FERTINNOWA

Deliverable 4.1
Identification of gaps

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1. Executive summary

For sustainable water and nutrient use in fertigated horticultural crops, a lot of methodologies and technologies are available to help the growers to optimize water and nutrient efficiency and improve productivity and profitability on the one hand and reduce environmental impact on the other hand.

Work package 4 (WP4) aims to bring the sustainable water use to a higher level introducing innovative technologies from other sectors to the horticulture sector to overcome remaining technological gaps. The first task of this WP (T4.1), as described in this report, is the identification of these remaining gaps.

In this report, a “bottleneck” is defined as “a critical point in a process and might stop or delay the process” whereas a “gap” is defined as “a bottleneck for which no (appropriate) solution exists.” In the context of FERTINNOWA, a bottleneck is defined as a critical point that keeps growers from improving the efficient and sustainable use of water and fertilisers. A bottleneck becomes a gap if no or no appropriate solutions are available to solve the bottleneck.

T4.1 builds on the outcomes of the work packages 2 and 3 of the FERTINNOWA project. In WP2, FERTINNOWA partners surveyed 371 growers, covering 531 growing systems, all over Europe. The results of these questionnaires were analysed in WP3 and provided a basis to identify the primary interests of growers but as well the bottlenecks and needs expressed by the growers. On the other hand, WP3 carried out an inventory of the technologies currently available in the fertigation sector, providing for each of these technologies a detailed description. Those documents, based on expert’s knowledge, feedback from stakeholders and bibliography review, established the core materials for the BREF-like document, the fertigation bible.

T4.1 members analysed the information provided by both the benchmark survey and fertigation bible and identified the remaining gaps, being problems for which no appropriate solution was available at the time this report was written.

From T4.1 it was clear that part of the problems was more general and did not count for one topic and/ or required not only a technological but as well a socio-economic and legal context. Other problems are more related to a specific area, technology or subject. Moreover, it is often a combination of technological and non-technological solutions that can help to bring the grower to the next level of sustainability.

A. The main general gaps identified are

As a general observation, the survey showed that part of the growers were convinced they were already applying the most efficient and sustainable practices regarding irrigation and fertigation. Growers thinking they still could make further steps forward were not aware of all the available technologies that could assist them to resolve some of the issues and problems they were facing. They had not heard about these technologies or did not know these technologies were also applicable in their situation.

In case a technology is known by a grower, the grower first has to be convinced of the effectiveness of the solution. In general, growers doubt about the reliability of new technologies or tools. Growers think that their situation is unique and that the solution is not applicable in their situation. They are afraid that the new system requires considerable changes in the current way of operating.

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Moreover, growers fear to risk yield or quality losses when introducing new technologies. For many technologies, proper operating practices are fundamental. Systems that are not operated in a right way are regarded as not applicable, what will also affect future users. This illustrates the need for specific knowledge for growers on how to operate new technologies, models, or methodologies correctly.

In many cases, the growers reported that the scale of the existing technologies is too large compared to the smaller scale of their farms. The earn-back time is therefore too long and makes it economically not attractive to invest in new technologies.

B. Specific gaps

Fertigation can be considered to involve a sequence of processes as illustrated in Figure1. This report aims to focus on the remaining gaps of all aspects of the fertigation chain, which has been broadly organised into the following sections:

B.1 Providing water, water storage

The availability of sufficient and qualitative water is one of the critical factors for optimal production of horticultural crops. The benchmark survey showed that in some regions growers are interested to implement (larger) water storage facilities, but they faced several gaps, keeping them from installing these storages.

In the area of water storage, there is a need for models to dimension water storages for specific crops, growing systems, and regions. Models should include a cost-benefit analysis to calculate the cost per m^3 of used and stored water. Models should as well address the expected medium-term impact of climate change.

In the past years, a set of innovative, practical concepts has been developed for protection, enlargement, and utilisation of freshwater resources in coastal areas. These subsurface water solutions (SWS) combine innovations in well design and configuration. In this way, advanced ground water management and maximum control of freshwater sources are achieved. There is a need to clear out the suitability of specific regions to implement SWS.

B.2 Improving water quality

Numerous technologies are available to optimise the quality of water being introduced into the fertigation system. Water from different types of water sources can have different treatment requirements. Often a series of technologies are used, starting with a coarse filtration removing particles and other insoluble components and ending with fine filtration or disinfection. The applied technologies can be considered as being in four general groups of techniques. For each of these groups, specific gaps were identified:

1. Nutrient removal

The chemical elements that need to be removed differ strongly, depending on where the water source is applied to the production process. In case of ground water, removal of salts such as sodium (Na), and other elements such as iron (Fe), and manganese (Mn) might be appropriate. When it comes to discharge water, nitrogen (N) and phosphorus (P) concentrations might be too high, and these elements need to be removed before the discharge of this water.

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In general, desalination processes are carried out for the removal of salts. The main gap here is the insufficient selectivity, especially about the removal of sodium. Accumulation of sodium in recycled drain water restricts the recirculation process, leading to the discharge of the drain water. Selective removal of sodium would, therefore, foster further steps forward towards closed water and nutrient loops for fertigated crops.

For membrane technology, such as reversed osmosis, fouling is a problem for which unappropriated solutions are available.

Besides, current separation processes produce concentrated waste water flows with high salt content. Technologies that foster the further concentration of these waste streams or enable recycling of the concentrated elements are limited and costly. Also, other waste products such as sludge and adsorbents that have to be disposed of can cause environmental problems. The EU guidelines for discharge of waste and concentrates are not always implemented in the same way in the different European Member States. Some technologies, therefore, might only be applicable in specific Member States.

2. *Particle removal*

Clogging of the filters and the production of waste are the primary gaps regarding particle removal.

3. *Algal removal*

There is a need for low-cost, long-term methods to control algal blooms to replace the currently applied chemicals. Illumination of the water storage through covers might be an option in some cases. However, the financial cost is often too high. Ultrasonic devices might offer an economical solution, but, their efficiency depends strongly on the environmental factors.

Besides, there is a need for large-scale demonstration sites for biological algal control to have a better view on their efficiency.

4. *Disinfection*

There is a lack of reliable, quick and payable (qualitative and quantitative) DNA-analysis for a good insight into the presence and development of hazardous (for plant and human) and beneficial microorganisms.

Besides, there is a need for system-related disinfection methods. Nowadays, disinfection techniques are available that allow a sufficient disinfection at specific points (like water storage tanks) in systems whereas there is a need to disinfect the complete irrigation system (irrigation pipes, drippers) to avoid the spread of plant pathogens present in biofilms. Some disinfection techniques with longer-lasting disinfection effect are available but might have toxic effects towards specific crops.

Concerning biological disinfection: There is too little knowledge about the effect of all type of parameters (climatic, biological and chemical conditions of the water) at the development of (beneficial) microorganisms and biofilm, to make biological disinfection transferable and usable in all regions.

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B.3 Fertigation equipment

Fertigation equipment includes the equipment related to irrigation and the addition of nutrients.

Proper design and an adequate selection of materials and equipment are crucial to achieving proper standards of water use efficiency and uniformity. This is especially the case for large-scale systems and irrigated areas on sloping fields. There is a need for good models and tools to support this design.

Efforts should be made to incorporate affordable, more resistant and environmentally friendly materials. This is especially the case for irrigation lines. New materials or technologies are needed to avoid biofilm build up as this clogging of the drippers.

For the preparation of the nutrient solution in acceptable fertigation technology is currently available. However, the cost of the best technologies is often a limiting factor for their implementation.

Besides, some problems exist like the quality of the raw materials. A higher development of fertilizers to be applied by fertigation for organic production is necessary. Specific problems are often related to the measurement, monitoring of the (recirculated) water and the injection systems. The availability of affordable selective ions sensors for the optimal management of closed systems is limited as are good crop monitoring techniques.

B.4 Fertigation management

In irrigation management, determining the needs of irrigation and nutrients of the crop throughout its cycle and the balance of water and nutrients in the soil, are the most important factors when managing fertigation. However, these data are specific to each farm, cultivation and even variety.

Heterogeneity of the soil within one fertigation area leads to different water and nutrient needs of the crop and require particular attention to position the sensors that support irrigation and fertigation management.

There is an important knowledge gap reported regarding irrigation and fertigation management tools based on sensors and/or decision support systems. Correct implementation of both sensors and decision support systems require specific agronomic knowledge which is in many cases missing at the farm's level.

B.5 Reducing environmental impact

The adoption of fertigation was an important step to optimise both water and nutrient use efficiency in horticultural crops. Nevertheless, nitrogen, phosphorus and pesticide contamination of aquifers and surface water have been observed in regions where fertigation is used intensively.

This report focuses on the remaining gaps regarding the removal of nutrients and plant protection products. Also, gaps related to the recovery of nutrients from horticultural waste water streams are adressed.in this report.

In general, the treatment of horticultural waste water, such as drain water or drainage water, will require a combination of technologies to remove the most essential pollutants being nitrogen, phosphorus and plant protection products. Reversed osmosis, forms an exception as this technology can both remove nutrients PPP residues. However, reversed osmosis will produce a very

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concentrated waste stream leading again to environmental issues. Most of the alternative technologies, like modified ion exchange, are relatively new for the horticultural sector and, therefore, demonstrations should be set up to showcase these technologies.

Some biological technologies are available for the removal of nutrients, but they imply important constraints. As an example, *Lemna* species or duckweed can remove both N and P, but, are sensitive to the environmental conditions and presence of others insects of parasites. Constructed wetlands remove P, N, and K but after 5 years, the P removing effect of the wetland decreases significantly.

Further research is necessary to study and further develop technologies to efficiently recover nutrients from horticultural waste water streams. Long-term demonstration sites are needed to showcase the potential of the recovered nutrients and produced fertilisers to growers and advisors. Besides, there is a need for a harmonized European legislation regarding the production, quality, and use of recycled fertilisers.

The main technological gaps towards the removal of pesticides are related to the uncertainties about the effect and efficiency of the technologies and the complexity of the operation. Most available techniques are based on oxidation. There is only limited knowledge on the possible formation of toxic by-products from these processes. Good monitoring and control are needed. Low selectivity of the oxidation processes can result in a low efficacy, as the water to be treated often contains a lot of other organics in much higher concentration than the pesticides.

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2. Introduction

2.1. Objectives

Work package 4 (WP4) aims to bring the sustainable water use to a higher level introducing innovative technologies from other sectors to the horticulture sector to overcome remaining technological gaps.

The specific objective of T4.1 is to identify the remaining gaps amongst the bottlenecks listed in the Benchmark Survey (D3.3) and retrieved from the Benchmark workshop (D3.5). In this report, a "bottleneck" is defined as "a critical point in a process and might stop or delay the process" whereas a "gap" is defined as "a bottleneck for which no (appropriate) solution exists."

Fertigation can be considered to involve a sequence of processes as illustrated in Figure1. This report aims to focus on the remaining gaps of all aspects of the fertigation chain, which has been broadly organised and discussed in the following sections:

Table 1. Overview of the main topics

Topic	Group title	Group leader
3.1	Availability of water (storage, systems, tools)	PSKW
3.2	Optimizing water quality - Nutrients	TNO
3.3	Optimizing water quality - Removal of particles	PCH
3.4	Optimizing water quality - Removal of algae	PSKW
3.5	Optimizing water quality - Disinfection	APREL
3.6	Fertigation management – Irrigation equipment	IFAPA
3.7	Fertigation management – Nutrient addition equipment	FC
3.8	Fertigation management – Irrigation management	CC
3.9	Fertigation management - Nutrient management	UAL
3.10	Limiting environmental impact- Nutrient removal and recovery	FRAU
3.11	Limiting environmental impact- Pesticide residues	ZW

The outcomes of D4.1 will feed T4.2 in which the WP4 members aim to scout for solutions for the identified gaps. WP4 members will scout for technologies from other sectors than the horticultural sector, like the process industry or mining industry. These results will be reported in deliverable 4.2.

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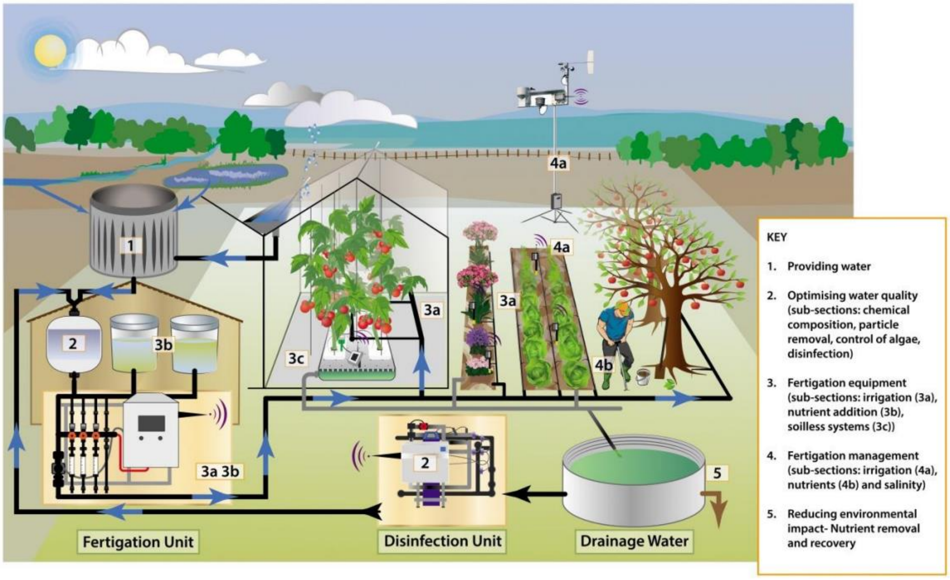

Figure 1. Schematic diagram to illustrate the various stage of the "fertigation process."

2.2. Methods

T4.1 builds on the outcomes of the work packages 2 and 3 of the FERTINNOWA project.
In WP2, FERTINNOWA partners surveyed 371 growers, all over Europe using the FERTINNOWA questionnaire that was developed in T3.1 (D3.1). These surveys resulted in the Benchmark survey in which the applied technologies and experienced bottlenecks were listed. The draft outcomes the benchmark survey provided a basis to identify the primary interests of growers but as well the bottlenecks and needs expressed by the growers. These outcomes can be found in deliverable 3.3. Additionally, a "benchmark workshop" has been organized in Brittany, France, in October 2016 to consult stakeholders to get input on where they see bottlenecks and gaps. More detailed information on the outcomes of the benchmark workshop can be found in D3.2. Both the benchmark survey and the benchmark workshop included a technological, socio-economic and legal approach of the technologies applied to sustainable water and nutrient use in fertigated crops.

Secondly, WP3 carried out an inventory of the technologies currently available in the fertigation sector, providing for each of these technologies a detailed description. Those documents, based on expert's knowledge, feedback from stakeholders and bibliography review, established the core materials for the BREF-like document, the "Fertigation bible."
T4.1 members analysed the information provided by both the benchmark survey and fertigation bible and identified the remaining gaps, being problems for which no appropriate solution was available at the time this report was written.

As mentioned, the basis of the work in task 4.1, resulting in this deliverable 4.1, is formed by:

1. The benchmark survey (D3.3)
2. The benchmark Workshop (D3.2)
3. The Fertigation Bible (D3.4)

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These documents can be regarded as the main references. More general background information and explanation of the technologies and their use can also be found in these documents.

2.3 Relation with Climate change

The horticulture sector is highly dependent on the prevailing climate. The expected climate changes could have a major impact on this sector. Climate impacts can have a big (financial) impact on the operations of horticultural growers and there may also be economic, ecological and or social impact on larger scales. For example, consider shifts in growing conditions (water availability, temperature, pests), markets or changes in land use and spatial planning 18.

Climate change and global warming

Climate Change, also referred to as Global warming, is the observed rise in the average temperature of the Earth's climate system. In 2013, the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report concluded that "It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century." The largest human influence has been the emission of greenhouse gases such as carbon dioxide, methane and nitrous oxide. Climate model projections summarized in the report indicated that during the 21st century, the global surface temperature is likely to rise a further 0.3 to 1.7 °C in the lowest emissions scenario, and 2.6 to 4.8 °C in the highest emissions scenario 18.

Future impacts of climate change will differ from region to region around the world. Anticipated effects include increasing global temperatures, rising sea levels, changing precipitation, and expansion of deserts in the subtropics. Likely changes include more frequent extreme weather events such as heat waves, droughts, heavy rainfall with floods and species extinctions due to shifting temperature regimes. Effects significant to humans include the threat to food security from decreasing crop yields and the abandonment.

Possible societal responses to global warming include mitigation by emissions reduction and adaptation measures like building systems resilient to its effects.

Threats that are relevant for the horticulture sector related to water are:

- Change in water requirement of crops
- Change in water availability by drought or flooding (climate change induced extreme weather events)
- Increasing salinity of fresh (ground) water systems in coastal area's (salt intrusion).

How is climate change affecting the water requirement of agricultural crops across Europe? (EEA).

The projected increases in temperature will lead to increased evapotranspiration rates, thereby increasing crop water demand. This increase may partly be alleviated through reduced transpiration at higher atmospheric CO_2 levels.

Climate change will also affect water availability. The Mediterranean area is projected to experience a decline in water availability, and future irrigation will be constrained by reduced run-off and groundwater resources, by demand from other sectors and by economic costs.

Europe's freshwater resources are under increasing stress, with a mismatch between demand for, and availability of, water resources across both in time and spatial scales (EEA, 2012). Water stress

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already affects one third of the EU territory all year round, and water scarcity and drought are no longer issues confined to southern Europe. Despite their temperate climate, regions in northern European countries, including UK and Germany, are also faced with seasonal water stress. Freshwater sources are under pressure from the increasing demands for water from growing populations and industrial use supporting their economies. As an effect of climate change, the frequency and intensity of droughts and their environmental and economic damages appear to have increased over the past thirty years (EC, 2012). Water over-abstraction, particularly for irrigation purposes but also for industrial use and urban development, is one of the main threats to the EU water environment. This is not only an issue for arid regions with low rainfall and high population density that are prone to increasing water stress; temperate areas with intense agricultural, tourism and industrial activities also suffer from frequent water shortages and/or expensive supply solutions.

In some countries in Europe, more than 80 % of the total freshwater abstraction is used for agricultural purposes (irrigation). Crop water demand (the water consumed during the growing season), depends on the crop type and the timing of the growing season. Some of the effects of estimated changes in the crop water deficit may also be related to the duration of the crop growing period, which is shortened under higher temperatures, thus leading to less water being consumed.

To illustrate the effects of the projected temperature changes, the crop water deficit for grain maize is shown in Figure 2.2 for two different climate models. 18.

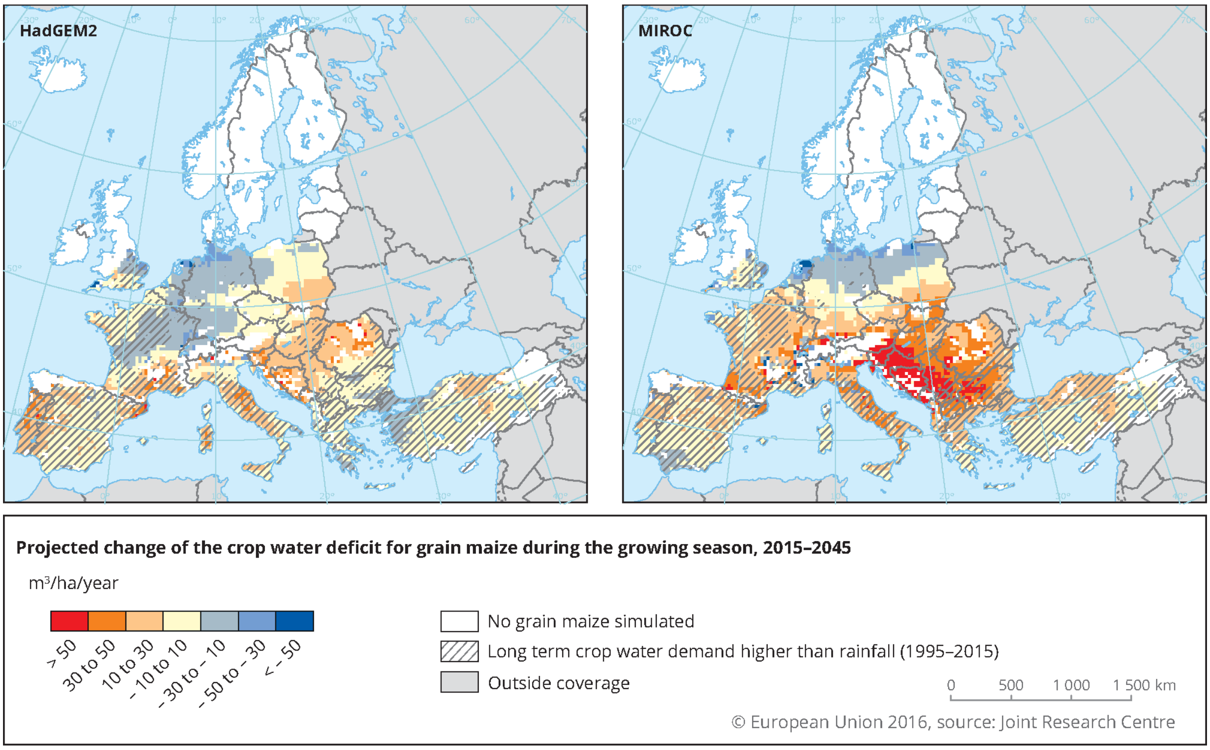

Figure 2. Projected annual rate of change of the crop water deficit of grain maize during the growing season in Europe for the period 2015-2045 for two climate scenarios.).

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The simulations for both climate model projections for the 2030s show an increasing crop water deficit for large areas of Europe, in particular over central Europe. This will increase the water requirement for irrigation, including in areas not currently applying irrigation.

Adaptation measures and the integrated management of water, are needed to address future competing demands for water between agriculture, energy, conservation and human settlements. New irrigation infrastructure will be required in some regions.

The impact of increasing water requirements is expected to be most acute in southern and central Europe, where the crop water deficit and irrigation requirements are projected to increase. This may lead to an expansion of irrigation systems, even in regions currently without irrigation systems. However, this expansion may be constrained by projected reductions in water availability and increased demand from other sectors and for other uses.

However, apart for extreme weather events, the time scale on which climate change is proceeding can be characterized in decades which allows for time for adaptation of the European horticulture sector to make itself more resilient. Adaptation measures can be taken on several levels and in different technological or operational ways, like reduction of the amount of water needed by drip-irrigation, closed systems with recirculation of irrigation water, etc… This is exactly what the intention of the FERTINNOWA project is about.

2.4. References for more information

[1]. Slobbe R., A. Breukers & M. Ruijs. 2010. Is de tuinbouwsector klaar voor een paar graden meer?, LEI nota 10-046

[2]. http://www.ipcc.ch/report/ar5/wg1/

[3]. https://www.eea.europa.eu/data-and-maps/figures/projected-annual-rate-of-change

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3. Discussion on Gaps

3.1. Water storage, systems, and tools

3.1.1 General description of the problems

The availability of sufficient and qualitative water is one of the critical factors for optimal production of horticultural crops. The FERTINNOWA benchmark survey showed that still, 60% of the surveyed farms apply groundwater as one of the sources to irrigate the crops. Groundwater is the most commonly used source for the vast majority of the farms in Poland (88%), France (88%), the Netherlands (83%), Italy (82%), and South Africa (52%). On a European scale, horticulture, therefore, contributes in a considerable way to overexploitation of aquifers.

However, the benchmark survey showed that amongst the respondents there is a general tendency for alternative water sources, such as rainwater or mixed water that is provided by irrigators communities. In Spain, the majority of the farms (79%) appeals to water provided by irrigators communities[1] as a primary water source. The water provided by these irrigators communities can consist of different sources like groundwater, rainwater, surface water, and in some cases desalinated water. In Belgium, the Netherlands and the United Kingdom, rainwater is the primary water source for irrigation (77%). Other water sources like surface water (9%), mains tap water (7%) and desalinated or disinfected urban wastewater (2%) are implemented only by a minority of the surveyed farms.

The grower’s survey revealed that farms in the North Western part of Europe like in the Netherlands (52%) or Belgium (51%) experienced water supply-related issues. 36% of the respondents using rainwater reported supply problems. Within this group of respondents, rainwater availability was listed as the primary problem (40%) followed by unsufficient water storage capacity as the second biggest problem (19%). On farms where water is provided by irrigators communities, like in Spain, 17% of the farms experienced water shortages in spring and summer due to the insufficiency of meeting water demand during the establishment of the crops. In both cases, providing a sufficient water storage capacity could offer an outcome.

Furthermore, the benchmark survey revealed that in some European regions like the Western part of Poland, the United Kingdom, Sicily (Italy), and Extremadura (Spain) the interest is expressed to move towards more sustainable water sources. On the other hand, a significant part of the growers responded negatively to this question, considering their current water sources already as the most sustainable. In some regions like Poland and Brittany, the storage of rain water could offer a valuable alternative for the extracted groundwater. In general, the surveyed growers considered the installation of water storage facilities or the improvement of water storage capacity as a good way to encourage the sustainability of the water use at the farms level. However, high investment costs, lack of space or unfavourable climate conditions are the main barriers that keep growers from

[1] Irrigators communities can be defined as a grouping of owners of an irrigable zone, which are bound by law, for the autonomous and common administration of public waters, without profit motive. A concession of water is granted to that specific area of irrigable land. These organizations are institutions with a long historical tradition, originating from associations governed by systems and rules of the Romans and Arabs (such as fraternities, unions, boards, etc.). They are equipped with an organization that allowed the administration and distribution of water for irrigation of crops. More information: http://www.fenacore.org/empresas/fenacore/documentos/ingles.doc

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investing in more extensive water storage facilities. Growers already storing water reported problems regarding sediment accumulation, algal blooms, and evapotranspiration losses.

Figure 1-3. The willingness of the surveyed growers to move towards more sustainable water sources (orange bars refer to the percentage of respondents willing to apply more sustainable water sources, the blue bars refer to the respondents that answered negatively on this question).

This section focusses on the most critical barriers identified by the surveyed growers that keep them from implementing (larger) water storage facilities. Therefore, this chapter will focus on:

1. Ways and tools to dimension water storages
2. Availability of innovative water storage systems with a minimal requirement for land
3. Safeguarding the water quality of the stored water. The problems, bottlenecks, and gaps regarding algal bloom are not discussed in this paragraph. 52 is dedicated to preventive or curative technologies for algae blooms.
4. Prevention of evapotranspiration losses

1. Dimensioning of water storage:

- Extension of water dimensioning tools on the regional and crop level

At this moment, only a few tools are available to advise growers on the dimension of the required water storage. These advising tools refer to specific regions and crops. In general, the advice for the dimensioning for water storage facilities is limited to greenhouse crops as these greenhouses provide sufficient surface to collect rainwater. The advice itself is mainly based on standard tables Table 1-2.Table 1-3.Table 1-4. , Table 1-3. and Table 1-4.) (32) and is restricted to a set of greenhouse crops.

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Table 1-2. Water requirement (litre/m²/year) per crop (Vermeulen, 2016/2017).

	Low <550	Normal 550-750	High 750-950	Very High 950-1000
Vegetables, herbs moreover, small fruit	Beetroot Carrot Fennel Herbs Kohlrabi Parsley Rhubarb White radish	Amsoy Asparagus Broccoli Bunching onion Cauliflower Celery Chinese cabbage Corn salad Courgette Endive Leek Lettuce Long beans (Garter) Oxheart cabbage Paksoi Purslane Radish Small fruit (woody) Spinach Sugar peas Turnip greens Turnip-rooted celery Vegetables (other)	Butter bean Cucumber Egg-plant French bean Gherkin Melon Paprika Tomato	
Ornamentals	Alstroemeria Anemone Euphorbia fulgens Eustoma Foliage Freesia Limonium Nerine	Carnation Decoration green Floriculture (other) Gerbera Gladiolus Gypsophila Lily (outdoor) Summer cut flowers Tulip (outdoor, forcing)	Aster Chrysanthemum Iris (outdoor) Matricaria	Amaryllis Rose

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Table 1-3. Estimation of the percentage of water consumption that can be covered with rain water, depending on water requirements of the crop and size of the basin (Vermeulen, 2016/2017).

water consumption crop (l.m^{-2}.year^{-1})	volume of water basin (m³.ha^{-1})					
	500	1000	1500	2000	2500	3000
750	70%	80%	85%	90%	95%	95%
800	70%	75%	80%	85%	90%	90%
850	65%	75%	80%	85%	85%	85%
900	65%	70%	75%	80%	80%	80%
950	60%	65%	70%	75%	75%	75%

Table 1-4. Necessary water storage capacity and required volume of alternative water sources for 1 hectare of greenhouse tomato soilless crops in Britany, France (Le Quillec et al., 2002).

Water storage (m³/ha)	% of rainwater in total water demand of the crop	Rainwater used (m³/ha)	Water volume required of additional sources (m³/ha)
500	65	4800	2700
1000	70	5200	2300
2000	80	6000	1500
3000	86	6400	1100
4000	92	6900	600
5000	96	7200	300
6000	100	7500	0

More recently, models have been developed to dimension the required water storage at the farm and crop level. Both the Flemish model WADITO (32) and the Dutch model of Glastuinbouw Waterproof (32 Glastuinbouw Waterproof, 2018) provide the possibility to specify the crop and greenhouse dimensions. These models proved the influence of, for example, the crop type on the recommended water storage dimension. Still, these models are restricted to the climate of Flanders and the Netherlands.

There is a need to extend the existing dimensioning models to a broader range:

1. of regions: These adaptations require detailed climatological data (daily rainfall and evapotranspiration). These data are available but should be collected and implemented in the models.
2. of crops: There is a lack of centralisation of crop water demand data for the different European regions.
3. of water sources: Today most models focus on rain water. However, the models could be adapted to the water supply pattern of irrigation communities. In this way, farmers would be able to dimension their water storage.
4. of growing systems: Existing dimensioning tools focus on greenhouse constructions as these greenhouses have a large impermeable surface to collect rainwater. However, all over Europe, other growing systems are applied that also have these large impermeable surfaces. Tunnels, container- and trayfields are some of the examples. As an example, in the Huelva

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region in Spain, the interest to collect rainwater from polytunnels is increasing. Models should be developed to dimension also the water storage facilities for these crops and systems.

Extension of the existing models would offer growers, advisors, industry, but also policymakers the possibility to estimate the importance but also the costs and benefits of rain water storage at the farm's level.

- Risk assessment of large scale lined reservoirs

Over the last few years, the dimension of greenhouses, container-, and trayfields has increased significantly. In case that large-scale companies are built, it has to be taken into account that enormous amounts of rainwater have to be stored and buffered in the storage systems at times of intensive rainfall to prevent flooding of the surrounding areas. Models and recommendations exist for large industrial buildings. Comparable models should be provided for the horticultural growing systems and conditions.

There is a need for tools to assess the required buffer volumes for water storage systems. These should take into account the regional circumstances (e.g., climate conditions), the growing systems and also climate changes.

- Economic evaluation of the stored water

In general, rainwater is considered as a "free" or “very cheap” water source providing highly qualitative water. Dimensioning tools are now based on the optimal dimension to fulfil the crops water demand. However, they do not take into account the cost per m³ of applied rainwater. When both the investment costs and the maintenance costs of rainwater storage facilities are considered, the price per m³ stored rainwater increases significantly. In case water basins are installed, large surfaces are required (cfr. Table 1-5.). When also the costs for this land and the financial drawbacks from lost cultivation are taken into account, the price per m³ of applied rain water increases even more (32). The cost of rainwater is therefore not unneglectable. This leads to a severe increase in the costs of rain water storage which can exceed the cost of the other available water sources, such as ground water. Therefore, dimensioning of the water storage should be linked as well to an economic model.

Table 1-5. Estimation of the required ground surface for basins depending on depth and volume (Vermeulen, 2016/2017).

