Table 8.3.3a — A summary of treatment options for waterborne pathogens in nursery and greenhouse irrigation systems (Page 1 of 2)

Treatment	Active ingredient	Readily soluble	Injection method	How It Works	Usual range in concentration[1]	Notes
Bromine Example: Agribrom™	1-Bromo-3-chloro-5,5-dimethyl-2,4-imadazolidinedione	No	Tablets or granules are placed in a container with water. The supernatant solution is injected into the irrigation water.	Oxidizing agents listed in this table interact with reactive chemical groups on organic matter. The oxidation of organic matter results in a change in the chemical structure of the organic matter, and death of the pathogen. The oxidizing agent itself is also "used up" during sanitation because the agent changes chemical form as it reacts with organic matter. Plant pathogens vary in their susceptibility to the agents listed in this table. Some plant pathogens and types of resistant inoculum structures may require higher rates of oxidizing agents and/or exposure times than those listed. The material being oxidized can include pathogens, peat, and fertilizer salts. Because all organic matter in the water will absorb and deplete oxidizers, good pre-filtration is essential.	5–35 ppm bromine	Because of low solubility, some time is required for the undissolved tablets or granules to replenish the bromine in the stock solution. Difficult to maintain a constant concentration of bromine over the course of the day, especially with high flow rates. Requires a special injector resistant to corrosive chemicals.
Chlorine gas	Cl_2	Yes	Chlorine gas is bubbled through the water, where it combines with the water to form hypochlorous acid (HOCl) and hydrochloric acid (HCl).		0.5–2 ppm free chlorine. Hypochlorite is a weak acid and can be found in solution in two different forms: OCl^- and HOCl. Because the HOCl form is much more effective at disinfecting than the OCl^- form, the water pH should be controlled, as sanitizing reactions tend to be slower at higher pH.	Hazardous gas requires special equipment, ventilation, and handling. As with all chlorine application methods, higher than recommended concentrations can be toxic to plants.
Sodium Hypochlorite	NaOCl	Yes	Liquid NaOCl solutions (5–15 percent chlorine) are injected directly into irrigation water.			Requires a special injector that is resistant to very corrosive chemicals and has a very high injection ratio. Has a limited shelf life. Warm temperatures and sunlight speed up breakdown. Never combine with fertilizers or other chemicals containing ammonium.
Calcium Hypochlorite	$Ca(OCl)_2$	Yes	Granules may be dissolved in water, or tablets can be eroded in a flow-through feeder for more automatic chlorination, at chlorine concentrations up to 10,000 ppm, depending on the feeder and operating conditions.			Calcium hypochlorite solutions of up to approximately 21 percent can be prepared, but due to the presence of insoluble materials such as calcium carbonate solutions of above 200 ppm tend to be cloudy. Sediment forms with very concentrated solutions. At less than 100 ppm available chlorine there should be no apparent cloudiness or sediment.
Chlorine Dioxide Examples: Ultra-Shield™, Selectrocide™	ClO_2	Yes	Dry packet or tablets placed in water, ClO_2 solution generated in stock tank.		Injected into irrigation lines. Continuous injection of residual concentration of 0.25 ppm or less. Twice a year shock treatment at 20 to 50 ppm depending on product.	Stock solution should be used within 15 days to minimize loss due to volatilization. Maximum stock concentration of 500 or 3,000 ppm, depending on product.
Ozone	O_3	No	An electrical arc is used to produce the ozone from bottled or atmospheric oxygen. The ozone is then bubbled through the water.		Residual effect from reaction products (peroxides, organic radicals). Breaks up biofilm. 10 grams/hr/m³.	Requires professional design based on water analysis. Proper design prevents ozone from escaping into the atmosphere in hazardous concentrations.
Activated Peroxygen Examples: ZeroTol™, SaniDate™	Hydrogen dioxide/ hydrogen peroxide (H_2O_2) and Peroxyacetic acid/peracetic acid ($CH_3COO\text{-}OH$)	Yes	A stabilized H_2O_2 and peracetic/peroxyacetic acid solution that is injected directly into irrigation water. Peroxyacetic acid is a more effective biocide than H_2O_2 alone.		27 to 540 ppm H_2O_2	Requires a special injector that is resistant to very corrosive chemicals and has a very high injection ratio, or the material must be diluted before injection.

