AHDB HORTICULTURE

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Methods of water treatment for the elimination of plant pathogens

Many plant diseases can be introduced to, and spread within, cropping systems by contaminated irrigation water, especially those caused by species of *Pythium*, *Phytophthora* and *Fusarium*. Fortunately, it is possible to eliminate or significantly reduce this disease threat by treating water before irrigation use. There is a wide range of effective water treatment methods available and selection of an appropriate method or system for a particular horticultural concern is very much the case that different business requirements need different water treatment methods. In this factsheet the current most readily available water treatment methods are outlined, together with some emerging technologies and some considerations to assist individual businesses in the selection of an appropriate technology.

Figure 1. Ultraviolet (UV) treatment rig (centre) with fast sand prefilters

Action points

- Unless using exclusively mains or most types of borehole water combined with enclosed water storage, it is advisable to consider some form of treatment for the exclusion/removal of plant pathogens from irrigation water.
- Different water sources carry different levels of disease risk – test water for plant pathogens to help determine where within a system to deploy treatment.
- A wide range of effective treatment options are available and the final decision on which technology(ies) to use will be based on a combination of factors, including economics, volumes of water to be treated, raw water quality, sensitivity of the crop, space available as well as personal preferences (eg chemical vs non-chemical treatments). Figure 2 is designed to help lay out the options and table 2 summarises the pros and cons of the most widely used technologies.

b) The tendency of SSF to block if the untreated water contains large quantities of suspended fine particles.

Recent developments in filter design have gone some way to reducing both of these potential problems. Details of the SSF process are explained in more depth in a Grower Guide available from AHDB Horticulture.

Microfiltration

Cross-membrane microfiltration has been successfully demonstrated to remove plant pathogens from irrigation water in realistic large-scale greenhouse trials. The systems tested use hollow fibre polypropylene membranes that reject solids of greater than 0.2 microns (0.002mm) diameter, to filter the water. Rejected particles, including plant pathogen spores, are removed periodically to waste by an automated compressed air backwash. Despite successful operation in other industries (eg for the clarification of fruit juices), and in irrigation water pathology trials, this technology has not so far been widely adopted by the horticultural industry.