Basin depth (m)	Volume of basin (m³)						
	1000	2000	3000	4000	5000	10000	15000
1.5	900	1650	2400				
2.0	700	1250	1850	2350	2950	5700	8550
2.5	500	950	1400	1900	2350	4650	6950
3.0				1550	1900	3900	5800
3.5					1600	3400	5150

2. Implementation of innovative water storage systems:

Water storage systems like lined reservoirs or ponds require significant surfaces of productive land what leads to a decrease of the latter. As a result, the costs of the stored water increase as well.

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Since many years, the scientific and industrial world has been searching for possibilities to store large water volumes without the loss of valuable land. In the past, small-scale sub surface water storage technologies have been developed and commercialized (c.f. Klimrek buffer, Gaasboxx, concrete citterns, etc.). These technologies, however, are not frequently applied by the growers as they are considered to be expensive. For the storage of large water volumes, similar technologies were developed. The sub surface water storage system (Subsol) is one of the examples that resulted from this research. At this moment it is not always clear:

- if these innovative subsurface water storage facilities can successfully be applied due to the novel techniques and lack of data of the subsurface.
- if these technologies meet the national and/or regional legislation in the different European Member States.
- if these technologies are financially or technologically feasible in their region or situation.

3. Safeguarding water quality

During both the 'collection phase'[2] and the 'storage phase'[3] different water quality problems can occur.

Table 1-6. Overview of water quality problems related to the storage and collection of rainwater

Water quality problem	Pathway
Chemical contamination	Drift of PPP on the collecting area, disposal in the water storage
Mineral contamination	pH control issues, carbonate contamination due to the cleaning of the roof
Sanitary contamination	Bird droppings
Water temperature	Increased water temperature due to lower water levels during periods of drought.
Sediment disposal	Sand particles are disposed on the collecting surface. The water transports these particles towards the water storage system where they settle down.
Algae bloom	C.f. 3.4

- Presence of PPP in the stored water

Due to drift, residues of plant protection products (PPP) can stick to the collecting surfaces. This is seen in case greenhouses are located in areas with intensive agricultural practices. As an example, herbicide residues are found in the collected rainwater. This causes two problems. In case the concentration of PPP exceeds set threshold levels (as an example discharge values or PNEC[4] and

[2] Collection phase: The phases before water enters the water storage. In case of rainfall this refers to the initial water quality of the rain, the possible contamination that occurs when the rain falls on the collecting surface.
[3] Storage phase: this phase refers to the possible water quality problems occurring during the period the water is stored.
[4] PNEC stand for predicted no effect concentration. PNEC values are intended to be conservative and predict the concentration at which a chemical will likely have no toxic effect on an ecosystem.

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MAC[5] values), the stored water cannot be discharged from the water storage in case there is an excess of for example rain water. This is the case in some regions such as the Netherlands and Flanders.

Also, residues of PPP can lead to phytotoxic reactions of the plants (herbicides) and the presence of undesired residues in the crops.

- Sanitary problems

As rain water is collected from large surfaces, the collected water might contain bacterial, fungal and viral contaminations due to, for example, bird droppings and by the wind supplied sand and soil particles.

- Increased water temperature

In general, the water temperature of the stored water increases significantly when the water level in the storage system is low. This can lead to:

- An increased risk for sanitary problems
- The decrease in oxygen content of the irrigation water
- Root problems, caused by an increased temperature of the irrigation water

- Sediment

Sediment particles settle down in the water storage. Consequently, the water in the lower section of the water storage (0.2 to 0.5m) cannot be used as the risk for pumping of sediment is too high. Growers cover the water storage but this leads only to moderate to very low satisfaction as the main part of the sediment is transported directly from the collecting surface to the water storage.

- Poor water quality of the first flush

After an extended period of drought, the first rain water may contain pollutants (drift of PPP, chalk, sediments) which can harm either the crops or the irrigation systems. Today, growers discharge this water as the technologies to purify this first flush are expensive.

4. Prevent evaporation losses

Evaporation can cause a significant loss of the valuable stored rain water. Measurements at a system in the Netherlands with lined water storage with cover showed that even in that case about 200 mm of the stored water evaporated during the year (about 280 m^3.ha. year). In the Mediterranean region, the evaporation from non-covered ponds is around 1200 mm per year, although it is reduced by 75% if shading is applied with a single layered black net.

3.1.2 A brief description of the socio-economic impact of the problem

1. Dimensioning of water storages:

- Economic impact:

It is a misconception to consider rain water as "free" or "very cheap" water. Depending on the crop's water demand and the water source availability pattern, large storage volumes are required to fulfil

[5] MAC stands for maximum allowable concentration.

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a significant percentage of the crop's water demand. For example, a net volume of 5000 m³ per ha of soilless greenhouse tomato crops is required in Flanders. The construction and maintenance of this storage are costly. Depending on the water storage type the costs vary from 4 to 45 € per m³ storage capacity. These costs do not include the costs for the land. To fulfil the last percentages of the water crops demand by use of rainwater demands a disproportional enlargement of the water storage, leading to higher installation costs.

Awareness should be raised at the level of the growers, advisors, construction companies, policy makers to estimate the actual cost of rainwater.

- Sociological / environmental impact:

In some European regions, rainwater is a relevant water source. More and more, both environmental and governmental organisations keep growers from collecting this water as this would harm the enrichment of the deeper underground water layers.

In densely populated regions, growers experience resistance from residents who fear potential flooding due to the loss of infiltration capacity caused by the construction of large scale greenhouses and water storage.

2. ***Sub soil water storage solutions***
   - Economic impact:

Sub soil water storage solutions require high investment costs. Making it only feasible for larger horticultural areas or more prominent companies.

- Sociological / environmental impact:

Storing water in sub soil water layers is a topic of discussion as it might affect the water quality of the original underground water layer.

3. ***Water quality problems***
   - Economic impact:
     Sediment, PPP residues, and microbiological contaminations can be removed from the collected water, but this requires extra investments what again should be considered when calculating the price of the rain water.

3.1.3 A brief description of the regulations concerning the problem

European level

On the European level, the Water Framework Directive (WFD) and the Common Agricultural Policy (CAP) are active. The WFD aims to achieve good qualitative and quantitative status of all water bodies. The Common Agricultural Policy supports investments to conserve water, improve irrigation infrastructures and enables farmers to improve irrigation practices.

Country level

On the country level different legislations occur regarding water storage:

- In most countries, specific guidelines are set regarding the construction of both subsoil and above soil water storage constructions. In most countries, a building permit is obliged.

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- In some countries, such as Belgium, criteria are set regarding the discharge flows of water storage facilities. In general, a limitation of 20 l/s/ha of the impermeable surface is set. In some cases, the discharged water has to flow in an infiltration bed.
- In some countries like Belgium, farms are obliged to provide buffer capacity in the water storage. Depending on the vulnerability of the zones for flooding, this requirement amounts 250 to 330 or more m³ per hectare of impermeable surface.
- Some countries like Belgium (Flanders), The Netherlands and France set specific guidelines for the volumes of the water storages. In Belgium (Flanders) and the Netherlands, it is required to provide water storage of at least 500 m³/ha.
- Some countries have developed specific legal guidelines to store rainwater in underground water layers, providing the possibility to regain this water.

Regional level

In most European Member States, local or regional authorities can tighten the national legislation. For example:

- Regarding required rain water storage:
    a. Belgium
        - Flemish legislation: 500 m³ /ha
        - Municipality Duffel: 1500 m³/ha
    b. The Netherlands: For collecting rainwater minimum water storage of 500 m³/ha is required. The obligation does not apply when the available spring water is of good quality.
- Regarding buffer volumes:
    a. Belgium:
        - Zones with low sensitivity for flooding: minimal 250 m³/ha of impermeable surface
        - Zones sensitive to flooding: minimal 330 m³/ha of impermeable surface

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3.1.4 Existing technologies to solve the problems

In the tables below an overview is given of the main existing technologies related to the problems concerning water storage

Table 1-7. Existing technologies to solve problems related to dimensioning of water storages

Existing technologies	Restrictions	Development phase	Potential to solve the problem
Dimensioning of water storage			
Standard tables	Restricted to a specific region and specific crop (mostly greenhouse tomato crop in the Netherlands)	Published, generally applied	Limited (restricted to region, crop, and system)
Waterstreams model	Series of greenhouse crops, the Netherlands	Published, generally applied	Moderate (series of greenhouse crops).
WADITO model	Greenhouse crops, a region of Flanders	Commercialized	Yes, climatological data and crop water demand have to be added
Model tray field strawberries (PCH)	Restricted to a specific region (Flanders) but with the potential to be expanded to other regions.	Available	High
Risk assessment of large scale lined reservoir			
Model WARITO (PSKW)	Risk assessment based on Flemish climate conditions but can easily be adapted to any region.	Development phase	Medium?
Economic evaluation of the stored water			
Publication: Quantitative information for greenhouse crops 2016-2017	Book chapter with water demands of about 64 greenhouse crops, Table showing the relation between the volume of storage and coverage crop demands. Tables with required ground surface and a table with some examples of calculations to estimate the investment costs and costs per m³ in case of a lined water reservoir.	Commercial available	Medium (restricted to region,
(Semi) scientific articles	Restricted to specific general situations, not possible to carry out the economic evaluation for a specific farm.		Medium, needs further development

Table 1-8. Existing technologies for subsoil water storage

Existing technologies	Restrictions	Development phase	Potential to solve the problem
Concrete water reservoirs	Costly	Commercialized	Yes in case of small volumes
Dynamic water buffers (Klimrek water buffer)	Mainly soilless growing systems as the soil is no longer available for production.	Commercialized	Yes in case of small to medium volumes
Infiltration crates (Gaassbox)	Mainly soilless growing systems as the soil is no longer available for production.	Commercialized	Yes, climatological data and water crop demand have to be added

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Subsoil water storage (SWS)	Requires specific soil characteristics, needs specific legislation	Field tests, commercialised	Yes, mainly for large water volumes, in specific regions
Managed aquifer recharge solutions	Requires specific soil characteristics, needs specific legislation	Field tests, commercialised	Yes, mainly for large water volumes, in specific regions

Table 1-9. Existing technologies to safeguard the quality of the stored/collected water

Existing technologies	Restrictions	Development phase	Potential to solve the problem
Prevention/removal residues pesticides			
Chemical oxidation	Flow rate limits. Chemical oxidation requires a minimal contact time to be effective. Costs (chemicals, energy). Residual oxidants and decomposition products	Commercial available	Low seen high water flow rates
Activated charcoal	Flow limits. Activated charcoal requires a minimal contact time to be effective. Costs!	Commercial available	Low seen high water flow rates
Adapted composition for pipelines, cisterns		Commercialized	High (for specific elements)
Photo catalysis	Possible for uncovered collecting surfaces. (Greenhouse rooftops, less in case of container fields as these areas are covered with plants).	Field tests	Moderate – high when applied to the collecting surfaces?
Disinfection technologies	(see section 3.4 Optimizing phytosanitary quality of water for improving water reuse)	Commercial available	High
Preventing/decrease temperature increase of the stored water			
Heat exchangers		Commercial available	
Covering the water storage	.	Commercial available	Medium
Preventing/treating sediment build up in water storages			
Remote removal of water storage sediment		Commercial available	High
Covering the water storage		Commercial available	Low – high: Low in case water is collected from impermeable surfaces. High in case water is transported by irrigation communities.
Filtration systems	Possible clogging, mold presence, biofilm formation	Commercial available	High
Preventing evaporation			
Covering the water storage		Commercial available	High
Subsurface water storage	Cfr Table 1-8.	Commercial available	High

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3.1.5 Analyses of bottlenecks and gaps

Dimensioning of water storages:

- Dimensioning models:

At this moment, only a few tools are available to advise growers on the dimension of the required water storage. These advising tools are restricted to specific regions (Flanders and the Netherlands), growing systems (greenhouses) and crops (mainly soilless crops like tomatoes, sweet pepper, cucumber). In general, the advice for the dimensioning of water storage facilities is restricted to greenhouse crops as these greenhouses provide sufficient surface to collect rainwater.

In areas, such as the Mediterranean region, main part of the irrigation water is provided by irrigation communities. Characteristic for these irrigators communities is that water is not provided continuously but according to set timing or schedule. During the growing season, this set schedule might not meet the crops fresh water demand. Therefore, growers provide water storages so that irrigation can be carried out at the preferred time and growers do not depend on the irrigators communities schedule. The size of these storages, usually in rafts, is according to the availability of land and the surface to be irrigated.

- Technological gaps:
    - Few dimensioning models are available in the North-West region of Europe for the rain water harvesting for greenhouse crops. These models should be extended, or new models should be developed towards other:
        - regions
        - water sources: in case of water from irrigation communities, condense water, water from other industries (e.g., sugar beet processing): The water availability pattern of these sources differs significantly from for example the local rainwater pattern. Combination of the different available water sources will give an added value to the models.
        - crops: crop water demands of the different crops under different growing (greenhouse crop versus tunnel, high versus low tech growing conditions, substrate versus soil) and regional climatological (coastal regions versus inland regions, sea level versus high altitudes) and soil type conditions (sandy soils versus soils with a high lutum[6] content) should be listed.
        - growing systems: models are available for greenhouses and tray fields in the Netherlands and Flanders. Models lack for container fields and tunnels.
        - the impact of climate change on a medium term (20-25 years) is missing in the existing models. This should be implemented.
    - Risk assessment: There is a need for tools to assess the required buffer volumes for water storage systems. These should be adapted to the region, growing system, and regional climate conditions. Again, climate changes must be taken into account here.
- Socioeconomic gaps:
  Economic: In general, rain water is considered as a "free" or "very cheap" water source. However, storage of this water source implies severe investments for water storage, algae

[6] Lutum refers to soil particles smaller than 2µm. Soil is categorized as clay in case the lutum fraction exceeds 25%.

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control, and so on. Above, some valuable land might be lost for commercial activities. On the other hand, rain water contains no ballast salts supporting recirculation of nutrient water in closed systems. In this way supporting the increase of water and fertiliser use efficiency. Both should be taken into account when calculating the cost of rain water storage and use. There is a need for tools to calculate the cost benefit for water storage at the company level.

Sociological gaps: Rainwater is a vital water source in many European regions with horticultural practices. However, both environmental and governmental organisations keep growers from collecting this water as this would harm the enrichment of the deeper underground aquifers. Furthermore, the improvement of irrigation efficiency by using drip emitters has an environmental cost since aquifer replenishment from percolation (up to 25% of the irrigation water) is severely hindered. In some areas drip irrigation is alternated with the ebb and flow methods if a hydric surplus situation is met due to a favourable meteorological scenario. However, in the other European Member States, both the environmental and governmental organisations prefer rain water use above retrieval of (deep) groundwater. For example, in areas with a significant concentration of greenhouses, local administrations are including infrastructures and systems for rain water collection as a legal obligation in new greenhouses.

In densely populated regions, like Flanders, growers experience resistance from residents who fear potential flooding due to the loss of infiltration capacity caused by the construction of large scale greenhouses and water storage.

- Legal gaps:

  Legislation regarding water storage facilities differs strongly on the European, national but also regional level. Even on a national level, the specific guidelines to construct water storages are not always transparent. There is a need for a clear national and regional overview of the specific guidelines concerning water storage legislation.

Implementation of innovative water storage systems:

- Technological gaps: There is a need to clarify the suitability of specific regions to implement large scale subsoil water storage systems which store rain water in the more profound ground water layers. This is not clear to growers at the moment.
- Legal gaps: There is a need to clarify the legal restrictions regarding subsoil water storage systems at the regional/national level.
- Socio-economic gaps: Small scale sub soil water storage systems like Klimrek Buffer, Gaasboxx, concrete cellars, ... are considered to be too expensive. There is a need for a correct economic calculation of the actual storage costs for storing rain water or irrigation water at the company level. For this, both the (dis)advantages of these systems in the broader company should be taken into account. Factors here are the loss of productive land, the influence of water temperature on the crops, evapotranspiration losses….

Water quality problems:

- Technological gaps:
  Numerous technologies are currently available to overcome most problems related to quality problems that arise during the storage of water. A first - in general easy to implement

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measure is discarding the first flush from entering the storage, preventing sediments and other pollutants. Prefiltration is also possible or conditioning of the stored water.

- Socioeconomic gaps:
  The available technologies are not implemented by growers as they might not be known or due to the related costs. There is a need to provide an overview of the cost benefit of these technologies taking into account the broader range of factors that a better water quality might affect (plant health, increased yields, less maintenance of the irrigation installation, …).
- Legal gaps:

No specific legal gaps.

3.1.6 References for more information

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3.2 Optimizing water quality: Chemical composition

3.2.1 General description of the problems

The supply of irrigation water of adequate quality is a fundamental factor for horticultural crop production. In addition to crop species, the type of cropping system influences the required water quality. For soilless growing systems with recirculation of drainage, the requirements for the quality of irrigation water are demanding. The accumulation of components such as salinity, Na or Cl during recirculation requires an input low of nutrients.

Where groundwater is used, salinity and chemical composition are issues that have to be taken into consideration for decisions related to crop selection. Optimally, groundwater requires treatment before irrigation. These issues are particularly important in drier Mediterranean regions where groundwater is commonly used. In some Mediterranean regions, increasing salinity of groundwater increases the need for treatment of irrigation water. Water treatment is likely to become an issue for soil-grown crops in these regions and will be of particular interest for free-draining soilless cropping with future recirculation obligations.

Given the common tendency of increasing salinity of the groundwater, and the possible obligation to recirculate drainage in soilless systems, the issue of the chemical composition of irrigation water is of growing importance in the European Union.

This section lists the problems and issues to assure a good chemical quality of the water used for irrigation*,* focusing on inorganic salts, nutrients, iron, and manganese.

The chemical elements that need to be removed differ strongly, depending on where the water source is applied to the production process. In case of ground water, sodium (Na), iron (Fe), and manganese (Mn) removal might be appropriate. When it comes to discharging water, concentrations of elements like nitrogen and phosphorus will need to meet the Nitrate Directive (Council directive 91/676/EEC) and the Water Framework Directive (Directive 2000/60/EC).

The problems associated with nutrients and salts can be divided into the following topics: (see also Figure 2-4):

- Preparation of irrigation water:
  - Removal of Fe and Mg
  - Desalination
- Selective removal of sodium to improve water and nutrient use efficiency by closing the water and nutrient cycle
- Costs of nutrient removal
- Water quality requirements
- Water quality monitoring

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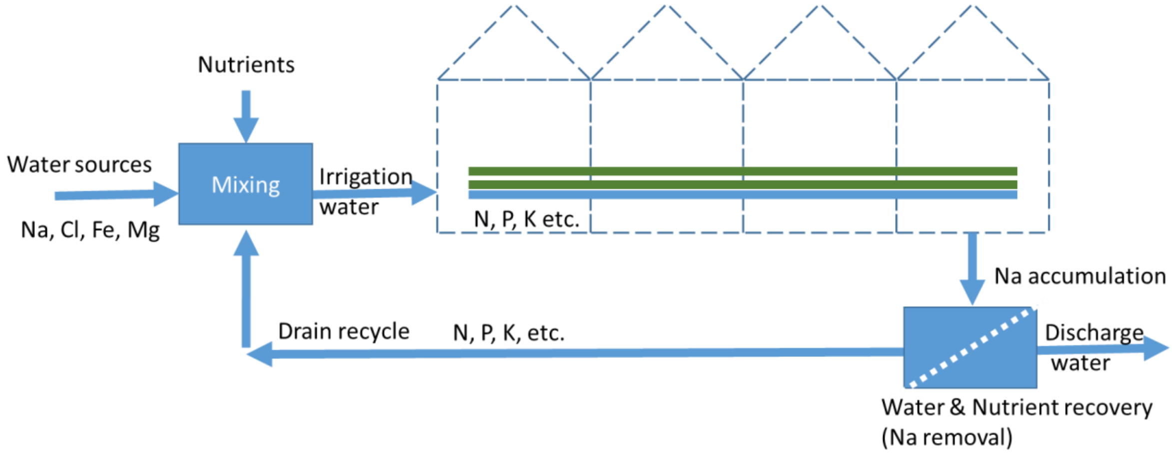

Figure 2-4. Schematic approach of a closed water system in (greenhouse) horticulture).

When focusing on water and nutrient recovery, there is either removal of sodium (Na), N and P. Na is removed to keep the recirculation process ongoing, while N and P are removed to meet the threshold values for discharge (according to the Water Framework Directive).

1. *Preparation of irrigation water by removal of Fe and Mg*

As soon as water containing iron[7] is pumped up for irrigation, partial oxidation occurs. During this process, iron-precipitates are formed which cause fouling and clogging of irrigation systems. Water sources containing 0.5 ppm of iron or more are not suitable for drip irrigation systems. In those cases, de-ironisation is recommended. FERTINNOWA asked growers about their main mineral composition problems and the measures taken to overcome these problems. Figure 2-5 shows that approximately 6% of the respondents, mainly Polish, experienced problems related to higher iron contents of the irrigation water.

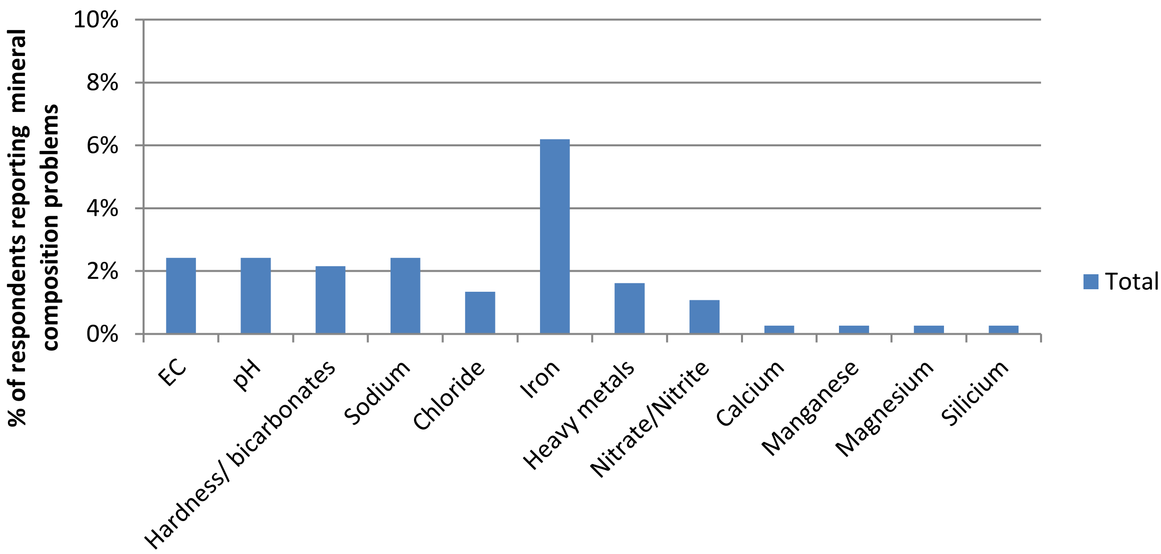

Figure 2-5. Percentage of responders facing problems related to water chemical quality.

[7] Dissolved, inorganic, complexes, organic complexes, colloidal or suspended

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De-ironisation is a common technology, however, for the optimal operation, proper control of the system is needed. Especially the pH, alkalinity and time of oxidation play a vital role in the proper operation of the de-ironisation process. Regulation in some European Member States limits the disposal of backwashed water containing iron precipitates. Some surveyed growers reported that the initial investment costs were the primary barrier that kept them from implementing de-ironisation Figure 2-6. Also, the required space for the technology (m²) was mentioned by the growers as a holdback.

2. Desalination

Approximately 5% of the respondents reported to experience problems related to salts and electric conductivity (EC) (Figure 2-6)., It is expected that a larger proportion of the surveyed growers either directly or indirectly faces problems related to the chemical composition of their water source. 6% of the surveyed growers, mainly Dutch growers, appeal to reversed osmosis to improve the chemical quality of their water source.

Many Spanish farms use desalinated water, depending on the region. As an example, the water provided by communities in Almeria contains a considerable proportion of desalinated water.

Desalination is associated with some problems and challenges, of which the following are briefly explained.

- Fouling of membrane systems

Membrane systems, like Reverse Osmosis (RO), Nanofiltration, Electro-dialyses and Membrane Distillation are sensitive to fouling. For the removal of small particles, a pre-filtration (screens, microfilter) is applied. Also, precipitation at the membrane surface by poorly soluble salts can cause fouling and decrease of capacity. Lowering the pH can solve this problem.

- Discharge of concentrates

Most of the desalination technologies are concentrating technologies. Besides clean water, refered to as the permeate, a concentrated (salt) stream or brine is produced that has to be disposed of. In case of RO, 75% to 90 % of clean water and 10 to 25% of concentrated brine are produced. The disposal of the brine causes environmental problems and is, therefore, limited by regulation in some European Member States. In case the concentrated stream cannot be discharged, additional treatments are required. These post treatments, such as crystallization, put an extra burden on the horticultural business.

- Low selectivity

Most of the desalination technologies are removing and/or concentrating all salts. This means that useful nutrients like N are also removed from water streams which are recirculated (also see section 3.61). Consequently, the concentrate or brine cannot be reused due to high Na and Cl levels.

3. Accumulation in closed water cycles

Accumulation of sodium, chloride and other harmful ions limits the re-use of the nutrient solution. Of the respondents with soilless growing systems, 43% mentioned bottlenecks related to drain water recycling. The main issue faced was ion accumulation (48%). It was reported to be a problem mainly for strawberry and tomato as well as other fruit and vegetables (cucumbers, pepper, eggplant, etc.).

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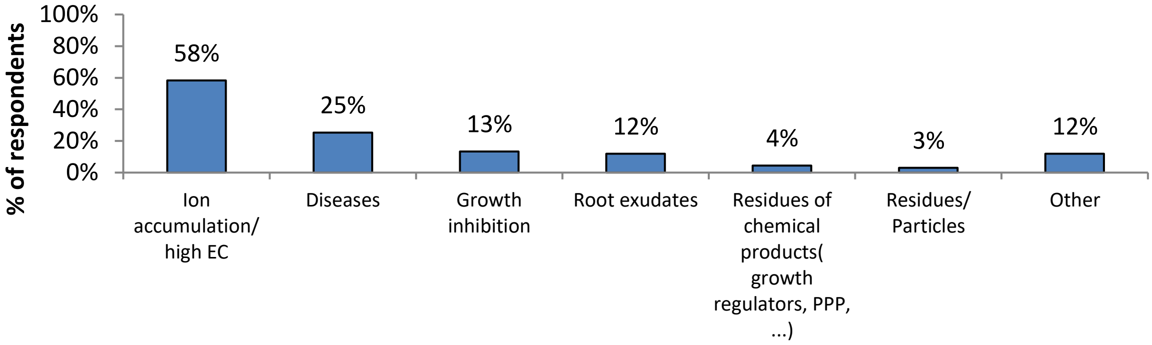

Figure 2-6. Issues faced by growers who recycle drain water (n=67)

As already mentioned above, there is a need for higher selectivity to remove only these harmful ions and keep the nutrients in the recycling water.

Also, there is an increasing need for more holistic technologies for nutrient removal but as well as the removal of crop protecting agents, micro-organism or other harmful components. 25% of the respondents of the FERTINNOWA survey mentioned issues regarding the spread of diseases and residues of chemical products as a problem related to drain water recycling. As desalination and disinfection technologies are considered to be expensive, it would be interesting to have more holistic technologies available.

4. Costs of nutrient removal

In comparison to (low) water costs, treatment costs to produce qualitative irrigation water are high, especially in case the requirements for recirculation have to be met. Costs of reversed osmosis vary from €0.50 to 3 per m^3 , strongly depending on the scale. Ground water is often for free or costs below € 0.20 per m^3. The FERTINNOWA survey revealed that mainly high investment costs related to desalination treatments kept growers from implementing these technologies (Figure 2-7).

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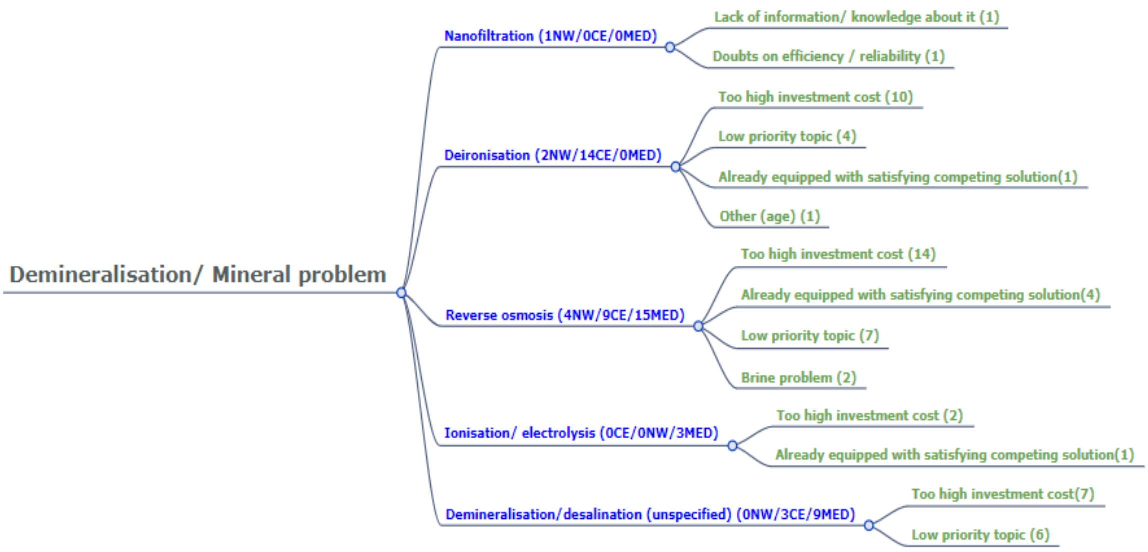

Figure 2-7. Reasons that are limiting the adoption of demineralisation treatments

If the removed nutrients can be recycled, the economical feasibility might be improved.

Possible solutions are standardisation, building simple installations for a limited number of capacities and the production of reusable concentrates. When opted to recycle the concentrates, these should meet the quality standards of fertilisers. In most cases, the regenerated fertilisers will be in the liquid phase. Storage or transport over long distances is expensive and involves specific legislation. It is therefore preferable that fertilisers either first be concentrated before transportation or used on site.

5. *Water quality requirements*

The sensitivity of crops to salinity and harmful individual elements such as sodium (Na) or chloride (Cl) differs considerably. For example, Phalaenopsis (moth orchid) is very sensitive to salinity while tomato is appreciably more salt tolerant. (for reference, 33). Much research has been carried out in this area, but the centralisation of this knowledge is desirable. Also, adaptation is a point of attention. This implies that growers should anticipate when they risk facing a shortage of rainwater shortly, for example. In that case, they should start mixing ground water and rain water (higher Na content) a long time in advance to support the adaptation of the crop.

6. *Water quality monitoring*

One of the problems associated with maintaining good water quality is the determination of sodium content. The monitoring of the chemical water quality is usually done through a combination of sampling followed by laboratory analyses and online control of total electrical conductivity (EC). The latter is an indirect determination, as all charged chemicals in the water add to this conductivity. See paragraph 106 for more information on this topic.

