EIP-AGRI Focus Group – Circular horticulture

Mini-paper – Water use in greenhouse horticulture: efficiency and circularity

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1. Water as a scarce and mismanaged strategic resource

Water is an increasingly strategic resource worldwide. The demand for high quality water keeps increasing up to levels higher than regional replenishment rate and excessive use of fresh water depletes reserves, resulting in decreasing groundwater levels (EEA, 2009; WWF, 2009; FAO, 2011; García-Caparrós et al., 2017; EEA, 2012). This mainly applies to dry regions (e.g. south Mediterranean European countries) but also regions with higher precipitation rates are experiencing growing water competition (e.g. Belgium) (Peeters, 2013).

EU countries are expected to face more severe water stress in the upcoming future with a major negative impact on the agricultural sector (Lavrnić et al., 2017) which is still the main pressure actor on renewable water resources using about 51% of the total water used in Europe (EEA, 2018). On the other hand, untreated wastewater creates environmental problems due to pollution. Again agriculture is often reported as a main contributor to the environmental impact due to leaching or discharge of e.g. nutrients and plant protection products (PPPs) to surface and ground waters (Beerling, 2011; Teunissen, 2005; EU, 2018). Especially in regions with ample surface water this is already for some years under the attention of governmental bodies and research. However,in regions with less surface water there is an increasing awareness and concern about pollution of (drinking) water sources (De Stefano et al., 2015; Rousis et al, 2017). Both types of regions and situations can be found within Europe.

Inefficient water management and lack of perception for water issues/problems are among the major factors contributing to water scarcity and related environmental problems. Therefore, water mismanagement at farm, regional and country level must be a major concern. In this context, a prime aim for intensive irrigated horticulture (e.g. greenhouse horticulture) must be to minimize the volume of irrigation water used by improving efficiency ("more crop per drop"). In parallel, improving water reuse (e.g. recirculating in the greenhouse, optimizing the use of treated urban wastewater in agriculture) must be implemented.

Water quantity and quality are relevant issues demanding attention and concern from consumers, farmers and politicians (FAO, 2013; Andrade et al., 2014; Van Ruijven et al., 2014; Quintas-Soriano et al., 2016). Efficient water management and water policies are crucial at regional and national level. Water issues should be studied considering two perspectives: 1) as a strategic and political issue and 2) as a "mismanagement problem". These considerations are important for the drier Southern EU regions where climate change will exacerbate water scarcity situations (e.g. the Southern Mediterranean Europe) and for densely populated areas where competition for fresh, good quality water resources is at high levels. In the highly productive greenhouse systems of North-Western European countries, crops may require more irrigation water per square meter than what is made available by rain water, even that though drain and condensation water are recirculated. Protected cultivation makes possible to optimize crop water use efficiency (WUE) and minimize the risk of run-off (Stanghellini, 2013; FAO, 2013) but this only holds true if precise irrigation and fertigation are implemented, or, in case of soilless cultures, the drain water is fully recirculated. In the context of circular economy, increased efficiency of natural resources is central for economic decision making to ensure added value and re-use of resources e.g. water and nutrients. The EU Commission launched its circular economy package on 2 December 2015 which includes developing quality standards for recycled nutrients/fertilizers and re-use of treated wastewater (WW) (EU, 2016).

2. Water source and demand: quantity and quality

2.1 Water quality issues

In general, water quality results from the combination of several physical, chemical and ecological characteristics and it can be classified in accordance to existing quality standards/guidelines (e.g. GobalGap, ISO) (FAO 2018; ISO, 2017). Declining water quality is a global issue of concern and the most prevalent problem is eutrophication due to high-nutrient loads (mainly phosphorus and nitrogen, and sulphur) which impairs water use (UN Water, 2015). Surface water resources such as lakes and reservoirs are vulnerable to eutrophication and pollution by nitrates and phosphates due to fertilizer leaching and runoff from agricultural areas. Meanwhile, overexploitation of the aquifers in coastal areas tends to promote seawater intrusion, a phenomenon which increases salt content of water, thereby decreasing its quality and suitability for irrigation. Irrigation water quality varies with the region, water type, the nature of aquifers, climate etc. Desired water quality depends on the cropping system, on the crop species, and on water and nutrient management. When focussing on circular horticulture, one should consider implementation of closed or semi-closed growing systems to use water and nutrients more efficiently. Recirculation requires growers to pay more attention to quality of fresh water resources as nutrient misbalance might occur and root-borne diseases might be spread through the system (Thompson et al., 2018). Moreover, since uptake of sodium and chlorine by most crops is very limited, these ions may accumulate with each recirculation step up to phytotoxic levels for crops (Sonneveld & Voogt, 2009; Van Ruijven et al., in press). In 2016, a European survey amongst growers using fertigation showed that about 60% of the growers using recirculation, faced problems due to ion imbalances or salt accumulation. Also iron presence was reported frequently. Problems with diseases due to recirculation of nutrient solution were indicated by 25% of respondents (Lechevalier et al., 2018).

