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Managing Plant Pathogens in Recycled Irrigation Water

A researcher from the University of Melbourne has reviewed the scientific literature related to managing plant pathogens in recycled irrigation water. Plant pathogens present in the irrigation system of commercial plant nurseries and greenhouses constitute a disease risk to plants, and the continual recycling of this water can exacerbate this risk. Plant pathogens in recycled irrigation water can be managed by treatment methods from four broad categories: cultural, physical, chemical and biological. An integrated approach using one or more techniques from each category is likely to be the most effective strategy in combating plant pathogens in recycled irrigation water. This Nursery Paper compiles this information to enable growers to compare treatments and consider the best strategy for their enterprise.

Managing Plant Pathogens in Recycled Irrigation Water

Issues with recycling irrigation water

Whilst recycling irrigation water in commercial nurseries and glasshouses has clear advantages, one major risk is the dispersal of plant pathogens, and the resulting potential increase in plant disease[1-4]. Infected plants may harbour and release large numbers of plant pathogens into leachate water, which are then delivered to the holding pond and when the water is recycled for irrigation, are subsequently redistributed to susceptible crops[5]. Plants irrigated with water containing plant pathogens can result in plant disease, and so an increase in unsaleable plants, increased use of pesticides to control disease outbreaks, and disease spread to previously uninfected production areas. Therefore, the management of plant pathogens in recycled irrigation water is important.

Management of Plant Pathogens in Recycled Water

The Nursery Industry Accreditation Scheme Australia (NIASA) Best Practice Guidelines state that 'water must be disinfested by one or several of the approved methods'[7] (page 9). The guidelines specifically advise at least a 20 minute exposure time to chlorine or bromine at the minimum effective concentration of 2-5 ppm. These guidelines reflect the most common practice of disinfestation in Australian nurseries, with more than 70% of NIASA accredited nurseries that recycle irrigation water using chlorination[8]. There are many other methods available and, depending on individual nursery situations, the timely and integrated application of one or more of these methods may be best. The main treatment methods available for disinfesting recycled irrigation water are discussed below and their advantages, disadvantages (Table 1) and approximate cost (Table 2) are summarised.

Cultural methods

It is important to prevent plant pathogens from being introduced into water sources in the first instance, by preventing contaminated soil and plant debris from being carried into the water[9]. Also, the irrigation type, duration and timing can affect the multiplication of plant pathogens and so, plant disease[9,10].

Physical methods

Various methods can physically remove plant pathogens from recycled irrigation water, including sedimentation, filtration and UV light. Sedimentation can be achieved via electro-coagulation, which produces ions via an electric current which then attract plant pathogens in the water. The ion-pathogen products coagulate and precipitate out of solution, forming a sludge[11].

Filtration of recycled irrigation water can be achieved by two main ways: slow media or membrane filters. Slow media filtration involves passing water through a filter medium at a slow rate to remove plant pathogens[12]. Sand is the most commonly used medium (slow sand filtration or SSF) but other media in use include rockwool (stonewool) or pumice (lava grains)[13]. The filter medium acts as a physical sieve, but also houses a diverse population of microbes which actively interact with plant pathogens in the water[14-17]. A granulated rockwool product, marketed as 'Grodan®', claims various advantages as a slow filtration medium over sand including greater surface area and uniformity and the top layer of the filter does not require regular removal[11]. Membrane filtration systems are probably impractical due to high pumping costs and rapid clogging of expensive filters[18-21].

For UV treatment systems to work well, good water clarity is essential, since suspended and dissolved materials can reflect or absorb UV light. For UV radiation to effectively disinfest recycled irrigation water, a minimum UV transmission rate of 60% is essential[22]. Of twenty-nine nurseries surveyed in a 1996 Australian study, less than 25% had water with effective UV transmission rates (over 60% transmission), whilst 62% of properties had water with ineffective UV transmission rates (less than 50% transmission)[22]. So, assessment of water clarity is imperative. Other physical methods such as heat are impracticable in Australia mainly due to cost, whilst very little information is available for other potential techniques such as sonication and pressure treatment.

Chemical methods

The chemicals mainly used to decrease plant pathogens in recycled irrigation water include chlorine, chlorine dioxide, bromine, chloro-

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bromine, iodine and ozone. Sodium hypochlorite is the most common type of chlorine used. However, chlorination is inadequate if the pH of the water is above 7.5 and ineffective above 8.5[22,23]. For maximum effectiveness, a pH of 5-6 is recommended[24], and since runoff water from Australian nurseries often has a pH above 7.5, acidification is necessary prior to chlorination[22]. For example, of 29 nurseries surveyed, most had a pH too high for effective chlorination on at least one occasion[25]. Solid chlorine, as compressed calcium hypochlorite powder, can also be utilised for disinfestation, where it is installed as slow release blocks into disposable cartridges (S. Woods, Klorman Industries P/L., pers. comm.).