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3.2.2 Brief description of the socio-economic impact of the problem

With an optimal nutrient composition of irrigation water which fits for fertigation as well as for the reuse of drain water, some benefits have an impact on a larger scale, such as:

For soilless crops:

- Avoiding the need to purge water causing emissions (decreasing the costs of purifying/discharging this water (especially for recirculation systems))
- Reduction of the requirement for fresh nutrients and source water leading to cost-reduction for growers and also savings in the production of these nutrients which are energy intensive commodities. Each cubic meter of nutrient solution contains a value of 0.5€ per EC (Grodan, Priva, WUR).
- Less ground water withdrawal
- Optimal growing conditions, especially for salt sensitive crops like sweet pepper, kaki, leading to higher productions and quality
- Homogeneous growing media (soils)

For soil grown crops:

- Decreased risk for clogging of drippers, enhancing homogeneous water and nutrient supply pattern throughout the irrigation system
- Optimal growing conditions, especially for salt sensitive crops like sweet pepper, kaki, …leading to higher productions and quality
- Homogeneous growing media (soils)

The FERTINNOWA benchmark survey showed that 27% of respondents growing soilless crops disharged drainwater on a daily base. Only 8% of the respondents reported discharging never. 44% of the respondents reported to disharge only a few times per year (data not shown). However, there is a regional difference noted. Soilless cultivation systems are already commonly applied in Dutch and Flemish greenhouse horticulture. Recirculation has become common practice, and growers strive to close the water and nutrient cycle. Although discharge occasions are limited, a Dutch study (2013) reported that each year on average 10% of the nutrient solution is discharged. One of the most common reasons for discharge seemed the accumulation of sodium (43). From this follows that soilless cultivation in the Netherlands uses 6.5 million m^3/year of fresh water, and annually emits 1300 ton N, 200 ton P, and 1134 kg PPPs. Calculations show that eliminating the need for discharge will reduce the use of fresh water by 2.6 million m^3/year and reduce the water pollution by nutrients and PPPs by 60% (43).

In greenhouse areas with soilless cultivations the quality of surface waters, therefore, might not meet the standards for chemical and ecological good water, as is demanded by the Water Framework Directive 2000/60/EC.

3.2.3 Brief description of the regulations concerning the problem

European Level

The Water Framework Directive is a broadly-focused directive that deals with various aspects of water quality in the EU. It aims to ensure the proper ecological quality of surface and subterranean water. Also, the Nitrate Directive is relevant in this framework.

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When maintaining an optimal concentration level of nutrients in irrigation water using desalination equipment, in many cases this equipment produces concentrates. These concentrates contain a high concentration of the undesired salts like sodium and, depending on the type of technology used, can also contain nutrients and other substances as crop protecting agents.

Country Level

Each European Member State passes national legislation on how the legislation will be applied in that country. Commonly, the legislation related to the Nitrate Directive is applied at the regional level, and that of the Water Framework Directive is applied at national level.

National legislation might as well pose specific regulation towards discharged of water containing concentrations of iron in the surface water.

Regional Level

For the discharge of the concentrates, it should be investigated what the region specific requirements are for handling and processing. Since these concentrates, sometimes also referred to as brines, contain high levels of salts and can contain residues of crop protecting agents, in many cases, it will not be allowed to discharge to surface water or sewer.

In general, there are:

- Limits for the discharge of concentrates (also BREFS of waste treatment industries)
- Transport of secondary materials

3.2.4 Existing technologies to solve the problem/ subproblems

To remove nutrients from water several technologies are available. Most of them are based on membrane technology. In general, these are state-of-the art technologies, already applied for more extended periods in different industrial sectors, like for the production of drinking water and process water, concentrating products and the treatment of waste water. Membrane processes have – depending on the pore-width - lower or higher selectivity. Dense membranes that are used for reverse osmosis (RO) remove more or less all pollutants. RO results in very clean water but leads to the production of a concentrate that is difficult to reuse.

An overview of the technologies is given in the table below. In this table also technologies to adjust pH or remove iron and manganese filters are listed. These are not meant for nutrient removal, but important for the control of pH and hardness of the water. In paragraph 3.10 other nutrient removal technologies are discussed, most biological treatment, focusing on the treatment for discharge to the surface water or sewer.

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Table 2-10. Existing treatment technologies for optimizing water quality (focus nutrients)

Existing technologies	Restrictions	Development phase	Potential to solve the problem
Iron or manganese removal			
Iron/manganese filter	Good design and operating practices needed	Commercialised	Yes, specific for iron and manganese
Zeolite filter	Low capacities, low concentrations. Expensive	Commercialised	Yes for small capacities
Nanofiltration	Fouling of the membranes, discharge of concentrates, limited separation	Commercialised for high capacities	Limited, low efficiency for small molecules, high costs at low capacities
Sodiumsilicate	Sodium is added to the irrigation water, only for salt tolerant crops	Commercialised	Salt tolerant crops
Fouling prevention of membrane systems applied for desalination			
Pretreatments by particle removal	See par 3.3		
Add chemicals to the water		Commercialized	Yes, to prevent fouling of desalination installations
Reduce concentrate production			
Reverse Osmosis	Fouling of the membranes, discharge of concentrates, low selectivity, complicated to operate for growers	Commercialised	Yes, for not too polluted feed water, otherwise pre-treatments required
Nanofiltration	Fouling of the membranes, discharge of concentrates, limited separation	commercialised	Limited, low efficiency for small molecules
Ion exchange and Modified Ion exchange	Hard to control of regeneration, some selectivity possible	IX Commercial, MIX Development, first tests in practice,	Yes, partly
Electro-dialyses	Fouling, selectivity possible between 1 and 2 valued ions	Development, Field test, Commercial in other sectors	Yes, partly
Capacitive Deionisation	Fouling, energy costs, low selectivity, more effective for low concentrations	Commercial in other sectors	Limited, In development
Membrane Destillation	Energy costs when no waste heat is available, no selectivity	Pilot tests	Yes
Forward Osmosis	The need of concentrated salt	Development	Yes, for further concentrating. Possibly to combine with RO
Increase selectivity			
Ion exchange and Modified Ion exchange	Hard to control of regeneration, some selectivity possible	IX Commercial, MIX Development, first tests in practice,	Yes, partly

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3.2.5 Analyses of bottlenecks and gaps

An overview of the gaps concerning the production of good chemical quality of water is given in table 2-2

Table 2-11. Overview of the gaps in the production of a good quality of water

Bottleneck	Techn	Reg.	Soc.	Description
Operating problems de-ironisation systems	x			De-ironisation is a conventional technology, however good control of the system is needed. Costs and footprint (m²) can be a problem and also the disposal of iron sludge
Fouling of membrane systems applied for desalination	x			Membrane systems, like Reverse Osmosis, Nano-filtration, Electro-dialyses, Membrane Distillation are sensitive for fouling. Often a pre-treatment is needed for prevention of fouling. Precipitation with poorly soluble salts can cause fouling. Lowering the pH can solve this problem.
Limited selectivity: Accumulation of sodium, chloride and other harmful ions limits reuse of concentrates.	X			For closing the cycle, separating technologies are used, splitting the streams in a clean stream and a concentrate. For the reuse of the nutrients in the concentrate other components have to be removed. There is a need for selective removal of sodium, chlorides and other ions from the concentrated nutrient stream.
Water quality threshold values for different crops are not always available or known?				Although many threshold values are known for crops, farmers are not always aware of this knowledge. The sensitiveness of crops for sodium and chlorine results in different -sometimes less stringent- demands for nutrient removal.
Discharge of concentrates of desalination		X		Most of the desalination technologies are concentrating technologies. Besides clean water, a concentrated (salt) stream is produced (5 to 20 % of the original volume) that has to be disposed of. This causes environmental problems and/or is limited by regulation. By Modified Ion Exchange (MIX) the reuse of the concentrates might be possible (see also section 3.10).
Accumulation of harmful (organic) components limits re-use of concentrates.	x	x	x	There is a need for technologies that selectively remove ions. At the same time, these technologies also remove PPP. For reuse of the concentrate, this might not be needed. A more holistic approach can be useful, both from a technical and economical point of view
High costs of nutrient removal			x	In comparison to the (low) water and nutrients costs, the treatment costs for reuse are high (long pay-back time). Possible solutions are: - standardisation - production of reusable side products - the use of mobile installations.
No or no uniform regulation for water (and nutrient-) re-use		x	x	There are no European rules for the reuse of water and nutrients in agriculture. A revision of the EU Fertiliser Regulation is pending.

The gaps mentioned in the table above can partly be solved by general measures, like good operating practices (e.g., for de-ironisation), standardisation and prevention.

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The most significant remaining gaps for nutrient removal are:

1. Fouling of membranes need for more insight in fouling processes
2. Insufficient selectivity for sodium removal and crop protecting agents
3. Insufficient insight into the water quality demands
4. Technologies for further treatment of brines and concentrates
5. High costs of the systems
6. Uniform regulation on EU level

1. Fouling of membranes (and other systems)

Fouling of the membranes is a very general problem when applying membrane processes. Often a pre-treatment step is carried out. Lowering the pH can as well offer a solution. However, in many cases, the origin of the fouling is not known. It might be useful to look more specific to the fouling problems about the water sources to be treated. Also, other systems like Ion-exchange can be sensitive to fouling.

2. Insufficient selectivity

The possibilities to selectively remove sodium from nutrient rich streams are limited. For membrane processes, there is a need for more selective membranes or more selective resins in case of ion exchange. With modified ion exchange (MIX, TD 6.10) it is possible to create some selectivity, for Na and K also in combination with the regeneration. Also, the selective removal of salts and not of crop protection agents are not always possible. For the recirculation of water, it can be important not to remove the PPP components but remove other components. With NF (f.i. used in the Poseidon technology) the nutrients in the drain water can be concentrated, but - as NF has very low retention for Na - this will not be concentrated and remain in the permeate.

3. Improved insight into water quality demands needed

As mentioned, growers are not always aware of the quality demands and choose “high quality water” for being at the safe side. This leads to a too far going treatment of the water and removal of the nutrients. Also, crops that can grow at higher sodium levels can be discussed within this framework.

4. Technologies for further treatment of concentrates and nutrient recovery

The application of separation processes leads to concentrates with high salt content. In general, membrane technologies produce 80-95% of desalinated water and 5-20% of the concentrated solution. It is often costly to further concentrate these streams or selectively remove components to make re-use of the salts as fertilizer possible. Technologies for further concentration, like membrane distillation, re limited and costs are often high due to high energy costs, high material costs or other specific equipment conditions (Jurgens et al. 2011).

Recovery of nutrients from the concentrated solution might improve the cost benefit ratio of these technologies. As far as known by the authors, there are no commercial installations available as far that provide this recovery step.

5. High costs of the systems

The payback time for water treatment equipment is often extended due to low water en nutrients costs and related low profits. This, however, strongly depends on the water sources. If (cheap)

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groundwater is available the benefits are low, if the grower has to use city water, the situation is different. Possible solutions are:

- standardisation, building cheap, simple installations of e restricted number of capacities
- production of reusable side products
- the use of mobile or collective installations: as the volume of the water to be treated is rather low for most of the growers, more growers can share the costs of the treatment by collective installations of a bigger scale (economy of scale) or using a mobile installation, more growers use that. The disadvantage is the need for transport and or storage.

6. Need for uniform regulation

The EU guidelines are not always implemented in the same way in the different countries, what makes it sometimes difficult to come up with standard measures.

7. Lack of awareness of water treatment costs of the growers

Besides the lack of knowledge regarding water quality threshold values, growers are often not aware of the techniques that are available and the actual price, payback time of the systems. For these reasons, they are on beforehand regarded as not applicable in their situation and/or too expensive

3.2.6 References for more information

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3.3 Optimizing water quality - Removal of particles

3.3.1. General description of the problem

The presence of particles in water can cause problems in the preparation of irrigation water, the re-use of water and sometimes in the discharge of water (to the sewage system or surface water). The quality of the water source applied for irrigation is therefore essential, even more in case drip irrigation is applied. As indicated by the FERTINOWA benchmark survey, growers make frequent use of ground water. Still, 60% of the surveyed farms apply to ground water to irrigate their crops. In general, ground water does not contain many particles, but as soon as the water is pumped up for irrigation, partial oxidation of iron might occur. This leads to precipitation of the iron as iron hydroxide ($Fe(OH)_3$). Rainwater is by far the optimal source to use, but water scarcity is often a limiting factor.

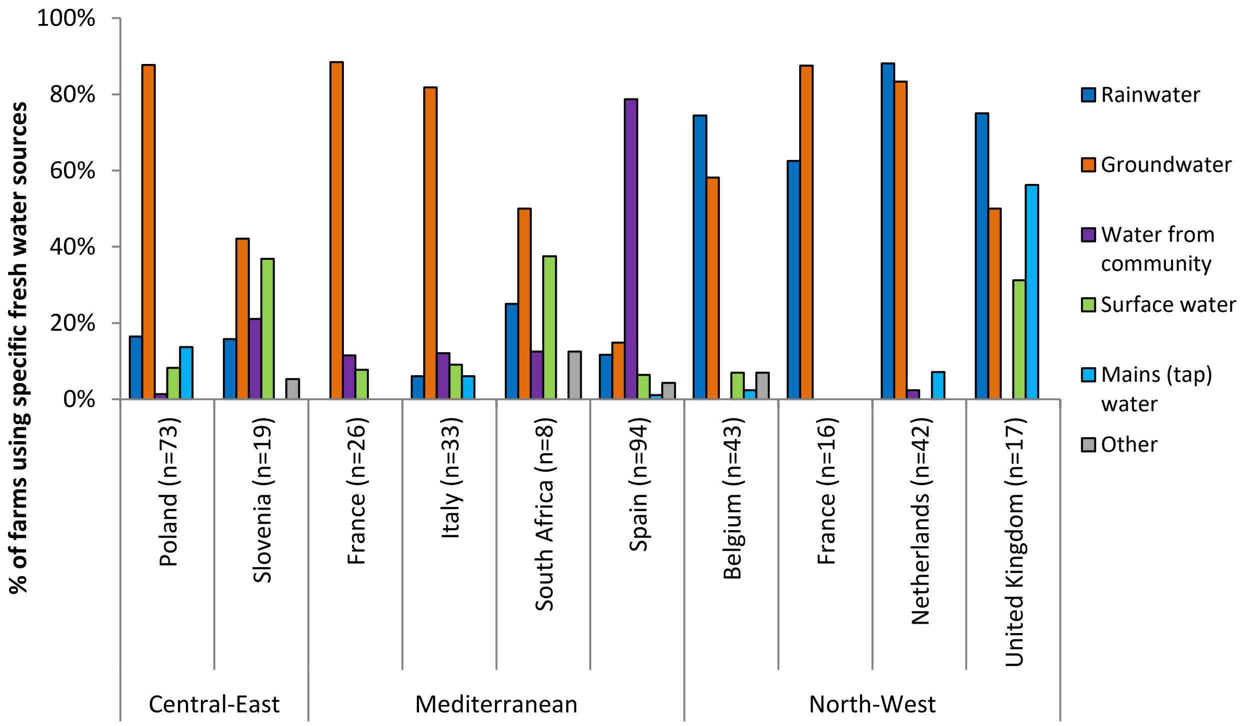

Figure 3-8. Type of fresh water source applied in each country. The number in the parenthesis indicates the number of farmers interviewed in each country (n)(Other refers to desalinated water and disinfected urban wastewater)

Rainwater harvested from larger surfaces, such as greenhouse rooftops, might contain higher amounts of sediments, mainly disposed of by the wind. The FERTINNOWA survey revealed that respondents all over Europe experience problems related to sediment disposal in their water storage, although to a lower extent compared to algae problems and insufficient water storage capacity.

Also, water originating from rivers or natural ponds is used as a water source. These sources contain higher concentrations of sediments.

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In general, removal of particles present in irrigation water is a fundamental requirement for drip irrigation to avoid clogging problems. Taking into account the small size of the dripper outlet, irrigation uniformity can be reduced, provoking a decrease of water and nutrient use efficiency and crop yield. As a general rule, it is recommended to install a filtration system behind the fertigation equipment with a maximum gap size of 1/10 of the dripper outlet.

Particular attention must be paid to closed soilless growing systems using organic substrates. Drain water tends to contain organic particles and can be discoloured, causing interference with some disinfection techniques such as UV disinfection. Growing on organic media like coco or peat poses a problem as the particles will drain through the substrate together with the fertigation water. These particles will colour the drain water and influence the light transmission of UV disinfection.

The main problems are:

1. Use of water source containing particles that can clog up dripping lines

In horticulture, water is the basis of the cultivation. The sources can vary from country to country and from farm to farm. Rain water is, without doubt, the best choice as a water source. Rain water contains no to very low concentrations of salts and floating particles. However, growers are dependent on the quantity of precipitation. Ground water is also a favourable source that is clear from particles. Water coming from rivers or ponds, however, can contain sediments when used as fertigation water. These impurities can cause obstructions in irrigation lines like drippers. Such obstructions will lead to heterogeneous irrigation patterns and plant loss caused by dry substrate or soil. Filtration steps to clear the water from organic material like leaves or sandy substances become a necessity in this case.

Figure 3-9. First drain water of a rock wool slab (left) and a coco slab (right) (source: Telen zonder spui, 2013)

2. Particles clog up filtering/disinfection devices

Drain water from horticulture using organic substrate often contains an appreciable amount of organic particles. In case recycling of the drain water is applied, commonly the drain water undergoes a disinfection treatment. Disinfection units require that the drainage water supply not contain particles. As such the unit (UV) can function optimally and continuous backflushing (filter

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techniques) is prevented. Commonly used filter techniques for horticulture are sand filtration and bio-filtration and ultrafiltration. Both of these techniques filter out most diseases and produce water usable for horticulture. Particles will remain in the filtering agent (sand or membranes) and start clogging up the filter device. Especially in cultivations with organic substrates, particles will quickly clog up the filtration unit, with increased back flushes as a result. Back flushes limit the filtration capacity and have to be avoided as much as possible.

3. Floating particles interfere with the transmission rate of drain water

Particles and especially fine particles can also darken drain water and will interfere with the efficacy of UV-disinfection. The water to be disinfected flows through the UV chamber. Bacteria, fungi, and viruses exposed to the UV radiation will be eliminated when sufficiently exposed to the UV light. Water with low transmission will limit the disinfection capacity of the UV-unit. It obligates the grower to apply a lower flow rate of the drain water through the UV disinfection unit. Also, multiple cleaning rounds will become necessary to keep the lamps clean and effective in the eradication of pathogens. The supplier of the equipment gives a minimum UV transmittance. UV treatment is highly dependent on water clarity (T10 value). Particulate matter suspended in the water causes shadows, while the particles can also carry pathogens. Therefore, pre-filtration with for example sand- or screen filtration is necessary. Particles should not be bigger than 25 µm, and the maximum quantity of particles should not exceed 5 mg/L.

4. Flush water with nutrients and/or pesticides cannot be discarded

Many systems used for the removal of particles generate backflush water containing nutrients and/or pesticides; the grower is required to collect this water and process it according to legislation. The benchmark survey showed that back flushing is the most common method applied to clean filters (applied by 65% of the surveyed Central Eastern growers and 70% of the North Western growers. The benchmark revealed as well the influence of the national or regional legislation. In the North West region, 33% of the respondents are recycling the back flush water while this does not occur amongst the respondents in the Central Eastern region. 72% of the NW respondents faced external controls regarding discharged water while this was only 12% for the CE respondents.

3.3.2. Brief description of the socio-economic impact

In general, groundwater is still the most applied water source for irrigation practices. The FERTINNOWA survey confirmed this as still 60% of the surveyed farms uses ground water to more or less extend to irrigate their crops. In general, ground water does not contain many particles, but as soon as the water is pumped up for irrigation, partial oxidation of iron might occur leading to precipitation of the iron as iron hydroxide (Fe(OH)3). In many cases filtration is required to remove the precipitate.

In North-West Europe, growers made use of the large quantities of precipitation and started to collect the rain water as a primary water source. This water can contain particles that were washed down from the collecting rooftops. However, problems related to sediments in stored water were reported by a minority of the surveyed growers. Other regions in Europe are not able to collect a sufficient amount of rain water to use it as a primary water source. Water coming from rivers is sometimes the preferred option. With a simple filtration step, the quality is sufficient to be used in several cultivations.

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However, the benchmark survey showed that amongst ther respondents there is a general tendency to apply alternative water sources like rainwater or mixed water that is provided by irrigator communities. In Spain, the majority of the farms (79%) applies irrigation water provided by irrigators communities8 as a primary water source. The water provided by these irrigators communities can be composed different sources like groundwater, rainwater, surface water, and in some cases desalinated water. In Belgium, the Netherlands and the United Kingdom, rainwater was the primary water source for irrigation (77%). Other water sources like surface water (9%), mains tap water (7%), desalinated or disinfected urban wastewater (2%) are implemented only by a minority of the surveyed farms.

The growing tendency towards closed or semi-closed growing systems is expected to pursue in Europe. The FERTINNOWA survey revealed that reducing nutrient inputs, saving water, complying with legislation and reducing environmental impact were the main drivers for recycling drain water. When growers were asked what kept them from recycling drain water, 66% of the respondents indicated the high (investment) costs as the main barrier followed by the risk for spreading of diseases (31%). However, when growers were asked about the cost of filtration per m³ of filtered water at their farms only exceptionally growers could provide an answer (Figure 1-3.

In the case UV-disinfection is applied, a pre-filtration is required to remove all particles exceeding a size of 25µm. In general, a fast sand-filter is applied for this. In case around 20-30m³ of water has to be treated per day, the cost of UV infection would amount around 0.47€/m³, while the cost of the sand filtration amounts 0.26€/m³. However, as well the savings in water and fertilizers should as well be taken into account when calculating the cost-benefit ration, amongst additional investments like gutters, pumps, storage equipment.

3.3.3 A brief description of the regulations concerning the problem

There are no specific regulations to counter the presence of particles in horticultural water. There are, however, regulations regarding the presence of particles when water is discharged towards sewage or surface water. In case of back washing of the filters, this water can contain higher concentrations of floating particles (for example sand filters, de-ironisation installations). Moreover, discharging wash water of filters might harm regulations towards nutrients and pesticides 51.

European level

As far as known be the authors, there are no specific EU regulations regarding the presence of floating particles in the discharge water.

Country level

[8] The irrigators communities can be defined as a grouping of all the owners of an irrigable zone, which are bound by law, for the autonomous and common administration of public waters, without profit motive. A concession of water is granted to that specific area of irrigable land. These organizations are institutions with a long historical tradition, they have their origin in associations governed by systems and rules of the Romans and Arabs (such as fraternities, unions, boards, unions, etc.) equipped with an organization that allowed the administration and distribution of water for irrigation of crops.

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Towards the discharge of horticultural waste water, Member States have set up specific regulations. As an example: the presence of floating particles in the discharge water.

Examples:

1. In Flanders, the Flemish Environmental Regulation (VLAREMII) sets a limit of 60mg/l of floating particles or 0.5ml/l settling substances[9].
2. In Bologna, Italy, the limit lays on 80mg of floating particles when discharged on surface water [10].

Regional level

At regional level, no specific regional regulations are in force.

3.3.4 Existing technologies to solve the problem/subproblems

Table 3-1 provides a non-exhaustive overview of the technologies to remove particles from water streams.

Table 3-12. Overview of existing technologies for removal of particles

Existing technologies	Restrictions	Development phase	Potential to solve the problem
Sieve bend screen filtration	>150µm - >5 mm, waste	Commercialized	Yes, high capacities possible (36-1000m³/h), coarse filtration
Hydrocyclone	Heavy particles (sand), > 50µm, waste	Commercialized	Yes, high capacities possible (2-360m³/h)
Automatic cleaning filters	10-800µm	Commercialized	Yes, a limited amount of wash water, 7-400m³/hr
Sand filtration	10-800 µm Bach wash waste	Commercialized	Yes
Disc filtration	55-400µm, 0.2-30m³/hr per disc filter, back wash waste	Commercialised	Yes
Rapid sand filtration	>30-50µm Back wash waste	Commercialized	Yes
Band filtration	Determined by maze width min. 5-10µm, paper band waste, 2-50m³/hr	Commercialized	Yes
Cloth filtration	Min. 5-10µm		Yes, high capacities possible (10-570m³/hr)
Drum filtration	min. 5-10µm Back was waste	Commercialized	Yes, high flow rates possible (10-3000m³/hr)
Microfiltration (+ UF)	Fouling, 0.1-10 µm, sometimes prefiltration necessary	Commercialized	Yes,

[9] Source: https://navigator.emis.vito.be/mijn-navigator?woId=21204 **Settlings substances are particles that sediment within a time span of 2 hours.**

[10] **Source: For Italy, region of Bolgona valori limiti di emissione in acque superficiali e in fognatura** D. Lgs 152/06 (Parte terza, Allegato 5, Tabella 3.)

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	Costs, energy, Concentrate		
Ultrafiltration	Up to 0.01µm, pressurized flow required, back wash water/concentrate, sometimes prefiltration necessary	Commercialized	Yes

3.3.5 Analyses of bottlenecks and gaps

In table 3-2 an overview is given of the main gaps about the removal of particles

Table 3-13. Overview of the gaps for removal of particles

Bottleneck	Tech.	Reg	Soc.	Description
Production of filter waste		x		All filtration devices produce a waste product: highly concentrated water (the effluent), solid waste, strongly polluted filter paper. These waste products need to be discarded/processed according to the national legislation.
Prefiltration requirements	x			Some disinfection devices require very fine pre-filtration. Otherwise, continuous back flushes will occur due to clogging up, limitting the filtering capacity.
High costs of filtration techniques			x	In case very fine particles need to be removed, the costs for filtration might be considerable. Filtration devices, as well as pumps and consumables, will strongly increase the total cost. As a comparison: the costs per m³ filtered water through microfiltration are estimated at 0.80€/m³ and 0.89€/m³ in case of ultrafiltration. Filtration through a fast sand filter would cost around 0.26€/m³ (Watertool). However, filtration is needed for successful disinfection and/or to avoid clogging up of the fertigation system in the crop.

All the filtration solutions listed in chapter 52 result in a waste product. In most cases, this is filthy water originating from back flushes. In case of fast sand filters, the back flush volume amounts 1.5 to 5m³ per back wash treatment depending on the settings and scale of the installation 51. Automatically cleaning filters require only some liters of wash water. In this way, the amount of reject water is significantly reduced. Water from back-flushes needs to be treated before discarding by nutrient removal and pesticide breakdown. Some growers choose to recollect the back flush water in the dirty drain silo sometimes after a previous sedimentation step.

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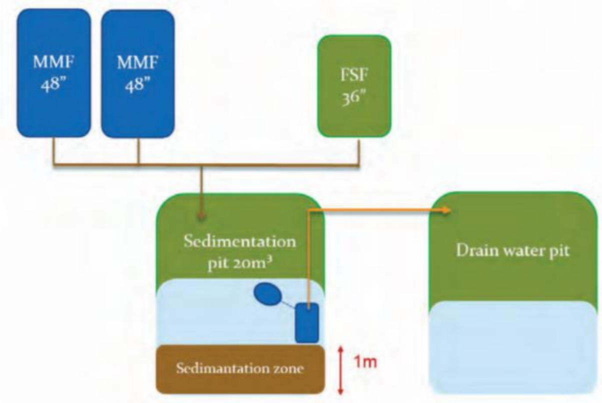

Figure 3-10. Setup of recycling of the wash water of 2 multimedia filters (MMF) and 1 fast sand filter (FSF) for a 3ha greenhouse in Flanders. Sedimentation occurs during 20houres after which the wash water is pumped to the dirty drain pit. In the sedimentation pit, a minimum level of 1m is maintained (Berckmoes et al., 2013).

Besides, reject water, it can also be a soiled paper band or organic substrate contaminated with fungal spores and nutrients. Techniques such as the sieve bend filter, hydrocyclone, and drum filtration only have particles as a waste product. Whatever the waste product is, the grower has to get rid of it. Still, growers are in need of techniques that will eventually remove all contaminating substances in the closed water system (for example the paper band filtration).

Figure 3-11. Paper band filter (source FERTINNOWA)

If the waste product is pure soil/organic material (a.o. via sieve bend filtration), the waste product should be tilled into the soil. In the majority of cultivations, the waste product will contain nutrients, and pesticides Micro-organisms and nutrient catching crops can deal with the environmentally burdening elements in the waste product.

However new techniques are needed in horticulture to remove the finer organic particles (<5µm) generating a waste product that only consists of the impurities in the filtered water.

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3.4 Optimizing water quality: Removal of algae

3.4.1 General description of the problem

Eutrophication is the process of nutrient enrichment enhancing the growth of particular species in an ecosystem. Aquatic ecosystems have evolved in conditions of very low nutrient concentrations. The addition of nitrogen (N) and/or phosphorus (P) originating from intensive agriculture changes the ecological balance, promoting the rapid growth of certain species. In freshwater systems, N is usually the nutrient that limits the growth of algae the most. In saline aquatic systems, P is usually the most limiting nutrient. Additions of N in freshwater systems and P in salt water systems provoke the rapid growth of algae on the water surface, known as “algal blooms.” Algal growth can have direct effects on the ecosystem through reduced light penetration and changed species composition. Additionally, toxins produced by the algae can be toxic to aquatic and mammalian species. Following the death of the algae, the subsequent decomposition of its biomass can consume much of the oxygen in the water resulting in conditions of low dissolved oxygen, known as “hypoxia” or negligible dissolved oxygen, known as “anoxia”(Fertigation Bible).

Lower oxygen levels of irrigation water can lead to the formation of nitrite formulations which can be toxic to plants. Besides, algae can lead to clogging of irrigation systems (drippers), which requires additional filtrations and therefore, investments.

Amongst the surveyed farms, the presence of (micro) algae was identified as the primary problem related to water storage. Growers reported problems related to algae in almost all the surveyed countries. Algae blooming can be associated both with the water source (nutrient content) or the water storage conditions (exposure to light). In the benchmark survey, the presence of (micro) algae was reported to be the main problem related to water storage. Growers from all surveyed regions experienced algae bloom as problematic. As an example, 29% of the Belgian respondents reported facing algae problems, mainly in cases where rain water was stored in uncovered storage facilities. In Spain, 24% of the respondents reported facing algae problems, mainly related to water from irrigation communities or stored water. The FERTINNOWA survey showed that respondents applied a broad range of technologies and practices to prevent or treat algal blooms (Figure 4-1). However, only a few respondents are satisfied with the achieved results.

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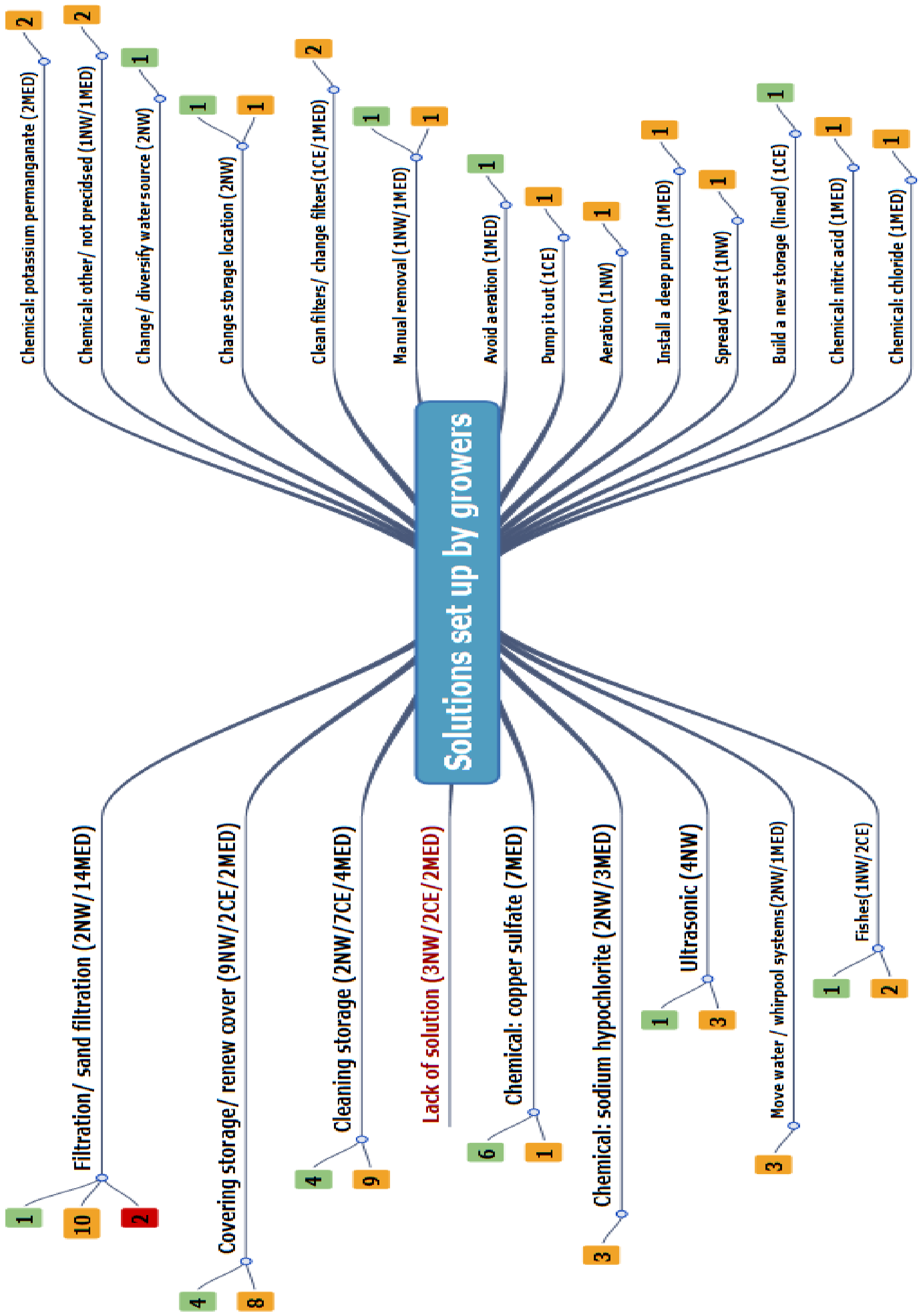

Figure 4-12. Solutions set up by growers to avoid algae proliferation in their water storage. The colored figures indicate the growers' satisfaction rate (green: satisfied to very satisfied, yellow: moderate satisfied, red: not satisfied). The numbers in the coloured squares reflect the number of growers per satisfaction rate.