2.1.1. Mineral water quality

To enhance efficient water- and nutrient management, growers and greenhouse managers should address several parameters to monitor and preserve water quality (e.g. pH, alkalinity, soluble salts).

a) **pH and alkalinity**: These two parameters, largely determine nutrients solubility in the rhizosphere and influence efficacy of biocides and plant growth regulators.

b) **Soluble salts, sodium**: The suitability of water for irrigation is determined by the total amount of salts and also by the type of salts (Table 1). As the total salt content increases, soil and cropping problems can occur, and specific management practices may be required to sustain yields.

c) **Specific elements, like iron, manganese, etc**: Higher concentrations of iron might disturb irrigation systems due to oxidation and thereby iron flocculation

Table 1. Example of different water quality classes and permissible limits as function of electrical conductivity and Total soluble salts (adapted from Gallardo et al., 2013 and Scofield, F.E., 1936).

Water quality Classes		**Concentration total dissolved solids**		
		Electrical conductivity (µS/cm)[a]		***Total soluble salts (ppm)***
Class 1. Excellent		250		175
Class 2. Good		250-750		175-525
Class 3. Permissible [b]		750-2000		525-1400
Class 4. Doubtful [b]		2000-3000		1400-2100
Class 5. Unsuitable [c]		3000		2100

a) µS/cm at 25°C; b)Leaching needed if used; c)Good drainage needed and probably harmful to sensitive crops /plant

2.1.2. Sanitary water quality and pollutants

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 (Tongeren et al., 2018). This can lead to serious crop damage or major yield losses in soil-grown and soilless crops. The phytosanitary water quality is determined by the water source being used, by the design/maintenance of the irrigation network including the installed water treatment technologies as well as by plant and human pathogens (Van Overbeek et al., 2014). The latter has been shown in recent *E. Coli* (EHEC) outbreaks.

Water scarcity leads to increasing pressure to use alternative, less suitable water sources that can be more polluted, such as surface water or disinfected urban wastewater. Therefore optimization of non-conventional water sources (e.g. catchment of rain water, condensation water for high quality water are relevant for circular horticulture) (Alsanius et al., 2017).

Water quality standards are important to minimize problems related to the water salinity excesses and soil contamination by undesirable compounds (pesticides, heavy metals, antibiotics and other pollutants). An emerging water quality problem is the impact of personal care products and pharmaceuticals (e.g. birth control pills, painkillers, antibiotics) on aquatic ecosystems. Little is known about their long-term impact on humans/ecosystems but they may mimic natural hormones in humans and other species (UN Water, 2015). Whether these pollutants influence quality of the irrigation water and have any effect on the cultivation is largely unknown. For organic production the presence of pesticides in irrigation water may lead to unacceptable residues in organic products. Non-soluble metals may accumulate in the rhizosphere and compete with uptake of spore elements. Nickel and aluminium where found to be toxic above certain levels for fruit vegetables (Van Marrewijk, 2013).

2.2. Water quantity issues

Water scarcity refers to long-term water imbalances, combining low water availability with a level of water demand exceeding the supply capacity of the natural system (EEA, 2007). Water availability and related primary and secondary resources (See Table 2a and 2b) are largely variable within the EU, especially if comparing Northern and Southern European countries, and their climate and water flow characteristics (EUROSTAT, 2017; Lavrnić et al., 2017). Severe drought spells are becoming more frequent in Europe. For instance Portugal had till February 2018 almost 80% of its territory under severe drought (IPMA, 2018) and similar critical situation has been experienced in other Mediterranean countries. The rainfall events occurring in March 2018 avoided a major catastrophe to the agriculture sector in these countries. Such rainfall events allowed growers to sow new crops in field and the greenhouse, but unfortunately, made also to forget again the problem! North European countries have been also experiencing drought and heat wave phenomena. This is a major concern if we attend to the fact that highly populated EU countries e.g. Germany, Poland, Italy, Spain and Southern UK, have the least available water per capita which can promote competition and result in future water scarcity problems (EEA, 2008). For example, in 2017 and 2018, in some Flemish provinces it has been forbidden to irrigate crops due to persistent drought which resulted in major crop losses. In England, during the period from May to July 2018, the country received only 54% of the 1961-90 rainfall long term average (52% of the 1981-2010 Long term average). It has been the second driest May-July period on record and the driest since 1921 (records since 1910) (Environment Agency, 2018).

Table 2a . Non exhaustive list of **primary water resources** than can be used in greenhouse horticulture and related pros and cons and future tendencies