Figure 7. Iris bed biofiltration system

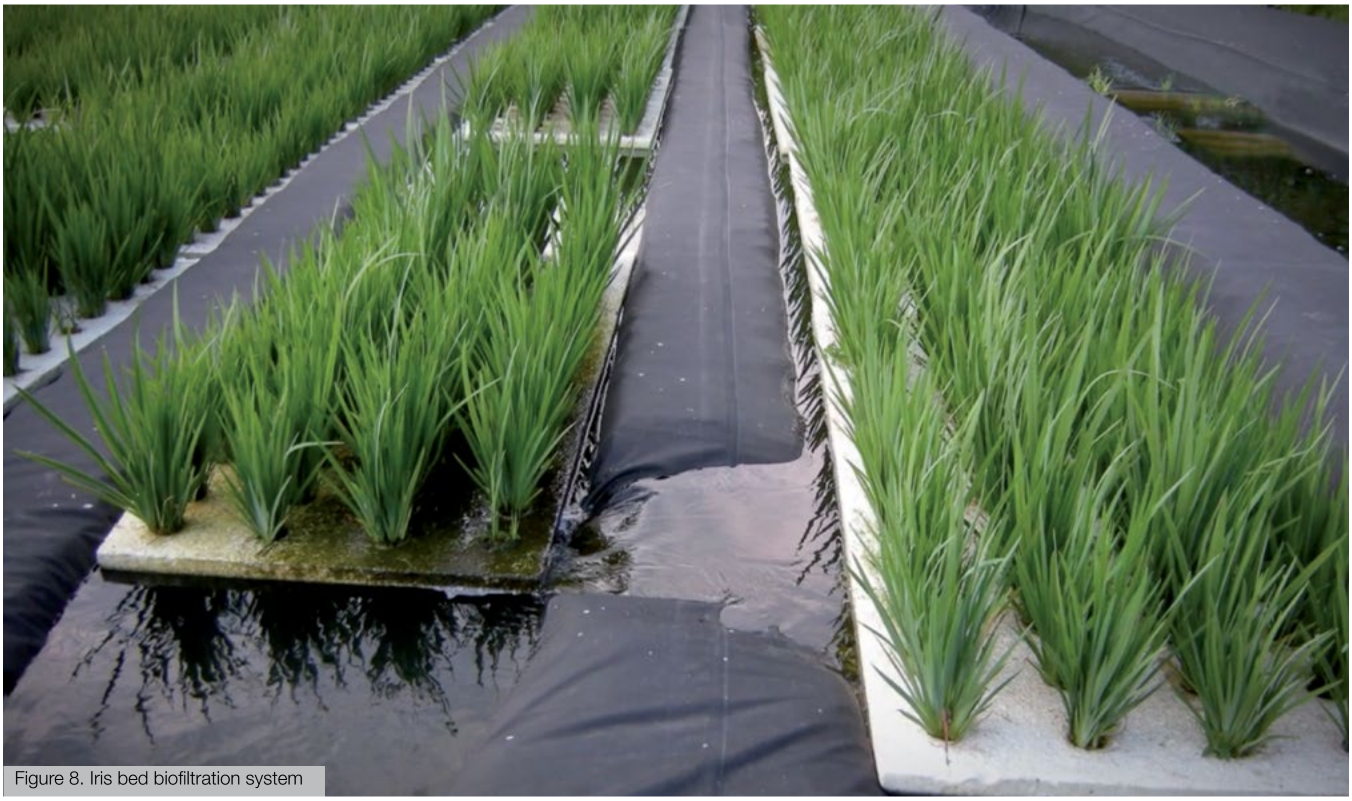


Figure 8. Iris bed biofiltration system

Promising technologies for the future

A number of technologies that are currently at various stages of development are worthy of a very brief mention. Firstly, there are a number of biological filtration systems that appear to successfully remove plant pathogens from recycled water. These fall into two major categories:

a) Various forms of ‘bioactive’ and ‘activated’ filter beds, normally consisting of systems to introduce oxygen to a biofiltration system to enhance its activity and increase its flow rate

b) Use of constructed wetlands, including iris beds.

Another area that shows great promise is the Advanced Oxidation Process (AOP), which combines the addition of hydrogen peroxide with the application of UV radiation – greatly enhancing the efficacy of both processes. Also the use of catalysts, especially titanium oxide (TiO_2), in photocatalytic oxidation water treatment shows great promise for breaking down organic molecules and eliminating plant pathogens in water by utilising photon energy either directly from sunlight or from UV light sources. These technologies have seen more application against human pathogens and still require further investigation into their efficacy against plant pathogens and the economics of their use in horticultural systems.

Selection of water treatment method(s)

There is no single water treatment technology that suits all situations or production systems, and selection of the most appropriate approach requires consideration of many, sometimes competing, factors. Besides the treatment efficacy, the key factors to consider include the following:

- The volumes of water required and the nature of demand (consistent or 'peaks and troughs')
- Space available for treatment plant
- Installation and operational costs; potential disruption of installation
- Raw water quality and target treated water quality
- Presence/absence of fertiliser or nutrient feed in the water to be treated
- Safety issues
- Residual efficacy, residues, by-products and possible phytotoxicity
- Simplicity of operation and maintenance.

Figure 2 gives a simplified flow chart that takes some of these points into consideration. Tables 1 and 2 give an indication of the possible interaction of the various water treatment techniques with raw water quality and weigh up their advantages and disadvantages. Every situation is different and selection of the right combination depends on individual circumstances.

Filtration before disinfestation – pre-filtration

Pre-filtration removes a significant proportion of the fine particles suspended in raw water that can cause much wear and damage to irrigation fittings, valves and outlets. By reducing the load of suspended material present in the water, pre-filtration also greatly improves the efficacy of all the water treatment techniques outlined in this factsheet. In the case of chemical treatments, this is achieved by reducing the amounts of active ingredient that would otherwise be wasted reacting with suspended material, while with ultraviolet radiation treatments loss of radiation by scattering and shadows would be reduced, and with slow sand filtration and micro-filtration the frequency of filter blockages would be reduced. There is a wide range of pre-filtration techniques available and selection of filter types and their placement should be carried out in consultation with an irrigation engineer. This kind of coarse pre-filtration will normally remove particles down to between approximately 40–100µm in horticultural systems. The types of filters that are used include: screen filters, disc filters, centrifugal filters (vortex separators), media filters and pressurised media filters (eg fast sand filters). The most frequently used in horticultural systems are screen filters and pressurised media filters.