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Explanations for the lower satisfaction rate of growers regarding algae prevention and treatment can be linked to the following observations:

1. Lack of growers' awareness of the working principles and side effects of the applied technologies or practices.

As shown in figure 4-1, the surveyed growers handle a broad range of technologies and practices to prevent or treat algae blooms. Firstly, some of these technologies or practices might have significant disadvantages explaining already the various satisfaction rating from the benchmark survey. Growers seem not always to be aware of the required labour, the economic value of the removed water…

Some examples:

1. Addition of chemicals has a short term effect, making repeated treatments necessary.
2. Placement of limestone at the bottom of the reservoir requires water removal during winter.
3. *Daphnia spp*. promotes a high risk of filter clogging.
4. Water movement through pumps or fountains only has a local effect. To move all the stored water, many pumps would be required.
5. Addition of food colorants such as Blue Dye will colour the stored water. Colouring the water might require a mind shift of the grower but might as well influence the transparency of the water in this way affecting the efficiency of for example UV disinfection.

Secondly, technologies might not always be implemented correctly. As an example, the position in the water storage is essential for an ultrasonic device to reach the maximal efficiency of the technology.

There is a need to inform growers of the proper implementation of the devices, the working principle, operational conditions, side effects etcetera.

2. Need for low cost long term algae control tools

Covering of the water storage is seen as the most efficient long-term practice to prevent algae blooms. The costs of the roof over water storages vary from €6 to €40 per m². These costs are the main barrier that keeps growers from implementing this technology.

3. Lack of practical experience regarding biological ways to prevent or treat algae

In literature, control and prevention of algae by use of biological measures like bacteria and water fleas is well described. However, field tests and practical guidelines are missing or have contradictory results. Moreover, some of the natural algae control agents, like for example water fleas *(Daphnia spp*.), cause filter clogging.

4. Legal restrictions regarding some interesting algae control tools

In case of algae control through chemicals, fish, bacteria, blue dye etcetera, some regulatory restrictions occur. As an example, not all fish species are allowed for this purpose in the different Member States. The same occurs regarding the use of blue dye food colorant and bacteria preparations. Although blue dye meets the European Food Additive regulations and uses European

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Food Approved Colours, it is not clear if it can be applied as a water treatment/algaecide in all Member States. Moreover, not all chemicals can be applied in the different Member States as there might be a legal restriction.

3.4.2 A brief description of the socio-economic impact of the problem

Algal bloom in irrigation ponds causes clogging problems in the fertigation system, with increased maintenance cost as a result. If uniformity of water and nutrient use is reduced due to clogging, crop development will negatively be affected leading to production and/or quality losses.

Additionally, some technologies for algae control, such as the covering of the storages, have a significant cost. Unit costs to cover the water storage can vary from €6 to €40 per m². To avoid light exposure of the water, 25% of the survey respondents treat algae blooms by covering their water storage. Although the satisfaction rate for covering the water storages was good to moderate, some growers see the cost as a serious barrier. Growers, therefore, are searching for alternative ways.

One of the alternatives to restrain the algae population is biological algae control. Hereto plants, fish, and bacteria are added to the pond. In the south of Spain, for example, growers install floats covered with plants to prevent algae blooms and to improve the average water quality.

3.4.3 A brief description of the regulations concerning the problem

To tackle algal bloom, several applications are subject to legal restrictions.

European level

Chemicals:

On the European level, the use of chemicals as algaecide is subject to the European Biocide Directive 98/8/EC.

Another European legislation, the EU Drinking Water Directive 98/83/EC, provides a maximum level of certain chemical elements (e.g., the threshold for copper is 20µg/l).

Country level

Although the use of chemicals as algaecide is subjected to the European Biocide legislation 98/8/EC, each member State can request further restrictions for the use of specific active ingredients. In Flanders, for example, it is not allowed to use copper as an algaecide.

Several Member States, like the Netherlands, focus on the PNEC[11] and MAC[12] values. The MAC value of copper, for example, is 200µg/l.

In case of algae control by fish and blue dye, some regulatory restrictions occur. Not all fish species are allowed for this purpose in the different Member States. The same counts for the use of blue dye. Although blue dye meets the European Food Additive regulations and is a part of the European

[11] PNEC: predicted no-effect concentration. This is the concentration of a chemical which marks the limit at which below no adverse effects of exposure in an ecosystem are measured.
[12] MAC: maximum acceptable concentration

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Food Approved Colours, it is not clear if it can be applied as a water treatment/algaecide in all Member States.

Regional level

No specific topics

3.4.4 Existing technologies to solve the problem/sub-problems

1. Tools for monitoring and identifying algae

To increase the grower's satisfaction rate for technologies preventing and treating algae, it is essential to know which algae species are present in their storage. Therefore, growers should firstly monitor the algae presence. The type of algae is a decisive factor in selecting the appropriate technology or practice to treat and prevent algae bloom.

When actions are taken to treat algae bloom, the effect of these measures should frequently be monitored. In case the actions only lead to a low or moderate satisfaction, the algae species should be determined again. Although these technologies are all commercially available, they are only exceptionally implemented by growers.

Table 4-14. Existing technologies to monitor and identify algae

Existing technologies	Restrictions	Development phase	Potential to solve the problem
Physical methods			
Secchi disk	Quantitative check measures the amount of algae.	Commercial available	High
Test kits and laboratorial analysis			
Laboratory analysis	Quantitative and qualitative check	Commercial available	High
Chlorophyl measurements	Quantitative check measures the amount of algae.	Commercial available	High
Continuous chlorophyl measurements in the water storage	Costs are high for smaller water storages(company level), more feasible for large water storage ponds	Commercial available	High
Bio-detectors	As an example, Bart™ test for algae. Semi-quantitative and qualitative check measures the amount of algae divided into 6 types of algae	Commercial available	High

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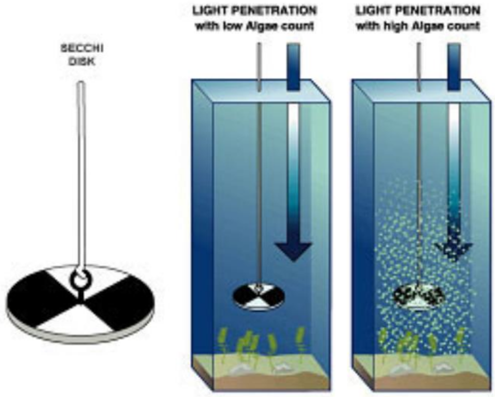

Figure 4-13. Applying a Secchi disk to measure water transparency.

Source:https://www.minneapolisparks.org/park_care__improvements/water_resources/lake_water_resources/loring_pond_water_resources/

2. Tools for long-term algae control

A major group of the actions taken to prevent or treat algae blooms is focussed on the addition of chemicals. In Table 4-15, a non-exhaustive list of the chemical treatments is provided. As mentioned already, the addition of chemicals will only have a temporal effect and will require frequent additions. Also, there might be a risk for phytotoxic effects of the added elements towards the crops from irrigation water. Also, precipitation might be formed and therefore requiring a filtration step before irrigation occurs. Finally, risk towards the environment are prevailing.

Physical methods mainly focus on water movement, obscuration, and ultrasonic sound.

Table 4-15. Technologies to prevent or treat algae on a long term

Existing technologies	Restrictions	Development phase	Potential to solve the problem
Chemicals:			
Phosphorus fixation	Temporally effect, frequent additions required, precipitation formed.	Commercially available	Medium
Lowering the pH	Temporally effect, frequent additions required the risk for the phytotoxic effect to crops.	Commercially available	Low
Dissolved copper	Temporally effect, frequent additions required, environmental impact, not compatible with fish	Commercially available	Low, short term effect
Hydrogen peroxide	Short term effect, frequent additions required, might harm water storage	Commercially available	Low, short term effect
Ammonium	Temporally effect, frequent additions required the risk for the phytotoxic effect to crops.	Commercially available	Low
Liming ($CaCO_3$)	Removal of the water is required in case lime is placed on the bottom of the storage, hydrated lime is extremely corrosive	Commercially available	Medium, but the loss of water.

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Existing technologies	Restrictions	Development phase	Potential to solve the problem
Water movement			
Covering water storage	Costly, especially for larger water storages.	Commercially available	High
Food dye colorants	Unclear if food colorants can be applied in all EU Member States. Side effects towards plant health?	Commercially available	Further research required
Ultrasonic sound	Ultrasonic devices only work in the scope of 180°; multiple devices might be required to cover the complete storage, energy supply required, aquatic plants might negatively influence the devices efficiency	Commercially available	High
Biological methods			
Dapnia spp.			
Fish	Legal restrictions in some Member States?	Commercially available	Moderate - high
Straw bales	Straw might contain residues of plant protection products.	Commercially available	Low-Moderate
Bacteria and enzymes	Legal restrictions in some Member States?	Still in test phase	Further research required
Water movement	Limited capacity, multiple pumps required, floating particles might clog filters	Commercially available	Low

Figure 4-14 Installing a floating cover for a rain water storage.

3. Lack of practical experience regarding biological ways to prevent or treat algae

In literature, different biological algae control measurements are described. Depending on the mode of action and the water quality the effect of these bacteria varies from short to long effect. In general, these bacteria require specific water quality settings.

In the past decades, biological control methods for algae prevention or treatment have been described. In scientific literature, Daphnia *spp.* showed to be effective to treat small algae species. Moreover, specific water settings were required to achieve sufficient effect of the *Daphnia spp.* In case *Daphnia spp.* populations grow excessively; filters might clog.

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3.4.5 Problem/ sub-problems that cannot currently be solved currently: GAPS

There is a need to inform growers about the working principles and expected efficiency of the available tools and practices. The focus should as well go to the economic feasibility of the technologies. FERTINNOWA's Fertigation bible offers already an overview of a broad series of listed technologies to treat or prevent algae blooms.

1. Tools for monitoring and identifying algae

Physical methods, such as the secchi desk are available to monitor algae. Moreover, test kits and laboratorial analyses are commercially available to monitor and identify the algae species. However, these technologies are rarely implemented by growers. Demonstration of these technologies and their importance might increase the implementation rate of these test kits and analyses.

2. Tools for long-term algae control

As shown in the previous section, additions of chemical compounds to treat algae blooms have only a short term effect. Therefore, repetitive additions are required which imply extra labour and close monitoring of the algae development in the storage. Moreover, additions of chemicals might imply risks towards the irrigated plants (phytotoxic effects), workers and the surrounding aquatic life. Locally concentrated additions of chemicals might harm the foils.

Therefore, there is a need for alternative tools that have a long-term effect.

Physical methods might offer some possibilities. Covering the water storage is seen as the most effective technology to prevent algae blooms. Covering water storages through fixed or floating covers amounts €6 to €40 per m² and is considered as too costly for large scale storages.

Obscuration through food colorants, like for example blue dye might be an option, but implementation of these colorants implies:

- A mind shift of the growers as the water will be coloured.
- A clear overview of the legal possibility to apply food colorants in irrigation water
- Demonstration and research on the effectiveness and plant safety when food colorants are added to the irrigation water.

A broad range of ultrasonic devices is commercially available, but the experiences of growers vary significantly. Identification of the present algae species might be the first step to increase the efficacy of the ultrasonic devices as different algae species might require specific wave lengths. Secondly, the devices have to be adequately installed, and growers should be aware of the specific parameters that might influence its efficiency (for example the shape of the storage, the presence of water plants, vegetation of the banks …).

3. Lack of practical experience regarding biological ways to prevent or treat algae

Biological control of algae blooms by use of bacteria is reported in the literature. However, most experiences rely on laboratories trials or small-scale trials. A broad range of products based on bacteria and enzymes to treat algae blooms are commercially available, especially for the maintenance of small scale ponds in gardens. It is clear that for the control of algae blooms through

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bacteria and enzymes; the water quality needs to meet specific criteria. Experiences for larger scale water storages like present in the horticultural sector are few.

As a consequence, there is a need for long term demonstrations to evaluate the efficiency of bacteria and to investigate the economic feasibility of these products on a large scale.

Regarding algae treatments, we can conclude that:

1. There is a need for affordable technologies with a long-term effect. The current obscuration methods are efficient but too expensive, especially for large scale water storages.
2. There is a need for further investigation of the possibilities to implement bacteria and enzymes to treat algae blooms. As well the economic feasibility should be investigated here.
3. There is a need for further investigation of the possibilities to implement aquatic plants.

Table 4-16. Overview of the gaps for prevent or treat algae on a long term

Existing technologies	Technological/practical issues	Socio-economic issues	Legal issues
Coloring (Food blue dye)		Change of the mindset of the growers. Coloring the water? Environmental impact?	Legal restrictions in some European MS
Fish			Legal restrictions in some European MS
Bacteria and enzymes	Need for field tests Need for risk assessment plant/food safety	Request mental change of the grower. Changing “clean-empty” water storage to a “biological system.”	Legal restrictions
Aquatic plants	Insufficient experience with aquatic plants on a large scale	Request mental change of the grower. Changing “clean-empty” water storage to a “biological system.”	

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3.5 Optimizing phytosanitary quality of water

3.5.1 General description of the problem

Irrigation water can act as an inoculum source or dispersal mechanism for diverse biological problems including plant pathogens like *Pythium species, Phytophthora species, rhizogenic Agrobacterium*, algae and biofilm producing organisms 69). This can lead to serious crop damage or yield losses in both soilbound and soilless crops.

The phytosanitary water quality is determined on the one hand by the water source, being used and on the other hand by the design and maintenance of the irrigation network including water treatment technologies installed. Due to water scarcity there is a general pressure to use other water sources that are possibly more polluted, such as disinfected urban wastewater.

The water source determines the extent to which new infections can be brought in and on. Plant pathogens and other microbes are particulary problematic when irrigating with surface water or recirculated water sources 69). Surficial water sources tend to have higher concentrations of microbes compared with well and municipal water 69). As an example, high numbers of rhizogenic *Agrobacterium* have already been detected in closed rainwater storage (Van Calenberge). Treatment of recirculated and surface water is needed to reduce the risk of crop losses caused by plant disease, and emitter clogging due to algae and biofilm build up.

In soilless cultivation systems recirculation is the best practice to significantly increase both water and nutrient efficiency and thereby reducing the nutrient discharge towards the environment 69). Optimizing and guaranteeing the phytosanitary and chemical (33) quality of recirculated water is key to assure optimal growing conditions for the crops.

Recirculation/reuse of water/nutrient solutions is of increasing importance as fresh water of good quality becomes more and scarcer.

The FERTINNOWA benchmark survey revealed that only 42% of the respondents with soilless growing systems recirculated all the drain water while 26% did not recycle any drain water. Figure 1 shows that there is a clear regional difference between the surveyed regions. Of the respondents with soilless growing systems, 25% reported to have experienced spread of diseases when recycling the drain water, making disinfection of the irrigation water essential.

1. Need for combined use of local and system-related disinfection methods

One of the main issues with disinfection is that in most cases, it is a point-disinfection. This means that irrigation water is disinfected at one point during its cycle around the irrigation system. The options for system-disinfection are limited when plants are present as most of the reactants can damage the roots when applied in too high concentrations.

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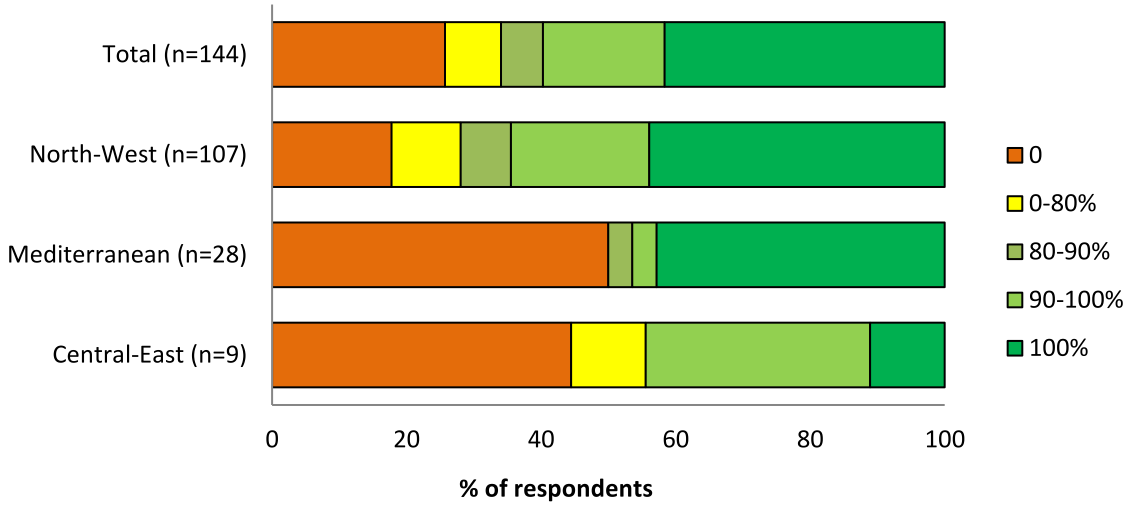

Figure 5-15. Levels of recirculation by the respondents in each region.

The irrigation network forms a suitable habitat (nutrients, pH, temperature ...) in which micro-organisms can grow. The use of this irrigation network therefore implies that a biofilm can easily develop on every horticultural company. A biofilm is a layer of micro-organisms attached to a surface, such as the inside of irrigation pipes, and surrounded by self-produced protection layer, so that bacteria are protected against disinfectants 69. Biofilms, however, may contain plant-pathogenic microorganisms such as *Phytophthora spp., Pythium spp., Clavibacter spp.*, etc. 69) which may end up in the irrigation water from the biofilm. When no action is taken against the development of this biofilm, large yield losses can occur due to infection of the plant with these pathogens. In the long term, the irrigation system, and in particular the drippers, can also clog through the biomass that is built up in the biofilms and loses in the irrigation system. The re-contamination of irrigation water from the biofilm is further enhanced by the reuse of contaminated drain water. A well thought-out approach, therefore, calls for a sustainable phytosanitary strategy to be developed.

A combined use of local and system-related products and techniques is appropriated here. Techniques such as UV, heat treatment, membrane filters have a local disinfecting effect. Once the water has made its way into the irrigation network after this disinfection step, a systemic disinfectant such as hydrogen peroxide, chlorine dioxide, and sodium hypochlorite is designated 69

As implicated before, the use of disinfectants can be risky as they can damage the roots and lead to loss of crops or reduced production. It is very important to know what the dose effect is on pathogens and biofilm but also on plants. To maintain the right concentration, reliable and payable monitoring and application techniques are necessary.

2. Need for cost-benefit analysis of the disinfection technologies

Presence of waterborne plant pathogens in the irrigation water can lead to serious crop damage or yield losses in both soil grown and soilless crops. Water born fungi, viruses and bacteria (for example *Fusarium* sp., *Phytophthora sp., Cucumber Green Mottle Mosaic Virus, Clavibacter, rhizogenic Agrobacterium*) pose a severe threat to the crop health 69). It is, therefore, more efficient to prevent these diseases from entering the irrigation system instead of treating them after the first crop symptoms or yield losses occur. Disinfection technologies can significantly contribute to improving

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the quality of irrigation water while saving costs when water is recirculated. Depending on the technology, investment costs can be high, but pay back times are relatively fast. The benchmark survey revealed however that growers estimate the initial investment costs to be too high. On the contrary, only few growers knew the costs per m³ of disinfected water at their own farm.

Part of the analysis should also be a risk analysis: what are the problems and potential damage that can occur when a grower chose for certain (combinations of) disinfection technologies or decides even not to disinfect?

In this risk analysis also the level of disinfection (effectiveness) and the formation of by-products should be integrated as this to a large extent determines the chance of serious damage. The risk analysis also could include the costs and benefits of additional measures to increase the effectiveness of the disinfection.

3. Need for a decision supporting system

Various disinfection technologies are available, in development or expected to be developed. The grower has to take a lot of things into account when deciding which technology or combination of technologies are best given the situation: potential phytosanitary threats for the crop, local circumstances, water source, the advantages and disadvantages/risks of the disinfection techniques, availability of technical support, costs etc. A good, up-to-date decision and of course objective supporting system could help to select the best technology or technologies.

4. Need for reliable and payable analysis of the sanitary quality of water

A good insight in de presence and development of hazardous (for plant and human) microorganisms but also beneficial microorganisms is important for the decision concerning disinfection but also to determine and monitor the effects of disinfection. Available DNA-analysis techniques are not accurate enough and/or too expensive for frequent use in horticulture.

3.5.2 Brief description of the socio-economic impact of the problem

Under the framework of the nitrate directive, water and nutrient discharge is strictly supervised. In some countries, it is forbidden for nurseries with soilless cultivation systems to discharge drain water to surface waters over a maximum nitrate limit. Therefore, disinfection of drain water becomes a necessity as it will support recirculation. But also in soil grown crops without circulation, disinfection can become necessary either to prevent infestations or to prevent dispersion within the farm or from farm to farm. Especially when surface water is used, the risk of dispersion diseases such as *Fusarium* in lettuce and carnation is high.

Currently, the following socio-economic issues could be listed regarding disinfection:

1. Risk-benefit: technological improvements should be reached without compromising crop yield and quality
2. Cost effectiveness: Depending on the technology, investment costs can be very high, but pay back times are relatively fast. The surveyed growers frequently reported they considered the initial investment cost for disinfection to be too high. In contradiction with this, only very

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few growers could answer questions regarding the cost for disinfection per treated m³ of irrigation or drain water.

3. Socio/ethical view: Recharge and reuse of drain water may be valuable to reduce environmental pollution and could contribute to reduce the consumption of irrigation water.
4. Human health: Disinfection technologies based on chorine can also be toxic to humans. When chlorine is exposed to organic matter, by-products will be formed such as chlorine vapours, chlorates, chloramines, etc. The chlorine vapours in particular present a direct danger of inhalation. Chlorates can be absorbed by the fruits and end up in the food chain in this way. As long as the MRL is not exceeded, this does not pose a direct health problem, but it remains a point of attention. On the other hand, disinfection can indirectly contribute to human health as it helps to keep the crop healthy and as a result of that reduce the use of PPP.
5. Awareness: growers are not always convinced of the use/benefit of a disinfection technology.

3.5.3 Brief description of the regulations concerning the problem

European level

With regards to phytosanitary, the EU has a framework where chemicals used for phytosanitary disinfection are classified (Harmonised Classifications, European Chemicals Agency). Chemicals used for disinfection like chlorine and sodium hypochlorite are listed under the Biocidal Product Regulation (BPR) EU 528/2012. The list – to be found on the website of the European Chemicals Agency (ECHA) – informs about the status (approved/under review) of active substances as well as the intended use (for example for treatment of drinking water or as disinfectants and algaecide not intended for direct application to humans or animals).

Relevant are also regulations (maximum residue levels) concerning the by-products of (chemical) disinfection like chlorate and perchlorate.

For equipment that produces substances on-site that are considered active substances also the systems have to be registered by the suppliers with a Letter of Access. This would be the case for ozone and advanced oxidation, which working principle is based on free radicals.

Country level

Countries rely on the regulations set by the EU. However, if a country wants to impose stricter regulations, they are free to do so. In France, it is not allowed to treat drain water with peracetic acid. Even retailers adhere to stricter regulations than EU wide or country wide.

Regional level

Within countries – for example Belgium (Flanders, Wallonia), Germany (federal states), United Kingdom (England & Wales, Scotland, Northern Ireland) and Spain (Navarra, Valencia, Andalusia, Extremadura) - differences in regulations exist.

3.5.4 Existing technologies to solve the problem/sub problems

The main disinfection technologies to solve (partial) phytosanitary problems are listed in the table below. They are based on chemical, physical or biological processes.

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Some of the mentioned technologies may be combined to increase their efficacy to control pathogens in irrigation and drain water.

Table 5-17. Technologies to solve the problem/sub problems

Existing technologies	Restrictions	Development phase	Potential to solve problem
Chlorination	High rates cause phytotoxicity (damage roots), reacts with ammonia (hazardous compounds), iron and manganese (precipitation), corrosive, for humans harmful chlorates can build up in edible products	Commercialised	High
Ozonisation	Toxic by-products, strict health and safety requirements, selective, high costs, corrosive, pre-treatment needed in case of high amounts of dissolved organics or suspended particles, high concentration could damage roots	Commercialised	High
Peroxides	High levels could damage roots	Commercialised	High
Copper/Silver ionisation	Risk of phytotoxicity , ineffective on some fungi and viruses, efficacy depends on pH, water analysis needed to monitor efficacy	Commercialised	Medium
Electrochemically Activated (ECA) water	High maintenance, soft water required, corrosive to metals, harmful by-products (perchlorate), efficacy less than UV and ozone	Commercialised	Medium
Photocatalytic oxidation	Selectivity, by-products, corrosive, in some cases less effective than UV and ozone	Experimental phase	Medium
UV disinfection	High maintenance/investment/operational costs, destroys iron chelates, not selective, efficacy relies on water transparency	Commercialised	High
Thermal disinfection	High maintenance, no removal of ions, high energy demand, not selective	Commercialised	High
Micro filtration	Restricted effects on pathogens. All bacteria are removed, part of viral contamination is caught in the bacterial biofilm retained, production of concentrated (waste)stream	Commercialised	Low-medium
Ultra-filtration	Removes (nearly) all viruses, production of concentrated (waste)stream	Commercialised	Medium
Nano filtration	Removes (nearly) all viruses, production of concentrated (waste)stream	Commercialised	Medium
Reversed osmosis	Costly, also removes nutrients, production of concentrated (waste)stream	Commercialised	High
Slow sand filtration	Costly, requires significant amount of space, filter has effect on flow rate of water, maintenance, only effect on bacteria and some fungi, risk of proliferation of Legionella at high temperatures	Commercialised	Low-medium
Bio filtration disinfection	Low disinfection flow, requires significant amount of space, installation needs to be covered as to avoid external influences, lack of data/knowledge regarding effect on microorganisms	Commercialised, but still needs testing	Low-medium

Useful combinations are for example:

- Peroxides with ozone
- Peroxides with UV

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- Ozone with UV
- Micro/ultra-filtration with UV

Existing technologies only partial meet the need for combined use of local and system-related disinfection methods. First of all technologies with both local (point) and systems effects are limited (ozonisation, peroxides and Electrochemically Activated (ECA) water). Alternatives are combinations of a technology with a local (point) disinfection with a technology with system effects. The main problem however is that the technologies suitable for system disinfection are not or only partial selective. The use of them is always a compromise as higher concentrations improve their effect as disinfectant but increase the risk of damage to roots and therefor loss of crop.

3.4.3 Analyses of bottlenecks and gaps

1. Need for combined use of local and system-related disinfection methods

The currently available disinfection technologies help the grower solving many phytosanitary problems. However, these technologies do not fully tackle all of the problems described above. Some technologies create some problems because of their use (toxic by-products, indiscriminate cleaning). The following table gives a summary of the bottlenecks which still need to be solved

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Table 5-18. Overview of the gaps in the production of a good quality of water

Bottleneck	Tech.	Reg.	Soc.	Description
Chemical methods				
Toxicity of by-products or of oxidants themselves		x		Regulation on chemical compounds may hinder the use of some oxidants in some countries, such as chlorine and its by-product chlorate. Chemical oxidants are regulated by the Biocidal Products Regulations (BPR) EU 528/2012, which regulates the availability on the market and the use of biocidal products. Regulations may also require continuous monitoring of oxidants in the effluence. Furthermore, chemical oxidants must adhere to set maximum residue levels (MRLs) in open water, that must be guarded and monitored
º1Used (toxic) products affect other equipment	x			Using highly corrosive products, such as chlorine or created by-products such as chlorate, could affect not only the dosing equipment, but also the equipment further along in the facility (feeding tubes, gutters, and so forth). This requires more expensive materials to be installed. A balance is to be found between cheap products and the relatively expensive materials required to handle these products.
Toxicity of by-products or of oxidants themselves	x	x		Some chemical compounds are highly toxic for workers when inhaled or put in contact with. Hence, the use of such chemical compounds may be hindered by such a level toxicity. Next to that, regulations may also apply for toxic products. The economic benefits seem to outweigh the possible hazards
Water containing high concentrations of dissolved organic mater	x			Action of oxidative compounds on organic matter may produce very toxic compounds like nitrosamides. Hence, those technologies alone are not well adapted to treat this type of water. Combinations with prefiltration or pre-treated water wo reduce the organic matter concentration prior to chemical disinfection could prove a usable solution. However, this still needs to be executed in practical applications.
Physical and chemical disinfections			x	The available technologies are expensive and requires high investments and maintenance costs due to the high level of technology. Costs may be a strong bottleneck for growers to implement those technologies.
Bottleneck	**Tech.**	**Reg.**	**Soc.**	**Description**
Biological methods				
Large surface demand/footprint			x	Biological disinfection methods, like constructed wetlands, may not be applicable to small scale growers, due to the required land for the installation and the high costs that
Behaviour of antagonist microorganisms and biofilm	x			Abiotic parameters such as temperature, light, pH, etc. have a strong effect on microorganism populations. Hence, it is essential to study the behaviour of antagonist microorganisms and biofilm formations in different situations, under different climates and conditions to be sure of the disinfection effectiveness and that the technology is transferable and usable in all regions

Chemical oxidation and physical treatments are non-selective techniques, i.e. almost all organics are degraded, which means chemical/physical treatments cannot be combined with biological disinfection. Treatments with conventional oxidation, non-AOP's (Advanced Oxidation Process) will often end up in carboxylic acids, these are much more difficult to remove by ozone or hydrogen peroxide alone. Non-AOP's are very suitable for treatment of aromatic and unsaturated compounds.

As chemical oxidation techniques are non–selective and systemic, application always imply a certain risk for the crop.

On the other site, non-systemic treatments cannot disinfect the whole system. As a result of that pathogens can still survive (for example in a biofilm) and disperse.

Restrictions are found in the following situations:

- high COD content (> 500 mg/l), resulting in high dosages and hence high treatment costs
- high amounts of radical scavengers, like bicarbonates, resulting in higher dosages (relevant for all AOP's)
- toxicity of the treated water (formation of unwanted breakdown by-products) when insufficient oxidant is used (e.g. nitrosamides)
- toxicity of the oxidant itself, especially ozone
- Formation of chloride derivatives, dichloramine and trichloramine

The high toxicity and the risk linked to the use of some oxidative compounds, like ozone, in a working place can be a problem that may remain unsolved if current technologies do not address this issue.