PRIMARY WATER RESOURCES		PROS	CONS	FUTURE TENDENCIES
Precipitation water		Cheap or Free: In some EU regions, precipitation is available in larger amounts. In most EU regions, precipitation water quality is good to excellent. Low sodium content makes this resource interesting for recirculation practices. Collection of rain water during heavy showers may serve the community by prevention of floods.	In case precipitation water is used, it will not feed the (un) deeper aquifers. As the precipitation pattern and the crops water demand pattern differ, water storage facilities have to be provided to buffer the precipitation water. Costs related to these water storage facilities might be significant (depending on land price, the size, type, additional infrastructure (prevention of algae proliferation, evapotranspiration losses) . Water storage facilities require moderately costy infrastructures and in some cases rain water can become more expensive than ground water. In west NL this is costly because needs storage and land price is high. Therefore some growers prefer to spend money on ground water desalination (expensive Reversed Osmosis)	Decreased precipitation, especially in Southern EU Countries but also in North. More extreme rainfall events "Climate change influences precipitation pattern and volumes. This might also imply the increase or decrease of annual precipitation and a shift in precipitation characteristics (e.g. more extreme rainfall events with longer intervals). Therefore, climate change will affect storage of precipitation water and make it more relevant.
Aquifers or (un)deep groundwater		Additional water source Water quality strongly depends on aquifer and region. In some case good water quality.	Difficult to control illegal water extraction; Risks of over exploitation Energy use for pumping In some cases expensive installations to remove sodium, iron or boron need to be used. Good quality strongly depends on location In the Netherlands water near the coast needs to be treated with Reversed Osmosis to be suitable for greenhouse use due to high salinity	More strict legislation to monitor water extraction Stricter regulations on brine handling related to reversed osmosis. Decreased precipitation results in lowering of ground water levels
Surface (ditches, rivers, dams, lakes)		Easier to monitor both quality and quantity Moderate to good, but less constant quality compared to rain water	Lower quality due to pollution by organic material and sodium, High risk of pathogens (discharging neighbours e.g.)	Increased competition (in the Southern regions but also in Northern countries due to climate change)

Table 2b. Non-exhaustive list of **secondary water resources** than can be used in greenhouse horticulture and related pros and cons and future tendencies

SECONDARY WATER RESOURCES		PROS	CONS	FUTURE TENDENCIES
Tap water		Always available, good quality with respect to nutrients, pathogens, pesticides, heavy metals, etc.	Expensive. Sodium level too high thus preventing recirculation of drain water. Least preferred in sustainable systems	
Treated urban wastewater		It is an additional water source that, if not used in coastal areas, is lost due to its release to the sea.	Quality issues for both field and greenhouse use, (especially raw products) e.g. human pathogens, emergent pollutants, variable nutrient composition, suspended soils; Variable quality along the year Costs and Availability Negative perception Risk of spread of human and animal pathogens	Tendency for an increase and more investments Improved treatment technologies Decreasing costs Support circular economy
Desalinated sea water		It allows complementing water availability in coastal areas with overexploitation of natural resources.	The remaining concentration of sodium chloride is excessive for a complete recirculation of the drainage in soilless culture. Boron content may be excessive to grow sensitive crops. Its cost is high and high-value crops can only pay for it. The discharge of the brine to the sea can provoke damage in the aquatic ecosystem. It has to be diluted and the place of discharge has to be carefully selected.	Development of improved desalination technologies reducing the cost and the quality of the water.
Drain & drainage water		The reuse of drain water (soilless crops) and reuse of drainage water (soil crops) allows reducing the use of water and fertilisers and avoids soil/water pollution. In NL reuse is obliged	High salinity makes difficult (or even impossible) to recirculate the drainage. Pathogens can be disseminated by recirculation. Expensive disinfectors are needed. Reuse of drainage water is not possible during periods with high ground water levels and seepage from rivers etc., because drainage water is mixed with large quantities of external water with often unsuitable quality	Increased regulation of its use
Water from condensation		Good quality water In the Netherlands reuse is obliged	In open/ventilated greenhouses the volume of condense water is small in comparison to water requirements. Water can be also collected from a dehumidification unit for reuse. Not economically feasible In NL; In Arab countries it is.	Higher development of closed greenhouses where most of the evapotranspiration may be recovered.

3. General bottlenecks and solutions for water issues & strategies to optimize water use

3.1. Improved storage of rain water

Greenhouses usually allow collecting rain water from the roof. This is relevant for water management in greenhouse horticulture attending to the high quality of such water resource. In the Netherlands for example, rain water storage of 500 m^3 per year per ha greenhouse is obligatory) and, on average, there is an mean annual precipitation of 800 L/m^2 Next to that, there is an obligation to reuse drain and drainage water to a certain extend. In the Southern European countries rain water is much scarcer (e.g. less than 200 mm on average in Almeria-Spain) and greenhouses depend more on other water sources.

Reuse of drain(age) water is not common attributed to a number of factors: lack of high quality input water, relatively high costs for necessary equipment for low and mid-tech enterprises, and lack of knowledge concerning complicated nutrition schemes when recycling. Rain water could be used as a strategic resource when it is mixed with the primary resource to reduce salinity-derived problems. However, (rain)water storage has bottlenecks. A grower's survey, done in the EU in 2016, showed that growers that store water faced problems mostly due to i) algae proliferation, ii) insufficient water storage capacity, iii) sediments, and iv) other issues e.g. evaporative losses (Lechevalier et al., 2018). Prevention of problems should be kept during storage period. Common in the Netherlands is covering of the basins to shut out sunlight to prevent algae growth. Algae proliferation frequently occurs when storing water with high nitrogen and/or phosphorus content. In case of algae blooms, water quality will be negatively affected. A wide range of technologies/practices can prevent or treat algae blooms but their effectiveness is highly variable and it demands more research. In turn, stored rain water must remain clean. Ultrasonic sound waves can help to keep the water free from algae. When possible this is done in parallel with the closure of storage to remove sunlight and prevent droppings from birds. Upon using the stored water filtering before mixing with nutrients (and recycling drain water) is common practice for example in NL In some cases, e.g. nurseries, also disinfection (e.g. UV, ozone) of stored rainwater takes place before use .