Chlorination

Chlorine is added to water as either sodium hypochlorite, calcium hypochlorite or as chlorine gas. The most frequently used in Europe is sodium hypochlorite while the potentially hazardous use of chlorine gas is rarely seen. Sodium hypochlorite is purchased as a liquid concentrate that is injected into water using a simple electric dosing pump; calcium hypochlorite is normally supplied as solid granules that need to be made up into a concentrate in water prior to adding in the same way as sodium hypochlorite, while chlorine gas is added by being bubbled through the water. Chlorine added by these methods reacts with the water by hydrolysis to form hypochlorous acid – the main active ingredient of chlorination. Hypochlorous acid acts by oxidation and by transfer of chloride ions (chlorination). As well as effective disinfection, the latter process can result in the formation of potentially hazardous chlorinated hydrocarbons when the organic matter content of the water is high, which is partly why it is important to pre-filter water before treatment and why chlorination might not be appropriate for waters containing high concentrations of dissolved organic matter. Hypochlorous acid also readily reacts with ammonium ions to form chloramines, which means that nutrient feed solutions containing ammonium salts should not be deployed in systems using chlorination. Formation of hypochlorous acid is strongly influenced by the water pH and is best at pH 6–7.5. The hypochlorous acid is consumed in reactions with pathogen propagules and also reacts with (kills) other microorganisms such as algae as well as with organic matter and some salts present in the water. The amount of chlorine used is known as the chlorine demand and that left over is referred to as free chlorine. This varies greatly with the season and with water quality and, to make sure the added chlorine dose meets the chlorine demand while not producing free chlorine concentrations toxic to the plants, it is advisable to regularly measure the free chlorine concentration in the irrigation system. This can be readily carried out using a colorimetric test kit and is best carried out at the point in the irrigation rig furthest from the dosing system.

ECA or EO water

Electro-chemically activated (ECA) or electrolysed-oxidised (EO) water essentially appears to be a form of chlorination as the active biocide involved is hypochlorous acid, although the mixture produced by this process is claimed to be significantly less irritant than hypochlorite, normally used in chlorination, and is used for hand sanitisation and cleansing of wounds in some hospitals in Japan. The basic process involves passing a potassium or sodium chloride solution through an electrolytic cell with the anode and cathode electrodes separated by a dielectric membrane. Applying a voltage results in the formation of two solutions by electrolysis. A mixed oxidation solution is formed around the anode (the analyte) in which hypochlorous acid predominates and it is this that is then dosed into the irrigation water. The ECA/EO process is still relatively new to horticultural practice and shows great promise but still requires in depth trialling and efficacy/residue assessments before any firm recommendations on its effectiveness can be made.

Chlorine dioxide

Although a chlorine compound, chlorine dioxide does NOT act by chlorination. It dissolves readily in water and does not react to form hypochlorous acid and, unlike hypochlorous acid, chlorine dioxide's mode of action is solely by oxidation. This makes it far less reactive with non-target substances in water such as ammonium ions and it does not form problematic chlorinated hydrocarbons when reacting with organic matter. Chlorine dioxide has long been used for sanitising drinking water but only recently have systems started to become available for treating irrigation water. Chlorine dioxide is produced and dissolved in water on site using a number of different procedures. These normally involve two solutions, one of sodium chlorite and the second normally of hydrochloric acid, that are mixed in a reaction vessel and the product is then added to the water according to a pre-set dose or in response to sensor readings. As many of the companies currently supplying chlorine dioxide systems are focused primarily on large-scale industrial systems (eg for elimination of Legionella from cooling towers), it is wise to select a supplier with stated experience of horticultural irrigation systems.

As with chlorination, the dose rate is best regulated by monitoring the chlorine dioxide content of the water at the point of delivery located furthest from the dosing system. Chlorine dioxide concentrations can be estimated using electric sensors or very simple, robust and accurate colorimetric test kits that are readily available and can be used instead of sensors or to provide calibrations and carry out spot checks.