With chlorination, it is essential to monitor routinely the chlorine demand of the water, to ensure there is enough free chlorine to treat the plant pathogens[26]. Organic and inorganic material in the recycled irrigation water 'use up' chlorine (i.e. chlorine demand), which influences the amount of chlorine available to treat plant pathogens[27]. In Australia, water is generally high in organic substances, and so the chlorine demand can even be in the vicinity of 25 to 30 mg/L, but it can vary greatly with location and season[26,27]. Chlorination is also affected by the type and amount of pathogen, and the pH and temperature of the water[9,28,29]. Chlorine dioxide works across a broader pH range than chlorine, and so seems very useful in Australian nurseries which generally have high pH levels in their recycled water[6].

Whilst the pH of water to be treated is much less of an issue when using bromine compared to using chlorine, there have been few studies to support the claim that bromine works better against a broader range of pathogens than chlorine[30]. Similarly, combining chlorine and bromine is said to result in very effective disinfestation[31], though data is lacking.

Various other chemical treatments show promise. Water can be passed through a series of iodine filters to remove plant pathogens[11]. The iodine dose adjusts automatically according to the organic load of the water (J. Franks, Ioteq, pers. comm.); and after treatment, iodine residues are removed using an anion-exchange resin[11]. Ozone reportedly works well against all pathogens[21,23], though in water with a high pH, high in organic matter, and high in nitrite, manganese, iron or bicarbonate concentrations, it is not as effective[32]. Hydrogen peroxide is not as effective as ozone and has many of the same drawbacks.

Acidic electrolyzed oxidizing (EO) water, produced by electrolysis of deionized water containing a low concentration of a salt, is said to control fungi, bacteria and viruses[33-35]. An EO product called Envirolyte is currently on the market in Australia for other applications and may have potential for disinfesting irrigation water in nurseries (K. Mason, Envirolyte Australasia, pers. comm.). Ionizers (electro-oxidizers) can pass an electrical charge through water to release copper and silver ions from the anodes, which kill pathogens[11]. Whilst it is effective against algae, certain bacteria (C. Clifford, Oz Aqua-Qld, pers. comm.) and

Phytophthora and Pythium, it has not been tested against a wide range of pathogens[11]. To date, it is ineffective against Alternaria and Fusarium (C. Clifford, Oz Aqua-Qld, pers. comm.).

Other potential treatments include peroxyacetic acid (PAA), nutrient amendments and carbon dioxide, but little information is available on their effectiveness and use in nursery systems.

Biological methods

Biological methods can include applying nutrient amendments and selected agents, the use of biofilters and constructed wetlands. Adding specific nutrients to recycled irrigation water can increase 'good' microorganisms and decrease disease-causing pathogens[36-38]. Adding selected biological control agents such as bacteria that 'attack' fungi may be useful[39], but there are many challenges in their commercialisation[40].

Biofilters contain a porous filtering matrix, such as peat, rockwool or scoria[41], which host 'good' microorganisms and work with faster flow rates than SSF. These 'good' microorganisms are antagonistic to undesirable pathogens and break down various other contaminants such as heavy metals, nutrients, and phenolics[11].
Constructed wetlands may be useful for removing plant pathogens from water, but have received little attention to date. They are usually comprised of a lined basin filled with a substrate, such as coarse gravel, that supports a diverse microbial population and usually, higher plants (Berghage et al 1999).

Conclusion

While a variety of treatment methods are available to manage plant pathogens in recycled irrigation water, further research is required to assess the effectiveness of emerging treatment technologies on important plant pathogens in recycled irrigation water. Further research is also needed on the amount and type of pathogens in water and if there is enough to cause disease, and so, whether treating the water is economically justified.

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__Table 1.__ Advantages and disadvantages of common treatment methods employed to disinfest recycled irrigation water. Cost is included only generally since Table 2 outlines the cost comparison more specifically.