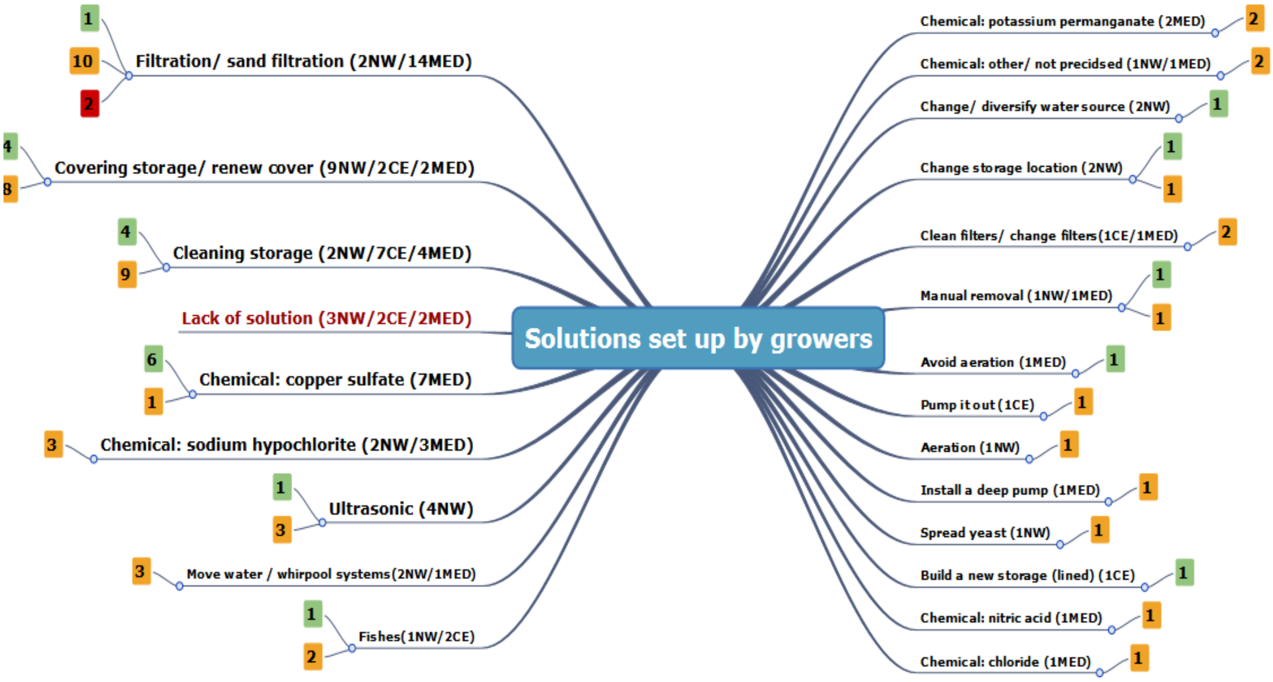

Figure 2. Solutions set up by respondents in a survey conducted near EU growers in order to avoid algae proliferation during water storage. Coloured figures indicate respondents' satisfaction rate (green: satisfied to very satisfied, yellow: moderately satisfied, red: not satisfied). The numbers in coloured squares reflect number of respondents per satisfaction rate (Lechevalier et al., 2018). (CE = Central East, MED = Mediterranean, NW = North West).

Although rainwater is a low-cost water resource, storage of rainwater can make it expensive. Indeed, storage capacity must be big enough to allow accumulation of abundant rainfall. Furthermore, storage requires additional investments to minimize evaporation losses and/or algae proliferation. This means significant construction costs and land occupation (if storage is aboveground). In Almeria, for example, high greenhouse concentration and the high land price limits the size of ponds hindering rain water collection in many farms. In addition, about 30% of greenhouses in Almeria are still flat (Lorenzo et al., 2016) which makes almost impossible to collect rain water. Furthermore, rainfall patterns in Mediterranean type climates (with rainfall concentrated in a few days, but very low annual average) can be another problem. Solutions may involve collective collection storages. This may also boost cooperation between regions and growers associations. We may also consider the possibility of storing water under the greenhouses, which would limit evaporative losses and save space (Waalblok 4B concept: Verhoeve et al. 2010). Another solution could be to store rain water in aquifers, as might be the case of Almeria. However, in the case of the Almeria region, this water should be desalinated before use in irrigation as the aquifer is salinized. In turn, in the Netherlands sweet water is being stored in salt water aquifers, with some losses along interfaces of sweet and salt water but in general the good water quality remains (COASTER, 2016).

3.2. Circularity to improve and enlarge water sources (cleaning water from different resources)

Circularity of water might increase water availability at both farm and regional scale. At farm scale, some secondary water sources should be accounted (See Table 2b). One of the most well-known secondary water sources is **drain and drainage water. Water from condensation** of greenhouse roofs can be another water source at farm level. Use of disinfected urban wastewater might offer a valuable water source on a larger scale. However, the reuse of secondary water sources hides specific bottlenecks. In case of drain and drainage water recirculation, accumulation of sodium often keeps growers from recycling the water (Lechevallier et al., 2018). Therefore technologies allowing selective sodium removal are on demand (Tongeren et al., 2018). However, a Dutch survey among 'soilless growers' found that the sodium content in discharged water was often well below the advised maximum concentration, and that discharge takes place when there is the slightest doubt about water quality, which might also be fear for pathogens, nutrient imbalances and growth inhibitors (Beerling et al. 2014).