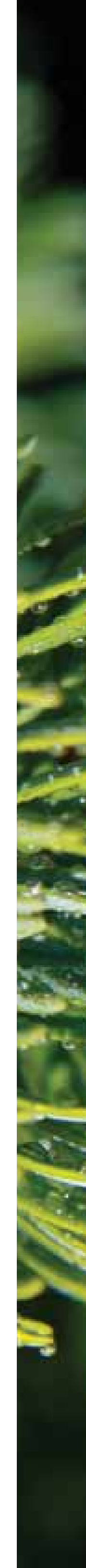

Table 8.3.3a — A summary of treatment options for waterborne pathogens in nursery and greenhouse irrigation systems (Page 2 of 2)

Treatment	Active ingredient	Readily soluble	Injection method	How it works	Usual range in concentration[1]	Notes
Ultraviolet (UV) radiation		N/A	Water is exposed to high doses of UV light in tubular chambers. Most common are low pressure mercury vapor lamps with a wave length of 254 nm, close to the optimum range for killing pathogens.	UV radiation disrupts the genetic material in the cell, effectively killing it. Dose, exposure time and turbidity determine effectiveness.	250 mJ/cm² eliminates most pathogens. No residual effect on pathogens downstream of treatment.	The effectiveness of the lamp decreases with age. Any particulate matter in the water will disperse the light, making the application of UV radiation less effective. Good pre-filtration is essential. Often used with other disinfecting material to get some residual effect.
Copper ionization	Cu^{++}	Yes	An electrical charge is passed between copper bars or plates, releasing copper ions into the water.	Copper ions are a toxin to most pathogens, including *Pythium*, *Phytophthora*, *Xanthomonas*, and algae. Recent advances in controls produce consistent copper levels and reliable results.	0.5 to 1 ppm Cu for pathogens. 1 to 2 ppm for algae and biofilm.	Less effective if water pH is above 7.5. Choose a system which actively controls copper output according to flow and EC. Applied copper concentrations are within U.S. drinking water standards and a fraction of plant toxicity levels.
Heat treatment/pasteurization		N/A	Water is heated to specific temperature, and waste heat is recovered to pre-heat incoming water.	Pathogen resistance to heat varies. Effect largely independent of water quality.	An example treatment is 203 F for 30 seconds. No residual effect on pathogens downstream of treatment.	High energy use makes it expensive for large flow. To prevent scaling of heat exchangers from hard water, pH needs to be reduced to 4.5, then raised again as needed for irrigation. Best for low-flow, high-sanitation applications.
Slow sand filtration	N/A	Water moves passively through sand bed that supports a biologically active layer (*Schmutzdecke* or biofilm crust) on the filter surface. Clean, filtered water is stored in a covered reservoir until use.	Sand filtration works through a combination of physical removal of particles and biological activity of the biofilm crust. Effective at eliminating *Phytophthora* spp. from water.	An example rate of filtration is 30-90 m³/hr. A filter bed area of 260 m² and 1 m deep can yield approximately 40,000 m³ filtered water/mo.	While the biofilm crust or *Schmutzdecke* is important for the functioning of the filter, it must be maintained by periodic raking or the filter can become clogged. Slow sand filtration may not be rapid enough to supply the volume of water during periods of peak irrigation demand. Space limitations may also limit the size of the sand filter and the volume of water that can be treated.	

Notes

1. Desired concentration depends on the application (e.g. shock treatment versus continuous treatment of clean water, and the specific pathogens targeted). See product label and manufacturer's instructions for your application.
2. All the methods mentioned above are non-specific and will react with any type of organic matter, whether it is a pathogen, algae, or a particle of peat. In all cases, the cleaner the water is before the application, the more effective the disinfection method is at removing pathogens.
3. Bromine, chlorine products, ozone, peroxyacetic acid, and hydrogen peroxide are strong oxidizing agents. Metal micronutrients (copper, iron, manganese, and zinc) are easily oxidized (particularly iron). It is likely that long-term exposure (greater than 20 minutes) of metal micronutrients to these oxidizing agents will decrease their solubility. Chelated micronutrients should be only slightly less affected than sulfates.
4. Ultraviolet radiation is a photo-oxidizing agent. Research by Cornell University on photo-oxidation of iron in fertilizer solutions indicates that the greater the light exposure, the less iron that will remain in solution.
5. Quaternary ammonium compounds such as Green-Shield®, Physan 20™, or Triathlon™ are listed for disinfection of walkways, benches, tools, flats, etc., but are not for use with irrigation water.
6. Liquid hydrogen peroxide/hydrogen dioxide (H_2O_2) solutions (35–50 percent H_2O_2) are not EPA-registered for water treatment in greenhouses, and are less effective and stable compared with registered activated peroxygen products.

Chemical names and trade names are included in this publication as a convenience to the reader. The use of brand names and any mention or listing of commercial products or services in this publication does not imply ndorsement, nor discrimination against similar products or services not mentioned. Individuals who use chemicals are responsible for ensuring that the intended use complies with current regulations and conforms to the product label. Be sure to obtain current information about usage and examine a current product label before applying any chemical. For assistance, contact your state pesticide regulating authority.

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