Figure 3. Chlorine dioxide reaction vessel and dosing equipment

Hydrogen peroxide and activated peroxygens

A strong oxidising agent widely known for its sterilant and antiseptic properties, pure hydrogen peroxide can be used as a water treatment but is quite unstable and has a short shelf life. It is, therefore, marketed in a number of stabilised forms or peroxygens. These products form very effective sterilants that can be used to clean water storage tanks and irrigation lines but unfortunately not all are cleared for use in directly treating water for irrigating plants. The highly effective sterilant peroxy-acetic acid is not registered for treating irrigation water. Nevertheless, other peroxygens are currently available, for example, peroxy-formic acid and hydrogen peroxide stabilised with chelated silver. These materials are supplied as aqueous concentrates that are relatively simple to use, being added to the water using simple dosing pump equipment similar to that used for chlorination. Monitoring dose rates is straightforward and can be achieved either with electric sensors and a meter or by the use of simple colorimetric test kits. As with chlorination and chlorine dioxide, testing is best carried out at the point of dosing to make sure that the dosing pumps are operating properly, and at the point of delivery furthest from the dosing system, to ascertain consumption of the peroxide and determine a sufficiently effective initial dose rate.

Figure 4. Hydrogen peroxide dosing equipment

Ozonation

Ozone is a very powerful oxidising agent, recognised as one of the most powerful microbiocides available, it is widely used in water treatment facilities worldwide for safe and effective disinfection of drinking water. Ozonation deploys the unstable gas ozone (O_3), which is produced on site by either of two main types of electrically operated generator; corona discharge or UV, and is bubbled through the water where it rapidly reacts with microorganisms and organic matter. The process is highly effective against bacteria, viruses, fungi, algae, protozoa and Oomycetes, and its action produces oxygen and oxidation products, leaving little or no residue or residual activity in treated water. This is a ‘double-edged sword’ as while not a problem with regard to chemical residues, ozonated water offers little protection from contamination downstream of treatment. This still means the technique would be suitable for ‘closed production systems’, especially where maximum residue limits (MRLs) are of high concern. Nevertheless, despite a reasonable body of experimental trials data indicating its efficacy, this technique has not been widely adopted in European horticulture, probably as a result of its comparatively high installation and running costs.

Figure 5. Experimental ozonation unit at HRI Efford

Copper ionisation

Copper has long been appreciated for its antimicrobial activity. Copper ionisation releases positively charged dissolved copper ions into the treated water by electrolysis. A small direct current (DC) is passed through copper electrodes immersed in the water being treated. The copper ions are released from the positive electrode into flowing water, which prevents them from migrating to and depositing on the negative electrode. The amount of copper released is governed by the DC voltage applied but is also strongly influenced by the electro conductivity (EC) of the water or nutrient feed being treated. Early, simple copper ionisation devices relied on manual regulation of the voltage settings and, consequently, gave highly variable and sometimes unsatisfactory results. However, equipment is now available that measures the EC and adjusts the voltage accordingly. It is also very important to monitor the copper concentration in the water to maintain efficacy while avoiding phytotoxicity – currently this has to be carried out with readily available colorimetric test kits. The few grower and consultant observations made on newer automatically adjusting copper ionisation units have been positive. However, more independent research on residue analysis, phytotoxicity and the efficacy of these systems under a wide range of conditions of water composition and pH is needed before operational recommendations can be made.

Ultraviolet (UV) irradiation

Water is treated in UV systems by passing it through a steel treatment chamber containing a UV lamp enclosed in a quartz sleeve. The flow rate through the chamber and the intensity of the UV radiation determine the UV dose applied to the water (mWs/cm^2 or mJ/cm^2). UV treatment of irrigation water and nutrient feeds has been widely tested since the early 1980s and found to be highly effective for eliminating plant pathogens from waters of high transmittance (eg recycled rainwater collected from greenhouse roofs). Transmittance is a measure of how much UV light can pass through water and is normally expressed as T_{10} or the % UV dose passing through 10mm of water (%/cm). T_{10} values of 60% or more are needed for effective UV treatment of irrigation water and for this reason prefiltration should be installed (see figure 1 – fast sand prefilters with UV installation). Transmittance is not simply a measure of transparency and moderately clear-seeming water, especially recycled hydroponic feed solutions, can have very low transmittance values as a consequence of dissolved organic compounds and chelated iron. It is, therefore, very important to monitor the UV transmittance and highly recommended that recycled hydroponic solutions as well as some surface-derived water should be diluted at least 1:1 with water of high transmittance such as recycled rainwater before UV treatment to maintain efficacy. It is also important to make sure that the quartz sleeve is kept clean and that the UV lamp is monitored to make sure it continues to emit an effective UV intensity. UV treatment systems are available over a very broad range of sizes and there are some excellent rigs available with automated monitoring and regulation to maintain consistent UV dose rates. The main advantage of UV treatment of water is that there are no chemical inputs and no residues in the treated water, although as with ozonation, this means that the treated water is open to recontamination downstream of treatment.