Concerning biological disinfection, factors that affect the biological community of the filter also impact filtration and disinfection effectiveness. Biological effectiveness depends on the microbial species and species diversity present in the microbial community of the filter (which can be manually inoculated with beneficial microorganism to create an earlier efficiency). However, there is currently too little information available in this area to encourage any inoculation of this sort.

Finally, for physical disinfection, poor reliability of the technology – also as they are point disinfections - as well as poor quality of the water (for example: heavy concentration of dissolved organic matter) is a strong bottleneck. Furthermore, these technologies may have a negative impact on the nutrient present in the treated water.

2. Need for cost-benefit analysis of the disinfection technologies

As far as known no integral and independent system is available. A lot of information on costs and effects of different technologies is available as well as the economic impact of an infection. Therefor the development of the analysis should be possible. But it needs an independent party with access to all required data.

3. Need for a decision supporting system

As far as known no integral and independent tool is available.

4. Need for reliable and payable analysis of the sanitary quality of water

The base technology for this (DNA-analysis) is of course available but the results are yet not specific enough (more or less only qualitative and quantitative indications of the presence of (specified) microorganisms) or too expensive (but very specific). With the fast technological development of DNA-analysis one may expect that an affordable and reliable analysis of water quality is possible in the near future.

To sum up briefly:

Technologically, two main options are competing: using highly efficient, but cost- and maintenance intense disinfection systems causing a crawlspace in the treated water with the risk of a quick

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recontamination with pathogens, or using biological treatment based on the monitoring of a balance between beneficial and pathogenic microorganisms. Both approaches have significant gaps and bottlenecks on technological, regulatory and social-economic aspects. However, combinations of multiple technologies could provide solutions.

To advance the optimizing of the phytosanitary quality of water there is a need for cost-benefit analysis of disinfection technologies, a decision supporting system as well as a reliable and payable analysis of the sanitary quality of water.

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3.6 Fertigation management - Irrigation equipment

3.6.1 General description of the problem

The different problems related to irrigation equipment can generally be detached from regions or cropping systems, although some specific patterns are linked with the possible land use systems. For example, and this would be the case of agriculture, in hilly areas where plots are normally sloping, irrigation uniformity might be quite deficient if the type of drip emitters is not carefully selected. These problems are related to those issues discussed in nutrient management in fertigation and irrigation management, paragraphs 3.7, 3.8, 3.9 of this document. Besides, in the Fertigation Bible, optimal nutrient management was discussed in sections 3.3, 3.4 and 3.5; technologies for optimal optimising water quality in sections 3.8 and 3.11; and technologies for removing nutrients or other chemicals from water 3.10.

Field of application

In all kind of crops, irrigation is widely applied to equilibrate water demand and supply. Monitoring of the crop hydric condition and soil (or substrate) water availability is then necessary to couple these two factors. All kind of technological tools are available in the market. These tools are very well adapted to the different climatological, soil, and crop characteristics. Irrigation tools support the growers to decide when and how much they should irrigate. Besides, these tools allow water distribution to plants in a uniform and efficient way. Since different methods of irrigation are available (ebb and flow, sprinklers, drip irrigation) and suited for all crops (protected and outdoor crops, soilless or soil-bound), it is not straight forward which is the best combination of such technologies to optimize the demand-supply coupling to maximize economic profits and environmental sustainability.

Micro-irrigation, also known as drip irrigation or trickle irrigation, is an irrigation method with a slow water release (from 0.2 l/h to 7 l/h per emitter). This is done by conveying pressurized water through a network of valves, pipes, tubing, and emitters, either on the soil surface or straight to the root zone. One or more water pumps, an array of electro valves installed at the heads of the different irrigation sectors and controlled with an electronic programmer, and, in the case of fertigation (irrigation + fertilization), a stock solution or fertilizer injection system. Improper selection or design of the equipment used, or maintenance work below the required standards may result in a significant decrease of the irrigation uniformity with immediate effects on the adequate development of the crop. Moreover, deficient irrigation uniformity when nutrients are applied together with the irrigation water implies bad control of nutrient supply with the concomitant consequences as described in other sections of this document.

Regions

An acceptable uniformity of irrigation distribution is an essential factor for the proper development of intensive horticultural and fruit crops. This is required in every region, and the selection and design of an irrigation system will depend in every case on the cropping system (protected vs. open field), the water source, the crop management (soil vs. soilless), and the topography.

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In Mediterranean areas, where a clear majority of crops are grown on soil, the most important issues concern the use of low quality waters in drip irrigation with open or semi-closed systems. As a higher percentage of systems in central and northern Europe are lifted out from the ground, particular importance should be given to avoid accumulation of nutrients, salts, or other chemicals in the recirculating solution and/or the drainage discharge. If recirculation is applied with irrigation water of poor quality (like in southern Europe), clogging due to the precipitation of carbonates and sulphates can be an issue since it negatively affects the distribution of irrigation water. In other areas, with high contents of iron or magnesium in the irrigation water, clogging is caused by the formation of iron and magnesium precipitates (see chapter 47)

General description

The area irrigated with drip irrigation continues to increase, especially in Mediterranean countries and not only due to intensification but also to a decrease in water availability. In Europe-28 the percentage of holdings with drip irrigation is 33%, in Spain 49% with an increase of 10% during the last decade. Drip irrigation technologies are applied in vegetable and ornamental production, and in intensive fruit tree production systems[13].

In these cases, drip irrigation and fertigation are commonly combined. Most open field and substrate crops are irrigated with drip irrigation, as it is expected to produce higher yields and lower environmental losses compared to other irrigation methods. However, as more systems in northern Europe are lifted out from the ground, other irrigation methods like the Nutrient Film Technique (NFT) are also used. The implementation of such techniques consists of suspended or self-standing gutters where roots develop. Soil contamination is avoided by minimizing or reducing to zero the nutrients and pollutants discharge. New Growing System (NGS), a multi-layered PE trough, is a clear example (Figure 6-16 D). This is a general trend, and legislation backs it up (European Framework Directive). However, compared with the open-loop systems, it requires more precise and frequent control of the nutrient solution, so the recirculating nutrient solution has to be treated to restore its original nutrient element composition or remove any harmful substances.

Designing the irrigation system. Limitations and components selection

Despite the theoretical benefits that micro-irrigation systems present, a correct design is a vital issue to maximize water distribution on the field. It starts with the water pump, as the working hydraulic pressure must comply with dripper operational parameters. This is achieved by installing a variable-frequency drive (Figure 6-16 A) coupled with the pump electromotor. Since pressure is flow dependant, the pump speed drive must change when plots of different size or height, thus variable demand systems, are sequentially irrigated. This helps to optimise water supply and energy use. Further away from the irrigation head unit, in open field vegetables in soil bound crops or even in protected crops, it is common to install drip irrigation systems in sloping fields (Figure 6-16 C). Particular care should be given to the design (following contour lines, length of laterals, pressure regulation, etc.) and the selection of the emitters, to avoid waterlogging at the lowest points in the farm. Ageing of the pipes due to climate or machinery stress may also affect water distribution in irrigated plots. One possible solution would be the use of thin walled dripper lines (Figure 6-16 B), of low cost and disposable, making it possible to use new materials in each crop cycle. A second alternative would be the use of subsurface drip irrigation (SDI). SDI (Figure 6-16 E) applies the water

[13] http://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_irrigation

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directly to the root environment at some depth (depending on the crop). This method presents many advantages like the potential use of treated wastewater, as water does not reach the soil surface and thus eventual fruit contamination is unlikely. It also prevents water loss through evaporation. However, as the system is relatively complicated and should be automatically controlled, it is more suitable for medium to large scale production.

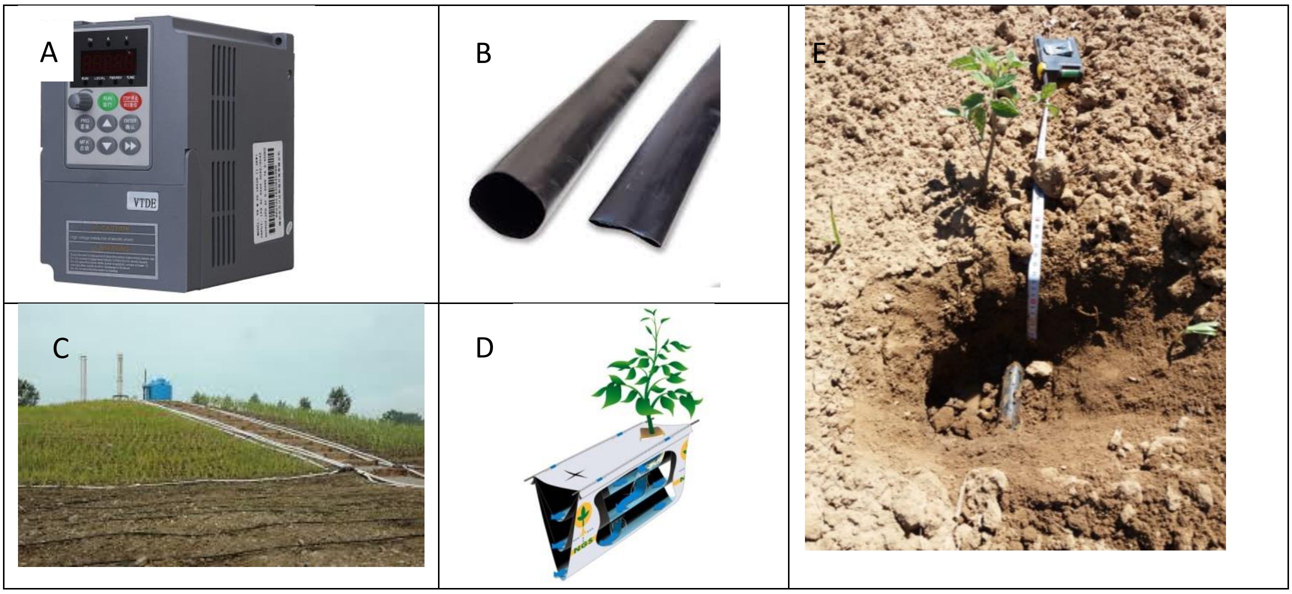

Figure 6-16. (A) Variable-frequency drive; (B) thin wall drip line; (C) sloping fields; (D) NGS system; (E) subsurface drip irrigation in a tomato crop in Extremadura (Spain)

Clogging of the emitters (both in surface and subsurface drip irrigation) may be one of the technical limitations of drip irrigation due to the accumulation of particles, organic matter, bacterial biofilm, algae, or chemical precipitates. This has been dealt with in 52as one of the specific problems described was the use of water sources containing particles that can clog up dripping lines. One first step measure to solve this problem would be the use of different types of filters as described in Table 6-19. As an end of pipe solution, new emitters are available for commercial use, and experiments at IFAPA (SE Spain) have demonstrated that emitters with turbulent regime perform better than self-compensating emitters when using waters with high biological loads.

Root intrusion could be an added problem in SDI. In this sense, new materials are being developed. The Riga project aimed to implement new irrigation systems based on standard polyolefin grades. New functionalities such as anti-microbial and anti-roots (trifluralin free), which allow increasing their functionality up to the end of their shelf-life (up to 50% higher) and contributes to water consumption reduction (up to 5% due to less pipe cleaning is required for correct performance), in comparison with the current systems in the market

3.6.2 Brief description of the socio-economic impact of the problem

There are serious concerns about the sustainability of the overall use of water resources in the long-term in most of Europe. Specific regions may face problems associated with water scarcity. Cyprus, Bulgaria, Belgium, Spain, Italy, and Malta are currently using up 20% or more of their long-term

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supplies every year[14]. It is likely that efficiency gains in agricultural water use (as well as other uses) will need to be achieved to prevent seasonal water shortages.

Regions associated with low rainfall, high population density, intensive agricultural or industrial activity may also face sustainability issues in the coming years, which could be exacerbated by climate change impacts on water availability and water management practices. As in some areas agricultural water use largely surpasses all other sectors, every measure designed to improve water use efficiency is extremely important.

Intensive agriculture systems require uniformity, especially in case of soilless growing systems as the substrate only offers low buffer capacity. Some problems are faced when using more sophisticated irrigation methods, for example, SDI. Requirements of high skilled labour, careful design of the system, technological advisory, and management of irrigation and fertilization schedules, to maximize efficiency and avoid emitter´s clogging, are needed. Generally, dripper irrigation systems have a high initial purchase cost compared to some other irrigation methods like surface or sprinkler irrigation methods. Such large investments may not be warranted in areas with uncertain water and energy availability. An intermediate, low cost alternative would be the use of thin-wall drip lines, mostly used for outdoor single season vegetable row crops and low flow irrigation regimes. The flow reduction makes the system less complex with lower energy requirements.

3.6.3 A brief description of the regulations concerning the problem

Growers are struggling to achieve good water status under the current European Water and Nutrient legislation. In countries like the Netherlands, Germany and Belgium growers of soil bound crops are forced to reduce their use of fertilizers to meet the national or regional criteria for N residues in the soil. As these criteria are sharpened year after year, growers are searching for an alternative, soilless, growing systems.

At the other hand, growers that already made the shift to soilless growing systems like NFT are looking for ways to discharge the nutrient discharge as it is not allowed to discharge nutrient waste water (nitrate contents above 50 mg/l) in surface waters.

This water should be spread on grassland or should be purified (removal of nutrients).

There are existing European Directives for waste management (Nitrates Directive, European Water Framework Directive), and the European Commission is firmly moving towards a scenario in which water saving and preservation of environmental water quality will be major priorities.

Recycling might be the norm at national and/or regional levels. At the regional level, authorities may limit the water consumption for agriculture due to drought. Two examples are given. In some Mediterranean basins, growers and irrigation communities will be forced to lower the use of surface water, mainly from national water diversions networks, and ground water extraction[15] as drought in 2017/2018 season is posing severe constraints to the sustainability of the current extraction and use of water for irrigation. However, this is not exclusively a Mediterranean region issue. In the

[14] http://ec.europa.eu/environment/pubs/pdf/factsheets/water_scarcity.pdf
[15] http://www.laverdad.es/murcia/ministra-tejerina-declara-20171025123111-nt.html

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summer of 2017 in West-Flanders, growers were no longer allowed to irrigate their crops with surface water due to the drought[16].

3.6.4 Existing technologies to solve the problem/subproblems

There are a lot of available technologies on irrigation management. The next table shows the most relevant ones and related topics.

Table 6-19. Overview of existing technologies for irrigation management

Existing technologies	Restrictions	Development phase	Potential to solve the problem
Pipes	PVC-related environmental issues	Commercialised	Good design improves irrigation efficiency.
Driplines	Selection of the most appropriate emitters requires some technical knowledge on materials and local conditions.	Commercialised	Good selection and maintenance improve irrigation uniformity and efficiency.
Thin walled dripper lines (irrigation tape)	Not suited for soilless systems, coarse soils, fragile to machinery or damage due to animals	Commercialised	Ensures high uniformity with low cost and easy handling
Subsurface drip irrigation (SDI)	Not suitable for sandy soils, bad quality water or inadequate maintenance of the irrigation system. Requires of high-tech machinery to bury it, damage due to animals	Commercialised	Yes, if operation suits local soil and cropping conditions.
Innovative pipes and drippers for micro-irrigation	Slightly higher costs of the final product compared to traditional polyolefins.	Field tests	To avoid clogging problems due to roots or biological activity
Installation of drip irrigation systems on sloping fields	Higher cost due to type of emitters and not suitable for medium or bad quality water	Commercialised	Increases water use efficiency and irrigation uniformity.
Adaptation of drip irrigation systems to water with high biological loads.	Lack of benchmark studies to determine the suitability of dripper´s models for regenerated waste water or high biological loads.	Commercialised	Yes, in case of proper maintenance
Variable-frequency drives	Cost, reliable hydraulic measurement of working pressures	Commercialised	Improves energy use efficiency and irrigation uniformity
Pure hydroponic systems (NFT)	Cost, exact control of operational parameters, good quality water is required	Commercialised	Reduction of emission nutrients and pollutants to the soil.
Constructed wetlands	Cost, availability of space, continuous monitoring. Applicable only if there is a legislative demand	Field test in soilless crops	Improves the quality of discharge water by reducing pollutants nitrates and other salts.

[16] http://www.landbouwleven.be/909/article/2017-06-17/west-vlaamse-oppompverbod-deint-uit

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3.6.5 Analyses of bottlenecks and gaps

Growers that switch to pressurized irrigation systems from surface or ebb and flow systems must adapt to a new situation in which a proper design and an adequate selection of materials and equipment are critical to achieving good standards of water use efficiency and uniformity. This is the case of non-optimal water quality, coarse soils, or topographical constraints. Besides, high investment costs and proper maintenance of the equipment may force growers to face a big change in management of their holding. According to the list of problems described in the first part of this section (section 70) several bottlenecks not sufficiently solved have been identified.

One of them is cost. According to the benchmark survey, a significant percentage of growers think that both investment and maintenance costs of fertigation systems are relevant. This probably explains the lack of automation of irrigation systems which, according to interviewed growers, is the second main disadvantage of fertigation systems. This implies fertigation to lack control and be time-consuming for this group of growers.

A second bottleneck deals with the required technical knowledge to efficiently run this type of systems. This implies the adoption of the proper combination of technologies better adapted to the local land and crop conditions and requirements. It is necessary to maintain in every moment the adequate operational hydraulic flow pressure for manifolds, drip lines and emitters which have been selected according to the terrain topography, or water quality (clogging due to salt precipitation or biofilm), a.o. This, of course, may pose some financial implications and thus links both cost and technological bottlenecks.

A third group of bottlenecks deals with durability and material lifetime, not only due to environmental factors like solar radiation, temperature and pressure changes, a.o. But also to the damaging effects of living organisms. Efforts should be made to incorporate affordable, more resistant, and environmentally friendly materials.

Table 6-20. Overview of the gapss in the production of a good quality of water

Bottleneck	Tech.	Reg.	Socio.	Description
Costs of the systems are not affordable for small growers in many European areas			X	Investments might be costly but savings in water and fertilizers + higher efficiency warrant safe returns.
Implementation requires technological knowledge for a proper layout and a right selection of materials and equipment	X	X	X	Skills for design to obtain maximum benefits. Good knowledge of local conditions (soil, climate, crops), and specifications of materials and equipment. Automatization of processes.
Clogging of emitters due to biofilm formation or precipitation of insoluble salts (iron, calcium, etc.)	X		X	Problems with adequate performance with the corresponding loss of efficiency and money. Maintenance is critical but new designs less prone to clogging should be developed.
Damaging effects of living organisms.	X		X	Avoidance of emitter clogging due to root development, or damage to irrigation manifolds due to insects and animals. New materials and designs are needed.
The durability of driplines and drip emitters. Ageing.	X		X	New materials or installation methods to increase durability in/on the ground for an extended lifespan.

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3.6.6 References for more information

[1]. http://www.rigaproject.eu/

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3.7 Fertigation management – Preparation of the nutrient solution

3.7.1 General description of the problem

The set of problems associated with the preparation of the nutrient solution is not specific to regions or crops. However, soilless crops are more due to show problems since no buffering capacity may hinder fertilization unbalances caused by deficient preparation of the nutrient solution.

Field of application

In fertigation, nutrients are (entirely or at least partially) applied to the crop together with the irrigation water as a nutrient solution. As a first step for optimal nutrition, water (par 84) and nutrient (par 96) crop requirements must be established, and the nutrient solution calculated. However, it is also important to consider the preparation of this solution by mixing fertilizers and water (this paragraph) since significant deviations can be found between the theoretical and the real nutrient solution, which can provoke an unbalanced nutrient supply. This is especially important when adjusting crop nutrition. In the case of solid fertilizers, they must be dissolved in a particular sequence, and some combinations of fertilizers in the same stock solution tank are forbidden due to precipitation of salts like calcium sulphate or calcium phosphate, with a very low product of solubility. This can be overcome using liquid fertilizers, with no risk of precipitation. Super concentrated liquid fertilisers are used to produce tailor made stock solutions that can be easily injected into the irrigation water without significant deviations in a very straight forward way (e.g., hydraulic proportional pumps). Finally, the nutrient solution has to be properly distributed to the crop (70).

If fertigation needs are calculated in kg/ha for each fertilizer, supply can be rather straight with a simple fertilization tank. A simple venturi or a proportional hydraulic pump can be used to incorporate the diluted content of the tank into the irrigation main (Figure 7-17 A). This would be a low-tech fertigation system. Other systems provide better control and more flexibility and automation. This is the case of multiple stock solution tanks in which the proportional injection of the concentrated fertilisers into the irrigation water is managed by an electronic controller ((Figure 7-17 C). The role of the controller is basically to open valves long enough to reach the desired EC and pH setpoints by increasing the concentration of fertilisers and acids in the irrigation main. Like before, venturis or dosing pumps are used to incorporate the concentrated fertilisers. Particular attention should be paid on how fertilisers are incorporated into the tanks. As a rule of thumb, calcium should never be mixed with sulphates or phosphates to avoid precipitation issues.

The accuracy of the fertilizer injection is a relevant issue in every region since it must always be considered when managing fertigation. It is important for every crop type and cropping system. As the buffer capacity of soils is not found in soilless culture, the preparation of the nutrient solution is more critical in this growing system (especially in closed systems). However, the accuracy of fertilizer injection must also be considered in soil bound crops when optimizing fertigation.

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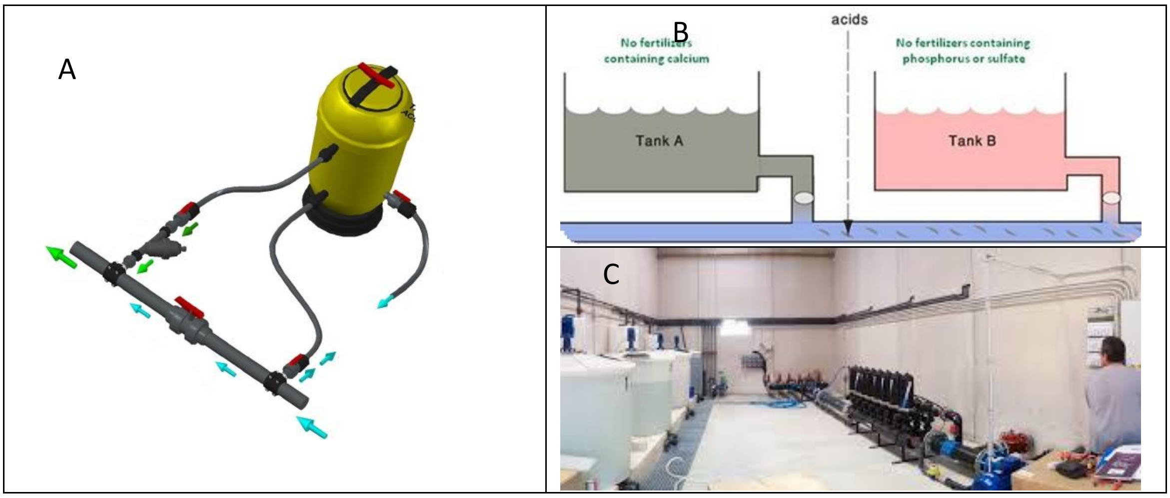

Figure 7-17. Simple fertiliser tank (A); schematics of multiple tank injection (B); Irrigation head unit with multiple fertiliser tanks (C). From https://www.mundoriego.es (A), http://www.haifa-group.com (B), http://riegosagricolas.com (C)

Specific problems

A commonly-occurring problem with the preparation of nutrient solution is that the established nutrient solution is not exactly what it is supplied from the drippers at the end of the irrigation submains. This inconsistency can be due to different factors that may alter the required rate of injection of the stock solution in the irrigation water to reach the EC and pH setpoints, as established in the fertigation head. The real-time measurement of EC and pH are the standard setpoint factors to determine the injection rates from the stock solution tanks (fertilizers + acid). This measurement is performed in intervals of fractions of seconds either in the mixing tank or directly in the main irrigation pipe. Injection is buffered in the first case, whereas the latter reacts faster to eventual deviations from setpoints. If the measured EC is below setpoint, the controller adjusts the opening frequency of the electro valves, and more stock solution is injected with venturis or electronic injectors. If more than one stock tank is used, the injection rate from each one of the tanks will vary accordingly to the initial injection percentages as marked in the irrigation head controller. If EC is above setpoint, the rate of injection decreases by reducing the time that stock solution electro valves remain open. After a few injection-correction cycles the EC and pH measurements should stabilize and reach the setpoints. Specific problems concerning the preparation of the nutrient solution are those related to the measurement of EC and pH and the injection of the stock solution.

Accurate measurement of fertiliser-injection determining parameters

Accurate measurement of EC and pH is essential to obtain the correct composition of the nutrient solution, so sensors should be durable, exact, and well maintained. Very often cheap sensors are installed, and thus deviations may occur, either due to inaccurate readings or inadequate maintenance. For example, excessive supply of nitrate based fertilisers could be triggered by an inaccurate measurement of EC or pH (if nitric acid is used) and thus the risk of groundwater contamination or nutrient unbalances at the crop level. Sensors used in the chemical or pharmacy industry, both heavy duty and precise should be set in robust fertigation machines. Periodical calibration is required to assess accuracy.

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Injection system and determination of the quantities of nutrients supplied

The most commonly used devices for stock solution injection are venturis. They are typically coupled with rotameters, a device that measures the volumetric flow rate of fluids in a closed tube-flow meter. However, the measurement is not exact because the flow of injected solution is not continuous, accuracy being at the most 5-10%. Since the suction exerted by the venturi is a hydraulic process, it depends on the weight of the corresponding fluid column; this is the pressure head exerted by the stock solution tank. Therefore, if two stock solution tanks are used, both should contain a similar quantity of solid fertilizers and water volume so their corresponding venturis would work under equal hydraulic conditions. To overcome this problem, automatic systems based on electronic dosing pumps are more appropriate. The price and fragility of these automatic systems are common limiting factors. A next step to improve accuracy would be the combination of dosing pumps and flow meters. Knowing the injected flow of fertilizers and the irrigation flow, the ratio between them can be calculated and the injection of fertilizers can be automatically adjusted on-line to achieve the desired proportion.

Availability of optimal fertilizers for organic agriculture to be applied by fertigation

Many fertilizers used in organic production are not optimal for application by fertigation and tend to clog the drippers due to biofilm formation. This issue could be reduced by using adequate drippers and/or disinfection or pipe cleaning methods. However, there is a need to have good quality fertilizers for this production system.

Adjustment of the recirculating solution in closed soilless systems

In closed soilless systems, it is necessary to replace the nutrients absorbed by the crop with an equivalent addition of nutrients by water and fertilizers to ensure the stability of the nutrient solution composition. For this objective, it would be optimal to install affordable (and with low maintenance) selective ion sensors in the fertigation equipment for continuous monitoring and automatic adjustment of the ion concentrations in the recirculating solution. These sensors are being tested, but unfortunately, their use has not spread since they are costly, and their operational life span is short. Besides, their use would involve that grower's work with liquid fertilisers to have an instant nutrient adjustment, which is more expensive.

Cost of good quality water and fertilizers

In some areas both the lack or high cost of good quality water encourage growers to use worse water, which is not ideal for the recirculation of the nutrient solution, making its management difficult or even impossible without bleeding the system almost continuously (thus water use would equal that of an open system).

On the other hand, it is convenient to use fertilizers with low levels of saline ions when managing closed systems to reduce their accumulation in the recirculating solution. However, they are often more expensive.

3.7.2 A brief description of the socio-economic impact of the problem

The application to the crop of an unbalanced nutrient solution can have repercussions on productivity due to antagonism phenomena, saline effects or even toxicity. Besides, excessive supply of fertilisers due to inaccurate measurement of EC may lead to contamination of

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groundwater, e.g., nitrate driven 83. Excessive fertilizer´s application, groundwater pollution, are directly connected with a short and long-term increase of production costs, so the purely economic impact is significant. The preparation of the nutrient solution is especially relevant in closed soilless growing systems to maintain the stability of the composition of the recirculating solution. For this reason, it is necessary to have adequate knowledge about nutrient requirements but also to have enough control on fertilizer injection.

An unsuitable nutrient solution, together with excess irrigation, can induce the release of nutrients to the environment by leaching, again with the subsequent pollution effect.

The use in fertigation of non-optimal fertilizers can provoke clogging problems and higher maintenance requirements, having a negative economic impact on the production costs.

3.7.3 A brief description of the regulations concerning the problem

European level

No specific EU legislation on the preparation of nutrient solutions. A review of the fertilising products regulations can be consulted here[17].

Country level

No specific regulations for fertilisers in general if they are registered in the EU. However, some of them like organic and organo-mineral fertilisers, and organic amendments, should be registered.

Regional level

In some regions (e.g., Andalusia, Spain) and according to the legislation transposed from EU Regulations, the maximum quantity of nitrogen to be applied to the crop is limited about yield[18]. Growers must fill in and retain the nitrogen fertilization sheet, indicating the supply of nitrogen, as well as the invoices related to the purchase of fertilizers. The nutrient supply is frequently estimated from the irrigation volume and the theoretical concentration in the nutrient solution, but not measured. Recommendations on the amounts of nutrients supplied are included in the Integrated Production Regulations.

3.7.4 Existing technologies to solve the problems

In the table below an overview is given of the main existing technologies related to the problems concerning the preparation of the nutrient solution. Injection pumps are more precise than venturi injectors since they operate electronically, so they are less affected by pressure head or density variations of the stock solution. However, factors like reduced cost, simplicity, and resistance, are clear advantages of the more standard venturi injectors which are widely used both in low-tech and high-tech fertigation systems. Accurate water and nutrient supply require good and reliable measurement of the pH and Electric Conductivity of the nutrient solution. Fertigation software uses these parameters to regulate the rate of fertilizer and acid injection, but since they are rather gross

[17] http://www.europarl.europa.eu/legislative-train/theme-new-boost-for-jobs-growth-and-investment/file-review-of-the-fertilising-products-regulation
[18] http://www.juntadeandalucia.es/boja/2015/111/1

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regarding independent nutrient injection, selective ion sensors would be preferred. Unfortunately, they are nor widely used due to high cost, robustness issues, and measurement accuracy.

A first step when adopting drip fertigation technology is the use of simple fertilisation tanks which by using a simple bypass mechanism incorporate the dissolved required quantity of fertilisers into the irrigation flow. If more complex irrigation machines are used, with venturi injectors, a multiple stock solution tanks system is recommended to take full advantage of the system.

Table 7-21. Existing technologies to solve problems related to preparation of the nutrient solution

Existing technologies	Restrictions	Development phase	Potential to solve the problem
Injection pumps	Bad quality water, cost, fragility	Commercialised	Yes
Venturi injection	Inaccuracy, requires regulation	Commercialised	Yes
Quantitative injection	Cost, maintenance, fragility	Commercialised	Yes
EC and pH based injection	Quality and maintenance of EC and pH sensors determine the accuracy	Commercialised	Yes
Simple fertilization tanks	Manual, no control on EC or pH, inaccurate	Commercialised	Partially
Multiple fertilization tanks	Automatic, good command of EC and pH setpoints	Commercialised	Yes
Selective ion sensors	Accuracy, cost, maintenance	Development of agro applications	Yes

3.7.5 Analyses of bottlenecks and gaps

In general, acceptable technology is currently available for the preparation of the nutrient solution in fertigation. However, the FERTINNOWA survey revealed that the cost of the best technologies is usually a limiting factor for their application, especially in less profitable productions and small farms. For that reason, simpler and cheaper technologies are frequently used. The lack of awareness by growers of more accurate and reliable technologies can also be a problem in some areas.

The availability of affordable selective ions sensors would be very interesting for the optimal management of closed systems. On the other hand, in areas where good quality water is scarce, affordable alternative sources are necessary to make recirculation of the nutrient solution possible.

Further development of fertilizers to be applied by fertigation for organic production is necessary.

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Table 7-22. Gaps concerning the preparation of nutrient solutions.