Cascading water involves the use of water in cascade taking into consideration water needs in different crops closely located to each other. Even without water treatment it can be considered for greenhouse horticulture. In fact, low quality water quality does not have to be a problem for other industries and clustering may minimize such problems and promote the use of cascade water.

Waste water regeneration by a tertiary treatment for agricultural use is widely done in countries e.g. Israel for long time (Haruvy, 1997). This has sense in coastal areas, where wastewater is discharged to the sea and lost as a non-saline source. In the inland, where it is usually discharged to surface waters, e.g. rivers after secondary treatment, it can be reincorporated to the water cycle in a natural way with lower costs. However, related environmental impacts due to effluents and energy consumption must be accounted.

Water recycling involves reuse of treated wastewater from other sources apart of the horticulture sector. The beneficial purposes include agricultural and landscape irrigation, industrial processes, toilet flushing, and replenishing a groundwater basin (referred to as ground water recharge). Water recycling offers resource and financial savings. Wastewater treatment can be tailored to meet water quality requirements of a planned reuse. For instance industrial wastewater could be used for horticulture when correspondent effluent meets quality standards. In fact, literature describes the use of composting leachates after nitrification of effluents with high ammonia content (Cáceres et al., 2015).

However, we must be aware and consider the risks involved in using wastewaters. Firstly, the risk of spreading human and animal pathogens must be thoroughly covered. Secondly, due to the application of chemicals to disinfect water (e.g. chlorine) or during its use (e.g. detergents), regenerated wastewater can present undesirable levels of specific ions, such as sodium, chloride, boron, etc.. Thirdly, the problems posed by pharmaceuticals and emergent contaminants must be carefully analysed when dealing with urban treated wastewaters. Moreover, the long-term impact of this type of waters on soils must be also studied as it can promote the build-up of salts depending on the type of soils and irrigation scheduling (Shen et al., 2019; Leuther et al., 2019).

3.3. Improve water savings and water use efficiency in the greenhouse

Protected cultivation can decrease irrigation water requirements by reduced evaporation, which is due to lower radiation and, at a smaller extent, to lower wind speed inside greenhouse. Möller and Assouline (2007) showed that daily ETo under greenhouse conditions in Israel averaged 62% of outdoor ETo values. Similar reduction is reported by Fernández et al. (2010) in a plastic greenhouse in Almeria (Spain). Moreover, higher yields per square meter are usually achieved under greenhouses as compared to open field, which also increases crop WUE (Sezen et al., 2005; Ertek et al., 2006). However, greenhouse water management if not optimal promotes water losses and nutrient leaching, and results in environmental pollution and less profit.

In soilless culture, a minimum leaching fraction is needed even using high quality water to compensate non-uniform water distribution. Hence, recirculation strategies must be applied to maximize WUE. The return drain water should be precisely complemented with fresh nutrients, but might result in an unbalance composition of nutrients solution. Precise monitoring is needed to avoid excessive imbalance that affects yield and product quality. If suboptimal quality water is used in closed systems, harmful ions or other substances accumulate in the recirculating solution, promoting a salinity effect and/or a decrease of nutrient concentrations to critical values. Massa et al. (2010) studied different recirculation strategies which can be satisfactorily applied as using moderate saline water in closed soilless growing systems. An alternative approach has been applied in some commercial farms to establish a cascade culture, so that drainage of a crop is used to irrigate other crops that are less sensitive to salinity. Under conditions of closed systems there is the risk of disease spread through recirculating solution, and disinfection technologies are recommended. However, total disinfection technologies are expensive and water and nutrient saving obtained by applying recirculation may not compensate that high cost, at least in some cases (Magán, 2001, Lechevallier et al., 2018). In the Netherlands, where recirculation is obliged, disinfection is common practice and done with UV or heat treatment (Van Os, 2010). Affordable technologies are being developed to disinfect recirculating solutions and to recover nutrients from discharged solutions. However, still many growers consider these technologies too expensive although they are not able to provide a cost per cubic of treated water (Lechevallier, 2018). The CLEANLEACH system (www.cleanleach.eu) was developed to increase water and nutrients use efficiency, and to avoid discharge of pollutants into the environment (Narváez et al., 2011; Cáceres et al., 2017). One of the elements (horizontal sand filter) has been demonstrated to retain plant pathogens, and then contributing to the sanitation of the leachates for its recirculation (Prenafeta-Bóldu et al., 2017).

Meanwhile greenhouse technology developments permitted to increase availability and use of sensors to better monitoring and control of environment and plants (e.g. tensiometers, wireless sensor networks, thermal IR and RGB cameras). These sensors allow cheaper, non-invasive and continuous measurements and remote control (e.g. via internet), and can be used alone or combined with evapotranspiration models to control irrigation. Electro-tensiometers, plugged into controllers, can trigger irrigation events or avoid them (Cáceres et al., 2007b; 2008). Other methods based on water consumption were developed, as the automatic irrigation-control tray system (Cáceres et al., 2006;2007a).Sophisticated weighing systems are being used to control irrigation in soilless culture in high technology greenhouses.