Figure 6. Water treatment rig incorporating two UV treatment chambers

Heat treatment – 'pasteurisation'

Pasteurisation is one of the most reliable methods of eliminating plant pathogens from water and is widely used, especially in the Netherlands. Its main drawback is its large consumption of energy and, therefore, comparatively high running costs. Essentially, heat is applied to the water to be treated by means of heat exchangers. In the first exchanger the water is warmed to approximately 80°C by heat recovery from already disinfected water that is cooling down. The water then passes to a second heat exchanger where hot boiler water is used to bring the treated water to the desired final temperature and maintain it at this temperature for the required time. After this, the treated water is cooled down, releasing its heat to the next batch of untreated water in the first heat exchanger.

Slow sand (bio-) filtration (SSF)

In SSF, water is passed at a comparatively slow rate through a column of sand. The filtration process effectively removes fine particles of organic matter and microbes, including plant pathogen spores, bacterial cells and even virus particles by a combination of physico-chemical processes and biological activity. Before proper deployment, a SSF has to go through a maturation period during which biofilm layers develop over the surfaces of individual sand grains. This biofilm contains a microbiological ecosystem within a sticky matrix and, as particles of organic matter and pathogen inoculum pass between the sand grains in the filter, they are intercepted by the sticky film and are consumed by the microorganisms within it. Widely used for sanitising drinking water, SSF is also highly efficient at removing plant pathogens from irrigation water and SSF have been successfully used in most sectors of the horticultural industry. The main shortcomings of this technique are:

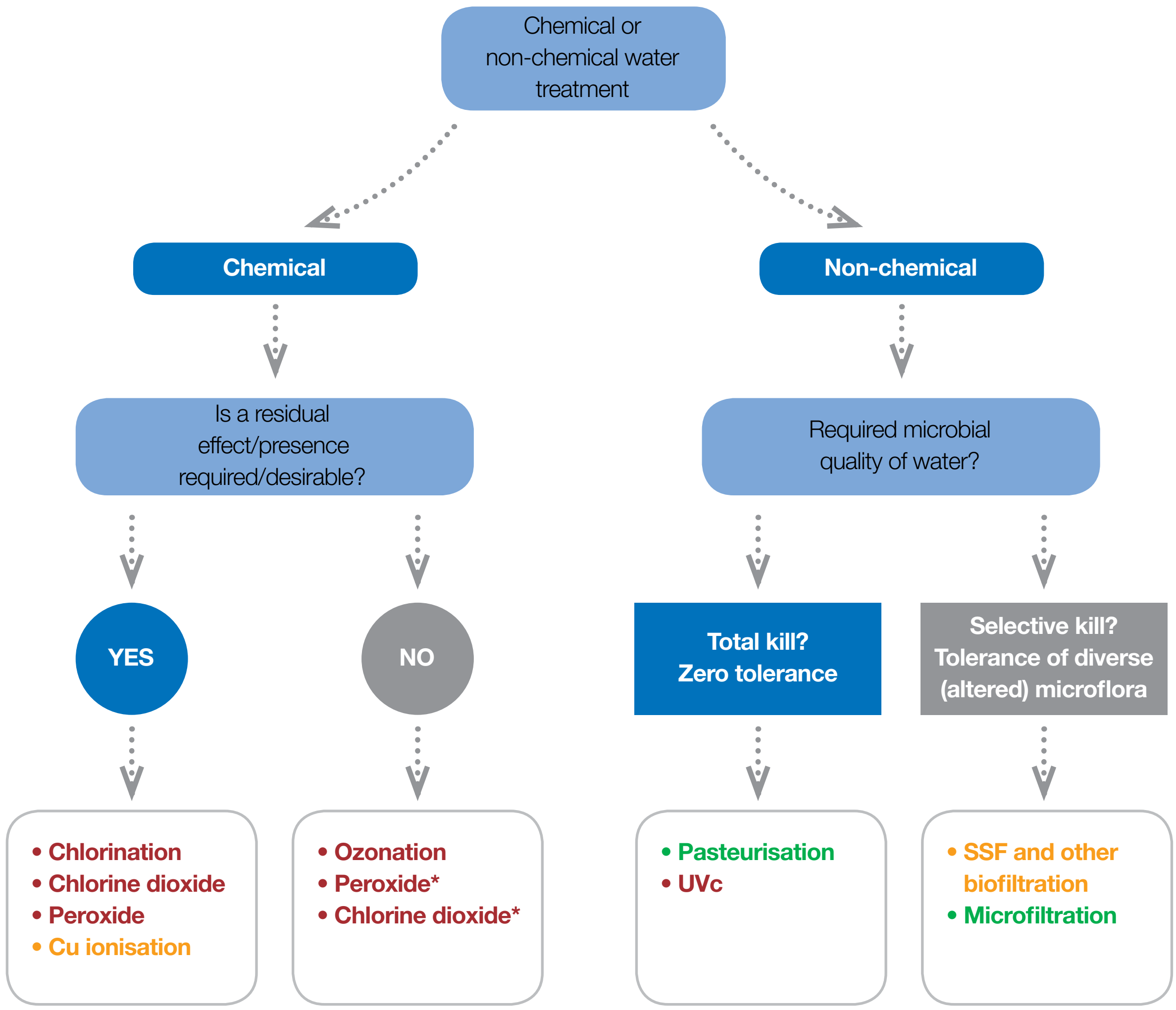
a) The slow flow rate and, therefore, the size of SSF that can be required to process large volumes of water; and

Why treat irrigation water for plant pathogens?

- Good quality irrigation water can often be contaminated with infective plant pathogens and can be the cause of rapid disease spread.
- A wide range of technologies is now available that are capable of entirely eliminating the risks of spreading plant disease via irrigation water.
- Treating irrigation water to eliminate plant pathogens can increase water source options available to a nursery and allow their use with confidence.

Assessing the disease risks

Water can vary enormously in its potential to carry and spread infectious plant disease depending on its source and the way in which it is managed. More information on the risks associated with different water sources and the methods available to determine and monitor disease risks can be found in Factsheet 21/15 'Testing Water for Plant Pathogens'. Water of otherwise good quality can often carry a high risk of rapidly initiating and spreading plant disease.



*Dose rate can be adjusted to leave little or no residual in water at point of delivery to plants
Interactions between treatments and physical/chemical quality of water **Strong**, **Medium**, **Little/none** see table 1

Figure 2. Simple flow chart considering a few of the issues that need to be weighed up when deciding on an appropriate water treatment technology

Table 2. Advantages and disadvantages of the main water treatment technologies currently available for treating irrigation water for the control of Oomycete stem and root rot pathogens

(Table adapted and expanded from Pettitt & Hutchinson (2005) with additions from Atwood (2014) and Fisher (2014))