Bottleneck	Techn.	Reg.	Socio	Description
Cost and maintenance of accurate systems for fertilizer injection	X		X	Automatic systems based on injection pumps are the most accurate. However, they are mostly used in hi-tech, intensive farm holdings. Furthermore, injection pumps tend to block or fail easily if fertilizers are not well dissolved, what provokes higher maintenance and risk.
Lower accuracy of cheaper injection systems	X		X	Cheaper systems like Venturi injectors are frequently used, but they can have significant deviations. To reduce them, A/B stock solutions are prepared, but this system is much less flexible than using stock solutions for individual fertilizers and requires weighing exact amounts of fertilizers. This is a problem if the grower has to do it. In Northern Europe, there are companies selling the desired mixture of solid fertilizers, but this service is not extended in the South.
Un-known quantities of fertilizers supplied to the crop	X		X	The most used automatic injection systems are based on EC and pH and do not allow to know the exact amount of fertilizers supplied to each plot. Some equipment incorporates a flow meter per injector but the measurement is not exact because the flow of injected solution is not continuous, the deviation is at least 5-10%. Automatic systems based on injection pumps are more appropriate for this objective, but their price and maintenance can be limiting factors.
Automatic addition of fertilizers with a low effect on EC	X		X	Fertilizers with a low effect on EC like soluble organic nitrogen fertilisers are frequently used in organic production so that their addition by automatic injection systems based on that parameter is hardly managed. Quantitative injection is a solution to this problem. However, injection pumps are expensive and can be damaged by not well dissolved solids present in the stock solution. For that reason a filtration to 120 µm before pumping is convenient, but these filters are easily clogged when using non optimal fertilizers.
Adjustment of the recirculating solution in closed soilless systems	X			Affordable (and with low maintenance) selective ion sensors do not exist for continuous monitoring of the ion concentration in the nutrient solution. This would allow to accurately adjusting the addition of fertilizers to crop nutrient absorption, thereby simplifying management of recirculation and reducing deviations of the nutrient concentrations. The adjustment of the recirculating solution is presently carried out based on the periodical chemical analysis.
Cost of good quality water		X	X	The high cost of high quality water in the Mediterranean area (e.g., desalinated seawater if available) stimulates the use of worse quality water, making the recirculation of the nutrient solution in soilless culture difficult or even impossible.
Cost of good quality fertilizers for recirculation			X	It is convenient to use fertilizers with a low level of saline ions when managing closed systems to reduce their accumulation in the recirculating solution, but they are more expensive.
Cost of liquid fertilizers			X	Liquid fertilizers are less used in fertigation than solid fertilizers despite their advantages because they tend to be more expensive. They are more used on big farms to avoid the labour necessary for the preparation of the stock solutions when using solid fertilizers.

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Bottleneck	Techn.	Reg.	Socio	Description
Availability of optimal fertilizers for organic agriculture	X			Many fertilizers used in organic production are not optimal for their application by fertigation and tend to clog the drippers. This effect is reduced by using adequate drippers and frequently washing the irrigation pipes.

The gaps mentioned in the table above can partly be solved since most of the available technologies to overcome these issues are commercially available, though not all are affordable for standard growers in areas where the production model is based on low tech, subsistence or small-sized farm holdings. Therefore, is a matter of adapting technologies to local scenarios. General measures, like good design and operating practices, prevention and maintenance can help to troubleshoot this phase in the fertigation process. Some gaps in preparation of nutrient solutions are:

- Continuous, accurate injection of the stock solution into the irrigation water to reach the established setpoints. All aspects concerning sensors and methods of injection are relevant.
- Availability of suitable fertilisers to avoid constraints to efficient and environmentally sound nutrient solutions due to specific production scenarios regarding water quality, cropping strategy (organic, soilless), soil classes, etc.
- Direct, specific and real time measurement of ion concentrations in the nutrient solution. Selective ion sensors are available but not readily available for standard commercial use.

3.7.6 References for more information

[1]. Thompson, R.B.; Gallardo, M.; Gimenez, C. 2004. Reducing Nitrate contamination of groundwater from intensive greenhouse-based vegetable production in Almeria Spain – management considerations. From Controlling Nitrogen Flows and losses. D.J. Hatch. Wageningen Academis Pub. 2004

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3.8 Fertigation management: Irrigation management

3.8.1 General description of the problem

There is considerable and increasing societal pressure to use limited water resources efficiently. There is growing competition from other sectors such as tourism, industry and domestic use. Additionally, there is increasing pressure to maintain the recreational value and ecosystems services capacities of water resources. Environmental problems, such as aquifer depletion, saltwater intrusion into aquifers, nitrate contamination of aquifers, etc. are associated with poorly managed irrigation of agriculture and horticulture. These environmental problems are increasingly considered to be unacceptable and, therefore, legislation regarding irrigation and fertilisation practices is tightened in many European Member States. Consequently, horticultural growers are under growing pressure to use irrigation water as efficiently as possible.

Optimising irrigation at farm level requires providing the right amount of water at the right time to cover the needs of the crop at that moment. Proper irrigation management will foster a good yield and quality of the crops. The crops water needs vary with crop development, weather conditions, soil type, and other site-specific factors. Poor irrigation management can reduce the yield and quality of the harvested products. These losses can occur either due to an excess or a lack of water at critical growth stages of the crop.

Knowledge of the crop's water needs is essential. Monitoring technologies of the soil or the crop can provide vital information to guide irrigation management regarding the timing and amounts of irrigation. Insights into the crop water requirements and implementation of monitoring technologies can foster an implementation of irrigation management strategies.

This section will discuss issues associated with estimation of crop water requirements, irrigation management, and irrigation scheduling. The problems described in this section are also closely related to the issues described in section 70 (Equipment for irrigation), and section 96 (Optimal nutrient management), in relation with minimizing the environmental impact caused by improper use of fertigation (nutrient leaching and soil salinity).

1. **Specific problems**

Poor irrigation scheduling can lead to a loss of quality and productivity of the crop, either due to an excess or a lack of water at critical growth stages of the crop. Knowledge of the crops water requirements is the first factor to take into account. It will allow fulfilling the crops water demand in every moment of its cycle. However, in many cases, this calculation is complicated to carry out. Due to climatic variability, it is necessary to use different local sensor systems to obtain quantity differences of irrigation applied in every geographic zone. On the other hand, the determination of the needs in each crop is in many cases not real; it is a theoretical calculation that must be contrasted by the farmer on his farm, requiring different tools or technologies that allow verifying directly if the crop is consuming the full amount of supplied water.

These are the main problems that the farmers face when managing the fertigation of his crop:

- Correct estimation of the crops water and nutrients requirements
- Irrigation strategies adapted to different crops

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- Adjustment of the irrigation strategies to plant and soil water status.

1.1. Correct estimation of crop water needs

The implementation of a programmed irrigation schedule helps to ensure that the supply of irrigation considers local climatic conditions and crop development stages. The estimation of the crop water requirements is usually based on soil water balance or methods of potential evapotranspiration. Climatic parameters and crop development influence this methodology. The climatic parameters are critical to adjust the crop water needs in different locations. In this situation, the farmer can use either data retrieved from sensors at the farms site or public data (more information in Fertigation Bible TD 10.28) or use satellite information and weather forecast service (more information in Fertigation TD Bible 10.9). Other essential parameters for the correct estimation of crop water needs are the crop water transpiration and soil water evaporation during irrigation events. The transpiration and evaporation can be integrated into a crop coefficient (Kc). This coefficient is crop specific and can be calculated or estimated by:

1. The canopy crop development: with the typical crop development curve calculates by different authors for every crop
2. Remote sensing or image analysis (see (more information in Fertigation TD Bible 10.9) to adjust the crop water needs to its development.

1.2. Irrigation strategies adapted to different crops

Once crop water requirements have been determined, it is necessary to consider the effect of the irrigation volume on each of the different phenological stages. This knowledge will support irrigation management. Growers can use irrigation scheduling adapted to meeting crop water requirements, or with some crops can adopt a water saving strategy, such as controlled deficit irrigation (more information in Fertigation Bible 10.6). In case of controlled deficit irrigation, the water supply is less than the crop water requirements. Depending on the crop species and development, particularly of fruit trees, deficit irrigation does not negatively affect production. When correctly managed, deficit irrigation strategies can save considerable volumes of irrigation water, without reducing yield. In some cases, deficit irrigation can result in increased fruit quality or earlier fruit production.

The principal problem regarding deficit irrigation strategies is identifying:

1. the appropriate deficit irrigation dose for different crops
2. the suitable moment to apply irrigation
3. the water reduction
4. the risks of yield or quality losses.

Information on water requirements and irrigation strategies can be used to develop decision support system (DSSs) which can be used to advise growers on irrigation scheduling.

1.3. Adjusting irrigation to plant and soil water status

In many cases, theoretical irrigation scheduling (calculated through different methods) and irrigation strategies may induce situations of over-irrigation and/or water stress, and consequently, reduce water use efficiency.

New technologies, such as precision agriculture, can support adapting irrigation scheduling to the real-time crop water demand.

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In case of crop water status indicators, plant measures as soil measures, the information obtained is related to the amount of water available to the plant at a specific time. These sensors allow making decisions based on the changes observed over time in the range between a well-hydrated or stressed plant, and the exact situation at different times in the crop cycle, such as irrigation strategies for controlled deficit irrigation. The main problems raised are:

1. High costs for the equipment
2. The required knowledge to handle the equipment
3. The natural heterogenity of the soil or substrate. Heterogenity of the soil, which in the case for located irrigation, significantly increases the variability in the distribution of water in the soil.
4. Most of the sensors or instruments only have a limited action radius. Therefore, the retrieved results might not be considered representative for the complete irrigated area.

3.8.2 Brief description of the socio-economic impact of the problem

Adopting efficient irrigation management strategies in all regions is essential. However, for an individual region, or even for a given location within a region, the most effective strategies may differ because for example, the climatic or soil conditions differ.

In the Mediterranean region, the limited rainfall and increasing competition for limited water resources increasingly require the adoption of strategies, techniques, and technologies to optimise the water use efficiency of water applied as irrigation.

In other European regions, water scarcity is not yet a consistently limiting factor. Future climatic change can induce an increase in temperature and decrease of the precipitation in all countries, increasing the crops water needs. Besides water savings, efficient irrigation management can reduce nutrient leaching and energy costs.

Improvement of irrigation management will for sure require the implementation of sensors. The benchmark survey showed that growers were applying multiple tools and practices to support their irrigation management. 33% of the growing systems reported applying 1 to 3 tools. Some regional differences were observed. The benchmark survey revealed as well the low automation level of the supporting tools. In general, 49% of the reported tools used were applied manually. Automated tools were mainly reported for soilless covered growing systems to monitor weather parameters and water and drain water volumes.

The surveyed growers expressed willing to shift towards more automated sensors, but costs were reported as the primary bottleneck. Growers may not see the cost of these technologies as a worthwhile investment considering the financial returns that directly result from their use. The economic benefits for growers will most likely be indirect regarding reduced purchases of water and of fertilisers where fertigation is used.

Implementation of sensors supporting irrigation management requires a minimal level of agronomic knowledge from the farmers' side. This knowledge is essential to interpret the crop's water requirements and to adapt the irrigation practices according to the growth stage as well as the strategy of irrigation and the water state in the plant and the soil.

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Another issue influencing the adoption of these technologies by growers will be their attitude and familiarity with information and communication technologies. Many of the technologies for improving irrigation management involve the use of smart technologies such as computers, internet, smart phones, sensors, etc. Older and less educated growers are likely to be more resistant to adopt such technologies. Based on the benchmark survey, it was shown that for 57% of the cropping systems the irrigation schedule was adjusted throughout the growing season based on the grower's experience. These adjustments mainly based on the crop appearance and/or the soil or substrate. In 20% of the cropping systems, this crop and soil/substrate appearance was the only way to monitor the irrigation management.

3.8.3 Brief description of the regulations concerning the problem

There are no regulatory limitations concerning tools and technologies for irrigation management, besides those concerning the use of neutron probes. In case of neutron probes regulations focus on the use and transport of neutron probes. As these regulations are very restrictive, and seen the availability of alternative technologies, there is now very little use of neutron probes in farming practice.

European level

Various legislation governing the use, transport, storage and safety as:

- Directive 2013/59/EURATOM of the Council
- Directive2013/51/EURATOM of the Council
- Council Regulation EURATOM 1493/93
- Directive 2006/117/EURATOM of the Council
- Directive 2011/70/EURATOM of the Council
- Directive 96/29/EURATOM of the Council

European Agreement Concerning the Carriages of Dangerous Good by Road 2009 (ADR).

The Ionising Radiation Regulation 1999 (IRR99).

Country level

The Member States transfer the directives and European regulations to its corresponding national legislations. As an example, the following laws were set in Spain: Law 25/1964, Law 15/1980, Law 14/1999, Law 27/2006, Law 33/2007, Law 19/2013.

Regional level

If the region has the competences transferred, they will proceed and authorize facilities.

3.8.4 Existing technologies to solve the problem/sub problems

Numerous techniques and technologies can be used to optimise irrigation of horticultural crops. A non-exhaustive overview of available technologies is provided in the tables below.

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1. *Correct estimation of crop water needs*

As described in section 84, correct measurement of climatic and crop development parameters are essential to estimate the crops water requirements. The use of remote sensing can be of great help to assess the crops development stage and the current water requirements. Growers and advisors can input climatic data from climate sensors installed in fields and greenhouses, from national or regional climate monitoring services, or from weather forecast services. There are a lot of weather sensors and weather forecast tools (Table 8-23) to help the farmer to estimate the local crop water requirement. Many of these parameters are available and maintained by public or private systems. Other sensors can be easily installed on the farm to measure these parameters in situations where data are not available. Data management systems allow the integration of historical data and short-term forecasts of crop water, allowing weekly irrigation scheduling. Precision agriculture systems, such as aerial and satellite images, support monitoring of the crops development at the farm.

Table 8-23. Existing technologies to solve problems related to correct estimation of crop water needs.

Existing technologies	Restrictions	Development phase	Potential to solve the problem
Weather sensor	Restricted to a specific location	Published, generally applied	Web page and apps
Weather forecast related tools	Not all growers have access to these methodologies. Requires in-depth knowledge of data acquisition and processing, calibration and evaluation.	Published, generally applied	DSS systems
Remote sensing	It is necessary to differentiate the raw cost of the images and the cost of the final services, which will be used by farmers. It is necessary high knowledge in the geographic information system (GIS)	Published, Commercialised	Easy to detect problems in irrigation estimation or heterogeneity in crops

2. *Irrigation strategies adapted to different crops*

Once crop water requirements have been determined, the effect of the irrigation volume has to be considered. During certain development stages of some species, particularly of fruit trees, deficit irrigation does not negatively affect production. When correctly managed, the use of controlled water deficits during insensitive growth stages can save considerable volumes of irrigation water, without reducing yield. It can, in some cases, result in increased fruit quality or earlier fruit production. Different types of deficit irrigation strategies are used in different crops:

1. Sustained Deficient Irrigation (RDS). RDS consists of the application of deficit irrigation during the whole crop cycle. This strategy is the oldest and the most documented. However, this strategy entails a significant yield reduction, because the crop development is adjusted to the available water.
2. Controlled Deficit Irrigation (RDC), consists in optimizing water use by inducing stress only in crop phases that are not critical to production. Therefore, RDC implies knowledge of the response of the crop to water deficit, so that precautions are taken during critical phases, and the irrigation volumes are reduced in non-critical phases. Reduction of irrigation water volumes might even improve the quality of the crop without loss of yield (more information in Fertigation Bible TD 10.5).

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3. Partial Root Drying (PRD). This technique provides water to one part of the root, while the other part remains dry. During the following irrigation session, the dry root part is irrigated. Through this practice, a biochemical signal is initiated allowing the plant to maintain its adequate water status, increasing quality and without reducing production (more information in Fertigation Bible TD 10.4).

The DSSs allow the integration of different irrigation strategies and water needs to make irrigation recommendations and irrigation application schedules (more information in Fertigation Bible TD 10.4).

Table 8-24. Non-exhaustive overview of irrigation strategies adapted to different crops

Existing technologies	Restrictions	Development phase	Potential to solve the problem
Deficit irrigation strategies	Strong technical support is needed to setup the technic. Adapted only for areas suffering problems with water availability	Published, not generally applied	Research experiences transfer
Partial Rootzone Drying (PRD)	High management skills required. Potential increase in labor and irrigation system costs.	Published, not generally applied	Research experiences transfer
DSS water requirement	DSS with high data requirements, a limited number of farmers being able to implement the DSS correctly in soil ground crop and soilless crops.	Published, Commercialized	Redarex Sig agroasesor Vegsyst

3. Adjusting irrigation to plant and soil water status

As mentioned earlier, theoretical irrigation scheduling and irrigation strategies might induce situations of over-irrigation and/or water stress, thereby reducing water use efficiency.

There are numerous sensors monitoring crop or soil water status. Soil sensors use direct and indirect methods to determine soil water content. Plant sensors use measurements of parameters related to plant physiology. This requires precise monitoring of plant water status and productive performances. Plant water status can be accessed through different plant-based parameters such as stem water potential, sap flow, stem and/or fruit diameter variations. The monitoring of these parameters requires the installation of sensors and data-logger systems. In these regards, research should help to improve the adoptability of these decision support systems (DSSs) making them more universally applicable, user-friendly, and economically affordable. Table 8-25 lists some technologies to either measure crop or soil/substrate water status and indicates the corresponding restrictions. (More information in Fertigation Bible. Chapter 10. Fertigation management. Irrigation).

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Table 8-25. Non- exhaustive overview of sensors measuring soil or crop water status

Existing technologies	Restrictions	Development phase	Potential to solve the problem
Soil water status			
Auger method	Non-automated measurement. In some soil types, the extraction of soil samples can be difficult.	Generally applied	Measure water content and water drainage
Slab balances	The installation cannot be relocated until the end of the growing season. Non-automated measurement.	Published, commercialized not general applied	Measure water content and water drainage
Drain sensor	The device is costly compared to manual measurement. A connection to the process computer is required.	Published, Commercialized	Remote measure
Soil water sensors	User-friendly Specific knowledge requirements for data interpretation. Calibration required and problems with installation Variability between sensors	Commercialized	Measure water content. Irrigation management control
Digital penetrating radar	Measurement on a large area which allows overcoming the limitation of point sampling techniques. Large and complex system. Costly, usually used for soil surface. Interpretation of radargrams needs experience.	Commercialized ARIEL sensor	Measure water content.
Demand tray system	It does not give information about the water status of the substrate	Commercialized	
Water balance method	Requires the availability of suitable climatic data for the calculation of ETc.	Commercialized CROPWAT 8.0 (FAO)	Crop irrigation scheduling
Capacitance probe	Expensive. Careful site selection is critical. Influence of salinity and temperature. Need for calibration.	Commercialized	Crop irrigation scheduling
Irrigation management with soil moisture sensors	A large volume of data generated. Difficult handling. Close contact of the sensor with the soil matrix. The data logger is required.	Commercialized Decagon Devices Delta-T Sentek	Irrigation scheduling entails the use of sensors to obtain soil moisture status
Wetting Front Detector	Not to give numerical information about the water status of the soil. Spending time on device checking after irrigation is necessary.	Commercialized FullStop	Measure water status of the soil
Tensiometer	Difficult to find the right place in the monitored field. Maintenance required. Easily breakable during mechanical interventions.	Commercialized	Measure water status of the soil. Irrigation scheduling
Neutron probe	Expensive. Transporting and storage of radioactive material to use make it economically less interesting for growers. Need of a license for the use of radioactive substances.	Commercialized	Soil profile water content
Combined water, EC and temperature sensor	Calibration tables do not exist, and each sensor has to be calibrated. Inaccurate values in saturated media. High cost of the WET sensor.	Commercialized	Irrigation management Soil moisture
Time Domain Reflectometry	TDR probes are environment sensitive, and the probe length influences the accuracy of the moisture. It has limited applicability in highly saline soils. Expensive.	Commercialized	Soil Water Content

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Existing technologies	Restrictions	Development phase	Potential to solve the problem
Integrated sensor in DSS for irrigation water management	Installation and use require a certain degree of expertise. Settings have to be adapted to varying soil conditions. Can vary substantially in open field crops.	Published, Commercialized	Irrigation water management Smartfield ™ System WaterBee system IRRIX System
Crop water status			
Thermal Infrared	More expensive Requires information about air temperature and one zone with water stress	Commercialized	Temperature crop in different part of the farm relation with other plant water content sensors
Dendrometer	Generally reliable, robust and relatively inexpensive to buy. Absolute SDV values have to be normalized concerning those in non-limiting soil water conditions at the same evaporative demand.	Commercialized	Use DSS system to adapt measures to irrigation management
Leaf turgor	The devices frequently need maintenance, relocations, and calibration. Having internet access is necessary.	Commercialized YARA	Use DSS system to adapt measures to irrigation management
Water potential	Dedication of qualified staff, time to carry out monitoring checks, interpret measures and take agronomic decisions	Commercialized	Obtain local values of reference in own farm
Plant growth analysis balance system	Interpretation of the data is difficult if no other monitoring systems (EC, pH, slab weight) are used. No real-time data access. Expensive.	Commercialized Pascal-tech.	Growth analysis

3.8.5 Analysis of bottlenecks and gaps

Nowadays, the application of innovative technologies for irrigation scheduling still faces many difficulties. However, people are progressively becoming more aware of the environment-related problems, of the need to improve production sustainability and the efficient use of the natural resources, mainly water. Farmers who want to improve the efficiency of irrigation management in their farms have a large number of technologies available. The development stage of these technologies, however, differs. Systems determining the water needs of crops based on the climatic conditions of the area where the plot is located are available to farmers. Also, systems monitoring soil moisture, are available for use by farmers. Other systems such as systems for determining water content in the plant and the integration of different irrigation management strategies still need a high level of knowledge to be fully integrated into farmers' irrigation schedules.

Besides the various stages of development of the different technologies, the cost of the irrigation support systems is the main bottleneck that keeps growers from implementing these systems. According to the survey, 40 to 70% of respondents were convinced that these technologies are very expensive and therefore not profitable. Investment in infrastructure adapting the irrigation system to the real characteristics of the soil of the farm entails a substantial investment. Secondly, the farmer thinks that technologies supporting irrigation management are not reliable. Higher water

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prices, administrative water allocation or re-allocation lowering the supply could lead farmers to adopt water-efficiency practices or technology.

Training is a fundamental factor when it comes to the integration of irrigation management systems. Improvement in the interpretation of data obtained by sensors and the knowledge of the different techniques and existing technology will allow the farmer to adapt the technology to the productive and irrigation management objectives. This will also help to reduce the cost bottleneck since the farmer will acquire the adequate equipment. Meaning he will apply the equipment in a more efficient way, adapted to his farm

Other gaps to irrigation management are:

1. **Correct estimation of crop water needs**

Growers and advisors can input data from climate sensors installed in fields and greenhouses, from national or regional climate monitoring services, or from weather forecast services. Although the benchmark survey showed that weather sensors and stations are widely applied (especially in soilless covered crops (76%) and soilless outdoor crops (92% of the MED cropping systems), still some bottlenecks are observed regarding weather sensors and weather forecast tools:

Farmers are not sufficiently aware of the crops specific requirements related to the specific soil and climatic conditions. Firstly, the irrigated area might consist of different soil types. Although the same crop is cultivated on this irrigation area, the water requirements will differ depending of the different soil types. Secondly, the systems for estimating water needs only integrates the needs of the crop without taking into account the water retention capacity in the soil.

They are bottlenecks that prevent the techniques for estimating crop needs from being applied by farmers.

- Determination of water applied in each irrigation sector of the plot in each phenological phase of the crop. In the survey, the producers knew the minimum and maximum water consumption of the crop per day, but not the annual water demand. Although most producers indicated the annual water consumption in the crops, large deviations were observed in the water consumption data provided, even within crops, cropping systems and similar regions. This is an important factor that suggests an important bottleneck when it comes to improving the estimation of crop’s water needs. The farmer is not sufficiently aware of the amount of water used for irrigation and the differences in distribution in the different parts of the irrigated area. This bottleneck can be solved with the installation of meters. However, there is a lack of economic incentives to acquire systems to measure water consumption. In many countries or regions, it is not required to monitor or report the applied volumes of water in the farm. Water monitoring systems in different parts of the plot with integrated warning systems for identifying irrigation problems can help make the integration of these systems interesting for the farmer.
- The determinations of the development of the crop: the measures must be carried out in localized areas of the crop. This requires that the farmer selects the representative points to be able to carry out an irrigation adjustment for an area or the whole farm. In this sense, remote sensing technology is being introduced little by little to monitor the development of the crop, being able in a single measure to cover a large amount of plot surface. However,

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its cost and the needs of a great knowledge in geographic information systems and big data, to analyse the data and the cost, make them barriers when it comes to their integration in the calculation of irrigation on farms.

2. **Irrigation strategies adapted to different crops**

Further training of growers is required to provide more insights in the crops response (yield and quality) to different irrigation strategies throughout the crops growing cycle. Growers should be learnt how to adapt their irrigation management according to the heterogeneity of the farms soils. It is also necessary that the farmers have a compensation between the water saving and the risk of a possible loss of production and quality. Industry as well as the consumers should be aware of these waters saving measures. Water footprint measurement systems can identify this sustainability, however, they should be used within the same area. Otherwise, they would be very influenced by the different climatic characteristics of each country and not as an improvement over the same cultivation conditions.

3. **Adjusting irrigation to plant and soil water status**

As showed in Table 8-25, there are numerous technologies available to support irrigation management. Nevertheless, only few sensors are currently being implemented by growers to support their irrigation practices. Growers are not aware of the latest technological innovation and even less of the current stages of development these technologies have.

This was illustrated by the FERTINNOWA survey. It showed that in 57% of the cropping systems the irrigation schedule was adjusted throughout the growing season based on the grower's experience. These adjustments were mainly based on the crop appearance (61%). The soil/substrate appearance or substrate weight were also considered, but in lower rate (52%). In 20% of the cropping systems, the crop and soil/substrate appearance were the only way to monitor the irrigation management. In general, soil/substrate sensors were used more than crop water status sensors (50% vs. 16%). In 31% of the soil-grown cropping systems, respondents reported the use of tensiometers (TD 10.20) for monitoring the soil or substrate.

Substrate water content measurements were carried out in 20% of the surveyed soilless growing systems. Capacitance probes were applied in 13% of the surveyed soilless growing systems. Time Domain Reflectometry probes and neutron probes are only used by a few growers (3%). For crop water status among crop monitoring tools, leaf/stem water potential was the most used (monitored in 7% of soil-grown cropping systems), followed by canopy coverage (monitored in 6.5% of the soil-grown cropping systems). Finally, crop temperature and dendrometers (TD 10.13) were the least used, respectively in 3 and 1% of the cropping systems.

The main bottlenecks that kept growers from implementing technologies and sensors for their irrigation management were:

- High costs of the equipment in relation to the advantages that the farmer perceives with respect to the current irrigation management. Ease of use and the expenses involved are also important grower considerations.
- The required knowledge to handle the equipment, since a misuse of this technology is much worse than using traditional methods. Training adapted to the technical knowledge of the farmer is required to support the correct implementation of the technologies and sensors.

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The realisation of simple user manuals, such as the practice abstract, carried out in the FERTINNOWA project will facilitate the easy use and adaptation of the technology.

- The natural heterogeneity of the soil or substrate. Heterogeneity of the soil, which in the case for located irrigation, significantly increases the variability in the distribution of water in the soil. Most of the sensors or instruments only have a limited action radius. Therefore, the retrieved results might not be considered representative for the complete irrigated area. Soil humidity sensors are still neither easy to handle nor reliable. Moreover, these sensors are not well adapted to all soil types. Their installation and maintenance require the employment of specialised technical staff. The same occurs for the canopy sensors, whose proper application is limited to some crops and during specific growing stages, periods of day and climatic conditions. The introduction of precision farming techniques can help to integrate the totality of the cultivation surface, or/and determinate a representative control points to measure with different sensors. However, currently they require, as previously mentioned, high technological knowledge and measurement systems that require specialized staff.
- The automation of the processes when making the decision for irrigation programming: Automatic decision-making systems such as DSS systems integrate different information to help improve decision making when it comes to knowing how much to apply, however. It requires a lot of information to make the DSS comply with different crop and soil types and farm characteristics. In this sense, big data techniques can support obtaining and managing a large amount of data. Irrigation automation systems using DSS systems and sensors can help reducing the need to interpret data and make automatic decisions. Thus, more reliable information systems and expert capacity are necessary to guide farmers in using water more efficiently. However, a sufficient level of development to be used in commercial plots are not currently available, especially in open air crops, where the spatial variability is very high.

The following table summarizes the main gaps in relation to irrigation management.

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Table 8-26. Summarizes the main gaps

Bottleneck	Tech.	Reg.		Socio	Description
Deficiencies in the irrigation system.	X			X	Deficiencies either by saving money in the design of the above mentioned system or by not modifying the systems bad established, that finally, would turn out to be more economic.
Heterogeneity of soil within the irrigation section	X				Change the characteristics of the soil in the same orchard or plot.
Lack of agronomic knowledge. Technology designed by persons of the other sectors different of the agriculture.				X	It is necessary to know the phenological state of the plant, the sensitive periods of the culture and where and when to apply the irrigation. Information transfer is very necessary
Lack of training of the person who irrigates.				X	That is very important to take the final decision. It is necessary to reduce an irrigation scheduling based in traditional knowledge
Price of technology change. A lot of technological offerings. Farmer without knowledge for the best decision.				X	High cost of implantation with regard to the margins very fitted of the culture.
Extra work.	X			X	The utilization of sensors and irrigation programs carry as extra work as managing of software and internet connection.
Thieves and breaks and time battery performance. Lack of coverage of mobile networks for automatic equipment.	X				Everything is needed in order to ensure the continued operation.
The final irrigator does not see usefulness and he distrust in it.				X	Other times it is a des-interest since he does not see a clear benefit on his utilization and a clear thing is we can never replace the irrigator.
Some of them are top technologies.	X			X	Top technologies of difficult introduction in the orchard or plot and that need technical support in order to be interpreted by the farmer.

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3.9. Fertigation management - Nutrient management

3.9.1. General description of the problem

1. Field of application

In modern intensive agricultural systems, large amounts of nitrogen (N) are applied, as mineral fertiliser or in organic materials, to generate profitable yields. With conventional management approaches, an appreciable portion of the applied N is not recovered by crops and is lost from soil (or substrate) to the environment. Nitrogen contamination of aquifers is, therefore, commonly associated with intensive horticultural practices. Moreover, excessive application combined with low nutrient use efficiency leads to increased production costs.

Firstly, optimisation of the fertigation management will appreciably reduce pollution of aquifers. Secondly, in some cases improved fertigation management will also foster important savings in crop production costs. These financial savings might include reduced costs for fertilisation but as well costs related to an excessive crop development such as pruning and collection difficulties.

Similar to irrigation management, poor fertilisation scheduling can result in reduced yield and product quality, either due to an excess or a lack of fertiliser at critical growing stages of the crop.

2. Specific problems

Firstly, farmers might not entirely be aware of the exact nutritional requirements of their crops during the different growing stages. Secondly, growers might not take into account, for example, the nitrogen supply from the various sources in each field. If mineralisation would be considered, the applied fertilisers could be reduced. These nitrogen sources include i) the initial mineral nitrogen content in the soil root zone, ii) nitrogen mineralized from soil organic matter, previous manure applications and crop residues, and iii) nitrogen applied in irrigation water.

The main problems faced by the farmer when managing the fertilisation of the crop:

- Selecting the most appropriate type of fertilizer
- Contamination of subterranean water and eutrophication of superficial water bodies
- The correct estimation of nutrients needs
- Monitoring the soil and plant nutrient content
- To perform fertilization corrections in certain zones (precision fertilisation)

2.1 Selecting the most appropriate type of fertilizer

The fertilizer's quality (water solubility, the content of impurities) and form (slow or controlled release) can have implications for phytotoxicity (particularly in case of crops grown on substrate), the timing of nutrient availability to the plant and salt accumulation in the soil or substrate. Highly soluble liquid fertilisers offer some practical advantages for addition to irrigation water. Some advantages are the improved uniformity of application, lower storage cost, its speed in the application. Higher quality, slow or controlled release and liquid mineral fertilizers are more expensive than conventional mineral fertilizers. Growers must evaluate the advantages and its high price against the additional cost in labour to manipulate solid fertilizers and solubilize them in water (More information in section 70).