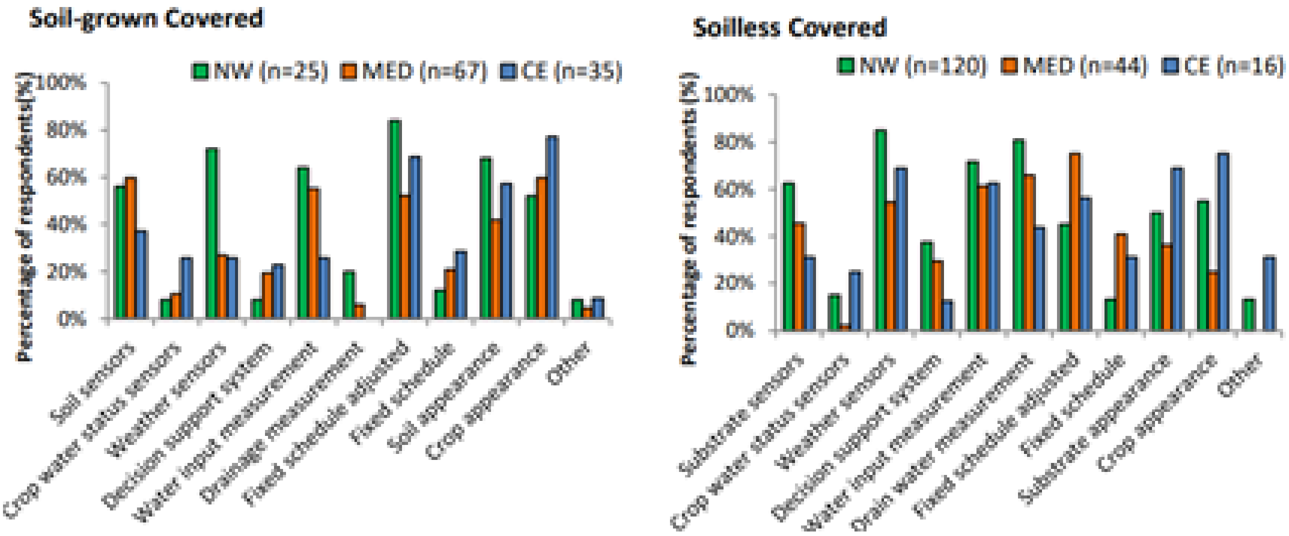

Figure 3.Percentage of soil and soilless covered cropping systems using the different types of management practices to inform irrigation management decision making, across regions. (CE = Central East, MED = Mediterranean, NW = North West) (Lechevallier et al., 2018)

At technological level, optimization of climate control can increase WUE as an optimal air vapour pressure deficit allows reducing crop transpiration and enhance yield. Closed greenhouses are very promising for increasing WUE as a consequence of the recovery of transpiration by condensation and setting a high air CO_2 concenration. Closed greenhouse systems in the Netherlands proved being able to produce 1 kg of fresh tomato with only 4L of fresh water whereas it would be around 15 L in case of a classic Dutch greenhouse with ventilation and applying recirculation (Stanghellini, 2013). Nevertheless, closed greenhouse concept was not taken up by Dutch farmers so far as costs, mainly the energy cost due to dehumidification and mechanical cooling are considered too high as compared to the benefits. Moreover, from 2014-2017 it has been shown that zero-discharge crop production is possible without the loss of productivity and product quality by optimising irrigation and fertigation strategies (Van Ruijven et al. (in press).

The use of alternative technologies e.g. cooling/dehumidification and collection of water outside of the greenhouses, by promoting condensing outside air vapour, can be applied for the recovery of good quality water. This is being applied e.g. in Arabic countries but it does require high energy cost.