Water treatment	Advantages	Disadvantages
Pasteurisation	Known, safe, reliable and robust method for treating water. No chemical inputs – no residues. Water mineralogy and pH largely unchanged.	Expensive to install. High energy consumption and, therefore, high running costs. Only effective on relatively small/medium-sized systems. No residual effect. Oxygenation reduced.
Ultraviolet (UV) light	Relatively low to medium running costs. UV units occupy comparatively small space. No chemical inputs – no residues. pH unchanged – relatively minor chemical changes (degradation of iron chelate).	Expensive to install. Water must be free from suspended particles or turbidity. Correct flow rate essential for thorough irradiation. High maintenance with cells requiring regular cleaning. Continuous electrical power supply needed. No residual effect. Limescale in cell at pH >6.
Ozonation	Strong oxidising agent – effective biocide. Adds oxygen. No noxious products formed. No chemical inputs – no residues.	Not widely used and limited guidelines on efficacy. High installation and running costs. No residual effect. Will oxidise iron manganese and sulphides, precipitating them from nutrient solutions.
Chlorination	Relatively simple to install and maintain. Long record of successful use. Creates environment hostile to algal growth. Keeps pipework and irrigation system clean. Economic installation. Residual disinfectant activity.	Most plants are sensitive to chlorine – if injected at high rates may cause phytotoxicity. Chlorine solutions are dangerous to humans and wildlife, and must be handled according to COSHH regulations. Risk of organochlorine formation. Chlorine reacts with ammonium, so cannot be used in conjunction with this form of nitrogen fertiliser. Reacts with iron and manganese, removing them from the solution and forming insoluble salts that can cause mineral fouling of irrigation lines. Corrosive. Horticultural grade hypochlorite must be used as other grades contain phytotoxic chlorates. Chlorination systems may lead to the accumulation of chlorate in edible produce. pH must be kept to 6–7. Depending on concentration, dosed water needs to be stored for a time to allow dissipation of chlorine.

Table 2. ***(continued)***

Water treatment	Advantages	Disadvantages
Chlorine dioxide	Strong oxidising agent. Active over wide pH range (pH 4–10). Primarily an oxidant – no chlorination, therefore no organochlorine formation. Low phytotoxicity. Can clean pipework with 'shock treatments'. Does not react with ammonium. Slow to react with organic matter. Single treatment systems economic to install.	Relatively costly chemicals. Chlorine solutions are dangerous to humans and wildlife and must be handled according to COSHH regulations. Although promising, efficacy against Oomycetes not fully understood. Can escape solution as chlorine dioxide gas under turbulence (eg sprinkler irrigation nozzles). Reacts rapidly with iron and manganese, removing them from solution and forming insoluble salts that can cause mineral fouling of irrigation lines. Will react with and be neutralised by very high organic matter loads. Chlorine dioxide injection may result in the accumulation of chlorate in edible produce.
Hydrogen peroxide	Strong oxidising agent. Simple injectors – low installation costs. No noxious products formed. Used widely for animal drinking water disinfection.	Very rapid breakdown in presence of organic matter. Concentrate solution potentially dangerous to humans and wildlife and must be handled according to COSHH regulations. Efficacy against Oomycetes not fully understood.
Slow sand filtration	Flexible and simple design. Easy to install and maintain. No dangerous chemical or noxious products. Low running costs. Environmentally friendly.	Filters and storage tanks occupy large area. Can require regular cleaning, although techniques exist to reduce this substantially. Treatment process comparatively slow necessitating storage of treated water.

Table 1. Incidence of interactions between some important parameters of irrigation water quality and the main water treatment techniques available for controlling water-borne Oomycete propagules

Water parameter	Pasteurisation	Ozone	Peroxide and peroxygens	Chlorination	Chlorine dioxide	UV	Copper ionisation	Biofiltration
pH >7.5	-	+		+	-	-	+	-
pH <4.5	-					-	-	-
Organic matter (OM)	-	+	+	+	+	+	+	-/+
Dissolved OM	-	+	+	+	+	-/+	+	-
Turbidity	-	-/+	-/+	-/+	-/+	+	-/+	-
'Colour'	-	-	-/+	-/+	-/+	+	-	-
Nitrates	-	-	-	-	-	-	-	-
Nitrites	-	+	+	+	+	-	-	-
Iron (Fe)	-	+	+	+	+	+	-	+/-
Manganese (Mn)	-	+	+	+	+	+	-	+/-
Sulphide	-	?	?	?	+	-/+	-	-
Ammonium	-	+		+	+	-	-	-
Bicarbonate	-	+		?	+	-/+	-	-

Further information

AHDB Horticulture factsheets and publications

AHDB Factsheet 21/15: Testing water for plant pathogens treatment for the elimination of plant pathogens.

AHDB Factsheet 23/15: Hygiene and disease avoidance underpin the management of Oomycete stem and root rots.

Instruction sheet for growers: *Pythium* and *Phytophthora* water baiting.

Slow Sand Filtration – http://horticulture.ahdb.org.uk/sites/default/files/Slow%20Sand%20Filtration%20Guide.pdf

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