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2.2 Contamination of subterranean water and eutrophication of superficial water bodies

A commonly-occurring problem associated with nutrient use in intensive horticultural systems is the contamination of subterranean water by nitrate (NO_3^-) leached from the root zone of crops. The presence of NO_3^- in water that is used as drinking water is considered to be a risk for human health. In many irrigation zones, identified as nitrate vulnerable zones, the maximum quantities for applying nitrogen are restricted. These restrictions might even be below the nitrogen requirements of the crops. Optimal nitrogen management therefore has become essential. Adjusting the nitrogen fertilisation to the real needs in each stage of the crop has gained importance.

2.3 Correct estimation of crop nutrients needs

Accurately meeting the crops nutritional requirements implies firstly developing a fertiliser plan that considers i) the crops nutrient demand, and ii) all nutrient supply sources. It is essential to know the initial content of nutrients and the nutrient cycle in the soil before the uptake by the plants. In a second step, monitoring tools should be applied to identify the crops and soil/substrate nutrient status and identify any required adjustments to the nutrient supply during the crop.

It is necessary to maintain an adequate supply of all required macro and micro nutrients in the soil. Several strategies are being followed at international level, to rationally manage nitrogen fertilization, to minimize environmental risks and to increase efficiency. These strategies aim at establishing the optimal amounts applied to each crop. Strategies are mostly based on three methods: i) those based on soil analysis (e.g., Nmin), ii) those based on the monitoring of crops and plants, and iii) those based on the calculation of the N balance, which include the decision systems (DSS) that use simulation models.

2.4 Monitoring the soil and plant nutrient content

Monitoring tools should be applied to identify the crops and soil or substrate nutrient status and identify any required adjustments to the nutrient supply during the growing season. Real time data collection supports adjustment of the fertilisation quickly. However, in many cases, the data collection needs to be taken in a very systematic way by selecting a particular type of sample depending on the crop. These measurements might differ significantly due to the heterogeneity of the soil. This variation implies difficulties for establishing clear reference values for each crop species and even variety.

2.5 *To perform fertilization corrections in specific zones (precision fertilization)*

Precision agriculture will foster fertigation of crops according to the needs of the plants in different areas. Adjustment can be made by applying leaf fertilization in the different zones, during the crop cicle and more eficient fertilization use and saving costs.

The different problems related to nutrient management are not specific to a region, crop or cropping system. These problems are related to those discussed in 84 (Irrigation management), 33 water quality and 106 (Limiting environmental impact).

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3.9.2. Brief description of the socio-economic impact of the problem

The main socio-economic impact of suitable fertigation management is to achieve the highest production at the lowest possible cost maintaining soil fertility levels and avoiding the losses of nutrients.

Other socio-economic impacts are associated with the consequences of impaired water quality (see par 106). Nitrate contaminated groundwater cannot be directly used for human consumption. Either alternative sources must be found or NO_3^- removal processes must be used to ensure that the water meets the required standards for human consumption. These effects can influence the cost of water supplied to human populations.

Eutrophied surface water bodies are unpleasant which affects their amenity value for human activities. In addition to being unpleasant, this can negatively affect activities such tourism. The loss of aquatic life can appreciably economic activities such as fishing.

Additionally, as consumers, particularly those in north-eastern European countries, become more environmentally conscious they are likely to require that the products that they purchase are produced with minimal negative environmental impact.

3.9.3. Brief description of the regulations concerning the problem

The regulations concerning proper fertigation management are most related to the environmental issues about the pollution of surface and groundwater (see 106)

European level

The relevant EU legislation are the Regulation (EC) No 2003/2003 of the European Parliament and the council, 13 October 2003 relating to fertilisers and a series of regulations that modify it.

Nitrate Directive (Council directive 91/676/EEC) and the Water Framework Directive (Directive 2000/60/EC). The Nitrate Directive requires Member States to identify areas that have or are at risk of having groundwater with NO_3^- concentrations more than 50 mg NO_3^- /L or eutrophication of surface water. Such areas are declared to be “Nitrate Vulnerable Zones” and there is subsequently an obligation to implement an “Action Plan” of improved crop management practices to reduce NO_3^- contamination.

The Water Framework Directive is a broadly-focussed directive that deals with various aspects of water quality. It aims to ensure good ecological quality of surface and subterranean water. It is implemented by water basins.

Country level

Each member country of the EU passes national legislation on how the Nitrate and Water Framework Directives will be applied in that country. Commonly, the legislation related to the Nitrate Directive is applied at the regional level, and that of the Water Framework Directive is applied at national level. There have been differences in the degree to which the Nitrate Directive has been applied in different countries. In some North-west EU countries or regions (e.g., Flanders, The Netherlands, Germany), this legislation is being strictly implemented, whereas as in more southern and eastern countries, the implementation is more relaxed.

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Regional level

The EU Nitrate Directive is commonly applied at the regional level.

3.9.4. Existing technologies to solve the problem/subproblems

The existing technologies organized about their general approach are:

Knowing the amount of available mineral nutrients in the soil, the quantity absorbed by the crop, fertilizer characteristics (e.g. solubility, nutrient release), the response of crop growth and production to nutrient supply, the behaviour of the nutrient in soil are all essential to achieving good management of nutrients and limiting nutrient losses to water bodies or the atmosphere.

To conduct soil analyses, the farmer needs to have a procedure for soil sampling and must know how to obtain a composite soil sample that is representative of the fertigated area. Correct sampling may be laborious for the farmer, and there are costs involved in the analysis. New technologies help to determine the number and location of soil samples, through the rapid elaboration of soil maps of apparent electrical conductivity or pH, from automated measurements using different sensor types (eg: electromagnetic induction sensors) (more information in TD 11.10). High numbers of point measurements from sensors mounted on vehicles or the use of aerial or satellite images enable the identification of differential spatial zones that may indicate a nitrogen deficit. The spatial variability in the field can be caused by different types of soil, by topography, or by previous cultural or cropping practices. As a consequence of spatial variability, a homogeneous application of fertilizer can lead to some parts of a field receiving an adequate amount of fertilizer while others are over or under fertilized. The use of variable rate fertiliser application to deal with spatial variability is a new technology with, until now, very limited adoption in horticulture.

The FERTINNOWA benchmark survey revealed that crop observation was frequently used to monitor the crop nutrient status, soilless covered crops excepted. 37% of the cropping systems were monitored in this way, and they were mainly located in the Central Eastern region.

Electric conductivity and pH sensors were reported as the primary ways of monitoring the nutrient solution. Usually, both EC and pH sensors were implemented together, except for drain water sensors in soilless covered cropping systems where pH was measured less frequently compared to EC.

For soil-grown cropping systems, the use of soil analysis was frequently reported in all regions (64 % in average in covered and 59% in average in outdoor cropping systems).

With an adequate training of growers with good technical advice to change their concept of fertilization, according to the Fertinnowa brenchmark survey 57% of the growers performs the management of fertilization with the help of the technician, likewise, 61% perform soil analysis, 71% do not perform sap analysis, 68% perform one and / or another analysis, having to wait for results for a long time, so they have to go to technologies where results can be obtained immediately and be able to make a decision in real time about fertilization management, they can finally choose sensors that are affordable for standard grower, and with development and improvement of these technologies, it can reduce its cost and implement its use by the growers.

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Table 9-27. Existing technologies to solve problems related to fertiliser recommendations.

Existing technologies	Restrictions	Development phase	Potential to solve the problem
N Fertilizer recommendation schemes for horticultural crops	The use of N schemes requires a certain technical knowledge. N schemes based on simulation models or soil Nmin have software or DSS to make calculations. Time to take the soil or foliar samples and lab processing that usually are part of N fertiliser recommendation scheme.	Research into different vegetables and conditions, commercialised	Specialised companies are producing apps or computer program
P Fertilizer recommendation schemes for horticultural crops	The use of P schemes requires a certain technical knowledge. The P-recom-mendation is part of complete soil analysis. The samples are taken before planting/sowing of each new crop.	Commercialised	Growers receive information about available soil P

Table 9-28. Fertilizer recommendations

Existing technologies	Restrictions	Development phase	Potential to solve the problem
Soil analysis	Finding time to take soil samples, to process them and to send them to a laboratory can be a problem given the many demands when preparing a new crop.	Generally applied	Gives accurate information about soil characteristics and interpretation of the results.
Dutch 1:2 soil: water extraction method	the method only estimates the availability of nutrients to crops, but there is no guarantee that plants will absorb it. Take samples	Commercialised and generally applied in the Netherlands	to fertilise the crops more efficiently
Soil solution analysis	The use requires a certain technical knowledge and training. Growers need to be able to understand and interpret soil solution result data	Commercialised	Analysing soil solution provides a quick, easy and economical way to measure salinity and nutrient levels in the soil throughout the season
EC measurement in soil using sensors	Sensor salinity measurements often lack accuracy, to improve accuracy, site-specific calibrations are needed, which require field soil sampling and laboratory analyses.	Commercialised, non generally applied	Most of these sensors measure soil dielectric permittivity which is strongly related to soil water content but are also affected by soil salt content.
EC measurement of substrate drainage	EC only gives an idea about total dissolved ion content in the solution, but it does not provide a measure of the quantity of each ion	Commercialised, non generally applied	Fine control of fertigation and recirculation water quality. Reduced salinity problems.

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Measurement of soil EC by conventional methods	The long time required for the soil sampling to obtain results and interpretation. The spatial variability of soil salinity should be considered to determine the soil samples numbers.	Published, not generally applied	Real information on soil salinity which can be used for soil or irrigation management.

Crop needs are closely related to crop development and production. Models of crop growth and development can assist better adjusting fertilizer rates. However, these models often require a large amount of data and are difficult for farmers to use.

Different types of crop/plant monitoring approaches can be used to provide information on the adequacy of fertilizer management, particularly for nitrogen. These approaches provide information on the nitrogen nutritional status of the crop and are less laborious than soil measurements. Some of these approaches to characterize the nitrogen nutritional status of the crop/plant are:

1. The nitrate content in the sap of a leaf petiole
2. The rapid measurement of chlorophyll in leaves with an optical sensor
3. The rapid measurement of crop reflectance with an optical sensor.

A challenge with these approaches is the determination of reference values used to interpret the results. The use of leaf analysis can help to improve the interpretation of the results from optical sensors.

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Table 9-29. Crop/plant monitoring.

Existing technologies	Restrictions	Development phase	Potential to solve the problem
Nutrient analysis of substrate root zone solutions or drainage water in soilless systems	In the case of a laboratory: the grower has to wait some days before he receives the results. In case of continuous monitoring, need frequent calibrations and sensors are not available for some specific elements.	Commercialised	Gives accurate information on nutrient availability in the root area of the substrate slabs
Chlorophyll meters	Comparing measurements taken from different meters may be difficult if the relationships between measurements of the different meters are unknown. Can be time-consuming to measure a representative sample area of the crop. Measurement can be difficult e.g. carrot, onion and conifers	Commercialised	Information of the current N status of a crop at the time of measurement
Canopy reflectance for N management	Specialist knowledge of sensor operation and good computer skills often required. The need to sample several areas of the crop and time-consuming to measure a representative sample area of the crop.	Commercialised	Information of crop N status at the time of measurement
Fluorescence	Specialist knowledge of sensor operation and good computer skills often required. Time-consuming to measure a representative sample area of the crop when the crop is large. The need to sample several areas of the crop in large farms and when there is large variability.	Commercialised, non-generally applied	Information of the current nitrogen status of a crop at the time of measurement.
Sap analysis	Basic agronomic knowledge. A limited amount of information available for assisting with data interpretation	Commercial not generally applied	Information of the current nutrient status of a crop.
Plant tissue analysis	The laboratory- test takes time to complete. It is strongly recommended that a soil test accompany each plant analysis.	Commercial. Specialized laboratories offer plant analysis	Information of the current nutrient status of a crop.

Additionally, monitoring of reflectance of crop cover by aerial or satellite remote sensing can identify zones with slower crop development. The combination of these data with data of soil variability, enable the use of techniques of precision fertilization. The vegetation indices do not directly indicate the crop nitrogen content. However, qualified technicians can interpret these results as to the crop nitrogen nutritional status and crop nitrogen fertiliser requirements.
Various sources of information can be integrated into software programs known as Decision Support Systems (DSS). DSSs are software based on simulation models that simulate crop growth and nutrient uptake depending on agronomic aspects (date of planting, density of sowing, etc.), climate conditions and soil characteristics. The DSSs can estimate crop nutrient extraction (generally for N).

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Additionally, they can estimate N mineralisation and consider soil mineral N at the beginning of the crop. Using the information on crop demand and of the soil N supply, the DSS can develop a fertilizer plan for the amounts and timing of fertilizer application. To support uptake by farmers and advisors, DSSs must be simple and easy to use.

Table 9-30. Decision Support Systems and models for nutrient management.

Existing technologies	Restrictions	Development phase	Potential to solve the problem
Decision Support Systems (DSSs) for supporting nutrient management	the availability of data and technical support for the user, the time required to obtain data and associated with its use.	Commercialised, applied, public institutions and some companies.	Reduced fertiliser use, reduced environmental impacts
Models for nutrient uptake	Not suitable for use by growers; they are additional tools for use by trained advisors or scientists. Time involved in the process, the initial difficulty to learn the system.	Commercialised, applied, public institutions mostly	DSS systems, to calculate crop fertiliser requirements
Models for nutrient leaching	Not suitable for use by growers; they are supplementary tools for use by trained advisors or scientists	Commercialised, applied, public institutions mostly	DSS systems, the models can be used as a tool to estimate nitrate leaching losses and then optimise N fertiliser management

Table 9-31. Fertiliser aspects.

Existing technologies	Restrictions	Development phase	Potential to solve the problem
Organic fertilizers	Necessary to know nutrient content and patterns of nutrient release; those important for correct rate application and timing, specialised equipment may need to be purchased	Commercialised, specialized Companies on fertilizer production	Improved soil quality. By good management, it can reduce the risk of surface and groundwater pollution.
Use of slow and controlled release fertilizers	Necessary to know patterns of nutrient release; this is important for correct dose rate application and timing	Commercialised, non-generally applied	Fewer fertilizer applications, better control of fertilization, reduced N-leaching
Rapid, on-farm analysis of nutrients	The accuracy of this equipment is lower than obtained in the laboratory	Commercialised	These are portable devices allowing in situ measurements and quick results.

3.9.5. Analysis of bottlenecks and gaps

The main gaps that are related to fertilization and nutrient management are given in the table below. Costs, knowledge gaps in research and knowledge gaps for growers are the three main bottlenecks impeding the adoption of innovative techniques. Some of them do not have an easy

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solution, as nitrate vulnerable zones, where applications are restricted by law. The bottlenecks mentioned in the table below can partly be solved since most of the available technologies to overcome these issues are commercially available, though not all are affordable for standard growers. Also, the need to determine threshold values adapted to each crop, including the variety and climate zone, requires an understanding of the measurements of each sensor.

Traditional laboratory analyses, such as leaf and soil analysis, are used by farmers, but one of the main problems is the selection of representative points to take these analyses (principal problem in soil bounds crops) and interpretation of the data.

Traditional analyses may take on to two weeks before the results are available for the farmer. In many cases, fertiliser management has to be adapted in a shorter time frame.

Portable plant and soil sensors are difficult to use. The collected data is difficult to be correctly interpreted since in many cases there are no threshold values are available for well-fertilisated and poorly-fertilisated plants. Moreover, these sensors need to be taken in the field in a determinate moment, and there are currently no techniques that allow continuous and direct monitoring of the nutritional status of the crop.

The farmer does not have enough background to adapt the fertigation management based on the neither to carry out precision fertigation, meaning to adapt fertigation only in those areas where it is needed.

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Table 9-32. Summarizing gaps

Bottleneck	Tech.	Reg	Socio	Description
Fertigation management - Nutrient management-				
Suitable fertiliser recommendation schemes and/or decision support systems are not available for given local conditions	x	x		Comprehensive schemes have been developed for countries/regions such Germany, The Netherlands, Flanders, and the UK. However, many regions mainly in southern and eastern Europe do not have schemes.
Growers are often reluctant to take soil samples for soil analyses and for use in fertiliser recommendation schemes		x	x	In addition to cost, the lack of time is an issue for growers.
Traditional crop monitoring techniques such as sap analysis require local verified reference values	x			A serious research program dealing with different crops and nutrients in a given region, or a co-ordinated research program, is required. The time analysis is often longer than it takes to make the decision.
Optical sensor technologies (reflectance, chlorophyll meters, fluorescence) while promising, require more development for practical use in horticulture	x			A serious research program dealing with crops in a given region or a co-ordinated research program. Calibration is required for cultivation and varieties
The different types of soil in a plot or orchard.	x			It makes difficult or impossible the uniformity of the fertigation.
Lack of information, training and agronomic knowledge.			x	The farmer does not know how to act.
Deficiencies in the fertigation system and equipment	x		x	Problems with fertigation planning and managing with the corresponding loss of money and efficient.
Nitrate Vulnerable Zones.		x		On having limited the maximum quantity to reaching of N, knows the balance of N in the soil it is important for the farmer to make the fertigation more efficient.
Over fertilization			x	The farmer prefers over-fertilizer, to do not lose production
Lack of knowledge in soil nitrogen balance			x	The farmer does not take into account the different sources of nitrogen on the farm.

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3.10. Limiting environmental impact - Nutrient removal and recovery

3.10.1. General description of the problem

The adoption of fertigation was an important step to optimise both water and nutrient use efficiency in horticultural crops. Nevertheless, appreciable environmental impacts have been observed in regions where fertigation is used intensively. As an example, in the Flemish and Dutch soilless greenhouse areas, the threshold value for nitrate of 50 mg/L is frequently exceeded in nearby surface water bodies.

The FERTINNOWA survey showed that drainage water from soilless cropping systems was usually collected in some European Member States, especially in North-west countries such as Belgium, the Netherlands, and the northern part of France. Out of the 144 respondents answering the question on recirculation, 42% recirculated all the drain water while 26% did not recirculate any drain water, see Figure . The remaining 32% recirculate part of the drain water varying between 1 to 99%.

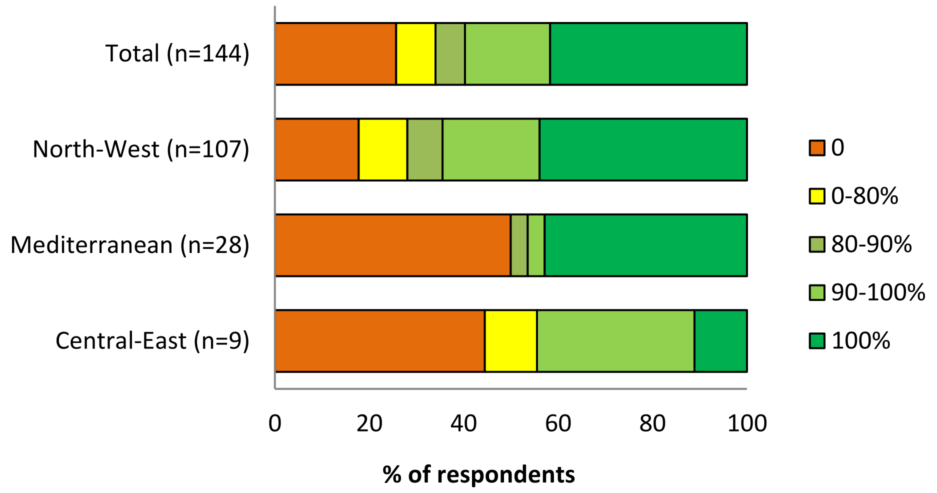

Figure 10-18. Levels of recirculation by the respondents in each region.

Eutrophication is a particular problem where nutrients from soilless systems enter the surface water. The FERTINNOWA survey revealed that 25% of the respondents discharged drain water to the surface water or ditch. 24% of the respondents reported discharging drain water in the sewage. The survey showed as well that recirculation is interrupted due to sodium accumulation, the fear of unknown growth inhibiting factors, imbalances in nutrient composition, and fear of spreading diseases. This implies with the earlier studies carried out by 112 and 112. Flemish and Dutch publications indicate that 5-10% of the nutrient solution is discharged per year from soilless systems with recirculation. Where the discarded recirculated nutrient solution is discharged in the surface water, this can result in an appreciable environmental impact.

In recent decades, numerous research activities have been undertaken to develop technologies for nutrient removal and recovery of some nutrients present in the discharged drain or drainage water. The treated water could be either reused in the same system or discharged. This solution could also offer growers the possibility to use a locally produced fertilizer with less expensive chemicals or to sell it to other growers. A concrete example is the Berliner Pflanze® a fertilizer (MAP) obtained from

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municipal wastewater and commercialized by Berliner Wasserbetriebe. Moreover, countries like Netherlands, Denmark, and Flanders (Belgium) have stablished special authorizations for struvite use as fertilizer 112.

The problems described in this section are also closely related to the issues in section), 33 “Optimizing water quality – nutrients”, which aims to produce a good water quality for re-use and section 96 “Fertigation management - Nutrient management”, which aims to achieve an optimal fertigation to have a better quality and productivity of the crop. In general, improving water quality means maintaining the concentration of nutrients at the right level and removal of unwanted salts and other components for reuse of discharge.

1. Need for specific legislation regarding the use of recovered nutrients

Regarding the use of recovered nutrients as fertilisers, there is a new proposal, which will replace the current 2003 Fertilisers Regulation that includes all types of fertilisers (mineral, organic, soil improvers, growing matters, etc.). The objective is to encourage large-scale fertiliser production from domestic organic or secondary raw materials in line with the circular economy model, by transforming waste into nutrients for crops.

The proposed legislation is currently undergoing trilogue negotiation between the European Parliament, Council of the European Union and the European Commission. Industry organisations have recently organised a meeting in Brussels on 11th April with the purpose to discuss how the revised regulation should provide for the use of plant materials and organic by-products.

2. Need for business models

There is a need for business models regarding end-of-pipe solutions. Removal of nutrients is costly and usually requires considerable investment and operational costs. Consequently, it is essential to make available sound business models that inform growers of the costs and benefits associated with using these technologies, such as the extra costs, the possible fertiliser savings associated with nutrient recovery, and exploring the options of on-site, mobile or collective end-of-pipe solutions.

3. Need for a long-term demonstration of the nutrient recovery technologies

Most of the technologies that enhance nutrient recovery are still in the research phase. There is a need for long-term field tests and demonstrations to evaluate the regenerated fertilisers obtained.

As transport of recovered fertilisers is expensive and also would require additional legislation, it is likely that recovered nutrients would be applied at the farm from where they were recovered. Long-term demonstration sites, implementing the recovered fertilisers in the fertigation schemes should be conducted to showcase the efficiency of these fertilisers.

4. Other contaminants and need for a holistic approach

In addition to water use, the emission of nutrients and of plant protection products (PPP) to the environment are amongst the most important environmental issues associated with agriculture in Europe. Most of the technologies for removing nutrients and PPPs are end-of-pipe solutions that generally focus on the removal of specific nutrients, e.g. N or P, or of PPPs. For end-of-pipe solutions, a more holistic approach would be beneficial because generally a range of discharge criteria must be satisfied to ensure proper water quality, e.g. chemical oxygen demand (COD), PPP, N, P, Na, Cl, etc.

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3.10.2. Brief description of the socio-economic impact of the problem

In soilless grown crops with recirculation, a surprising amount of drain water is discharged. Flemish and Dutch publications indicate that 5-10% of the nutrient solution is discharged per year from soilless systems with recirculation. Where the discarded recirculated nutrient solution is discharged into the surface water, it can contribute to nitrate contamination of the surface water. As mentioned in 112, 10% of the points that exceeded the nitrate limit (50 mg/L) in Flanders, were significantly or exclusively influenced by soilless cultivation systems with direct discharge of nutrient rich wastewater into the surface water.

A Dutch study estimated that the Dutch soilless greenhouse sector discharges 1300 tons N, 200 tons P and 1134 kg PPPs/year 112. As mentioned before, accumulation of salts in the irrigation water could cause problems in the system 112. To avoid these problems, growers have to spread the discharge water on cultivated land or purify the discharge water causing additional transport and disposal costs. Also, waste water discharge represents additional disposal costs for growers, for instance, a commercial cucumber greenhouse of 3 ha with a yearly discharge of 2,000 m3 amounts to approximately 5,000 € a year 112. However, existing technologies such as the electrochemical phosphorus precipitation “ePhos®” 112 and ion exchange 112 allow the recovery of nutrients from discharge water as fertilizer. The recovered fertiliser could be used by the growers resulting in economic benefit. For example, the phosphorus price at the end of 2017 was around 0.07 Euros/Kg 112.

The implementation of technologies for the removal and/or recovery of nutrients will involve dealing with a series of socio-economic issues:

- A “mind shift” of the growers will be required as growers will have to pay additional attention to the treatment of a “wastewater stream.”
- At the moment, growers are not sufficiently aware of the potential value of discharged drain water. Drain water will have a residual value for both the nutrients contained as well as the value of the water itself. The value of the water will differ depending on the type of water source
- Purification of wastewater can require considerable investment. Recovery of (some) nutrients and on-site production of fertilizers might cover (part) of the investment and operational cost for these installations

3.10.3. Brief description of the regulations concerning the problem

Some Directives and policy requirements have been developed by the European Union (EU) as well as the sector itself (e.g., certification schemes) that affect fertilizer use and irrigation in horticulture in the EU.

The Directives on urban waste water treatment and nitrates pollution from agricultural sources from 1991, and the EU water policy and legislation, the Water Framework Directive of 2000. These regulations limit the concentrations of nutrients in water bodies, and therefore they could encourage growers to shift to the use of new technologies that reduce and recover nutrients.

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Regarding these new technologies, which could be implemented to recover nutrients from the waste water, there are also initiatives in Europe for new regulations to promote the recovery and efficient use of nutrients. For example, the new EU Fertilizer regulation will include recovered fertilizers. The final version will be available in 2017.

3.10.4. Existing technologies to solve the problem/subproblems

Various "end-of-pipe" solutions are available for nutrient removal and recovery of specific nutrients from the drain or drainage water. The nutrient removal and recovery techniques include physio-chemical procedures such as adsorption media for phosphorus, electrochemical phosphorous precipitation, moving bed biofilm reactor, modified ion exchange, and biological approaches such as nutrient removal in constructed wetlands and the use of duckweed.

Other desalination technologies to remove nutrients, such as reverse osmosis, membrane distillation, ion exchange and nanofiltration were described in section 3.2. The main problem regarding these technologies is the fouling of membranes and the disposal of the residual concentrate or brine. Therefore, a pre and/or post treatment could be required.

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Table 10-33. Restrictions and problems of the nutrient removal and recovery technologies.

Existing technologies	Restrictions	Development phase	Potential to solve problem
Lemna Minor/Lemna Major	It can reduce P and N but no recovery of nutrients. A limiting factor is on one hand the duckweed population density and on the other hand the space requirements. At a high density, there will be less light and nutrients available per plant. Duckweed production in open air is sensitive to damage by wind, but also by insects and aphids.	It needs further research for irrigation water.	Maybe,Duckweed reduces N, P and metals in waste water but need more research for irrigation water applications.
Moving bed biofilm reactor MBBR	The technology eliminates nitrogen but it does not recover it as fertilizer. The technology does not have an effect on phosphorus. Plant protection products can negatively affect performance.	Commercialised only for municipal and industrial wastewater. Use for irrigation water needs further research.	Yes, it reduces nitrogen in water.
Electrochemical Phosphorus precipitation (ePhos®)	For irrigation water is the system not cost-effective because the P-concentration is too low (< 80 mg/l). P must be first concentrated using for example ion exchange technologies. The regulation for the use of recovered P-salts is not uniform in all European countries. This makes it difficult to sell the product (struvite)	Field tests only for municipal waste water. Use for irrigation water needs further research.	Yes, it removes Phosphorus.
Adsorption media for Phosphorus	It only removes Phosphorus but this is not recovered. Further research is necessary to study the possibility of the reuse of the phosphate saturated iron grains as a fertilizer for plants. It needs specific legislation	Field tests with wastewater. Further research is necessary on the possibe reuse of the phosphate saturated iron grains as a fertilizer and its application for irrigation water.	Yes, for smaller companies with a limited amount of waste water, whereas biological removal processes require bigger installations.
Nutrient removal in constructed wetlands	It removes Phosphorus (P) , Nitrogen (N) and Potassium but after 5 years, the P removing effect of the wetland disappears. It requires big areas.	Commercialised only for wastewater treatment. Use for irrigation water needs further research.	Yes, it is used to remove excess of nutrients such as N and P from drain water before releasing water into the environment.
Recovery of nutrients using modified ion exchange (MIX)	The amount of water that can be treated using MIX is limited by the fertilizer that can be used or sold to users close by, since transporting the fertilizers can be costly and hence uneconomical.	Commercialised for groundwater desalinization, Nutrient recovery, In-line semi-selective treatment of recycled greenhouse water to prevent salt build up.	Yes, the technology is transferable to any crop, climate and cropping system.

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3.10.5. Analysis of bottlenecks and gaps

1. ***Need for specific legislation regarding the use of recovered nutrients***

Legal barriers to sell the recovered fertilizers are bottlenecks that can be solved mainly at a regulatory level and this is an issue that concerns many of the nutrient recovery technologies. However, in countries like Netherlands, Denmark, and Flanders (Belgium) there are currently special authorizations for struvite use as fertilizer.

2. ***Need for business models***

As listed in table XX, the available technologies are commercialised for waste water treatments, not specifically for horticultural discharge water. The specific composition of this water might affect the business models for the technologies treating waste water. For example, electrochemical Phosphorus precipitation is not cost-effective for the treatment of discharged water of ornamental crops because the P-concentration is too low (< 80 mg/l). P must be first concentrated using, for example, ion exchange technology. In this way, treatment costs will increase.

In countries like Germany, successful study cases such us the Berliner Wasser Betrieb Process have demonstrated the possibility of nutrient recovery at big scale and its market potential, see more information in D4.2 Inventory innovative technologies of other sector.

3. ***Need for a long-term demonstration of the nutrient recovery technologies***

Most of the technologies that enhance nutrient recovery are still in the research phase. As indicated in **Table** there is a need for long-term field tests and demonstrations to evaluate the regenerated fertilisers obtained. Numerous demonstrations sites have been established throughout Europe. European projects or initiatives (like FERTINNOWA, Nuredrain, etc.), as well as numerous national projects (Apropeau (Be), SOSpuistroom (Be), Glastuinbouw Waterproof (NL), etc.), are investigating and demonstrating end-of-pipe solutions. Most of these projects have been initiated recently. The first outcomes are expected in the coming year(s).

4. ***Other contaminants and need for a holistic approach***

In addition to water use, the emission of nutrients and plant protection products (PPP) to the environment are amongst the most important environmental issues associated with agriculture in Europe. Most of the technologies for removing nutrients and PPPs are end-of-pipe solutions that generally focus on the removal of specific nutrients, e.g. N or P, or of PPPs. There is a need for a more holistic approach offering growers a complete solution which will remove both nutrients and PPPs. Again recent initiatives have been taken (S.O.Spuistroom (Be), Verhoeve Milieu & Water (Be, Nl) to offer growers technologies both removing nutrients and PPPs. However, practical experiences are lacking so far.

5. ***Need for adaptation of waste water treatment technologies to discharge water***

Also, some technological bottlenecks require the adaptation of the technologies to the field of horticulture; this is the case of ePhos®, where a phosphorus concentrating technology could fill the gap of low phosphorus concentration of the drain water. In other cases, the bottlenecks associated with the technologies cannot be immediately solved, and they need further research.

The problems and sub problems that cannot be solved currently are showed in Table **Table** .