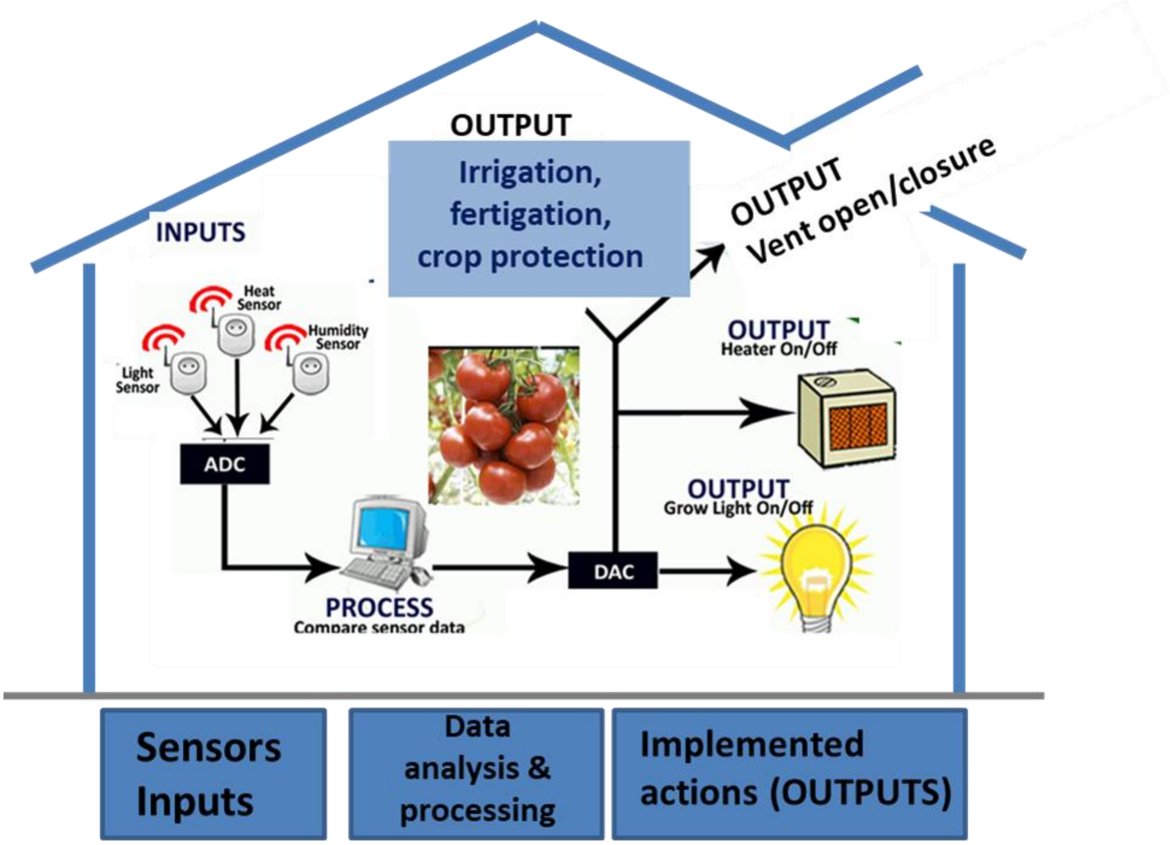

Figure 4. The use of sensors and technology for precise greenhouse monitoring and management of inputs and outputs in a greenhouse. Adapted from https://www.ictlounge.com/html/control_applications_examples.htm

3.6. Strategies to save water: methods and policies

3.6.1. Educational and sensorial

One of the first items to promote water savings is farmer's perception of problems related to water use/management and to increase perception of retailers and consumers for the added value of "water saving products". A survey, carried out in 2016, amongst 371 growers applying fertigation in the EU, showed that overall, they believed that water availability would remain the same. However, in Spain and Poland, the majority of respondents believed that water availability would be reduced in future (Lechevallier et al., 2018). The survey was taken the year before the droughts of 2017 and 2018, therefore, it is likely that grower's perception might have change since then.

3.6.2. Technological

Some technological strategies and solutions to save water can be proposed:

Optimize climate and crop growing control (Figs. 3 and 4). Higher WUE in greenhouse production is possible by optimizing climate control and cultural practices. Controlled environments can guarantee more efficient modulation of both environmental and cultural parameters according to crop needs and development stage;

More research is required on greenhouse water management and fertigation (De Pascale and Maggio, 2005; Costa et al., 2017);

Increase water productivity (more crop per drop) by using deficit irrigation for less sensitive crops to moderate water stress);

Increase importance of the assessment of fresh water quality. In case of recirculation, water quality is key issue to assure recirculation practices;

Switch to crops with higher value or reducing crop production costs that lead to higher economic water productivity;

Adopt more integrated approaches—agriculture/aquaculture systems, better integrating livestock into irrigated and rain-fed systems, using irrigation water for households and small industries—all are important for increasing value and jobs per drop;

Promote clustering of horticultural water household to increase efficiency and to optimize water recycling.

3.6.3. Institutional and governmental

Several institutional and governmental measures can be suggested to promote a more sustainable use of water:

Water policy must provide suitable external incentives to growers to use irrigation water more efficiently, but water policy must also guarantee water savings in agriculture, especially in dry regions (Llop and Ponce-Alifonso, 2018);

Stricter regulations are expected in the future. In the Netherlands, from 2018, growers can only discharge water after using a purification system that is certified for removing 95% of all pesticides (WUR, 2018). This is a short-term solution to improve quality of surface water. The real, long-term, solution lies in the nitrogen emission standards that are in force since 2013 and become step-wise stricter. This will result in a ‛zero-emission greenhouse in 2027, meaning that discharge water can then no longer contain any nitrogen (or phosphate). “This means that the horticulture industry will have to recirculate more water and requires more equipment for maintaining water quality” (Van Os, 2018). This will also force growers to check their water systems for leakages and unknown discharge pipes. Most of the discharge occurs because it is the easiest way to improve water quality at the company level (whether it is needed or not). The impact of the pesticide purification legislation is reflected on growers investing in purification technology. However, the real gain is in the willingness of an increasing group of growers investing in technologies for a long-term solution with no discharges at all.

