currently being applied in practice by several growers on a commercial scale. One lettuce grower and one blueberry grower have invested in small scale commercial system. Several other growers are testing new cultivation systems on a small scale. They have the expectation to scale up within a few years.

The main challenges still left are improving the robustness and disease suppression of the cultivation systems. This seems especially important for the DF systems and the sand beds. In the DF system new diseases in leek and lettuce have appeared which reduce yield and product quality. In the sand beds, disease suppression is an important item as well. For apple, the question is if nematodes in the substrate can be kept at sufficient low levels during the whole cultivation period of 8 years or more. Connected to this is the need to reach minimal emissions of nutrients and pesticides. Optimal disease suppression diminishes the needs for discharge of water or investments in disinfection techniques.

To reduce emissions control of rainfall surplus is also necessary. Ideas developed to control rainfall surplus will be tested such as covering of the system outside production periods, discharge of rainfall before it enters the nutrient solution.

In DF and NFT systems options to reduce energy use are needed. Solutions to reduce energy use and GHG emissions are reducing the flow rate of the water, decrease the depth of the water layer, pumping air instead of water and the use of sustainable energy sources as wind and sun energy.

For perennial crops as fruit crops and tree nursery crops frost resistance of the systems is important. There are still many questions about the cause of frost damage. Many factors may play a role in the cause, such as wind, temperature, moisture and dehydration.

Next to the main challenges above, there are many optimization questions in e.g. optimizing fertilization, substrate choice, mechanization and water application. In the next years, we are planning to help growers further to implement and upscale their systems to reliable, sustainable and profitable systems.

Conclusion

Soilless cultivation of outdoor horticultural crops is technically feasible and expected to be profitable for high value crops. It gives new possibilities for growers to grow better products for new market sectors with higher yields. New cultivation systems are still in development and many technical challenges have yet to be overcome to realise reliable, sustainable and profitable systems. Besides to the technical challenges, market opportunities have to be developed and the advantages and disadvantages of the developed systems have to be communicated to authorities and citizens. Soilless cultivation has the potential to reduce nitrate emissions drastically. However, how much reduction is possible with these recirculation systems is still under investigation. Development of new cultivation systems also results in new knowledge that can be applied in conventional production systems. Soilless cultivation systems give opportunities to improve sustainability of cultivation on many themes. Therefore it can be a solution for more countries depending on their specific challenges.

Acknowledgements

The research program ‘Soilless cultivation of outdoor crops’ (in Dutch: ‘Teelt de grond uit’) is financed by the Ministry of Economic Affairs, the Product Board for Horticulture and several other beneficiaries and carried out by Wageningen UR and Proeftuin Zwaagdijk in cooperation with farmers. We thank our colleague researchers in the program for their contribution to this article.

References

Breukers, A., Spruijt, J., Roelofs, P., Stokkers, R., Haan, J. de, 2013. Impact of soilless cultivation systems on sustainability of outdoor crop production. Acta Horticultura *(in prep).*

Groot Koerkamp, P.W.G, Bos, A.P., 2008. Designing complex and sustainable Agricultural production systems: an integrated and reflexive approach for the case of table egg production in the Netherlands. NJAS 55: 113-138.

Haan, J.J. de, Garcia Diaz, A. (eds.), 2002. Manual on Prototyping Methodology and Multifunctional Crop Rotation. VEGINECO Report 2. Applied Plant Research. Lelystad. The Netherlands.

Haan, J.J. de, Zwart, K.B., Smit A.B., van Geel W.C.A., 2009. Can intensive arable farming systems on sandy soils in the Netherlands meet the targets in the nitrate directive? Proceedings 16th Nitrogen Workshop, Connecting different scales of nitrogen use in agriculture, Turin, Italy, 28 June – 1 July 2009, 471-472.

Haan, J.J. de, Sukkel, W., Stilma, E.S.C., 2010. Technology versus Agro-Ecology in Designing Vegetable Production Systems in the Netherlands. Acta Horticulturae 852, 123 - 130.

Henten, E.J. van, Bakker, J.C., Marcelis, L.F.M., van ’t Ooster, A., Dekker, E., Stanghellini, C., Vanthoor, B., Randeraat B.V., Westra, J. 2006. The Adaptive Greenhouse - an Integrated Systems Approach to Developing Protected Cultivation Systems. ISHS Actae Horticulturae Proc. IIIrd 718: 399-406.

Lans, C. van der, Voort M. van der, 2013. Voedselveiligheidsrisico's bij nieuwe teeltsystemen. Wageningen UR Glastuinbouw. Bleiswijk. (in Dutch).

Os, E. van, Vermeulen, T, Slootweg, C., Bruins, M., Tuijl, B. van., 2013. Ontwerp en werkwijze om emissie uit “Teelt-de- grond-Uit”-systemen te voorkomen. Wat te doen met het jaarlijks neerslagoverschot? Rapport GTB-1245. Wageningen UR Glastuinbouw. Bleiswijk. (in Dutch).

Vereijken, P., 1997. A methodical way of prototyping integrated and ecological arable farming systems (I/EAFS) in interaction with pilot farms. European Journal of Agronomy 7: 235-250.