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Table 10-34. Problems and sub problems that cannot be solved currently

Problems/sub problems that cannot be solved currently.	Feasibility of solution for the problems based on the proposed technologies.
1. Need for specific legislation regarding the use of recovered nutrients	This problem will be solved when the new EC Fertiliser legislation is approved.
2. Need for business models	The electrochemical phosphorus precipitation and the modified ion exchange (MIX) are bussiness oriented technologies as far as they allow the grower to recover the nutrients in form of fertiliser withouth generating additional waste streams. The other technologies do not produce fertilisers but generate additional costs of waste disposal.
3. Need for a long-term demonstration of the nutrient recovery technologies	The MIX technology and constructed wetlands have been previously used in horticulture. The electrochemical phosphorus precipitation will be tested during a 3 months period in PCS Belgium from May to July 2018.
4. Other contaminants and need for a holistic approach	The listed technologies do not have a holistic approach. They can only remove specific nutrients.

3.10.6. References for more information

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3.11 Limiting environmental impact - Pesticide residues

3.11.1. General description of the problem

To grow qualitative crops efficiently, plant protection products (PPP) are needed. These products are applied to protect the crop against pests and diseases or to control them.

In the past, Europe has taken action to evolve towards a more sustainable use of PPP (Directive 2009/128). Although PPP are only applied locally, residues can be found on a significant distance from the area of application through drift, evapotranspiration of the treated surfaces, and deposition through rain or dust, discharge of drain water and the water used for cleaning equipment to the surface water or the sewing system [19]. Therefore, the problem of emissions of PPP to the environment is relevant for all European regions with (intensive) horticultural production as PPP are applied in all those regions.

A survey conducted by the Pesticide Action Network [20] retrieved official analytical data from some of the major river basins in Spain and detected traces of not only products with endocrine disruptive action but ppps like lindane or endosulphan. Another issue is the presence on surface waters of the so called emergent pollutants like pharmacological products used for human and animal health, surfactants, or personal cleaning products. Different European projects are dealing with these situations. As an example Interreg OUBIOTICS tries to eliminate and reduce antibiotics from surface water by using innovative technologies like inert nano- and micro molecules.

Based on the directive, the European Member States are working on National Action Plans in which the goals and measures are described. Important measures for outdoor soil grown crops are, for example, the establishment of zones in which horticultural production and the application of PPP is not allowed or the obligatory use of drift reducing nozzles. Very relevant for protected crops are measures of discharge water. To minimize the environmental and health risks, cleaning and purifying of the discharge water is essential.

The EU Water Framework Directive deals with the management and protection of water. Part of this is to maintain or improve water quality by avoiding or minimizing pollution with for example PPP. Based on this Member States have the task to reduce or ban the emission of PPP to waterbodies. In the Netherlands for example, from 1 January 2018, the concentration of the PPP in water must be reduced by 95 percent before it is allowed to discharge.

Horti- and agriculture are among of the primary users of plant protection products. Use of PPPs by other sectors and users are, for example, pavements in the urban area, on sports and recreational areas, in parks and nature reserves and citizens in their gardens. One of the most used means to control weed is glyphosate.

Problems/bottlenecks are:

For open field production:

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Important emission routes for PPPs after application are to the soil (for example in case of the use of herbicides, by run off, when the crops not fully cover the soil or by drift) and open waterbodies (by drift). As open field production takes place in open systems, it is not possible to completely prevent the emission. The main challenge therefor is to reduce the emission as much as possible. This can be done with a good monitoring system (development and distribution of pests and diseases), models describing the development of pests and diseases, a good knowledge about the available PPPs and a reliable weather forecast. This makes it possible to optimize the timing, the choice of the (adjustments of the) application technique and the spatial distribution of the application. Last but not least improvement of application techniques (for example to reduce drift and run off) is an important step.

Work is already done on all these technologies but there is still a lot of work to be done. For successful implementation of new technologies it is of course important that this has major (financial) advantages for the grower.

Indoor production:

The production in (almost) closed systems makes it possible to collect PPP's and remove them or break them down before water is discharged.

In general the expectation is that discharging is often not really necessary. There are various reasons for growers to discharge: this can be to prevent the spread of diseases, too high sodium concentrations or the impression that crop development is deteriorating for example by root exudates. More knowledge about the impact of for example sodium and root exudates and also a reliable and affordable monitoring system are desirable and would provide a solid base for decisions to discharge water.

If water has to be discharged and PPP's have to be removed or broken down the following problems and bottlenecks may turn up:

1. ***Technologies to remove or break down PPPs might be harmful for people***

To reduce the concentrations of PPP in discharge water techniques are used which can be harmful for people and therefore liable to regulations.

At the European level the use of ozone, which can be used to break down PPP, has to be approved. It is registered as a biocide under the Biocidal Products Regulations (EU) 528/2012 framework (see http://www.euota.org for more details).

2. ***Techniques to remove PPPs: the removed PPPs have to be disposed***

In systems in which the PPPs are removed (for example filtration systems), the PPPs are not broken down but concentrated. The concentrate has to be disposed.

3. ***Techniques to break down PPPs: still in development***

Until now the effect of these techniques were tested with a limited number of PPP's, the effect on the breakdown of other PPPs (and new molecules) are not investigated and can only be deduced from the results of the tested molecules or have to be tested yet.

4. ***High costs – no direct financial benefits?***

To use the purifying techniques only to meet the requirements for discharging implicates costs but no financial benefits for the grower. To stimulate the introduction of the purifying techniques in situations in which this is not obliged one has to work on the profits. Therefor the techniques should

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as much as possible also be used for disinfection to make recirculation possible and safe (save of water and nutrients and prevention of losses caused by diseases).

5. New development: timing of introduction of the technology

The regulations on the discharge of water lead to new technological developments, probably more effective and/or less costly than existing technologies. This may create a waiting attitude and delay progress.

3.11.2. Brief description of the socio-economic impact of the problem

Government, producers, retailers, consumers and other stakeholders in horticulture wish to have sustainable products and production with limited impact on the environment. The emissions of PPPs during crop production have a negative impact on the environment. For example, if the concentration of PPP in surface water is too high, this can be a direct or indirect risk to human health. In a survey European citizens ranked environmental pollution very high when asked what could personally affect them.

Furthermore there is an issue with food safety related to human health. Traces of crop protection products remain a concern for the consumer – as was underlined by the above mentioned European survey - even if objectives in the area of residue standards (MRLs) have been achieved. There is also concern of exposure of consumers to several substances at the same time (accumulation), while this aspect is not yet included in the regulations.

Plant protection products can also affect biodiversity when used incorrectly. For example, a lot of attention has been paid recently to the influence of using crop protection products on bees. This may affect food production directly as bees are very important for pollination.

Pollutants in open water generate also a lot of bad publicity for farmers. Reducing or eliminating pollution altogether is becoming a strong point of Dutch local and national governments as well as the European Union. To meet the regulations, growers are obliged to invest in new technologies to purify the discharge water or to pay for external services to purify this water.

3.11.3. Brief description of the regulations concerning the problem.

On different levels (European and national), regulations are being drafted to reduce the emission and reduce the concentration of PPP in waterbodies like surface water. A short summary of the most important regulations per level:

European level

DIRECTIVE 2009/128, set by the European Union, is meant to reduce emissions of PPP used by farmers. This directive states establishes a framework to achieve a sustainable use of pesticides by reducing the risks and impacts of pesticide use on human health and the environment and promoting the use of integrated pest management and of alternative approaches or techniques such as non-chemical alternatives to pesticides. The directive also requires specific measures to protect the aquatic environment and drinking water. Besides and as a legislative complement, Directive 2013/39/EU amends the priority list of substances that are subject to action in order to prevent deterioration in the chemical status of surface water bodies. This action consists of

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establishing supplementary monitoring programmes and a set of measures to prevent environmental and human health risks.

Country level

Member States shall ensure that appropriate measures to protect the aquatic environment and drinking water supplies from the impact of pesticides are adopted. Those measures shall support and be compatible with relevant provisions of Directive 2000/60/EC and Regulation (EC) No 1107/2009. For farmers, this requires them to actively control their emissions and reduce them.

To reduce the concentrations of PPP in discharge water techniques are used which can be harmful for people and therefore liable to regulations.

At the European level the use of ozone, which can be used to break down PPP, has to be approved. It is registered as a biocide under the Biocidal Products Regulations (EU) 528/2012 framework (see http://www.euota.org for more details).

In the Netherlands there are problems with the surface water quality in the large and dense populated areas with many greenhouses. This is one of the main reasons that there is a strong legislative force on the reduction of the emissions of PPPs from the companies.

The 2nd Note on Sustainable Crop Protection (2e nota Duurzame Gewasbescherming), set by the Dutch Ministry of Infrastructure and Environment states that the Dutch water quality needs to improve. This means that the number of violations of PPP Maximum Residue Levels (MRL) in open surface water must be reduced. The PPP in discharge water cause a MRL violation, therefore they need to be removed from the discharge water. This has an impact on for growers. **Fout! Verwijzingsbron niet gevonden.** gives an overview of the required emission reductions in percentages in 2018 and 2023 per company type related to the situation in 2010.

Table 11-35 Overview of required PPP emission reductions (related to the situation in 2010) in the Netherlands

Company Type	2018	2023
Horticulture	95.0	99.7
Tree Nurseries	67.0	98.0
Fruit growers	80.0	99.5
Flowerbulb growers	83.0	99.3
Open field vegetables	67.0	98.0
Agriculture	57.0	93.0
Livestock	50.0	75.0

To purify discharge water from PPP, certified equipment is needed by 2018. At the moment only limited certified methods exist yet (see next paragraph).

3.11.4. Existing technologies to solve the problem/sub problems

1. Technologies and practices to reduce emissions of open field crops

Especially in open field production the use of drift reducing nozzles but also improved application techniques as well as optimizing timing (especially with regard to weather conditions like precipitation and wind) can reduce the emission of PPP to open water bodies. More and more

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technologies are developed to forecast infestations but also to map the distribution of pests and diseases within a plot. This improves the functionality the application both in time and space.

2. ***Purification of the remnants of the spraying solutions***

Remnants of the spraying solution as well as the waste water coming from cleaning the application equipment can be purified with for example systems like Phytobac, Heliosec and bio filtration. As well mobile systems are available like for example Sentinel.

3. ***Removal of PPP from drain water***

In protected crops the aim is to recirculate a reuse as much as possible and to purify the water if it has to be discharged.

For the purification several technologies are available. They are summarized in Table 11-36 and Table 11-37 Table 11-37 . In the Netherlands a protocol was developed to test technologies and determine whether the efficacy meets the requirements (95% reduction of PPP concentrations in discharge water on average related to the situation in 2010, starting January 1st 2018). Various technologies have been approved (certified) for removal of PPP from (discharge) water (Table 11-36). But there are other technologies available that are not approved yet (Table 11-37).

Table 11-36. By Dutch authorities approved technologies for removal of plant protection products (PPP)

Existing (combinations of) technologies	Issues and restrictions	Development phase	Potential to solve problem
Ozonisation	Toxic by-products, strict health and safety requirements, high costs, corrosive, pre-treatment needed with high amounts of dissolved organics or suspended particles	Commercialised	High
Peroxides + UV	UV: High maintenance/investment/operational costs, efficacy relies on water transparency	Commercialised	High
Ozonisation + carbon filtering	Ozonisation: Toxic by-products, strict health and safety requirements, high costs, corrosive, pre-treatment needed with high amounts of dissolved organics or suspended particles	Commercialised	High
Peroxides + UV + ozonisation	UV: High maintenance/investment/operational costs, efficacy relies on water transparency Ozonisation: Toxic by-products, strict health and safety requirements, high costs, corrosive, pre-treatment needed with high amounts of dissolved organics or suspended particles	Commercialised	High
Peroxides + catalyst + ionized air	Toxic by-products	Commercialised	High
Nano filtration + carbon filtering	No chemical breakdown of PPP → needs follow up	Commercialised	High

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Carbon filtering + ultrafiltration	No chemical breakdown of PPP → needs follow up	Commercialised	High

But there are other technologies available that are not approved yet (table 11-3).

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Table 11-37 Existing technologies for removal of plant PPP (not approved by Dutch authorities)

Existing (combinations of) technologies	Issues and restrictions	Development phase	Potential to solve problem
Electrochemical flocculation	No chemical breakdown of PPP → needs follow up	Commercialised	High
Reverse osmosis	Costly, no chemical breakdown of PPP → needs follow up	Commercialised	High
Phytobac	Developed for purification of waste water coming from spraying equipment (relatively small volumes). Higher capacity is possible but would require a lot of space.	Commercialised	Medium (part of the problem)
Heliosec	Developed for purification of waste water coming from spraying equipment (relatively small volumes). Higher capacity is possible but would require a lot of space. No/only partial decomposition of PPP → needs follow up	Commercialised	Medium (part of the problem)
Photocatalytic oxidation	Selectivity, by-products, corrosive, less effective than UV and ozone, legal bottleneck (probably registration as PPP required)	Experimental phase	Medium
Bio filtration	Complex ecosystem: Efficacy depends on several factors → relatively high probability of disruption, limited capacity/lot of space needed	Commercialised	Medium (part of the problem)

3.11.5. Analyses of bottlenecks and gaps

In open field production without recirculating infrastructure emission to water bodies through drift or leaching/washing-of cannot be avoided completely. The aim is to reduce these emissions as much as possible.

Important elements for an optimal system are among other things:

- Pest and disease monitoring and predicting systems
- Decision supporting systems (using data of the pest and disease monitoring, weather situation and forecast, crop stage and characteristics, soil characteristics (with regard to weed control), mode of action of PPPs, available application techniques)
- Application techniques with low or no emission which are able to apply – based on distribution of a pest or disease - locally and efficiently

In general most of the required technologies are still in development and, therefore, emission of PPP's – but for the same reason also fertilizers – is a technological bottleneck.

Another bottleneck is that emission reducing measures are not directly profitable for growers.

In more or less closed/recirculating systems – where water streams can be monitored and treated almost everywhere – the water can be purified effectively (95% to 99%) reduction of PPP) with various (combinations of) techniques. Also, new technologies are in development.

However, the effect of the purification is (in The Netherlands) only tested with a limited number of PPP and not with all in Europe registered PPP. Also, for the scheme that is adopted in the

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Netherlands, the certification procedure of the water treatment equipment is set with a standard solution of PPPs. However, the drain water in horticulture companies can differ in composition as well as in concentration and this may have an influence on efficacy. Also, for future active ingredients and formulations the technologies have to prove themselves again and again.

In some countries, like for example Belgium, there is no clear regulation regarding the required reduction percentages for PPP in discharge water to allow discharge on the surface water.

Up till now the tests are only taking into account the breakdown of the PPPs. The results of the tests don't include information on metabolites of the PPP nor by-products of the purifying technologies. So, it cannot be guaranteed that discharge water not contains more than a low percentage of the original present PPP. And also it cannot be guaranteed that metabolites and by-products don't have a negative impact on the environment.

Most of the technologies are costly, both with regard to investment and maintenance. Therefore to use them to purify discharge water only means an economic disadvantage for the growers. But the use of them cannot be seen isolated from other benefits: most of the techniques are also used to disinfect the water in the recirculating systems and help to save water and nutrients and prevent serious losses caused by diseases. This makes the investment profitable.

The combined use of the technologies (disinfection and purifying) will also make it likely that maintenance is carried out properly as a grower doesn't want to take the risk of incomplete disinfection.

In case the technology is only used to purify discharge water it is important that growers check if the technique works well. Especially as in these situations growers probably use the installation only temporarily. In the Netherlands for this situations mobile installations are available.

Conclusion

Open field production (without any recirculation infrastructure)

Further research and development has to be done concerning:

- Pest and disease monitoring and predicting systems
- Decision supporting systems
- Application techniques with low or no emission which are able to apply – based on distribution of a pest or disease - locally and efficiently

Part of this R&D should be an cost-benefit analysis which can be used to convince growers to implement the new techniques and technologies.

Closed/recirculating production systems:

- Supplementary research has to be done with regard to metabolites and by-products of various technologies.
- Depending on the results it can turn out to be necessary to improve the techniques or develop new technologies.

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Table 11-38. Gives an overview of the gaps

Bottleneck	Tech.	Reg.	Soc.	Description
Open field production without recirculating infrastructure				
Lack of pest and disease monitoring and predicting systems	x		x	For some crop/pest combinations such systems exist but not yet for all. As a result of that applications are done without knowing if they are really necessary and/or effective
Lack of decision supporting systems	x		x	For some crop/pest combinations such systems exist but not yet for all. As a result of that applications are done without knowing if they are really necessary and/or effective
Application techniques with low or no emission	x			The development is still going on and the expectation is that the technology will provide better results
Reduction of emission has no direct and visible advantages for the grower			x	Technologies leading to reduction of emission must also have verifiable (economic) advantages for the grower
Closed/recirculating systems				
Results of purification of discharge water are based on a limited number en specified PPPs	x			Further research is needed to determine the possibility to remove or break down other PPPs
No information is available on de metabolites of the PPPs and the by-products of the used purification techniques	x			The tests of the purification only focussed on reduction of the active ingredients. It has to be clarified if and so what metabolites and by-products can develop with the different technologies

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4. Conclusions

4.1 Introduction

A lot of methodologies and technologies are available to support growers to use water and nutrients more sustainably and efficiently at the same time allowing to improve productivity and profitability. However, still steps forward can be made to support further improvement of water and nutrient use and sustainability. The benchmark survey revealed that growers all over Europe are facing problems, either on a technological, legal or socio-economic level. Some of the problems faced occurred in specific regions, crops or growing systems, while other problems were experienced in all areas of Europe. Part of the problems are more general and not count for one topic and/or do not have a technological origin. Often a combination of technological and non-technological solutions seemed to be required to support growers bringing their growing systems to the next level of sustainability.

4.2 General gaps

As a general observation, the survey showed that part of the growers were convinced they were already applying the most efficient and sustainable practices regarding irrigation and fertigation. Growers thinking they still could make further steps forward were generally not aware of all the available technologies that could assist them to resolve some of the issues and problems they were facing. They had not heard about these technologies or did not know these technologies were also applicable in their situation.

In case a technology is known by a grower, the grower first has to be convinced of the effectiveness of the solution. In general, growers doubt about the reliability of new technologies or tools. Growers think that their situation is unique and that the solution is not applicable in their situation. They are afraid that the new system requires considerable changes in the current way of operating. Moreover, growers fear to risk yield or quality losses when introducing new technologies. For many technologies, proper operating practices are fundamental. Systems that are not operated in a right way are regarded as not applicable, what will also affect future users. This illustrates the need for specific knowledge for growers on how to operate new technologies, models, or methodologies correctly.

In many cases, the growers reported that the scale of the existing technologies is too large compared to the smaller scale of their farms. The pay-back time is therefore too long and makes it economically not attractive to invest in new technologies.

Besides, not only the investment of the system itself but also the need for supporting materials and technologies, such as storages, pumps, and pipes increases these costs.

4.3 Specific gaps on technologies, methodologies and tools

4.3.1. Water storage, systems and tools

The main gaps in water storage are:

- Dimensioning models of required water storages are not available for all situations (regions, crops):

In general, the few available advising tools are restricted to specific regions, growing systems and crops. The available tools for the dimensioning for water storage focus on greenhouse crops as these greenhouses provide sufficient surface to collect rainwater. ***There is a need to extend existing models or develop new models***:

  - For different ***regions***: especially in those regions where rainwater could cover a major part of the crops fresh water demand. Focus should go to the impact of the annual precipitation volume and pattern.
  - For a broader range of ***water sources***: Existing models focus on rainwater as rainwater is the main source stored. However, alternative water sources such as condense water of greenhouses, drainage water from underneath greenhouse constructions or water provided by irrigators communities, could be stored as well to fulfil the crops fresh water demand. The availability patterns of these sources might differ significantly from the precipitation pattern the models are based on. Therefore, these different sources should be taken into account to dimension the storages as efficient as possible.
  - For diverse ***crops:*** crop water demands of the different crops in relation to the specific growing conditions (for example in case artificial growing lights are applied).
  - For different ***growing systems:*** models are available for greenhouses and tray fields in the Netherlands and/or Flanders. Models lack for container fields and tunnels.
  - To implement the impact of ***climate change***. Effects on the dimensioning of water storages due to changes in precipitation patterns and/or volumes on a medium term (20-25 years) is missing in the existing models.
  - To include ***dimensioning of buffer volumes for large scale reservoirs***: There is a need for tools to assess the required buffer volumes for water storage systems. These buffers should be designed in such way that risk for flooding of the surrounding areas of the farms is prevented at time of intensive rainfall. This is especially the case for large surfaces such as greenhouses, container fields, and tray fields. These models should be about the region, growing system, and regional climate conditions. Also,
  - climate changes must be taken into account here.
  - To include **economic evaluation of the stored water:**
    There is a need for tools to calculate the cost benefit for rain water storage at the company level taking into account all related costs, like the loss of productive land, influence of water temperature on the crops, evapotranspiration losses.
- Limited knowledge on applicability of innovative water subsoil storage systems:

There is a need to clear out the suitability of specific regions to implement large scale subsol water storage systems. This is not clear for growers at the moment. There is a need for a correct

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economic calculation of the actual costs for storing rain water or irrigation water at the company level.

- Need for national and European guidelines for storage

In some European regions rainwater is an interesting water source. However, in some area's both environmental and governmental organisations keep growers from collecting this water as this water would harm the enrichment of the deeper underground water layers

Legislation regarding water storage facilities differs strongly on the European, national but also regional level. Even on a national level the specific guidelines to construct water storages are not always transparent.

There is also a need to clarify the legal restrictions regarding subsoil water storage systems at the regional/national level.

4.3.2. Optimizing water quality

The most important gaps for nutrient removal are:

- Insufficient selectivity

The possibilities to selectively remove sodium from nutrient rich streams, such as recycled drain water, are limited, what restricts recirculation. In case of membrane processes, there is a need for more selective membranes, for ion exchange more selective resins are needed.

- Fouling of membranes

Desalination is generally applied in regions where sodium rich water sources are applied. Most desalination technologies are based on membrane systems which are sensitive to fouling. Often a pre-treatment step such as pre-filtration or addition of acids is carried out. Still, in several cases, the origin of the fouling is not precisely known. It might be useful to look more specific to the fouling problems for the different applications in agriculture and in relation to the water sources used.

- Improved insight in water quality demands needed

The required water quality for irrigation and fertigation water differs strongly depending on the crop and growing systems. Growers are not always aware of the required water quality for their specific crops and growing systems. Therefore, they choose "high quality water" for being at the safe side. This might lead to a too far going treatment of the water and removal of the nutrients.

- Technologies for further treatment of concentrates

Most of the available technologies for nutrient removal produce concentrates with high salt content. At the moment, it is often costly to further concentrate these streams or selectively remove components to make re-use of the concentrate possible. Technologies for further concentration are limited, and costs are often high due to high energy costs, high material costs or other specific equipment conditions.

- Need for uniform regulation

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The EU guidelines for discharge of waste water and concentrates are not always implemented in the same way in the different countries, what makes it sometimes difficult to come up with the right measures and universal solutions (see also 106 for nutrient discharge).

4.3.3. Removal of Particles

The main problems with particle removal are:

- Fouling/ plugging of the filters.
  Filter technologies apply filter materials such as sand or membranes for retention of solids, what makes these technologies sensitive for fouling. These technologies have to be back flushed
- Production of waste products
  All the particle removal technologies have a waste product. In most cases, this is wastewater originating from back flushes. The waste water streams or products are contaminated with fungal spores, plant protection residues, and nutrients. It can also be a soiled paper band or organic substrate.
  The costs for the waste disposal are high.

4.3.4. Algal Bloom

The main gaps to prevent algae bloom are:

- There is a need for low-cost, long-term methods to control algal blooms
  Chemicals are generally applied but most have only a short term effect and therefore require repeated treatments. Addition of chemicals to the stored water might, at varying degrees, present risks to living beings and the water storage construction (foils). For small to large water storage systems, illumination through water covers might be an option. However, the financial cost is often too high. Ultrasonic devices might offer an economical solution but, their efficiency depends strongly on the environmental factors.
- Need for large-scale demonstration sites for biological algal control.
  Biological control of algal blooms might have benefits both for long-term prevention of algae and also for algae control in very large water storages. In case of coloring additives, aquatic plants, bacteria, and enzymes, only a few studies are carried out for large-scale water storages in horticulture. Demonstration of these biological treatments is necessary to have a better view on their efficiency to control algal blooms. Phytotoxicity studies are required to test the possible effects on the crops. For the application of most of them (coloring, fish, bacteria, enzymes) there are legal restrictions. For the growers, the use of biological methods like aquatic plants, coloring additives or bacteria might requests a mental change.

4.3.5. Optimizing phytosanitary quality of water for improving water reuse

The main gaps for optimizing the phytosanitary quality of the water are:

- There is a lack of reliable, quick and payable (qualitative and quantitative) DNA-analysis for a good insight into the presence and development of hazardous (for plant and human) and beneficial microorganisms.

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- Lack of system-related disinfection methods. Very effective disinfection techniques can only be applied at specific points in systems where no plants are present and therefore cannot prevent completely the spread of harmful microorganisms in the systems and/or the formation of biofilms.
  Lack of selective and safe disinfection technique. Existing techniques are not selective enough to - on one hand - disinfect whole systems perfectly and – on the other hand – be completely safe for crops. Physical techniques, like membrane technology and UV only have a point disinfection effect.
- Concerning biological disinfection: There is too little knowledge about the effect of all type of parameters (climatic, biological and chemical conditions of the water) at the development of (beneficial) microorganisms and biofilm, to make biological disinfection transferable and usable in all regions.
- Concerning chemical disinfection: Regulation of chemical compounds may hinder the use of some oxidants and the equipment for on-site regeneration in some countries. An example is the European Biocidal Products Regulation (BPR) EU 528/2012 which regulates the availability on the market and use of biocidal products. Regulations may also require continuous monitoring of oxidants in the effluent.
- About integration of techniques: chemical oxidation and physical treatments are non-selective techniques: i.e., almost all organic compounds are broken down, which means chemical/physical treatments are hard to combine with biological disinfection.
- Safety: the use of some techniques imply specific risks: ozonisation, for example, can be risky for people nearby the installation in case of leaks. Other technologies – for example, chlorination - can lead to by-products which can be harmful for the consumer.
- Insight into cost and benefits of disinfection technologies on company level. To convince growers to invest in disinfection more insight is needed.
- Decision supporting system: as disinfection technologies are available, in development or expected to be developed it is very important that growers – besides the economical motives – are supported with good (technical) information before taking decisions concerning disinfection.

4.3.6. Fertigation management - Irrigation equipment

Main gaps are:

- Lack of knowledge about costs. Growers think that the investment costs for irrigation and fertigation systems are relevant.
- Required technical knowledge to efficiently run this type of systems. Growers that switch to pressurized irrigation systems must adapt to a new situation in which a proper design and an adequate selection of materials and equipment are critical to achieving proper standards of water use efficiency and uniformity. This is the case of non-optimal water quality, coarse soils, or topographical constraints.
- Durability and material lifetime, not only due to environmental factors like solar radiation, temperature, and pressure changes. However, also to the damaging effects of living organisms. Efforts should be made to incorporate affordable, more resistant, and environmentally friendly materials.

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- Failling of emitters due to clogging caused by biofilm formation or precipitation of insoluble salts.

4.3.7. Fertigation management - Preparation of the nutrient solution

In general, acceptable technology is currently available for the preparation of the nutrient solution in fertigated crops. However, the cost of the best technologies is often a limiting factor for their application. Some points for improvements are listed:

- Improved quality of fertilizers (lower salt content), especially when applied in recirculation systems.
- Improvement of organic fertilisers. The current available organic fertilisers are not optimal to be applied for fertigation and tend to clog drippers.
- Continuous, accurate injection of the stock solution into the irrigation water to reach the established set points. All aspects concerning sensors and methods of injection are relevant.
- Direct, specific and real time measurement of ion concentrations in the nutrient solution. Selective ion sensors are available but not readily available for standard commercial use

4.3.8. Fertigation management - Irrigation management

Gaps in irrigation management are:

- Some irrigation management tools and technologies require a high level of knowledge: Growers who want to improve the efficiency of irrigation management in their farms have a large number of technologies available. The development stage of these technologies, however, differs. Systems for determining water content in the plant and the integration of different irrigation management strategies still need a high level of knowledge to be fully integrated into farmers' irrigation schedules.
- Lack of agronomic knowledge to implement irrigation systems and to take the best decision. Lack of automation and friendly systems to aid decision in irrigation time.
- Growers find irrigation management tools and technologies too expensive and not reliable. The Grower does not see a direct contribution to the cost saving and higher efficiency in the productivity of the crop.
- Moreover, growers experience that the risk for thefts of sensors and supporting materials is too high and they fear the technologies and sensors only have a short lifespan.
- The heterogeneity of the soil within one irrigation area leads to different water needs of the crop and require particular attention to position the sensors supporting irrigation management.
- Technology designed by persons of the other sectors different of the agriculture.

4.3.9. Fertigation management - Nutrient management

The problems and gaps in relation to good nutrient management are part of good fertigation management in general. For specific nutrient management next gaps are identified:

- Suitable fertiliser recommendation schemes and/or decision support systems (DSS) are not available for all crops, varieties and local conditions.
- Heterogeneity of the soil implies difficulties to select representative points to take samples.

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- Crop monitoring techniques such as sap analysis require local verified reference values. Besides, the time is too long to know the results and too late to make the correction on the farm.
- The available (optical) sensor technology is not always applicable in practice for horticulture and needs further development
- Lack of knowledge in soil nitrogen balance. The farmer does not take into account the different sources of nitrogen on the farm. Supporting tools are needed.
- Deficiencies in the fertigation system and equipment with the corresponding loss of efficient and money.
- The grower does not know how to act due to a lack of information and agronomic knowledge.
- The grower does not take into account the different sources of nitrogen in the farm, and the balance is essential to make the fertigation more efficient, even more at the nitrate vulnerable zones.
- The grower prefers over-fertilizer to avoid possible deficiencies and with that lost production

4.3.10. Limiting environmental impact - Nutrient removal and recovery

The introduction of nutrients recovery novel technologies to the market face specific gaps according to each technology, however, common gaps were also identified:

- In many cases, multiple technologies are required to removal both nitrogen and phosphorus. This implies a combination of technologies that might be new for the horticultural sector.
- The recovery of nutrients will require additional technologies.
- Currently, there is in general only a limited knowledge towards these new technologies, and this represents a challenge for the public to accept the technology and its products.
- Substantial up-front investments that SMEs and other first mover investors often cannot face due to the high economic risk.
- An absence of a harmonized European regulation regarding the production, quality, and use of recycled fertilizers. This implies difficulties to sell the products.
- In case nutrients are recovered at the farm's site, the amount of water that can be treated using modified ion exchange is limited by the fertilizer that can be used or sold to users close by since transporting the fertilizers can be costly and hence uneconomical.
- There is a need for long-term demonstration to proof the quality of the produced fertilisers

4.3.11. Limiting environmental impact - Pesticide residues

- The main problems about the removal of pesticide residues are related to the uncertainties of the effect and efficiency of the technologies, the complexity of the operation and the high investment and operating costs.
- Another bottleneck that can threat the application of emission-reducing technologies – for example, the use of drift reducing nozzles, the use of systems to clean wastewater after the application or the removal of ppp from discharge water - is the motivation of the user. By disinfecting recirculating water, the advantages are obvious: risk reduction, more efficient use of water and nutrients. The economic advantages of the technologies used to reduce the environmental impact are far less obvious or even not present.

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- There are only limited systems to remove PPP from discharge water. Especially for the Netherlands, this is an urgent problem as according to the Dutch regulations, on January 1st, 2018, companies must have a certified system to purify their discharge water about PPP (reduction of 95%).
- There are still questions about technologies suitable for the reduction of PPP from discharge water: they are only tested with a limited number of PPP, and more research is needed on the development and risks of the metabolites.
- Safety: the use of some techniques imply specific risks: ozonisation, for example, might include health risks for humans nearby the installation in case of leaks.

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