Figure 5. Respondents of the FERTINNOWA survey planning to implement new practices to limit effluent discharge in the next 3 years (n = 235). In Belgium and the Netherlands, more growers are considering investments due to the strict regulations (Lechevallier et al., 2018)

Water pricing is another sensitive issue to consider for efficient water management and as strategy to stimulate water savings, improved water use efficiency and rain water use via an increase in irrigation water prices. Moreover, prices and costs related to irrigation water vary substantially with geographic location, water sources, and institutional arrangements (OECD, 2010). In fact, water pricing has been one of the solutions used to improve water management (EEA 2017; FAO, 2018) in typically dry countries e.g. Israel. A major question emerges that is to what extent can greenhouse horticulture incorporate water pricing?. The answer to this could be to demotivate excessive water consumption by establishing a high price when a reasonable limit is exceeded by users, in accordance to crop water requirements for the growing cycle. This is relevant if we consider that water prices and related irrigation costs represent a minor cost item for both Northern and Southern European conditions and they are mainly related to energy costs of pumping. For example prices in Almeria for well water vary between 0.25 and 0.45 €/m^3 whereas the price of desalinated water reaches 0,55 €/m^3. It can be possible to reduce this price to 0.2 €/m^3. In areas in Spain where the water is coming from a dam by gravity and the energy cost is low, the cost of the water is much lower (only few cents of Euro/m^3).

4. Examples of projects related to water management and circularity in horticulture

WIRE - Water & Irrigated agriculture Resilient Europe (AG112) https://www.eip-water.eu/WIRE

CLEANLEACH Combined system to recirculate leachates and/or to clean up water using low demand methods (constructed wetlands). www.cleanleach.eu

COASTAR (regional underground storage of rain water) https://www.glastuinbouwwaterproof.nl/nieuws/coastar-zout-op-afstand-zoet-op-voorraad/

ZERO EMISSION GROWING . Dutch initiative to monitor emissions of the greenhouse sector **https://www.wur.nl/nl/Onderzoek-Resultaten/Onderzoeksinstituten/plant-research/glastuinbouw/show-glas/Emissieloos-telen-2017.htm**

RICHWATER project (Spanish project using wastewater of a slaughter for irrigation purposes)

FERTINNOWA thematic network on transfer of innovative technologies in the field of efficient water and nutrient use in fertigated crops.

ZUNUREC: Flemish project that recover both water and nutrients (fertilisers are made) on the site from discharged horticultural water

SuWaNu Europe: thematic network (will start in 2019) that will focus on the use of waste water

SuWaNU (EU project 2013-2016): Sustainable Water treatment and Nutrient Reuse Options: SuWaNu supported cooperation and integration between five research-driven clusters (Germany, Spain, Malta, Greece and Bulgaria) to promote research and technological development and to encourage implementation of technological solutions and to increase investments at regional level. **http://www.suwanu.eu/**

NEFERTITI (Networking European Farms to Enhance Cross Fertilisation and Innovation Uptake through Demonstration). Network 8. Water use efficiency . **https://cordis.europa.eu/project/rcn/213918_en.html**

5. Proposal for potential operational groups

- Local water storage;

- Regional focus group for increasing WUE : diagnosis of the current situation, sharing good practices and techniques, implementation of good practices or techniques, improved use of sensors;

- Use of alternative water sources, available at local/regional levels. Implementation of demo sites in commercial farms;

- Benchmarking of water use in commercial farms by automatic monitoring of water application;

- Keeping water quality;

- Strategies and technologies to optimize water treatments and purification of horticultural wastewater;

- Exploring regional potential for clustering circular water initiatives.

6. Proposals for present and future research needs from practice

- Novel irrigation technologies based on water reuse. Testing the use in different crop species;

- Efficient and affordable removal of emergent pollutants for recycling water in horticulture. Focussing on cosmetics and pharmaceutics;

- Novel and cheap solutions for water storage, to achieve a smart storing of water. For example in large reservoirs (100x100 m), floating covers are available but are expensive;

- Improved use of sensors for monitoring key parameters in irrigation water and effluents from horticulture (sensors measuring nutrients);

- The adaptation of existing techniques for cleaning up leachates;

- Water economics and accountability: there is need for economic research on the cost benefit of water streams (use of secondary water sources at the farms level – regional level);

- Research on the potential use of regenerated water and treated wastewater in horticulture, and on problems posed by pharmaceuticals and emergent contaminants must be also carefully studied when dealing with the use of treated wastewater from urban areas in horticulture.

7. Recommendations for further development

- Increased awareness for water use metrics and improved water accountability for improved governance (FAO, 2018). A recent growers' survey amongst 371 growers showed that growers can provide an indication of the fresh water used at the farm. However, these indications vary strongly even within the same region, crop and cropping system. This raises questions about the accuracy of these indications (Lechevallier, 2018). There is a need for more insights in the water economics at the farms scale and for awareness rising on the cost/benefit of qualitative water, the potential of using secondary water sources;

- It is still needed to improve public perception for the use of recycled wastewater via research and educational programs to promote the use of treated wastewater recycling in a successful way. This must be supported by research on factors influencing adoption of reuse technologies, such as the capital needs and cost and reliability;

- Improved standardization of quality parameters for water and guidelines and standards and assess the minimum water quality necessary to have different possible supplies;

- Make available robust statistics on water use and reuse and assess ways/solutions to make growers, associations and government to release up-to-date data;

- Dissemination actions (seminars; open days; visits to the experimental orchard; publications);

- Promote direct involvement of different stakeholders (farmers, policy makers, researchers, technicians);

- Water pricing versus land price;

- Certification and labelling related to water – e.g. blue label for highlight products obtained with minimum water requirements;

- To implement demo sites (at regional levels) where best practices and techniques could be tested by growers (e.g. NEFERTITI project);

- Development of automatic, reliable and cheap system for irrigation control;

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