Treatment Method	Advantages	Disadvantages
Physical		
Sedimentation (Electro-coagulation)	• Simple and safe (no chemicals) • Not affected by variations in water • Removes beneficial microbes	• Byproducts need to be removed regularly
Slow sand filtration – (SSF)	• Simple, low tech., built/installed by laymen • Safe (no chemicals) low energy • Retains natural microflora • Not affected by variations in water • No harmful residuals/byproducts • No prefilter required • Not toxic to plants	• Large setup cost • Too slow for large quantities of water • Frequent clogging requires maintenance • Legionella bacteria part of microflora • Occasional efficacy breakdowns • Sand is heavy – difficult to construct/relocate • Gravel layers makes for large unit
Slow filtration – rockwool or pumice	• As per SSF • Less dense than sand – easier construction and relocation • Does not require gravel, smaller unit • Much less clogging, less maintenance • More effective on certain pathogens	• Large setup cost • Too slow for large quantities of water • Legionella bacteria part of microflora • Occasional efficacy breakdowns • More complex system than sand
UV	• Non-corrosive • Not dependent on pH • Safe (no chemicals)	• Affected by solids in water >60% transmission • Prefilter essential • Lamp output decreases with age, so regular replacement • Potential growth inhibition of plants • Destroys iron chelate • Nontarget effects on beneficial microbes
Chemical		
Chlorine	• Stable residual to continue disinfesting • Cleans out algal and bacterial slime • Highly effective • As CaOCl, calcium is available for plant uptake	• Affected by solids (esp. N) in water • Affected by pH of water, requires acidification • Long-lived byproducts with human health and environmental hazards • Toxic to plants if too high level • Corrosive, (Chlorine gas unsafe)
Chlorine dioxide	• Broader pH range (compared with chlorine) • Not affected by nitrogenous compounds	• Human health and environmental hazards • Lack of data on toxicity to plants, lack of efficacy data • Must be produced and used onsite with specialised equipment
Bromine	• Still effective at higher pH (compared with chlorine) • Effective on broader range of pathogens • Not affected by nitrogenous compounds • Not toxic to plants even at high levels • Byproducts less persistent (compared with chlorine)	• Byproducts with human health and environmental hazards • Lack of efficacy data
Chlorobromine	• Improved effectiveness (reported) • More effective at higher pH (compared with chlorine)	• Lack of data on toxicity to plants • Lack of efficacy data • Corrosive
Iodine	• Dosing automated and safe (no chemical mixing) • Residues automatically removed • Not toxic to plants • Not affected by variations in water	• Potential for technical breakdown and user difficulty
Ozone	• Beneficial to plant growth (?) • Degrades pesticides • Low environmental hazard	• High capital cost • Affected by variations in water • Potential health hazard, potentially toxic to plants • Corrosive • Unused ozone removed by carbon – adds cost • No stable residual • Generated onsite, cannot be stored
Hydrogen Peroxide	• Simple • Long history of use in food industry	• Not as effective as ozone • Affected by variations in water • Potential health and environmental hazard • Can be toxic to plants • Corrosive • Safe handling/delivery/storage difficult, costly
EO water	• Simple and stable residual to continue disinfesting • Less formation of harmful byproducts (compared with chlorine) • Not toxic to plants • No health and environmental hazard • Effective against plant pathogenic fungi, other bacteria and viruses • Potential plant growth stimulant	• Lack of efficacy data in water • Little use to date in nursery
Biological		
Biological control agents	• Specific for target pathogen, reducing non-target effects • Can be used to complement other treatments • Some have plant growth promotion effects	• Specificity may limit applicability • Lack of efficacy data, especially adding to water • Issues with stability, reliability?
Biofilters	• Simple and safe (no chemicals) • Retains natural microflora • Faster flow rates than slow filtration • Removes nutrients • Not toxic to plants	• Need to replace nutrients • Little use to date in nursery
Constructed wetlands	• Simple and safe (no chemicals) • Removes pesticides and nutrients • Propagation of wetland species • Little maintenance	• Repeated recycling may increase soluble salts and be toxic to plants • Need to replace nutrients

Table 2. *Cost comparison of common existing and recent technologies for the disinfestation of recycled irrigation water.*

System	Capital costs ($) approx.	Annual running costs ($) approx.	Cost ($) /ML averaged over 10 yrs
Physical			
Slow sand filter[1]	11000	100	60.00
Slow rockwool filter (Grodan®)[2]	40000	0	200.00
UV radiation[1]	6500	490	57.00
Chemical			
Chlorine liquid injection[1]	1200	4850	248.50
Chlorine solid (CaOCl)[3]	1060[3]	1650	87.80
Chlorine Dioxide[1]	5000	1600	105.00
Chlorine Dioxide[1]	15000	950	122.50
Bromine[1]	2500	2440	134.50
Chorobromine[4]	5000	876	68.80
Iodine at 1 ppm[5]	6000	280	44.00
Ozone[6]	25000	1000	175.00
EO Water[7]	20000	60	103.00
Ionization[8]	2500	75	16.25
Biological			
Constructed wetland[9]	30000	200	160.00

[1](Rolfe 2001)[42]. Based on a typical nursery, disinfesting 20 ML of water annually, at a daily rate of 100,000 L for 200 days a year. The costs for other systems are based approximately on the same parameters.

[2]Scott Featherston, AIS Greenworks, pers. comm. 2009.

[3]Steve Woods, Klorman Industries P/L., pers. comm. 2009. This capital cost is for a unit with a flow rate of up to 7200 L/h; the cost for a unit that delivers a flow rate of 15,000 L/h was unavailable at the time of submission, but this would be more comparable to the other treatment systems in the table.

[4](Grover 1997)[43]

[5]Jared Franks, Ioteq, pers. comm. 2009. Greater annual running cost if used at greater concentration, but 1 ppm is typical

[6](Rolfe et al. 2000)[20]

[7]Keith Mason, Envirolyte Australasia, pers.comm. 2009.

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[9](Rolfe 2002)[44]

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